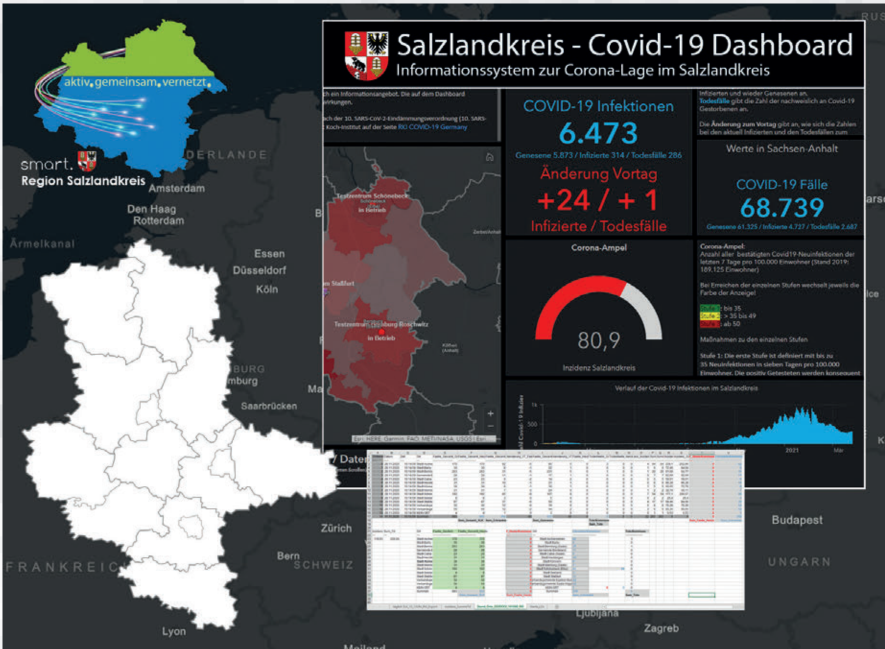
6-2021

JoDLA

Journal of Digital Landscape Architecture



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JoDLA
Journal of Digital Landscape Architecture

6-2021

To Wolfgang Haber
on the occasion of his ninety-fifth birthday.

6-2021

JoDLA

Journal of Digital Landscape Architecture

Editors:
Erich Buhmann
Stephen Ervin
Sigrid Hehl-Lange
James Palmer

Guest Editor:
Matthias Pietsch

Wichmann

Journal of Digital Landscape Architecture, 6-2021

Statement of Purpose

The Journal of Digital Landscape Architecture addresses all aspects of digital technologies, applications, information, and knowledge pertaining to landscape architecture research, education, practice, and related fields. The journal publishes original papers in English that address theoretical and practical issues, innovative developments, methods, applications, findings, and case studies that are drawn primarily from work presented at the annual international Digital Landscape Architecture conference. Its intent is to encourage the broad dissemination of these ideas, innovations, and practices. Proposals for guest editors, topics, and contributions for special issues are welcome. The Journal of Digital Landscape Architecture is listed in the international citation database Scopus.

Cover Picture

Special thanks go to Dirk Helbig and Matthias Grothe for JoDLA 2021's cover image. The county Salzlandkreis – located in central Germany with 1,440 square kilometers and population of 190,000 – has developed its own Corona dashboard to show citizens the current local situation. The Corona dashboard of the Salzlandkreis was first launched on October 16, 2020. It was developed for use on PCs, and for mobile use as well. In terms of function and content, the development was oriented on the higher-level Corona dashboards of the WHO, the German National Institute Robert Koch-Institut RKI, John Hopkins University JHU, and the software environment of https://experience.arcgis.com/. The objective is to show the local situation of the pandemic to the public with the same instrument used on state, national and international levels. Between the introduction on October 16, 2020 and March 23, 2021 this dashboard had already received 1,461,124 clicks.

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Preface

The cover of the sixth issue of the Journal of Digital Landscape Architecture JoDLA 6-2021 shows the Corona dashboard of Salzlandkreis. The county Salzlandkreis, including our campus in Bernburg – located in central Germany with an area of 1440 square kilometers and having a population of 190,000 – has developed its own Corona dashboard to show citizens the current local situation. Special thanks go to our graduates Dirk Helbig and Matthias Grothe for this year's JoDLA cover image. The objective is to show the local situation of the pandemic to the public with the same instrument used on state, national and international levels. Between its introduction on October 16, 2020 and March 23, 2021 (5 months) this dashboard had already received 1,461,124 clicks. The development and implementation of this dashboard shows the strength of visualization of digital spatial data.

The network of engaged individuals teaching new information technologies at the International Master of Landscape Architecture program MLA at Anhalt University established the annual Conference on Digital Landscape Architecture DLA at our school in 1999. The DLA has to date been held in Istanbul, Malta, Zurich, Munich, Aschersleben, and frequently in Bernburg and Dessau. In 2020, the DLA was hosted by Harvard University. Harvard was able to organize the DLA 2020 as a virtual conference when the Pandemic did not allow for personal contact. The Journal Digital Landscape Architecture JoDLA which we have developed for the conference is now listed in the international citation database Scopus. This publication is supported academically by eighty reviewers and board members. Here, we wish to thank them for their long-term support.

The 22nd international conference on digital landscape architecture was originally organized as an in-person conference at the conference facilities of the Umweltbundesamt UBA – the German Federal Environmental Protection Agency. The headquarter of the UBA in Dessau in the German State of Saxony Anhalt is located next to our Anhalt University Dessau Campus. Now being confronted with the next wave of infections, most countries of the participating speakers have been affected. Anhalt University therefore invites all to attend virtually.

This year's main theme "Resilient Digital Landscape and Global Change" is represented by selected images on the homepage of the conference: severe large-scale dead forest stands caused by global warning in the Harz Mountains of Saxony Anhalt, intensive agricultural for energy production, as well as drones that help monitor the environment: http://2021.dla-conference.com/. Our keynote speakers from Thailand and India will widen our view of the challenges environmental design faces to cope with global change.

As we are able to work with a digital twin of our globe, we can focus on how to use the tools of digital landscape architecture in order to meet the challenge of global warming.

This year we look forward to seeing even more participants virtually than those who would have been able to travel. At the same time, we are also looking forward to welcoming you again in person in the coming years.

March 31, 2021

Prof. Dr. Jörg Bagdahn, President Hochschule Anhalt / Anhalt University, Köthen

Grußwort[1]

Gerne hätte ich Sie persönlich in Sachsen-Anhalt begrüßt. Der aktuellen Situation geschuldet ist in diesem Jahr nur ein digitales Treffen möglich. Der persönliche Kontakt und Austausch sowie die fachliche Kommunikation – Herzstück einer jeden Konferenz – müssen ins Netz verlagert werden. Sie haben sich der Situation angepasst und damit Ihre Resilienz in diesem Bereich nachgewiesen.

Womit wir bei einem spannenden Thema dieser Konferenz wären. Fragen zur Resilienz, also die Fähigkeit, schwierige Lebenssituationen ohne anhaltende Beeinträchtigung zu überstehen, sind im Hinblick auf den fortschreitenden Klimawandel aktueller denn je.

Es gilt, unser Land, unsere Natur, unsere Gesellschaft an die großen Herausforderungen in Folge des Klimawandels anzupassen. Als Landwirtschafts- und Umweltministerin habe ich dabei besonders die Land- und Forstwirtschaft im Blick.

Erst vor Kurzem konnte ich den Monitoringbericht 2020 zum Klimawandel in Sachsen-Anhalt vorstellen. In diesem Bericht werden die Ergebnisse des Klimawandel-Monitorings anhand ausgewählter Indikatoren bewertet und beschrieben. Die Daten zeigen statistisch objektiv die Änderungen des Klimas an.

Die Klimakrise ist in Sachsen-Anhalt angekommen. Wir können die Veränderungen spüren und messen. Eindeutige Ergebnisse sehen wir bei der Temperatur: Das Jahresmittel ist seit 1880 um 1,5 Grad Celsius angestiegen. Die Anzahl der heißen Tage mit über 30 Grad Celsius hat gegenüber der Referenzperiode 1961 – 1990 zugenommen, in den Tieflandregionen sogar auf durchschnittlich bis zu 14,7 Tage verdoppelt. Die Vegetationsperiode hat sich schon um 13 Tage verlängert und die Apfelblüte setzt tendenziell immer früher ein.

Gleichzeitig fehlen Niederschläge: Die Bodenfeuchte – wichtig für die Landwirtschaft – geht in den meisten Regionen zurück. Besonders im Tiefland verschlechtert sich die Standortswasserbilanz und beeinflusst damit unsere Wälder. Die außergewöhnlich lang anhaltende Trockenheit seit April 2018 schlägt nun auch in höheren Lagen zu.

Wir wissen, was das bedeutet: Die Bäume können sich gegen Schädlinge immer weniger wehren. Im Zusammenspiel mit Stürmen sind in manchen Gebieten Sachsen-Anhalts ganze Wälder gefährdet.

Wir können diese Klimakrise aufhalten, wenn wir konsequent handeln. Jeder ist gefordert, zur Verringerung der Treibhausgasemissionen beizutragen. Deshalb hat die Landesregierung von Sachsen-Anhalt im Februar 2019 ein Klima- und Energiekonzept (KEK) verabschiedet. In den Erarbeitungsprozess und auch in die Umsetzung des KEK wurden und werden zahlreiche gesellschaftliche Akteure einbezogen. So ist sichergestellt, dass das Konzept in einem gesellschaftlichen Konsens umgesetzt wird.

Gleichzeitig passen wir uns an die unvermeidlichen Folgen der Klimakrise an. In Sachsen-Anhalt gibt es seit 2010 eine Landesanpassungsstrategie an den Klimawandel, die regelmäßig fortgeschrieben und in die die neuesten Entwicklungen und Erkenntnisse einfließen. Auch

1 This greeting is only available in German. See the English version at https://www.dla-conference.com/.

hier gilt: Die Umsetzung der darin beschriebenen Maßnahmen ist im Zusammenwirken aller Beteiligten und Betroffenen notwendig.

Das KEK und die Anpassungsstrategie an den Klimawandel stellen zwei wesentliche Bausteine auf dem Weg zu mehr Nachhaltigkeit in unserer Gesellschaft dar.

Nachhaltigkeit ist in allen Bereichen des gesellschaftlichen Lebens erforderlich, um künftigen Generationen eine lebenswerte Zukunft zu ermöglichen. Das Thema „Nachhaltige Entwicklung“ wird in Sachsen-Anhalt deshalb als ganzheitliche Aufgabe aller staatlichen Organisationen gesehen.

2019 beschloss das Kabinett für Sachsen-Anhalt eine Landesnachhaltigkeitsstrategie. Dabei erfolgte eine Anpassung an die Agenda 2030 der Vereinten Nationen sowie an die Deutsche Nachhaltigkeitsstrategie. Bestandteil der Landesstrategie ist ein Indikatorenbericht mit anspruchsvollen Zielvorgaben, die das Land bis 2030 erreichen will.

Für Landschaftsarchitekten eröffnen sich hierbei eine Vielzahl an Möglichkeiten, sich aktiv mit ihren Ideen einzubringen, um die Resilienz vieler Systeme zu stärken. Ich werde mir die Ergebnisse Ihrer Konferenz berichten lassen.

Eine gesunde und vitale Natur ist eine elementare Grundlage, um die vor uns liegenden Herausforderungen zu bewältigen. In diesem Sinne wünsche ich Ihnen eine inspirierende und erfolgreiche Konferenz.

22. April 2021

Prof. Dr. Claudia Dalbert, Ministerin für Umwelt, Landwirtschaft und Energie des Landes Sachsen-Anhalt

Editorial

A New Normal – Three Reflections on JoDLA 2021

Landscape Architecture as a discipline was already in upheaval at the beginning of this century; "digital landscape architecture" was already a community, and a conference, a body of work, and a fertile ground for innovation. At the beginning of last year, DLA2020 was intended as one more physical gathering of the tribe, with JoDLA 5-2020 slated to have the largest page-count yet. Then came the tidal wave of novel CoronaVirus complications and pandemic lockdowns. DLA2020 went virtual overnight, and ushered in a year of Zoom, Zoom, Zoom, videoconferences and virtual presence, all the time, everywhere … Now as we approach the anniversary of that time, with 're-entry' plans and promises of a return to 'near-normalcy', landscape architecture as a discipline, and DLA as a community, face an uncertain future with only one certainty – the usual one: change.

One such change that we have already benefited from, starting with DLA2020, is the inclusion of a larger and more diverse international audience for DLA than ever before, and with a lower carbon footprint for their participation than ever. In particular, more students from more parts of the world than ever before have been welcomed into, and contributed to, the community and the conference.

We – especially in educated / academic / affluent societies – have learned that many things analog and physical, such as telephone handsets and in-person meetings, printed pages and paper currency (though not good food, forest walks, or close human companionship) can be replaced with virtual equivalents, along with a balance sheet that tallies both advantages and disadvantages of all of these (perhaps false, but nonetheless functional) equivalencies. Less commuting, less air travel, potentially lower carbon footprint; more tools for online collaboration, more development of Mixed Reality software, more global outreach and participation. In education as well as practice, and in research and academic conferences, the results are mixed, and unevenly distributed, but there are many indicators that the 'new normal for the third decade of the 21st century will entail a number of dramatic changes, as well as more gradual ones; in economics, employment, entertainment, computation and communication, real-estate, environmental design, and construction, the irreversible imprint of COVID-19 will surely be visible.

In a 2021 Pew report (https://www.pewresearch.org/internet/wp-content/uploads/sites/9/2021/02/PI_2021.02.18_New-Normal-2025_FINAL.pdf) an impressive array of researchers, futurists and observers predict a vast panorama of post-pandemic changes – some good, some bad, some ugly – from better tele-medicine to worse proliferation of misinformation … Documenting how these changes reverberate in landscape architecture is the work of the DLA.

What are the essential tools of landscape architecture? Mixed Reality, drone-mediated site-visits, and machine-learning-from-big-data approaches to geospatial analysis have all been accelerated to launch velocity, as reported in this JoDLA 6-2021. What are the dimensions of 'landscape'? Beyond those I have called 'Olmstedian' (topography, vegetation, water and structures) we now must anticipate dealing with virtual and intangible equivalents, including digital signals and sensations, sensors and actuators, virtual and collaborative experiences delivered through new- and social-media. Can a video-game environment be considered a work of landscape architecture? Is a virtual forest a forest at all? Is a responsive landscape alive? What kinds of virus lurk in the cyber-wilderness? How do bio-informatics, autonomous vehicles (air-, land-, and sea-), high-tech urban farming and 'tele-everything' affect the lives and work of landscape architects, and planetary citizens? These questions are grist for the JoDLA mill. Read on!

* * *

In Digital Landscape Architecture circles the term virtual reality has been used for decades.

It was always associated with representing the real environments via a digital replacement. While these replacements of reality were rather crude in the beginning, they have now become convincingly real in a sense that it is hard to distinguish nowadays whether something is real or simulated and virtual.

Similarly, conferences such as the Digital Landscape Architecture conference were always held in real environments where we could meet real people. Nowadays, the term virtual also stands for meeting real people via online communication platforms thus introducing some sort of a virtuality as we do not meet other people in person, we only meet them virtually.

This is somewhat similar to a representation of a virtual reality which is always some sort of an abstraction of the real world. In a virtual conference environment interaction with other participants is less spontaneous, less interactive, less sensory, less everything, but it allows to interact with other people in the Digital Landscape Architecture forum and it allows to exchange ideas without the need of travelling. At least, this also helps somewhat to mitigate the climate change effects of conference travel.

From a more disciplinary perspective, the advantages of representing our environments virtually, also frees up time and opens opportunities for exploring distant locations when for some, in these times, travelling is either not permitted or when it has become rather difficult due to quarantine or other regulations.

In this sense, virtual reality, is a real bonus and suddenly the old claim that we can save time and money through virtual reality becomes somewhat real. E.g., estate agents have learned quickly and for prospective buyers instead of visiting property in person, they have adapted quickly to the new situation and offer panoramic explorations of property or even stereoscopic walkthroughs by using a mobile phone in a stereo device thus saving time and money on the side of everyone involved in the process of buying or selling property.

As in previous years, conference presentations at the Digital Landscape Architecture conference will make use of virtual reality and will let us all explore remote places around the globe, sharing ideas, new insights and providing inspiration for future research.

* * *

After a year of virtual work, we are conducting our second virtual DLA conference. Early reports indicated that many really appreciated this opportunity for working virtually; I have not been one of them. As an introvert I am fine not chatting with people, but I prefer "parallel play" – I enjoy the feeling of being around people who are also working. I suspect that it has also been a difficult year for everyone else. However, I can think of two quite positive things that may have resulted from being forced into virtual lives.

First is that a lot more people have been exposed to the DLA Conference. I hope that we continue to have inexpensive virtual attendance and that we explore more ways to integrate it with in-person attendance. I am also excited about the increased exposure for the Journal of Digital Landscape Architecture as an open-source journal about developments in the field. I hope many more people consider it as a way to share their research and practice experience.

Second is the search for ways to make the virtual experience more palatable; to reduce "Zoom fatigue." It looks like some of the techniques that have been discussed at the DLA for a decade and more are about to go mainstream. For instance, Microsoft intends to bring Mesh, the mixed-reality platform that works with its Hololens, to Teams. While we have been experimenting with VR, AR and MR for some time, this will give us an opportunity to actually use it for teaching and collaborative design.

Ben Franklin is supposed to have said, "Out of adversity comes opportunity." We have been shown the adversity, now we need to seize the opportunity.

March 31, 2021

Erich Buhmann, Stephen Ervin, Sigrid Hehl-Lange, James Palmer, and Matthias Pietsch

Introducing JoDLA and DLA2021

The core of the contributions in your hands are driven by a double-blind review process. Forty-two papers were selected from the original sixty-three submitted extended abstracts during the two-phase process. We also invited two current reports to give you a wider view on the many issues on BIM.

We are very proud to also be able to publish the two outstanding keynote lectures that were given by Prof. Dr. Carl Steinitz at the Digital Landscape Architecture Conference in 2019 in Dessau and in 2020 in Boston. The text on "From (Before) Analog to (After) Digital: A Personal Perspective" gives an introduction to the analog history of the systematics in landscape architecture which was waiting to meet the first computer at the Graduate Design School in Harvard in 1964. This perspective of Carl Steinitz also tells a great deal about the story of American Landscape Architecture. Carl Steinitz then describes the transformation from "analog to digital methods", which he sees mainly as transformation of older ideas to digital tools.

The second keynote of Carl Steinitz, which Brian Orland co-authors, focuses on the future of landscape architecture education and practice. As digital landscape architecture enables more varied and appropriate design methods for these challenges, Carl Steinitz urges that the challenge of more collaborative engagement in design for larger, more serious global challenges should be taken. In his final statement, he gives four clear possibilities for the future of digital landscape architecture, within the profession and as an academic field, and not all are digital!

After these essays on defining Digital Landscape Architecture, the Journal offers you a wide range of current research and practice in digital landscape architecture. Please find the reviewed essays on

- Resilient Landscape, Global Change and Hazard Response
- Visualization, Animation and Mixed Reality Landscapes (VR, AR)
- UAV Imagery and Remote Sensing in Landscape Architecture
- Geodesign Approaches, Technologies, and Case Studies
- Landscape and Building Information Modeling (LIM + BIM)
- Digital Landscape Architecture in Practice
- Algorithmic Design and Analysis Landscapes
- Teaching Digital Landscape Architecture

As already mentioned, we have invited two contributions on BIM to this issue. You will find the thank you to the reviewers and more details on this year's review process in the closing chapter Acknowledgements.

Besides publishing in this peer-reviewed publication, the exchange with many others working in the same area is essential to the idea of DLA. All authors who manage to master the strict review process for JoDLA are invited to present their papers at the DLA Conference. The outreach to the first all virtual DLA 2020 in Boston with 1000 registrations and up to 400 signed in at any given time was clearly much larger than the years before.

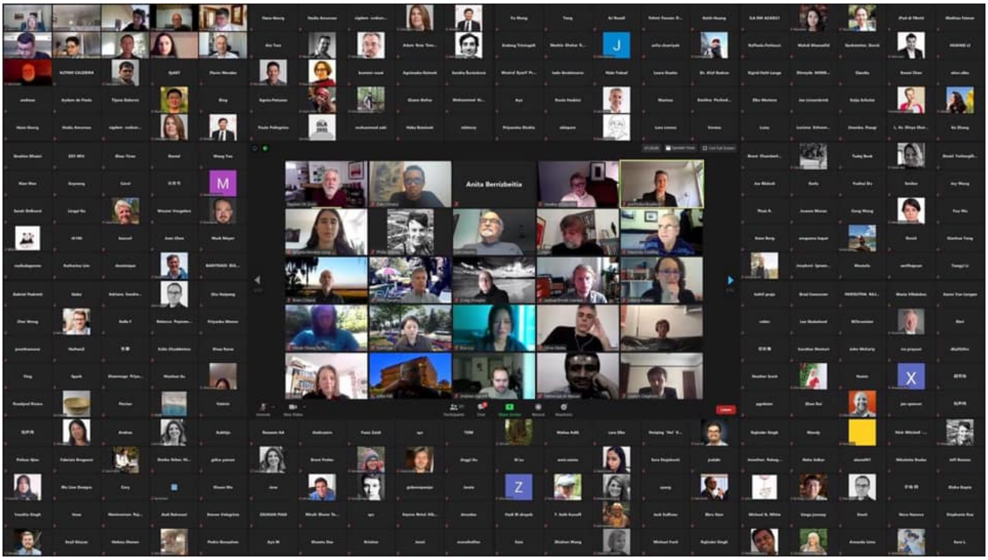
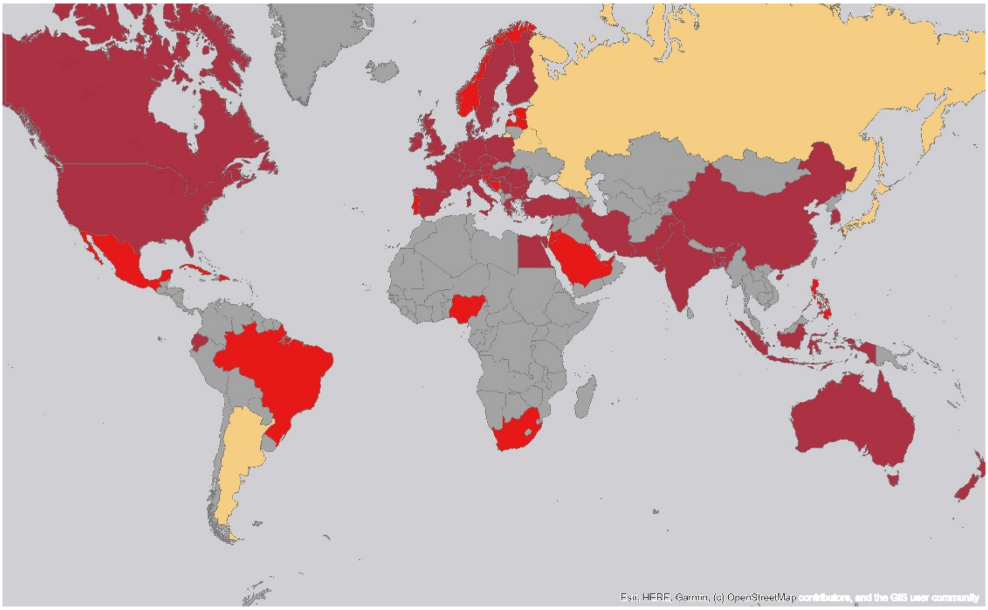


Fig. 1: The virtual DLA Family 2020 – screen dump by Stephen Ervin

We have learned that future DLA Conferences will include a virtual component in order to reach out to colleagues and students not able or willing to travel long distances. The participants of DLA 2020 came from 56 countries. Dark red indicates regular participation in previous years, bright red first-time participation. While the virtual conference surely contributed to the relatively high number of 17 new countries because visa restrictions and travel costs were not factors, due to current circumstances five earlier participants (indicated in yellow) were not able to participate this year: Belarus, Russia, Malta, Argentina, Israel. The DLA has now reached out to 61 countries, or to about a third of the world's nations.

The virtual communication tools will help us to continue to reach out to all who are working in the industry, in universities and in practice to further develop our digital tools. How can we use the digital twin in order to manage our resource landscape in a resilient matter?

After the outstanding first all-virtual DLA Conference in Harvard in June 2020, we had been preparing a hybrid version of the DLA at the spacious conference facilities of the UBA headquarter, the German Environmental Agency in Dessau to be held in May 2021. In March of 2021, we had to chance our plans as hardly any of our 80 speakers had been vaccinated at the time. Because the current infection rate in Germany is critical, we reduced the "hybrid" to around ten colleagues moderating live in order to have the best possible communication between speakers and participants.



Australia	Dominican Rep.	Italy	Saudi Arabia
Austria	Ecuador	Jordan	Serbia
Bahrain	Egypt	Latvia	Singapore
Bangladesh	Estonia	Lebanon	Slovenia
Belgium	Finland	Mexico	South Africa
Bosnia and Herzegovina	France	New Zealand	South Korea
Brazil	Germany	Nigeria	Spain
Bulgaria	Greece	Norway	Sweden
Canada	Hong Kong	Pakistan	Switzerland
China	Hungary	Philippines	The Netherlands
Croatia	India	Poland	Turkey
Cuba	Indonesia	Portugal	United Arab Emirates
Czech Republic	Iran	Republic of Korea	United Kingdom
Denmark	Ireland	Romania	USA

Fig. 2: World map of DLA 2020 registrant's countries in red, first time participants in bright red and previous participants who did not attend in 2020 in yellow (graphic by Nastaran Tebyanian)

We would like to thank all who are contributing to our attempt to strengthen the impact of landscape architecture in order to strengthen the use of digital methods and tools. You are invited to reach out to all colleagues worldwide to network on the benefits of digital landscape architecture to a more resilient future.

The documentation of the past and future DLA conferences is found at http://dla-conference.com.

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Defining Digital Landscape Architecture

From (Before) Analog to (After) Digital: A Personal Perspective

Carl Steinitz[1]

[1]Harvard University, Cambridge/USA · csteinitz@gsd.harvard.edu

Keynote at DLA 2019 on May 23 at the Bauhaus Aula, Dessau

Abstract: Where did the ideas that shape the methods that we have been talking about in this conference for the past 20 years come from? And what was the development process? The transformation from analog to digital is only a small part of that development process. My presentation has examples that span 5,000 years. In this presentation, I speculate about the history of the development of the ways in which we look at the landscape and propose to intentionally change it… by design. And I will also offer some speculations about the next years.

Note: This presentation is based on the transcription and images of my unscripted keynote lecture at DLA 2019, which have been lightly edited and added to for this 2020 version. My somewhat informal style has been retained.

Keywords: Design methods, design tools, analog methods, digital methods, history and development

1 Introduction

I have the advantage of having been among the senior colleagues and friends for the twenty years that Erich Buhmann has organized the Digital Landscape Conference and so I get advance notice as one of the people who gets asked about what the next year's theme should be. And when Stephen Ervin developed the 2019 topic there was a subtopic called "Analog to Digital". I immediately said to Eric and Stephen "That's the story of my life. I'm going to give that lecture."

I have been thinking about issues related to this theme for a very long time. I'm interested in the genesis of the ideas that shape the methods that we have been talking about in this conference for the past 20 years (STEINITZ 2009). Where did these ideas come from? And what was the development process? The transformation from analog to digital is only a small part of that development process. My presentation has examples that span 5,000 years. I am going to speculate about the history of the development of the ways in which we look at the landscape and propose to intentionally change it… by design. And I'll also offer some speculations about the next years. It's risky. In my work I like to think two generations ahead, but technically it's not so obvious what will happen in the future. Nonetheless, I'm going to make some speculations in the end of this presentation about the next years and where I think the most important questions for research and development are. And it is a personal perspective. I am not an historian. I'm a collector and an adapter and I sometimes get an idea that may make sense.

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2 Before Analog

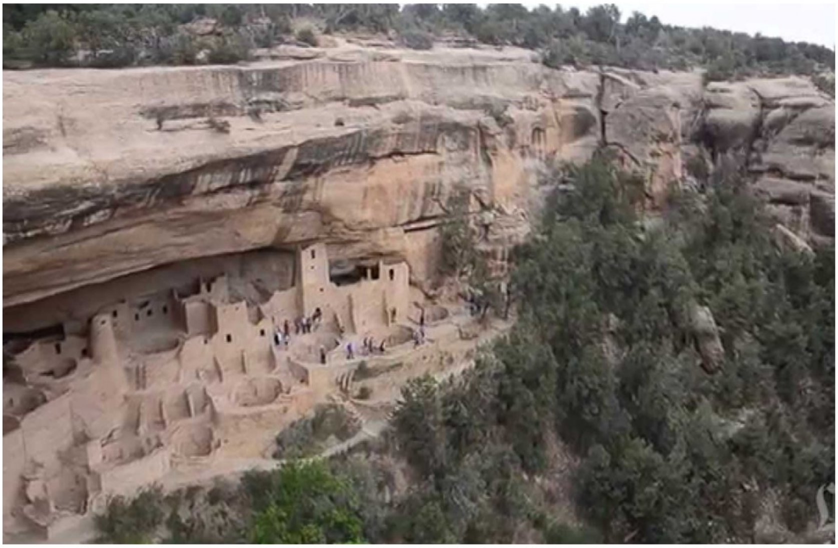
This first image is a settlement in a remote part of the Philippines. It's a settlement that could be a thousand years old. Nobody knows. It's an old photo. It was taken and given to me by Charles Harris who hired me at Harvard in 1964. I have often used this slide in my theories and methods course in my very first lecture. I always asked my students to write down the rules to explain this place. And they think about it for a little while and then we discuss it… and it turns out that there are about five or six rules… and these are the rules more or less, not necessarily in priority… but maybe they are in priority.

Luzon,
The Philippines
Charles Harris
1956

Fig. 1: A settlement in the Philippines

The first one is: don't build in the flood plain… it's hazardous. The second is: protect your agricultural land. The third one is: build where it's sunny. The fourth is: don't build where it's erosion prone. The fifth is: keep some forests for materials to build, for tools, maybe for food and for fire… and maybe that's enough. The resulting pattern is the pattern of life. It's probably family life, and it might be a very traditional process of agriculture… And while you can explain it in greater depth, those five or six basic rules are the important ones. So please remember this image, as I will show it again. It's based on rules. There is nothing special about the rules. They make sense. They produce an aesthetic. But they're basically for day to day life for normal people in their environment. There is nothing special about them.

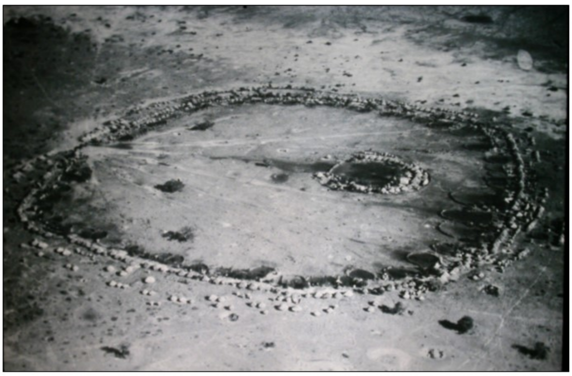
Another rule might be: protect yourself. Be prepared to defend yourself against enemies. It could also be to stay cool in a hot landscape. This is Mesa Verde, a very old Native American settlement in America.



Mesa Verde, USA

Fig. 2: Mesa Verde, USA

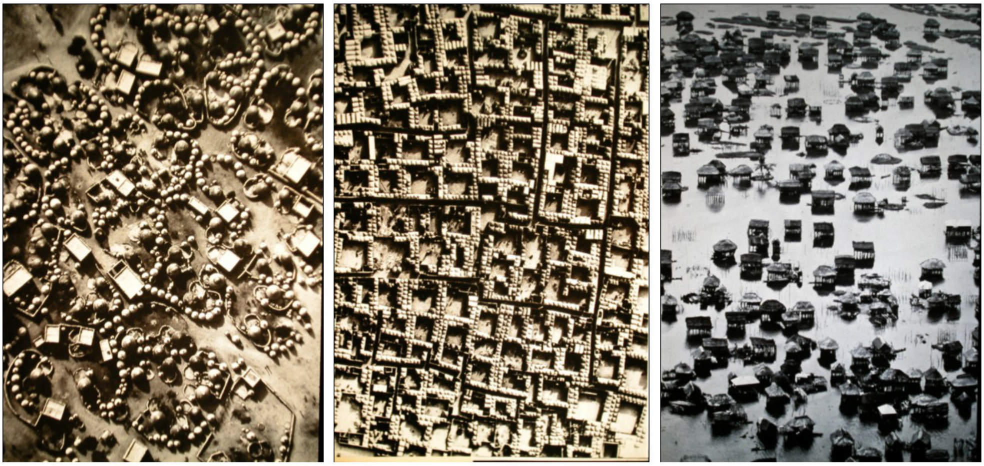
Another rule is if you have cattle and are polygamous and you have a Chief, then design your settlement in its landscape to protect your economy and organize your society. This is a polygamous, Chieftain-based society in which cattle are wealth and sustenance.



Bernard Rudofsky, Architecture Without Architects, 1964

Fig. 3: A polygamous, Chieftain-based society

And if the climate changes, change the way you live. Some of these images come from a wonderful book by Bernard Rudofsky called *Architecture without Architects,* which was a book that I read in 1964. It was very influential on a generation of architects of which I was one. It had an implicit basic message: People aren't stupid. They learn how to adapt, design and survive.



Bernard Rudofsky, Architecture Without Architects, 1964

Fig. 4: Adaptation to climate

3 Analog

Analog… Most of us use this word wrongly. We use it as representing a set of technologies that aren't digital. But analog really means that it is analogous – something that is comparable to another – an analog of the exterior world. In other worlds, there is an analogy… a larger idea… a construct that determines how we design things.

This is Upper and Lower Ogol, a Dogon settlement in Mali. It is very complicated. It's a highly symbolic pattern of organization. The roof *is* the family. Each family has to make the roof of its house, and then carry and place it on the tall and small building. And there are lots of them.

And the question is: What explains this pattern of settlement? And the answer is: the human body. This is a French priest's interpretation, having lived there (GRIAULE 1965). The altars are at the feet. The altars are masculine. The oil stone is feminine. The women's houses are on the sides, and outside when menstruating. The family houses are the chest and the assembly place is the head. And the council meets in the northern building near the forge, the source of fire, which is the community's enabling power. That is the organization of this place… And you either know it or you don't… and this knowledge is transmitted by oral tradition.

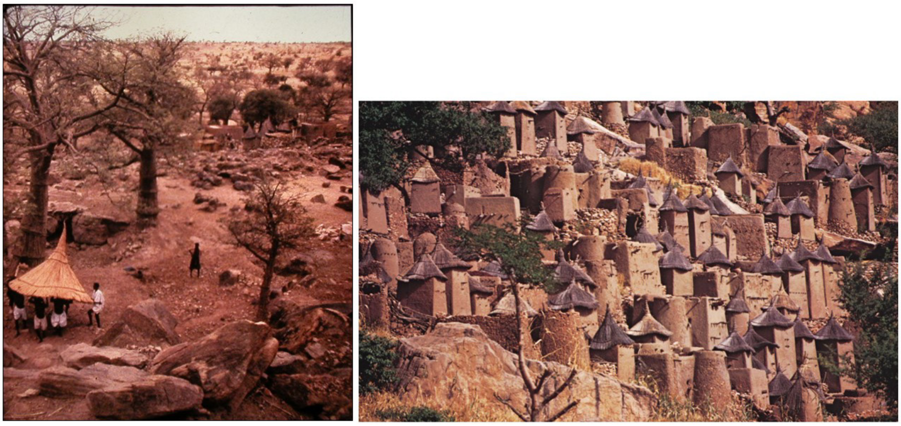
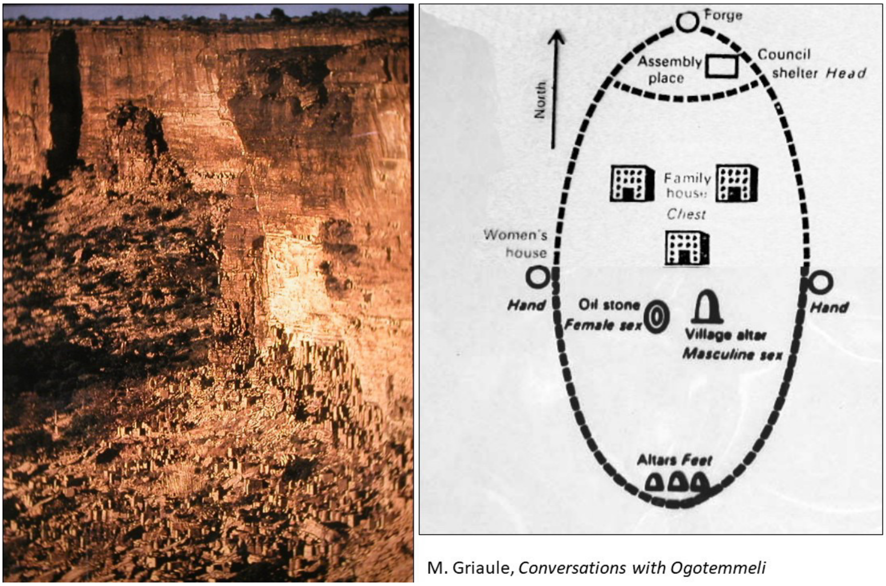


Fig. 5: Family houses, Upper Ogol and Lower Ogol, Mali



M. Griaule, *Conversations with Ogotemmeli*

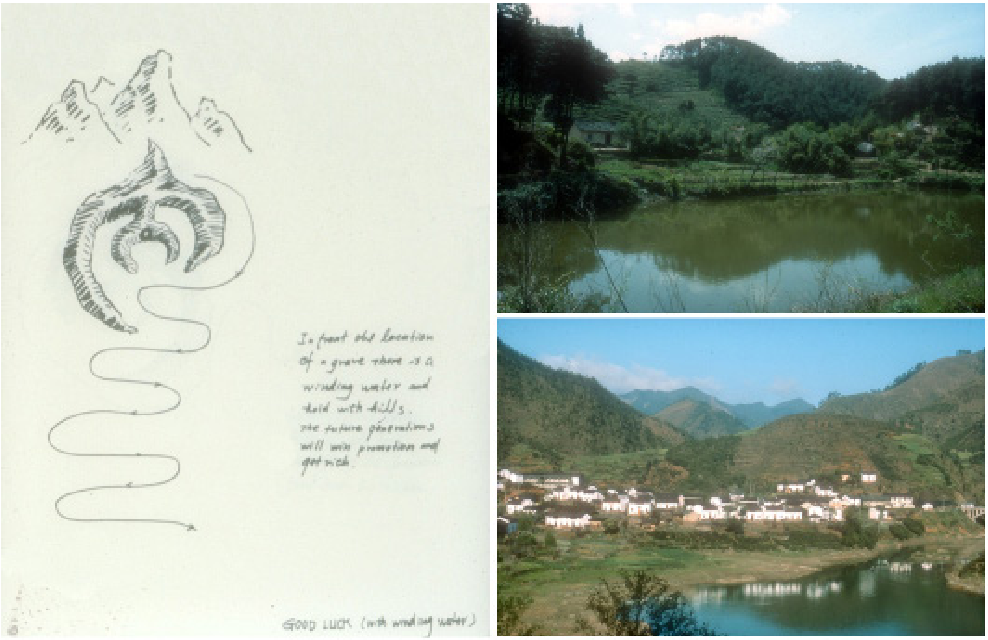
Fig. 6: Upper and Lower Ogol settlement pattern

There are Chinese books in the Harvard Yenching library about Feng Shui from three thousand five hundred BC (XU 1990, 2016). The ideal site in Chinese Feng Shui is for a grave. The grave takes precedence over the house. The house takes precedence over the city. The ideal form to locate a site is surrounded by the tiger and the dragon and has three layers of mountains behind. And there are thousand year old books that interpret these landscapes. There are two schools of interpretation. There is the form school that basically analyzes the physical landform for auspiciousness; you build or can make an site. Or there is the compass school which deals with orientation as the basis for assessment. These are competing schools. They are not compatible… Either you use one or the other.

Xu Ping Feng Shui, est. 3500 B. C. Form School Compass School

Fig. 7: Feng Shui form school and compass school

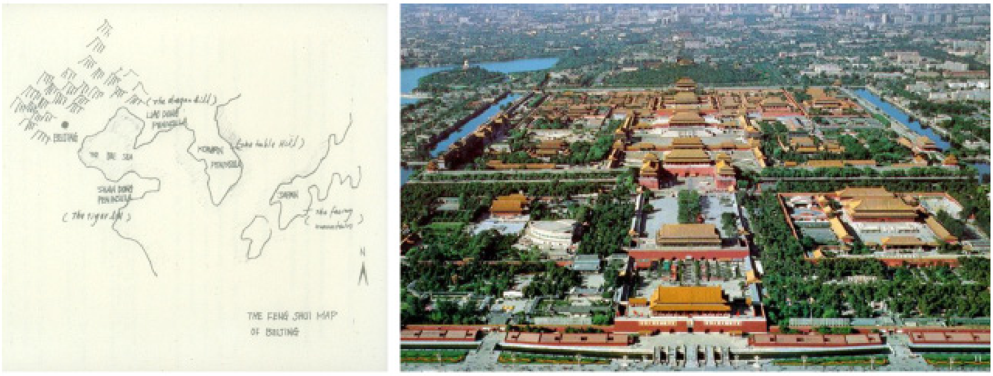
So the ideal site is this, with running water not aiming at you but going away from you. And those are the graves on the right in the best location and that's the house on the left. The graves – the more important ones. And that's a village in an ideal location.



Xu Ping

Fig. 8: Feng Shui form school ideal sites

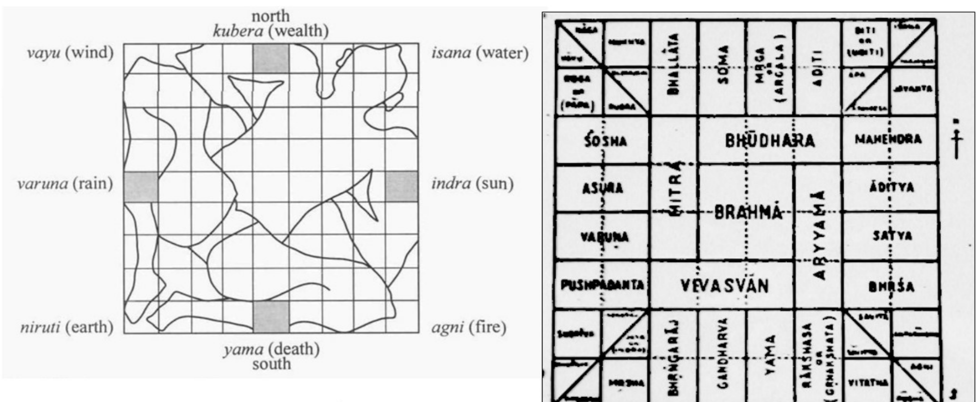
And that is the location of Beijing with the dragon and the tiger and Japan in the distance, and the water follows that principle. The location of the country's Capital city and the seat of the Emperor and a simple farmer's grave… they follow the same analog worldview. Feng Shui was considered superstition and outlawed in recent times… but it is still present.



Xu Ping

Fig. 9: Beijing, an ideal location from Feng Shui form school

The Manasara [1] is a sixth century Hindu document which identifies the conditions of the ground for a temple or for a town plan. There are instructions and tools. The conditions include smell and taste. You are supposed to taste the ground for acidity, and you are supposed to hit the ground with a hammer and if it's rocky it will make one sound and if it's sandy it will make another sound and if it's wet it will make a third sound. The organization of the community is based on the caste system and the roles they play in society, and the auspicious areas are for the higher castes and the less auspicious are for the lower castes, not unlike social class analyses of modern cities.



Manasara, Vastu Shastras, 6th C.

Fig. 10: Manasara, ideal settlement organization

The social organization must be designed in one of eight canonical town plans… and anything else is evil. The concept of evil is a site plan criterion. And this also applies to the house, where different functions are in different locations. There is a best location orientation and there is a worst… auspicious and evil… a worldview analog.

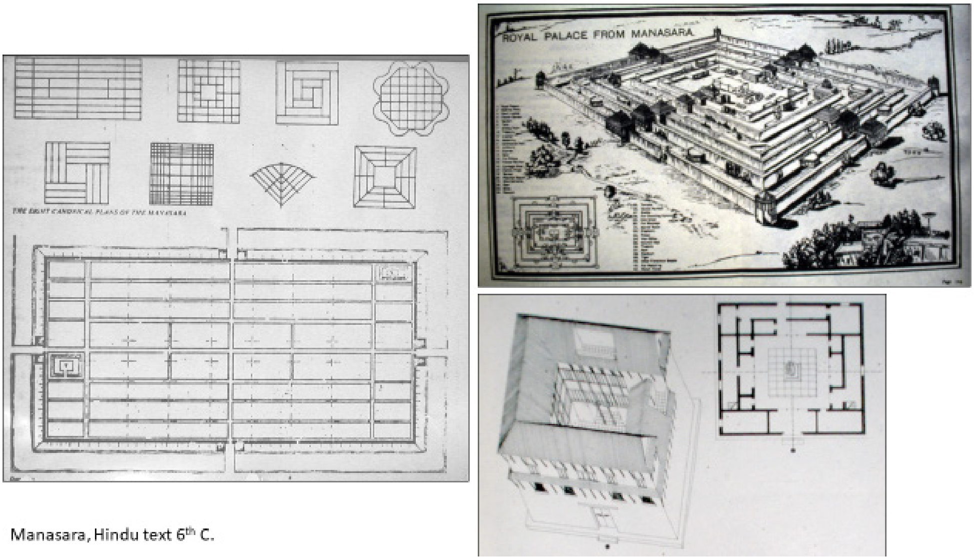
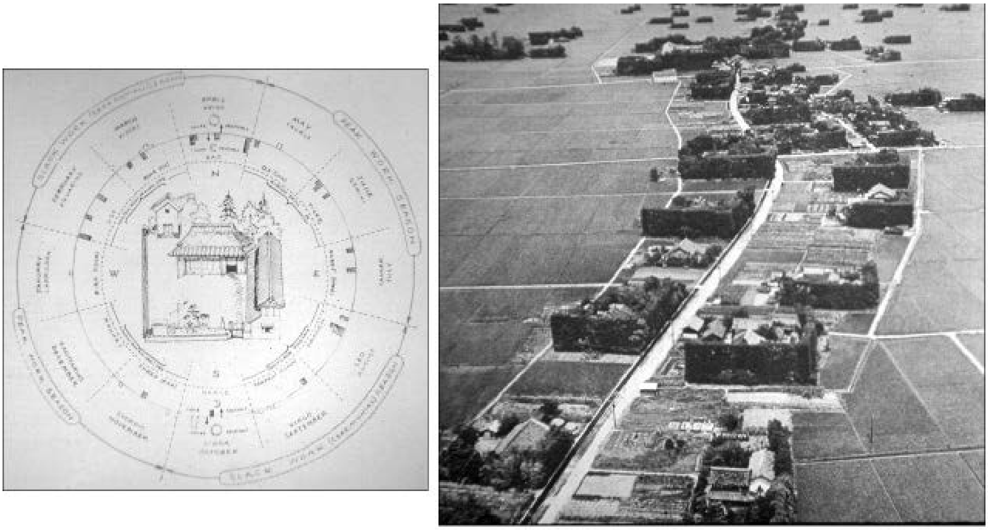


Fig. 11: Manasara, ideal organization of 8 town plans, temples and houses



Bernard Rudofsky, Architecture Without Architects, 1964

Fig. 12: The zodiac and Japanese farm houses

The zodiac is what determines the shape of rural farm houses in some parts of Japan (RUDOFSKY 1964). There is a reason they all look similar. That's because they're based on the calendar of the zodiac and where the winds come in different directions and where the sun comes in different directions at different periods, and the different seasonal activities of being a farmer. And you see them in Japan today.

Fig. 13: The zodiac and Japanese farm houses

So these are analogs: The central idea is that there are super-ideas that govern what we do technically with our methods and our technologies. And you can fairly ask… it is legitimate to ask the question of us today: "What is your super-idea? What is the analog?"

The most basic tool is really simple. It's a string and a rock. And the characteristic of applying a string and rock to the design for dividing land for tax purposes and ownership leads to a particular kind of orthogonal design with straight lines. It leads to simple geometries because they are easier to measure. Curves are hard to measure. Straight lines are easy to measure.

Fig. 14: Surveying in ancient Egypt to divide land for taxation and for building, 3000 BC +-

You need to make maps to record the landscape. Maps are also old tools. On the left is the earliest scale map according to Wikipedia, and this map is 3500 years old. It's Nippur, in Sumeria, now mainly Iraq. It's a carved clay tablet with a map of central Nippur. And on the right is a map of China that is a thousand years ago. China's coastline and river systems are clearly defined and precisely shown on the map. You measure and somehow record the lines in each grid cell, then you put a grid on a large flat stone and redraw your lines on the stone and carve them… and you have a scale map of a huge area.

Fig. 15: Map of central Nippur, 1500 BC +-, Map of China, 1137

This is the region of Angkor Wat in Cambodia. Its development is a thousand years old. It is huge, and it is orthogonal in a jungle. That's it on Google Earth. That's the city of Seam Riep. This temple complex is about 30 kilometers by 20 kilometers. And it is fully orthogonal. It was designed and constructed without Google Earth, without satellites, without drones. It was done on the ground, with bamboo sticks, string and stones. In a sense, surveying precedes landscape architecture by a long time… by about 5000 years… and the technologies of terrain analysis precede us by about 4000 years…

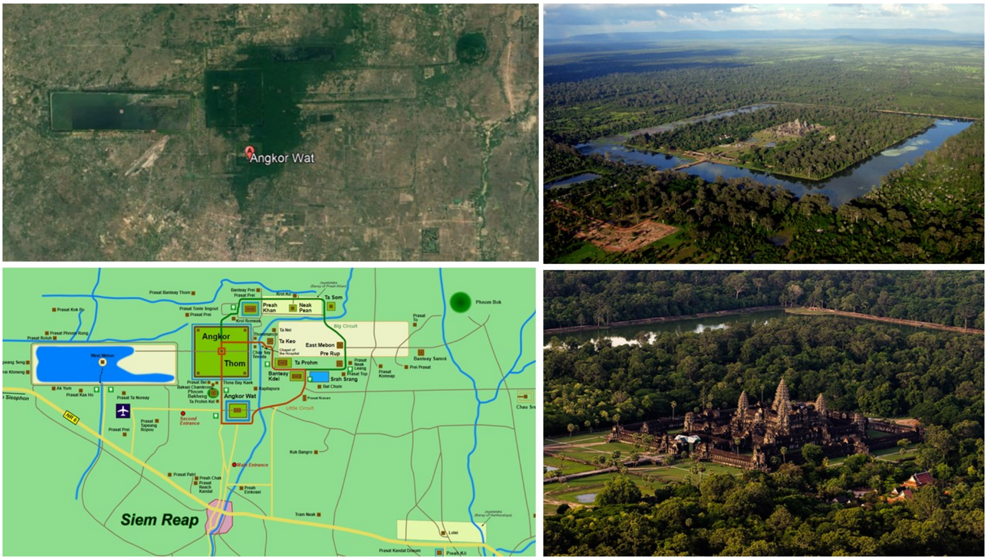


Fig. 16: Angkor Wat region, Cambodia, 12th C

Surveying eventually reshapes the land. That's Thomas Jefferson (1743-1826), third President of the United States of America. When he decided in 1785 to divide what is now the middle of the United States, he sent his surveyors and they changed the landscape. At the time, that one project was one third of the United States of America.

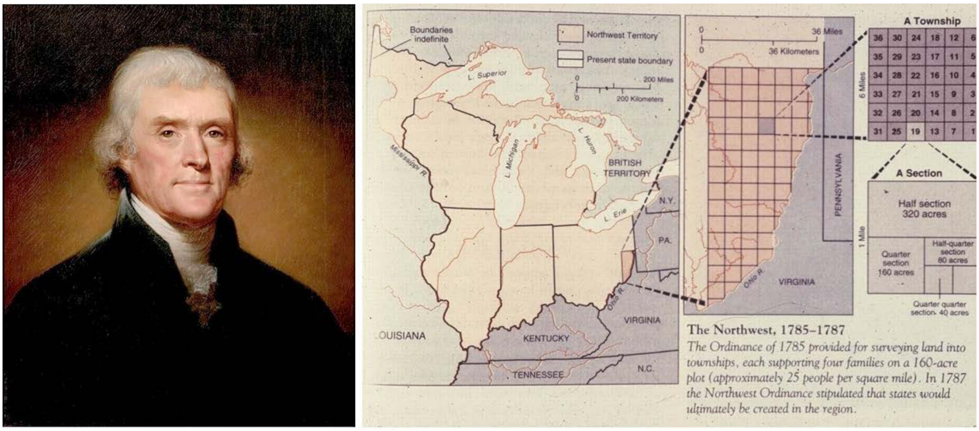


Fig. 17: Thomas Jefferson and the Northwest Ordinance

You can still see those patterns if you fly across the country. They are very powerful and lasting changes based on surveying techniques which are based on very simple measurements. But you have to do them, and now you can do them digitally from satellite-based measurements.

Fig. 18: Current land in the Northwest Ordinance

So the ideas of mapping are old and basic. We tend to consider tangible drawn maps on clay, stone or paper to be an analog representations, because they are symbolic representations of the real world. But we can map the same analogical representation digitally and we would call it a digital representation… how confusing. Surely it is the data which are the analog, and not the representation medium. So when we are working digitally, we're not so different from these earlier people. We're also making spatial analogs and using them. And some of us use them more cleverly than others… but the tool is to organize data as an analog of the real world… and then to represent the study-area.

Fig. 19: Before and After

One of the really important innovations was by Humphrey Repton (1752-1818), the idea that you can make a visualization of a design but that you need two of them, before and after… so I can know what was there before and what the designer changed. I have rarely seen a design presented in two drawings in this conference over the past 20 years, and in 50 years by students that aren't mine. How many of us tell our students it takes two drawings or maps to show a design? Repton was absolutely right! We're usually wrong.

The idea that maps were public as opposed to private is probably 17th century. The English Ordnance survey began in 1801. The Ordnance Survey in England had as its task to produce maps at the level of a house and at the level of at least a group of trees and with roads, streams and terrain, at a national scale. The equivalent still doesn't exist in many parts of the world.

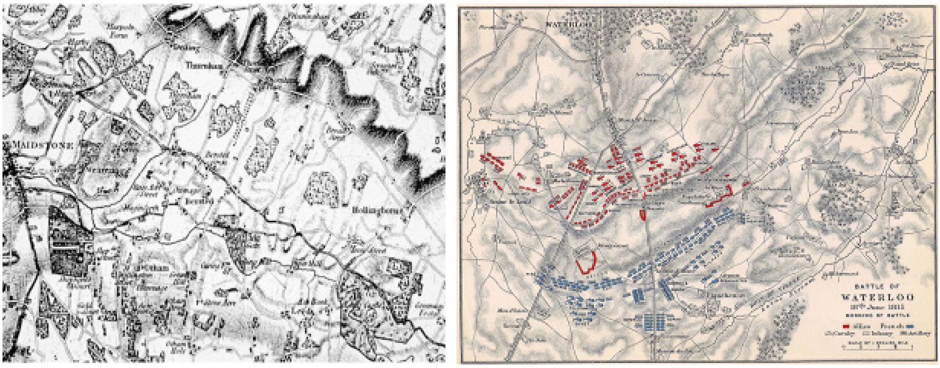


Fig. 20: Ordinance Survey, England, 1801 and map of the Battle of Waterloo

When Peter Joseph Lenné (1789-1866) designed the expansion of Berlin in 1833, you see a drawing made on a map that has every road and every building, and you have to ask where did that map come from? How did that happen? And it's clear that somebody decided… years before… to start making maps of every building in Berlin, and so, when Lenné makes his drawing, it is on a base map and in scale.

Fig. 21: Peter Joseph Lenné, Expansion of Berlin, 1833

And that's his drawing of his remaking of the Tiergarten. It is also a changed drawing based on a drawing.

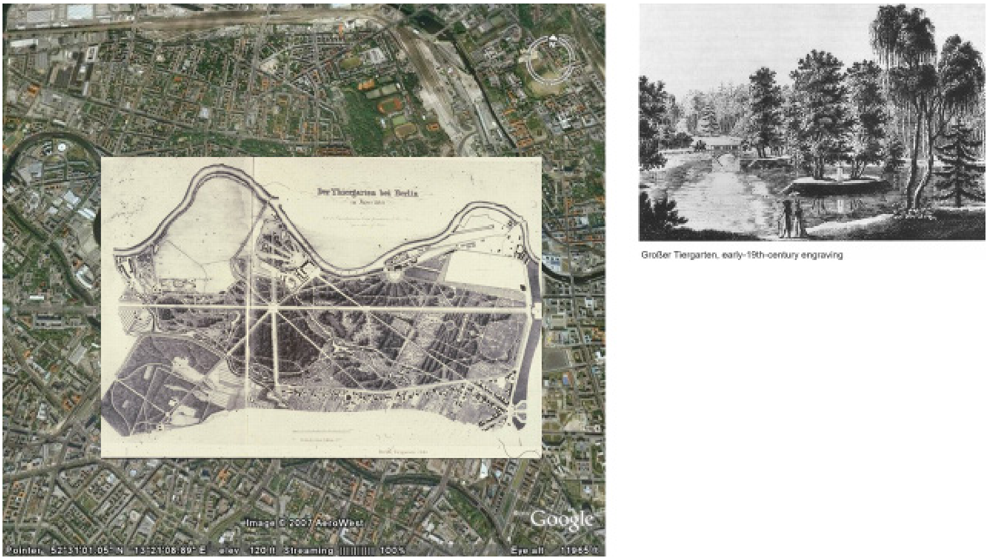


Fig. 22: Lenné, Tiergarten in central Berlin

And that's what the Tiergarten is today.

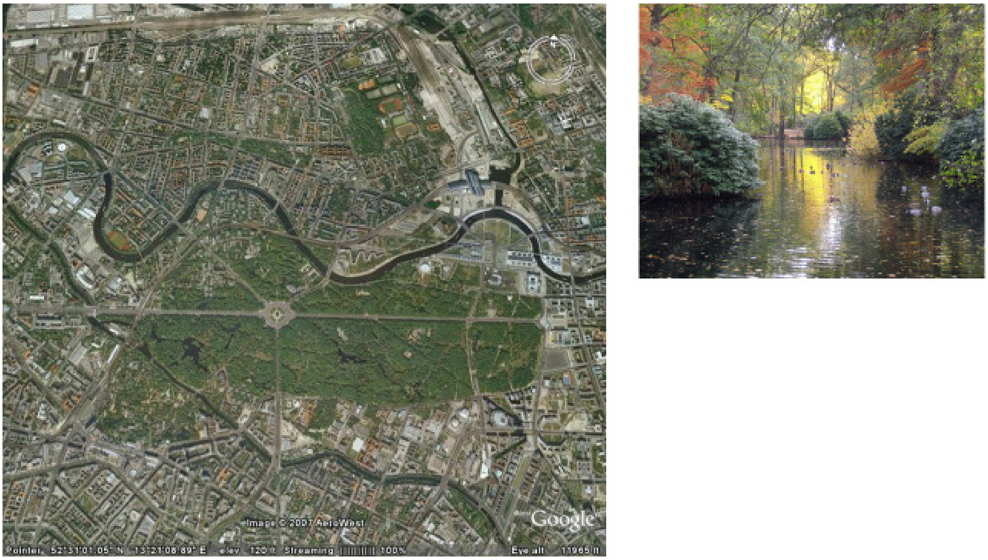


Fig. 23: Tiergarten, Berlin

But consider the time of Lenné. He had no air views. The surveys and assessments in the base map and his design were all from the ground; which is important because that's how the area could be perceived. Basically, Lenné was working in the way most landscape architects still work professionally most of the time. Today, we also have survey-based maps, and we change them by design into other maps. And we draw perspectives (probably only after-views), and we say: "This will be a great place… let's build this place…" In other words we haven't learned so much since the times of Repton and Lenné.

The next example is a methodological breakthrough. Warren Manning (1860-1938) was a landscape architect in America. He was a very important landscape architect. He initially worked for Olmstead and the Olmstead office had its technology at the right time. They had electricity and Charles Elliot wrote that there was a light table in that office. They also had materials to draw on that were translucent. They were not transparent but they let light through. So you could make a drawing, put it on a light table and put another drawing on it, and as long as those drawings were at the same scale and in the same geo-referencing system you could basically make overlays. So Manning made separate maps of different influential data for the town of Billerica Massachusetts… not one analogy-based map for the site analysis like the Chinese would do but separate maps… one of soils, one of roads, one of slopes… not too many, maybe five or six… and he put them all together and he evaluated where the houses should be. The method was published in Landscape Architecture in 1913. This is the first published use of overlay techniques from separate data maps that I'm aware of. I've written a paper on the history of overlay methods (STEINITZ 1976)… Manning's was the earliest published example.

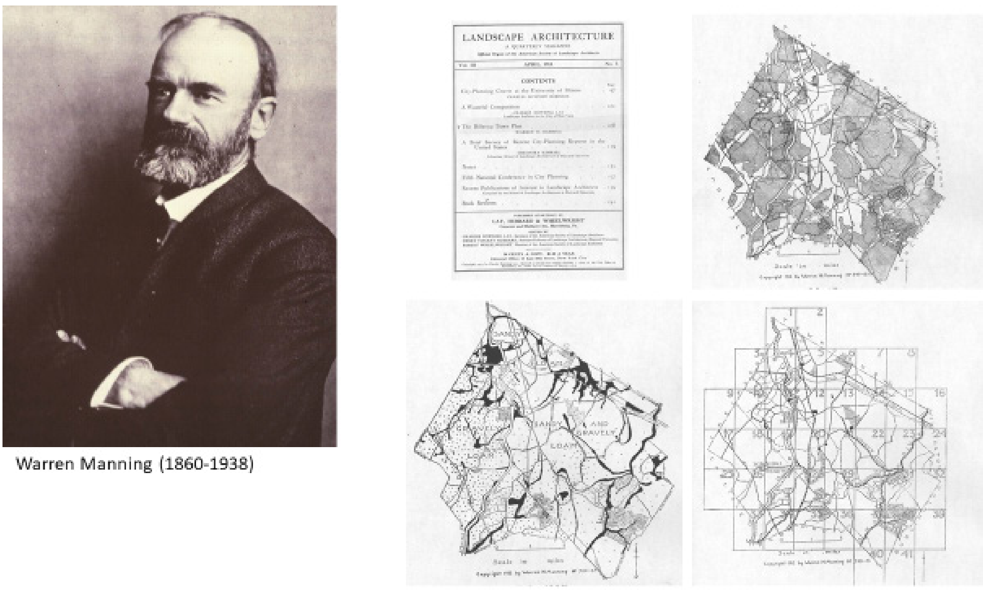


Fig. 24: Warren Manning, Billerica, 2013

The most important early example of overlays is this next one, also Manning's. The early part of the 20th century in America is when the country started producing national maps of its assets. It's a big country and the government wanted to know what we have. About 400 maps were made, and Manning redrew them to one scale in ink on a translucent material. Manning could then overlay these maps on a light table.

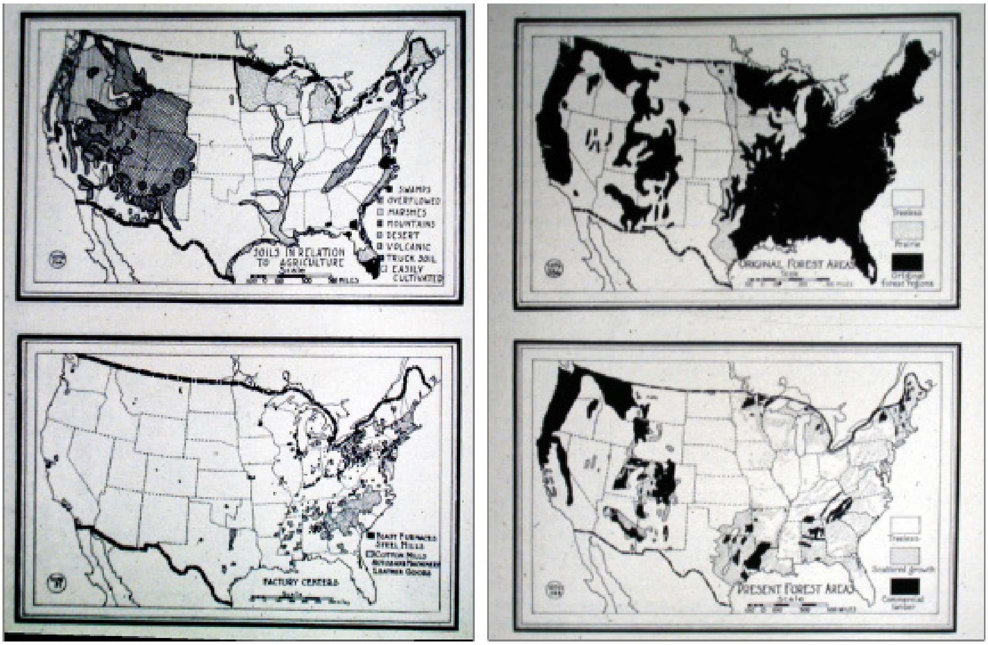


Fig. 25: USA data maps, redrawn by Manning, early 1920s

Manning then made the first design for the whole United States of America. This is one of the most important projects in the history of the profession. It was published in Landscape Architecture in July 1923 and to my knowledge, to this day it's the only physical plan for the United States of America as a whole that was ever made. And what does it have? It has the Interstate Highway Network. It has the national trails along the Atlantic and the Pacific. It has major reserves of National Parks, particularly in the West and the Southeast. It has future urban areas along the coasts and the South, on the West Coast, the Great Lakes region and the Northeast. It was designed with overlays of national data on a light table with pencil and ink and a lot of thought. It's very impressive.

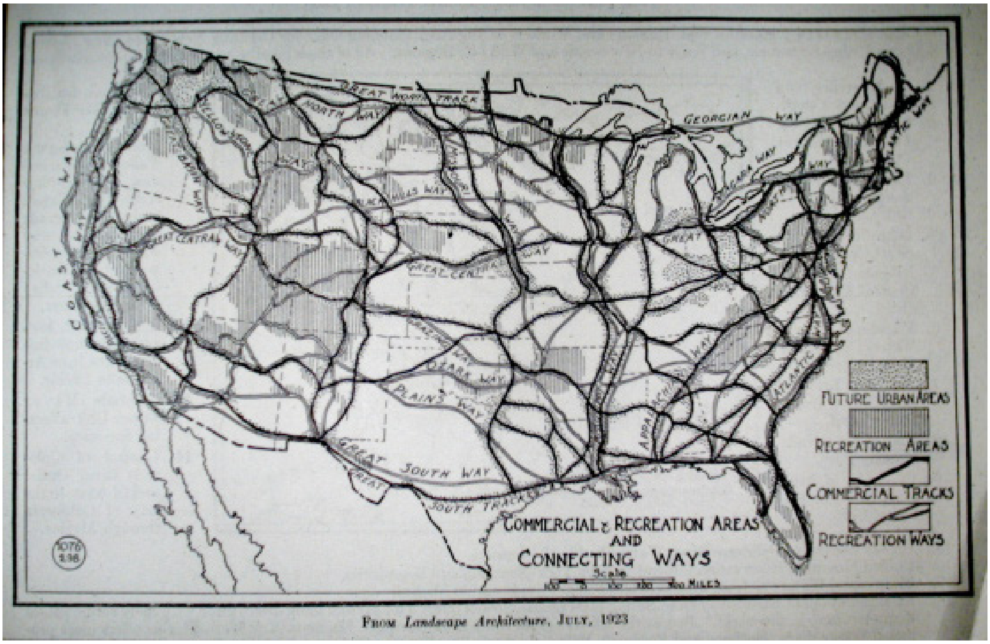


Fig. 26: Manning, Design for the USA, 1923

Patrick Geddes (1854–1932) was a philosopher, a biologist, and a planner… a polymath. As an evolutionist and a global thinker, he was interested in the interrelationships between people, their activities, and their environment. The Valley Section diagram expressed those relationships. The Section begins in the mountains and falls to the coast. At the highest elevations in the mountains, it is natural and usual to find miners; in less high areas to find forests and woodmen; lower to find hunters and shepherds; still lower, peasant farmers and gardeners; and finally, along the shore, fishermen. Failure to respect these human-landscape interrelationships either doesn't work or requires too much energy and too high a risk.

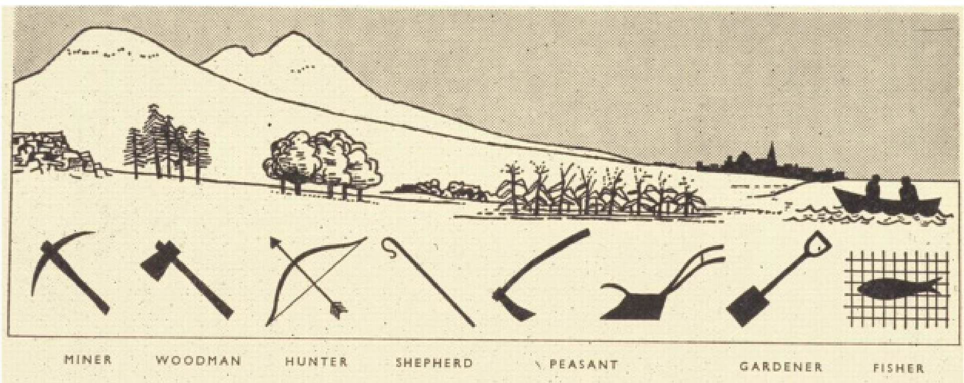


Fig. 27: Patrick Geddes, The Valley Section

This is the earliest diagram of systems interaction that I've ever seen, although there may well be others. It is from Fagg and Hutchings' 1930 book *An Introduction to Regional Surveying.* Fagg and Hutchings were influenced by Patrick Geddes. Human life and Civilization are based on vegetation and animal life which are based on drainage hydrology and the terrain and these are based on the earth's geology and climate. What else do you want to know? And each of these interacting processes implies a model. And when one process changes, that changes the others. That's what Fagg and Hutchings wrote in 1930 and that's exactly the kind of systems thinking that many of us are working in today.

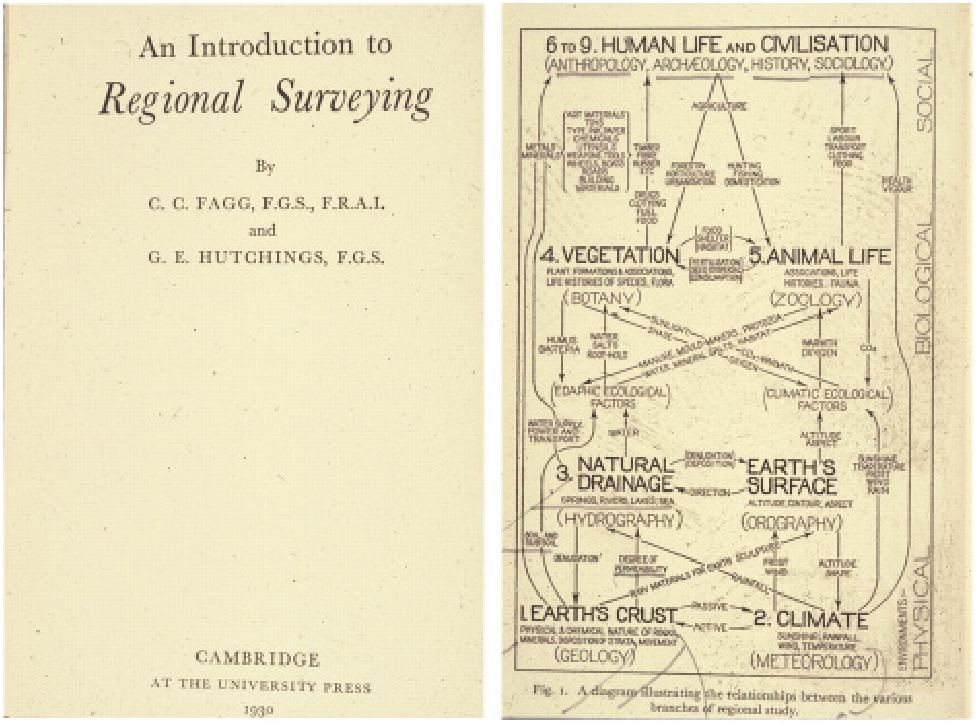


Fig. 28: C. C. Fagg and G. E. Hutchings, 1930, and The Branches of Regional Study

During the Second World War, the British had known that they had a huge rebuilding to make. This was also true in Germany, France, Italy and other countries, but the British were organized about this. "Regional Planning", by L.B. Escritt and published in 1943, is less than one centimeter thick. If my beginning students would read this book, they would know much of what I teach. For example, they would learn how to make overlays, and how to use them to analyze the landscape for particular purposes. The techniques are simple and effective. I want you to look really carefully at this drawn figure based on Boolean logic. There are five data categories, and there could be more. It doesn't matter what their contents are. But each of them is produced as a line drawing in a different orientation (or none). They happen to have different symbols but that's not the important part. It's the varied orientation which is important. Each combination of these is different and each different combination is used for a potential different purpose or constrained for different reasons. The advantage of making overlays in different orientations is that you know what the elements are, not just that there are more of them in any location.

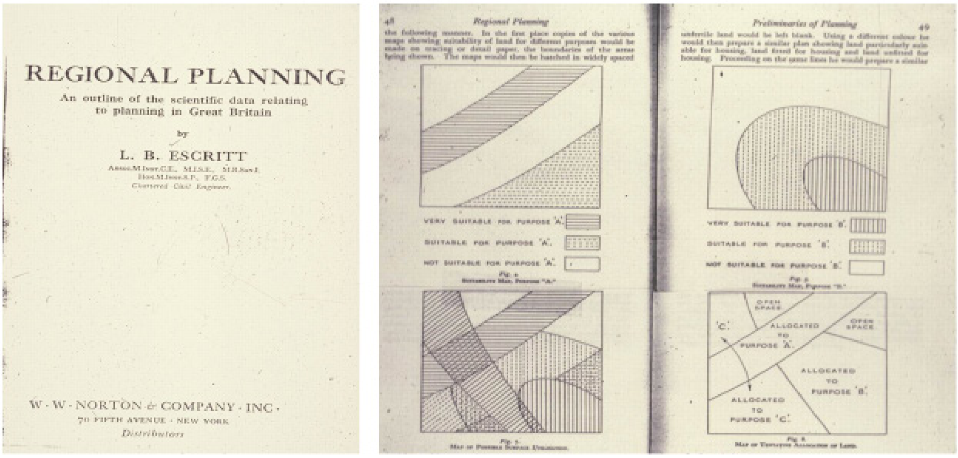


Fig. 29: L. B. Escritt, 1943, and overlays in Boolean Logic

The British produced very good correspondence courses for the military on the theory that the people who were then in the military managing the war would come back and manage the country. The textbook proposed that every place needing physical redesign needed twelve data-based assessment maps… and from those twelve maps they could make a town or/and country plan. They didn't need big data, they needed twelve. And these are how they should be drawn.

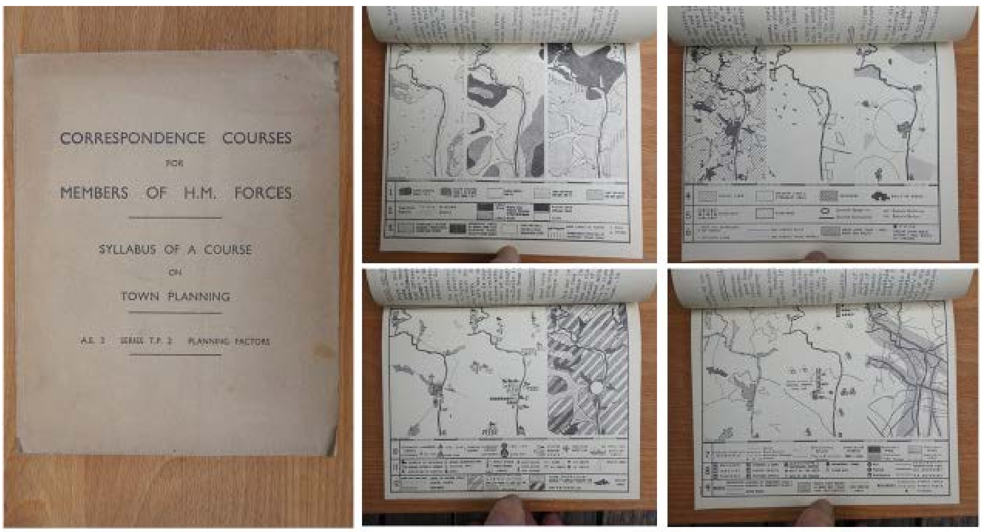


Fig. 30: Syllabus of a course on town planning, UK, and 12 data based assessments, 1945

Look at the postwar application to Exeter, which is the only example that I have found. Exeter was heavily bombed. Black means leave it alone, it's still functioning. White means it's unconstrained, you can expand the city there. And each of these overlain combinations can be read by their orientations as to what's going on there, and the more there are the darker it is and therefore it's more constrained. Almost no current GIS software produces as sophisticated an analysis as these examples then made by hand. These are more easily understood analyses than what we're producing today.

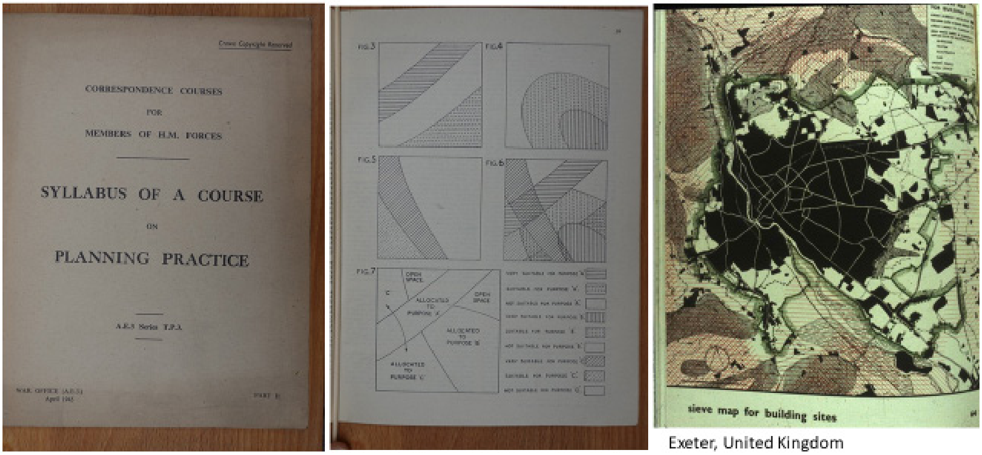


Fig. 31: Boolean logic overlays, and sieve map for the Plan of Exeter, UK, 1945

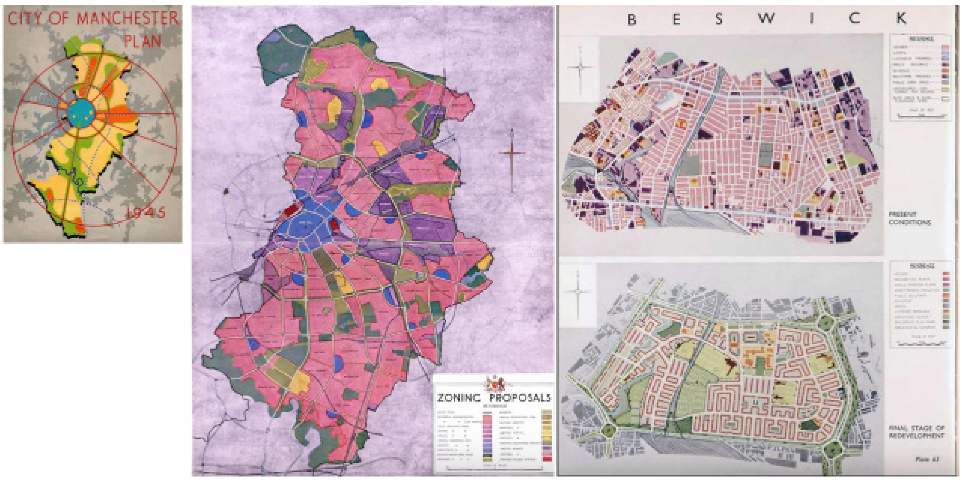


Fig. 32: City of Manchester Plan, UK, 1945

And not only that. Today, almost all digital software uses colors. However, when overlain and combined the summary map normally has changed all the initial colors and nobody can tell what the original elements were. If you were working in the Britain in the postwar period and making a colored plan drawing, these are the national colors that you would have to use, so that the sum of local plans could all be read and coordinated for larger regions. The colors of Windsor and Newton became the official colors of the planners who were educated around that time. After electing a socialist government, in 1947 the British nationalized planning control of all land. They were able to implement a very good planning system very quickly because they had the books to teach the planners and national conventions for analysis and representation. Who has a set of standard colors today? Who even makes a legend on every digital PowerPoint slide?

In 1964, Christopher Alexander and Marvin Mannheim were at MIT. Both were interested in design methods. Earlier, they had started a study of road location. They decided that there were twenty six factors that would influence the location of a highway.

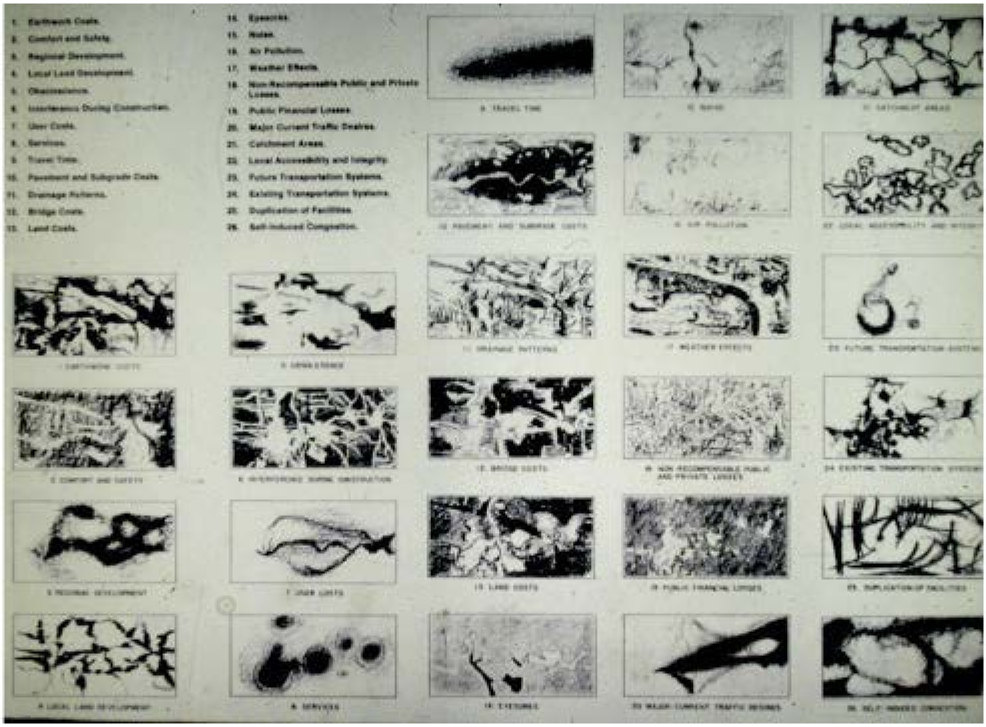


Fig. 33: Christoher Alexander and Marvin Mannheim, 26 highway criteria, 1964

These could be drawn as factor maps in black and white, and overlain and then redrawn in a hierarchical structure. These are the partial analyses and that is the final combined set of criteria. And those are the main choices, and that's a better choice than that, so this highway should probably go there. A similar experiment appears eight years later in Ian McHarg's very influential book *Design with Nature*.

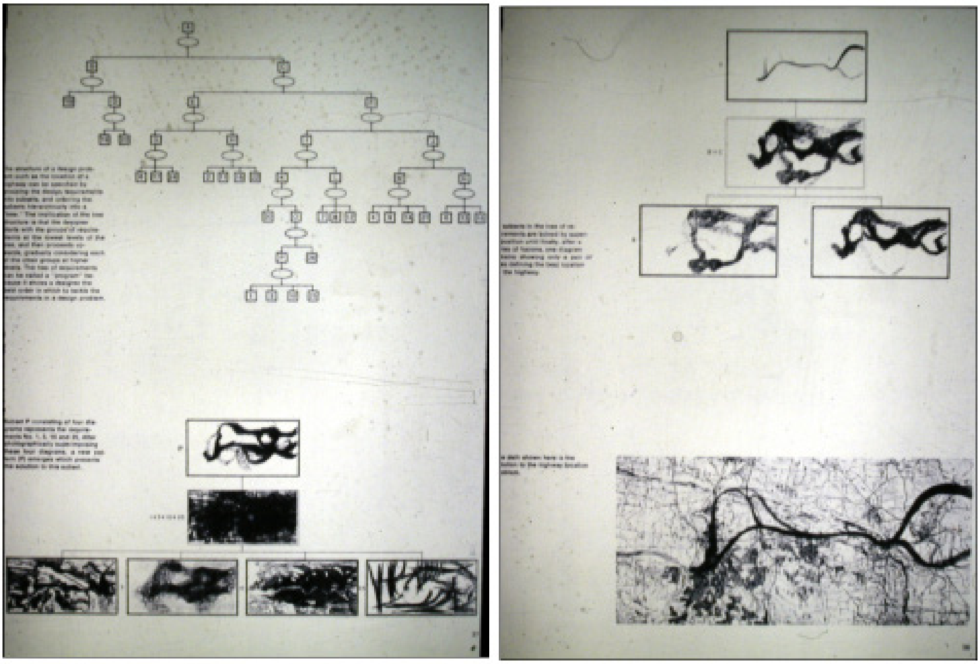


Fig. 34: Alexander and Mannheim, combining 26 highway criteria for the best location, 1964

Buckminster "Bucky" Fuller (1895–1983) was an American architect, systems theorist, author, designer, inventor, and futurist. He believed that the whole world was a design problem. He created the World Game in 1961 to be a comprehensive database and educational simulation tool to create solutions to overpopulation and the uneven distribution of global resources. He wanted to create solutions that shared resources globally in the most equitable fashion possible for what he called the real enemies of humanity: hunger, illiteracy, lack of health care, environmental degradation and selfish national thinking. Participants In the game were required to cooperatively solve global scale solutions to hypothetical scenarios, thus generating a more holistic global perspective. The game remained largely speculative throughout Fuller's life and he claimed that he had been playing it "longhand" since 1927. "Bucky" Fuller was prescient and right: the entire globe now reflects the most important problems requiring design.

Fig. 35: Buckminster Fuller and the World Game

4 The Transition to Digital

The transformation from what we consider analog to digital methods is mainly a transformation of older ideas to digital tools. The basic aims are also very old. We now have digital tools which can enhance our understanding far beyond our personal view, smell, taste and touch, but our ways of applying these digital tools to design today are also not really new ideas.

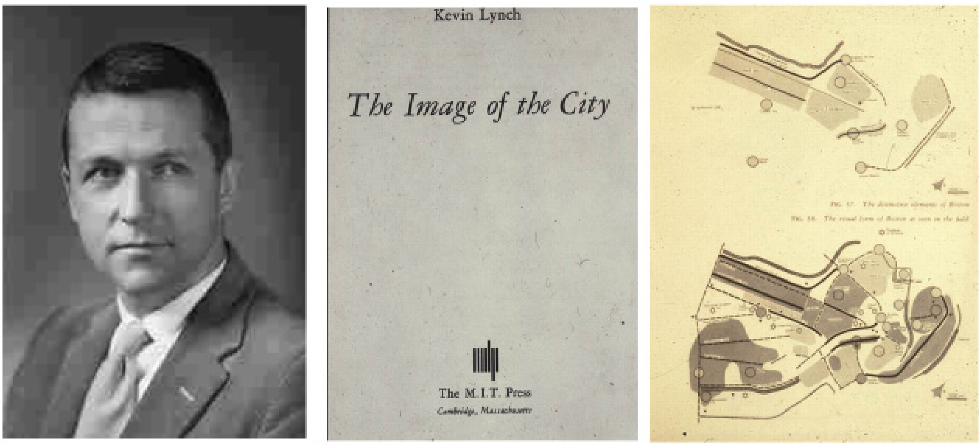


Fig. 36: Kevin Lynch, Image of the City, and the image of Central Boston

For me, 1964 was the transition year to some things being digital. I was then the first doctoral student of Kevin Lynch at the Massachusetts Institute of Technology. Kevin Lynch (1918–1984) considered the region to be a design problem. He was famous for having published the book *Image of the City* in 1961. That book is now in about fifty languages. It was based on interviews, and described how people spatially organized and understood the cities in which they lived. Lynch had studied Jersey City, Los Angeles and Boston. I was in his 1961 seminar in which he gave a lecture about how he did this work and I said to myself "This is a very important study", and it is. But while the book describes, it doesn't explain. It describes and interprets the results of the surveys, but it doesn't explain why some parts of the "image" map of Boston are included and dark, while some parts are excluded and white.

Why is something in or not in the *Image of the City*? I decided that was going to be the question driving my doctoral thesis. Graduate students often take an idea of their professor, thinking maybe that it is not the full answer… and this also was my attitude. So I decided that I would study and try to explain this area of Boston. I made three explanatory hypotheses… that the "image" could be explained by one or more of three different congruence-relationships between urban form and its activity patterns: type, intensity and significance.

I divided the same central part of Boston into hundred meter squares… metric, in 1964. And I walked every square of that part of Boston and took the most public photograph in each from where the most people were looking. In other words I would go to a place and I would say to myself that there are X people and most are looking in that direction… take that photo and make notes. So this is a map… of photographs. There are about a thousand of them in the full version.

Fig. 37: Map of photos, form zones and words, activity zones and words CS

I then interviewed a lot of people in a stratified sample of three variables: young people – old people, black people – white people, northeast people – southeast people – west people – residents. I asked each of them in two randomly ordered sets of questions about the physical shape of the city and its activity patterns… for example, on a base map of central Boston, to map the areas that are of similar physical character, and to write the words that they would use to describe those zones? And I redrew their maps on a single map of zones and words. I also asked them about the activity patterns. Where do things happen in the city and what are the adjectives and nouns that they would use to describe the activities? And I had a huge amount of data.

And it happened that one day in 1964 that I was at weekly lunch at the Harvard-MIT Joint Center for Urban Studies where I was a Fellow. I sat next to Howard Fisher (1903–1979), who I had never met… a total accident of life, one of many that governs one's life… believe me. He turns to me and says "Who are you?" and I say "I'm Carl Steinitz" and he says "What do you do?" And I said "I'm Kevin Lynch's doctoral student." And I said "Who are you?" and he said "I'm Howard Fisher. I'm here because I'm about to join Harvard, the Design school" And I said "Oh, that's very interesting. I'm going to be teaching at the Design school… What are you there for?" And he said, "Well… I've invented a computer program that can draw a map, and I will start the Harvard Laboratory for Computer Graphics." And I said "Well… I've got a lot of data. Maybe that's something I should do." And he said, "Tell me about your data?" And I told him about photographs and that I was going to encode aspects of the photographs. And he said "Oh yes, we could make a map of that." Now please understand that there was only one computer at Harvard at that time. And it was the size of this room. And it was controlled by three people who worked around the clock. And, if you were a faculty member, you had one access every day with a box of Hollerith cards and they would run it for you eventually and you would come the next day and collect your cards and your paper output.

Fig. 38: Howard Fisher, and the Harvard University computer, 1964 +-

Howard Fisher had figured out that the IBM computer made its printing with the same typing ball that was in the IBM electric typewriter. It's a ball that moves and it twists and it prints. He had figured out that you could stop that ball via Fortran program and it would overprint O, X, I, =, and that combination would turn that rectangular letter-position black. And he could make a map from black to white simply by stopping the printer ball and making it overprint. Fisher and his programmer Betty Barnes had made some algorithms that allowed one type of map to be transformed into another type. And I said "I need that thing… will you teach me?" And he did. I spent four weeks learning Fortran and learning how to use this program, SYMAP.

Howard Fisher and the Laboratory for Computer Graphics, Harvard GSD, 1964

Fig. 39: IBM Selectric Typewriter and SYMAP

I then encoded the form and activity characteristics in the photos that I thought people looked at and noticed, and field notes including noise and smell. And I made maps of those characteristics and I made what may be the first urban digital GIS.

I then took the interviews and I encoded them in the same format. I then had to write a program to assess my hypotheses and that showed graphs of the results of my hypotheses. So in the figure from the top row, type congruence was a powerful explanatory hypothesis, intensity congruence was not a powerful hypothesis, and importance congruence was a contributing partial relationship. And I could finish my thesis in 1965 (STEINITZ 1968).

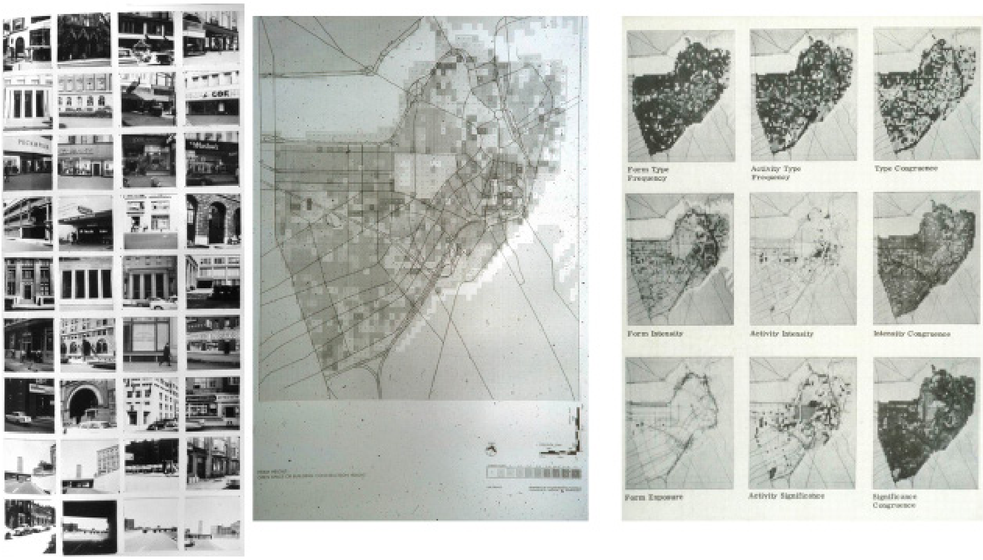


Fig. 40: A visual and GIS assessment of Boston, MA, USA

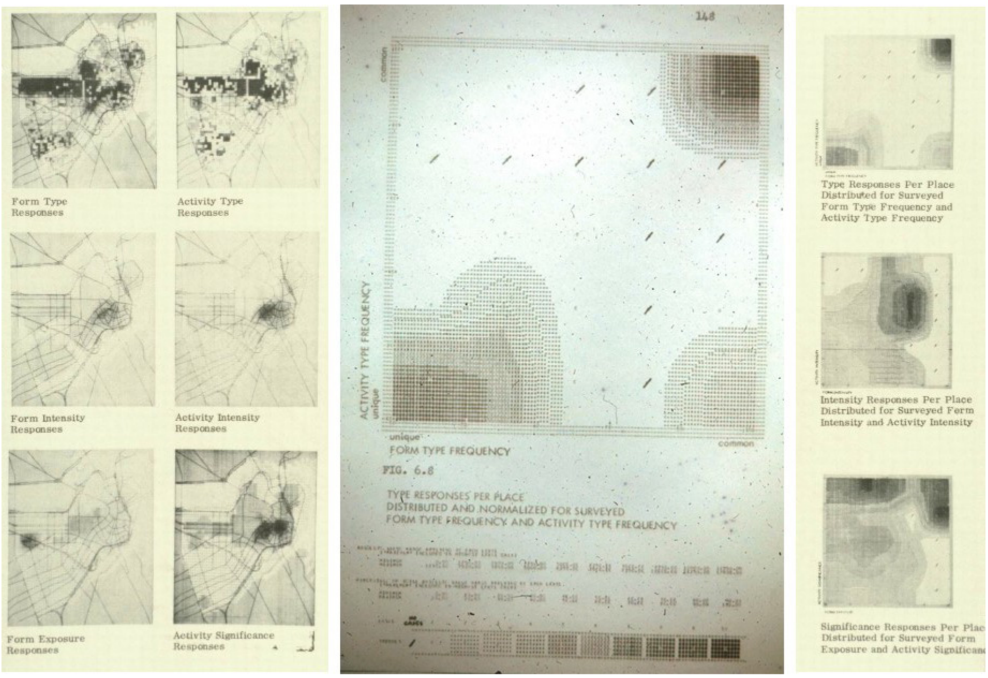


Fig. 41: Data, GIS and the congruence of form – activity type, intensity and significance CS

In 1965 I taught my first collaborative studio (STEINITZ 2014). That handsome young man is me. This base map is of the entire state of Delaware and parts of Virginia and Maryland, USA. The studio was funded by The Conservation Foundation and the central problem for design was the conservation strategy for this peninsula just south of Washington DC which was under pressures of rapid suburbanization and a growing chicken industry. This was a joint studio between the Landscape Architecture and the Planning departments. The visiting critics included Ian McHarg (1920–2001) and Phil Lewis (1925–2017), who were very important landscape architecture professors.

I told the faculty that I wanted to do this study with students who were prepared to do it by computer… and the faculty in Planning said "No". Chuck Harris, who was my chairman and co-teacher said "Yes". And so I took the four landscape architecture students who volunteered to work with me and this is what we did.

It took a month to make the base map. This base map took thirty tries and thirty days to make, and the grid of the data is one square kilometer. It took a month to organize data, much by air photo interpretation by eye and hand guided by Don Belcher who was expert in this.

Meanwhile, students guided by Ian McHarg and Phil Lewis in the first few weeks had filled the walls full of colored data maps made on paper with magic marker. Huge maps… but not overlaying them… just making them.

Fig. 42: Carl Steinitz, 1966 and the DELMARVA base map

The students then learned Fortran, and wrote algorithms to do spatial analysis operations that geographers like Waldo Tobler (1930–2018) were already thinking about. And in the second month we could run a Gaussian plume. We could make a linear traffic map. We could make a gravity model.

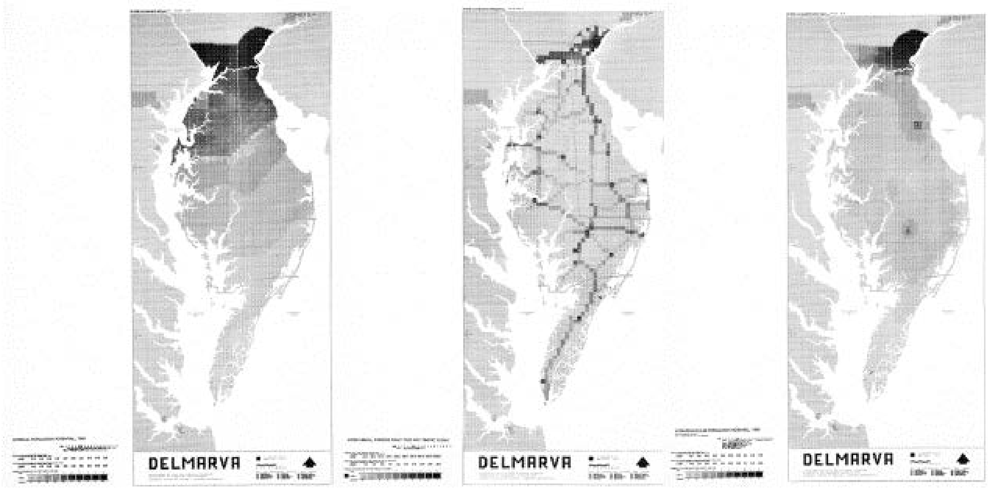


Fig. 43: DELMARVA: time to Washington DC as a Gaussian plume, daytime traffic and population gravity model

We then made… and remade… our three main synthesis analyses, all of which are weighted indices: Capability for Agriculture, a weighted index for conserving the most economically productive land, Capability for Forestry and Capability for Conservation of Biodiversity. So we had our analyses and we had three weeks to the final review.

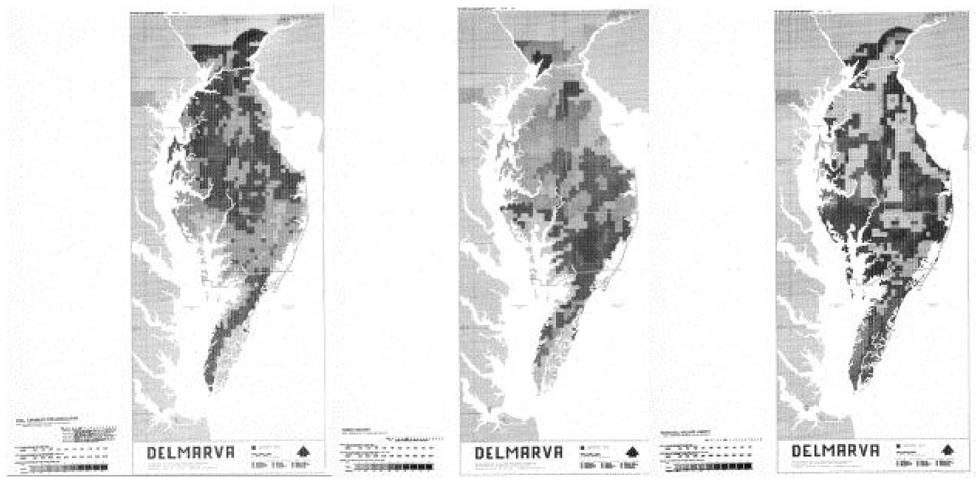


Fig. 44: DELMARVA: Capability for Agriculture, Forestry and Conservation of Biodiversity

And it took us two weeks to make two designs. One design mainly protects the agricultural interests and the other mainly protects the ecological interests. The students presented the two designs in our black and white maps, in a large jury room otherwise filled with colored maps. At the end, my students said: "…since no one told us who public clients are and what they want we can't tell you what the final design should be". And the reviewing-faculty and visiting critics refused to discuss my students' work, probably in part because our maps were made "by computer" and weren't colorful. That's a true story, and a common "computer" response in the early digital years. Chuck Harris came to me immediately afterwards and said "That was very interesting."

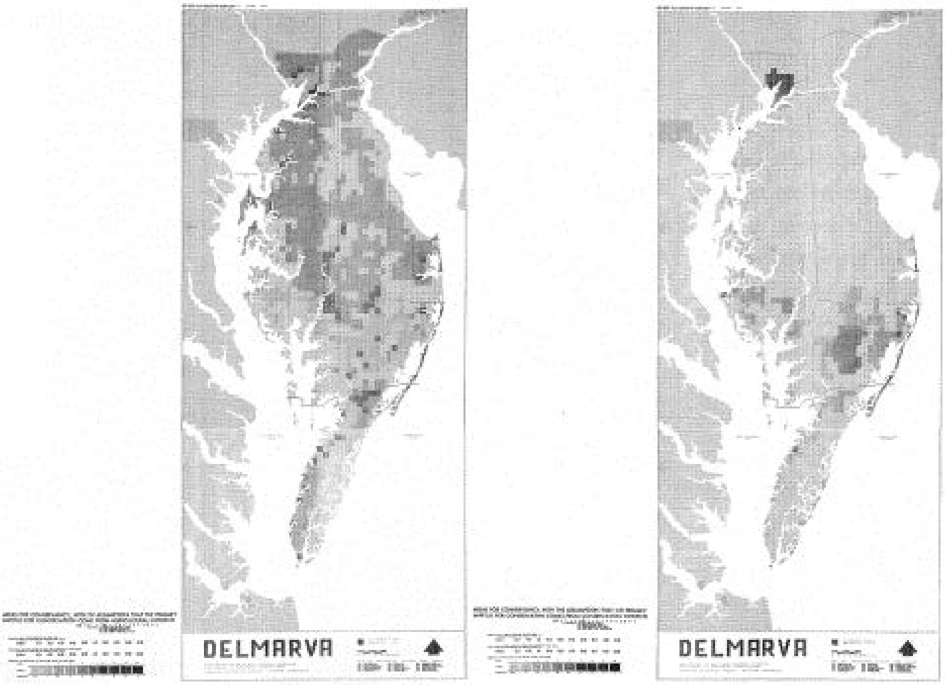


Fig. 45: DELMARVA: agricultural interests and ecological interests

Soon after that experience I made this diagram. This represents what may be the most important set of ideas I've ever had in my life. I made this diagram of how I thought landscape change works, in 1965-6. It is not inevitably directed by ecology, as Ian McHarg thought it was… or should be. I thought that it's a war between development and environment. And what I thought we needed (and still do) are: systems thinking, data, models, designs, impact models, decision models… and to apply design in linked systems-based simulation models.

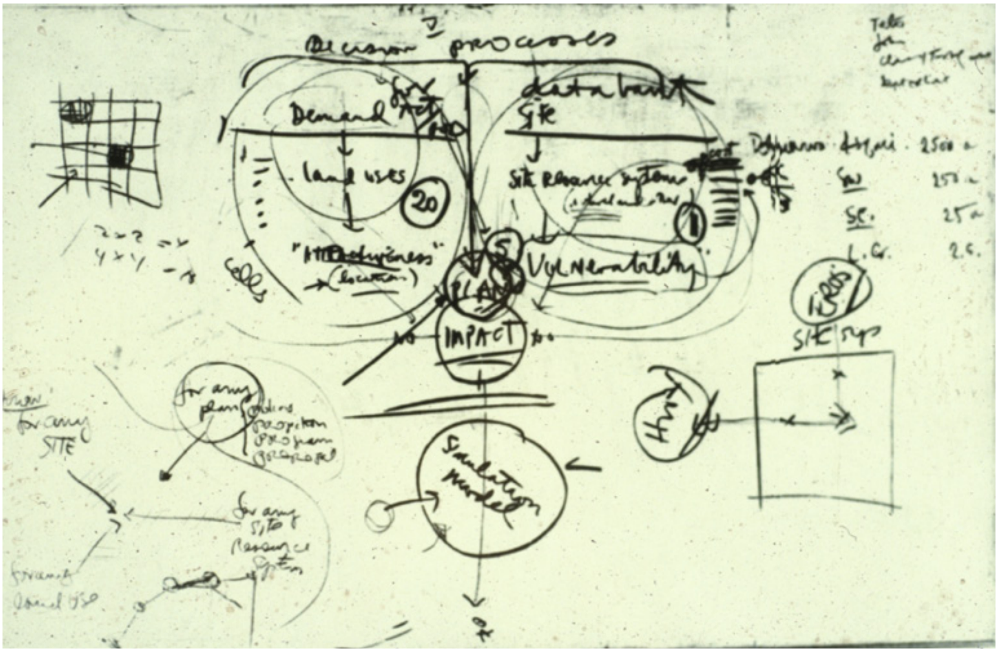


Fig. 46: Carl Steinitz, Diagram for a linked systems-based simulation model, 1965

And in 1997-8, Peter Rogers and I decided to do exactly that in our joint landscape architecture and planning studio, Urbanization and Change. Peter Rogers, who died last year, was an engineer, economist, and planner. I learned a lot from Peter, who was my close friend for very many years. And this is what we decided to do. We would grow and change about half of Boston by design within about ten linked systems models. We would have a population increase that drives growth and change, and the need for new industry, housing, recreation and commercial centers. This would require better transportation. The resulting urban pattern would impact local politics, local finances, visual quality and pollution. We would study these impacts and, if the design didn't work well, change the design, and if it did work well, add five years… and we would run it ahead for twenty-five years.

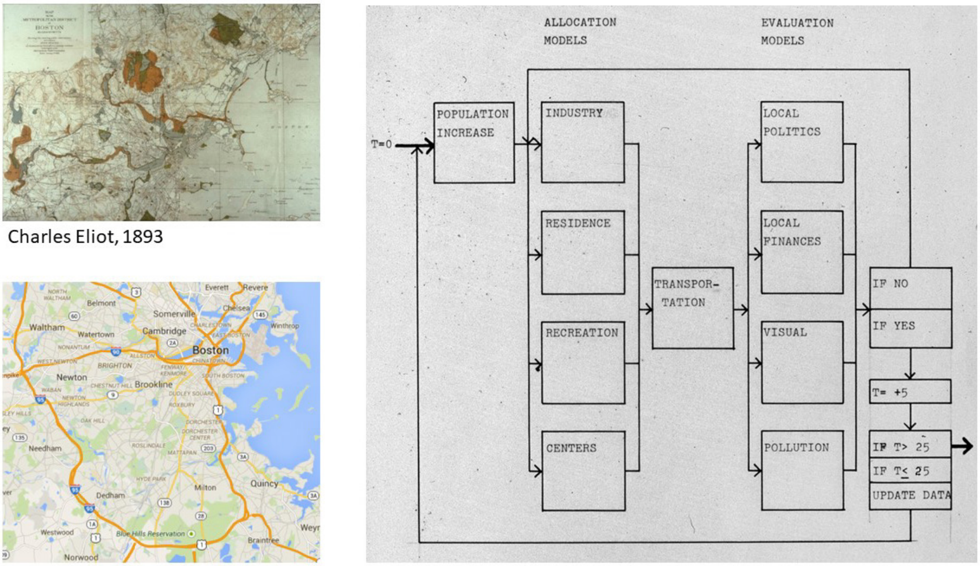


Fig. 47: Ten linked systems models for southwestern Boston

Each student selected the task of making and programming one of the digital models. For example, Jack Dangermond made the housing model and his design role would then be to find and acquire the land for housing. Jack now runs Esri, and his company makes the software that makes about half of the world's maps.

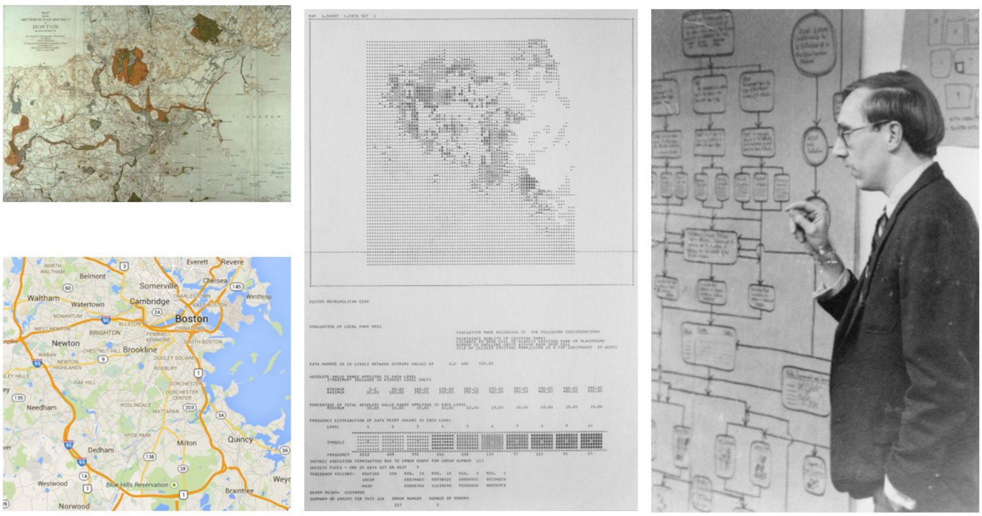


Fig. 48: The housing model, Jack Dangermond

Peter and I then took the students' models and we put them together into a chain of computer programs which would produce about twenty needed maps during each simulation period.

Fig. 49: Peter Rogers and Carl Steinitz

And then we ran a sequential land grabbing game where each square had a land use in a standard color and if you changed the land use you put a piece of colored paper in it with a pin and that represents changing that land use… and we remove one cell from our requirements. Today, this would be considered a human "agent-based model".

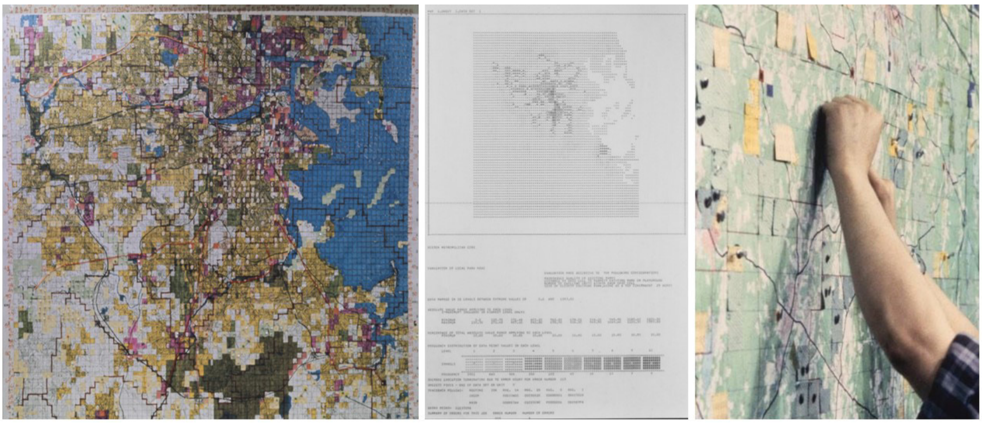


Fig. 50: Allocating new uses

We then ran each stage through the digital impact models that the students had made, had discussions and revisions as needed, and moved to the next stage in the design. This time, at the studio's final review we had a fully supportive faculty, by a different set of reviewers.

Fig. 51: Assessing impacts

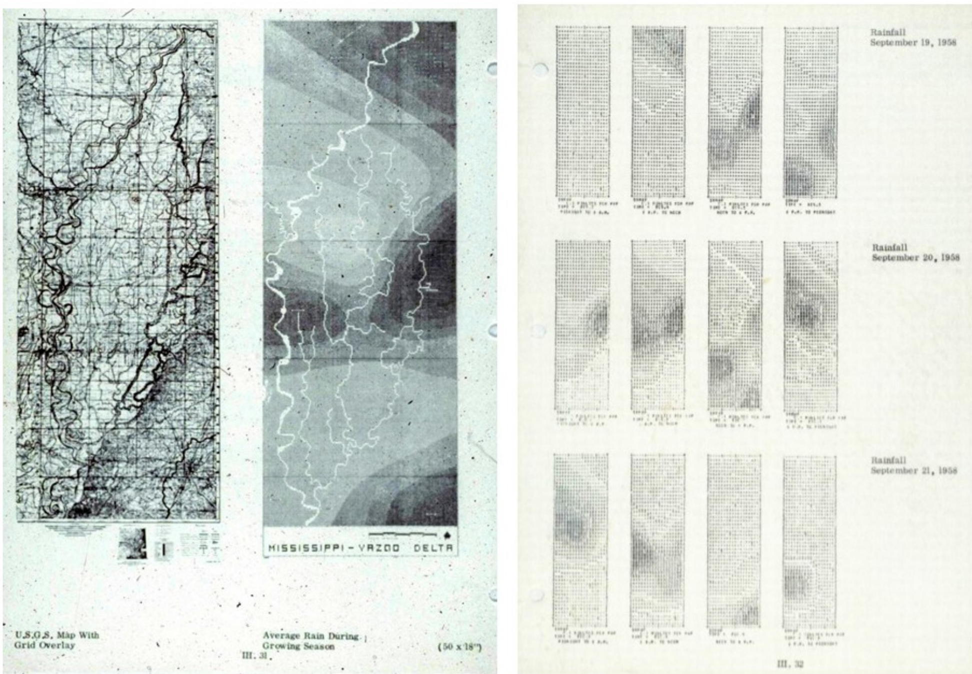


Fig. 52: The 1958 Mississippi flood, Peter Rogers

This early period of transition to digital methods from 1964 to about 1968 was an exciting and inventive one, but it was not always a happy period… except for the early adopters and those students who worked with us, all of who have had very substantial careers. It was an exceptionally creative period for digital innovation.

A lot was happening at the Harvard Laboratory for Computer Graphics and Spatial Analysis. There had been an enormous flood on the Mississippi in 1958 and Peter Rogers made the first digital time series maps, tracing the flows of rain and flood water through the Mississippi River.

Howard Fisher was really interested in three dimensional mapping. He devised many techniques for making maps in three dimensions based on blocks covered with maps of comparable slices… like a Rubiks cube… and take them apart and see them in different ways. Everybody understood that this three-dimensional mapping could be four-dimensional with time added.

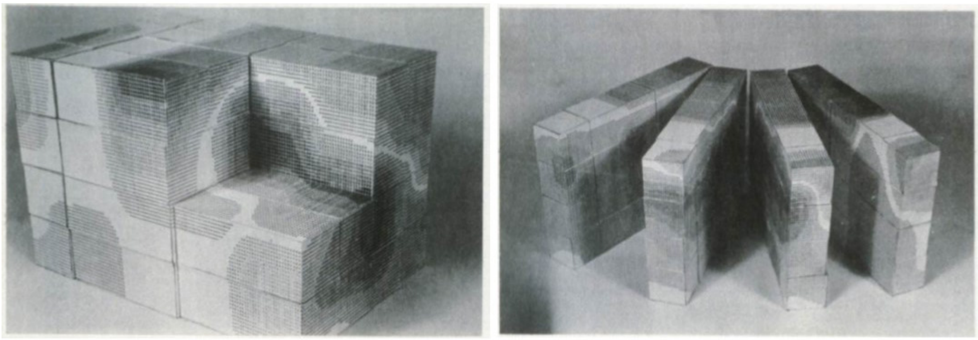


Fig. 53: Three dimensional mapping, Howard Fisher

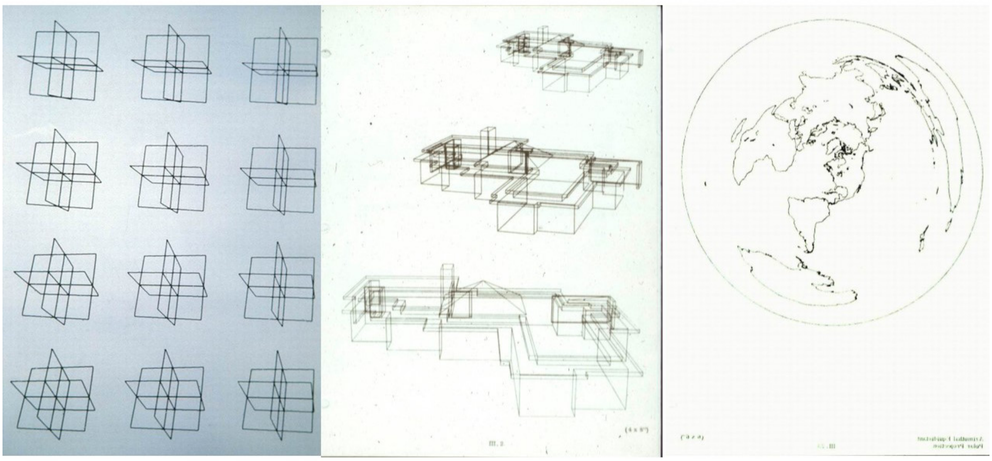


Fig. 54: Moving and Rotating 3-D forms in SYMVU, Frank Rens

Frank Wrens had designed a plotter program by 1966. He could take a set of lines and rotate them, like for the building, or the globe. We could move or rotate the line-based shapes and make any view or location the central point… the middle of the globe instead of whatever is the middle of the globe when you see it.

Bill Warntz (1922–1988) was a geographer who was interested in analyzing and representing surface topology and geometry. There are four kinds of geometry in terrain: pits, passes, peaks and pales, and they have different characteristics.

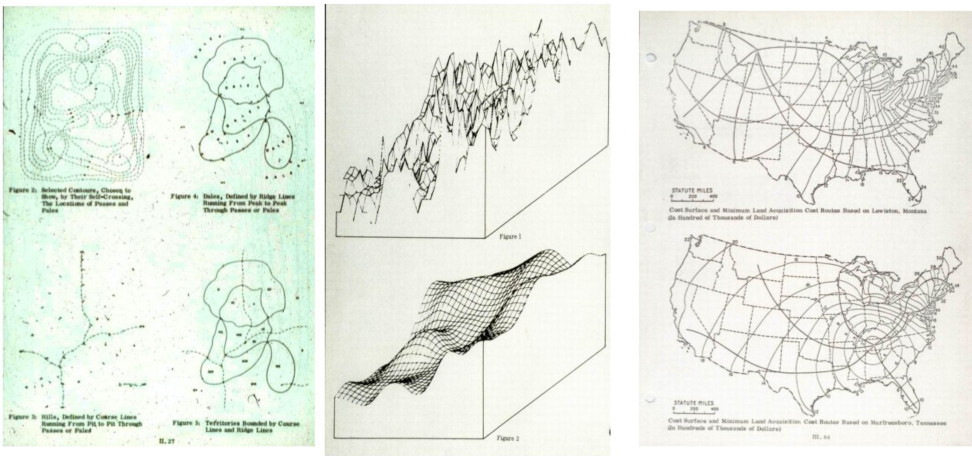


Fig. 55: Surface analyses, William Warntz

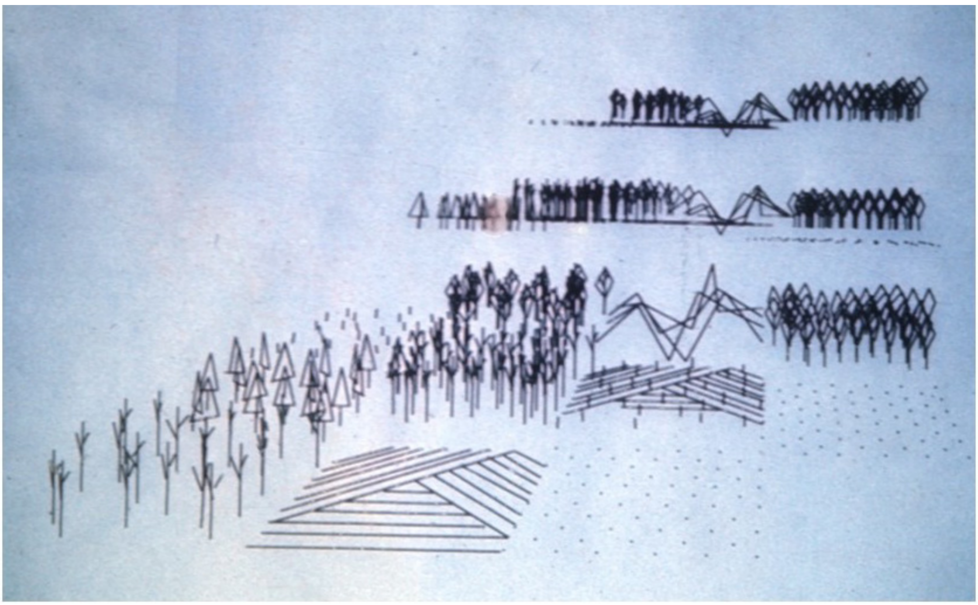


Fig. 56: Computer-generated allocation and varied views, CS

By 1966 I was algorithmically populating different kinds of trees and buildings into flat landscapes and seeing them in perspectives generated by Frank Wrens' SYMVU program. The U. S. Forest Service was also experimenting with these techniques.

And this is the same landscape with houses and an industrial building. My computer instruction placed a factory and houses in it. Look loosely… the houses don't hit the ground. So what? The next time we did hit the ground. So I knew we could animate viewing sequences in an automated landscape.

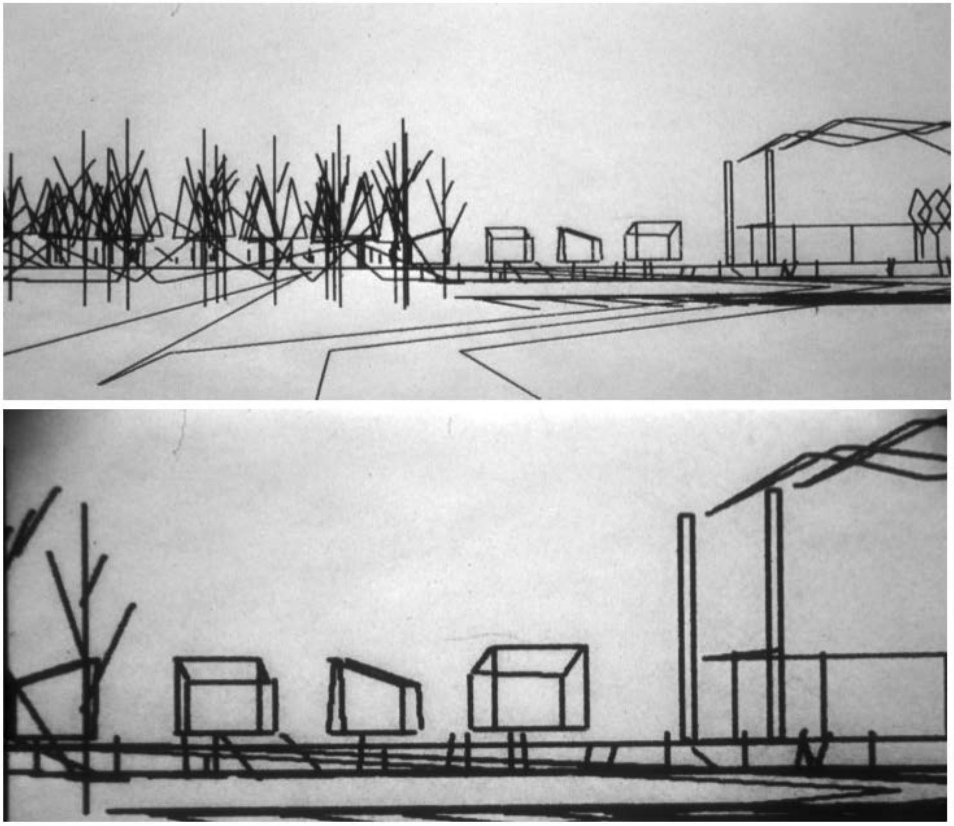


Fig. 57: Perspectives for animation, CS

Then Eric Teicholz and I decided to see if we could write the rules so that a more complex housing design could be automated. We wanted to be able to rapidly test the design implications of varying the requirements among different amounts of different housing types. Eric did all the computing. I said, "Eric we need 200 houses. They have to be orthogonally organized. They can't go in the water. They have to protect every tree and they have to be parallel to the street. There are four kinds of houses and they should connect in small groups. We will decide different numbers of each type of house for each variation of the design… you have to set the program up." And Eric wrote a program that would take about half an hour of computer time. If we changed the distribution of housing it would change the layout of the design but none would go in the water and none would cut down the trees.

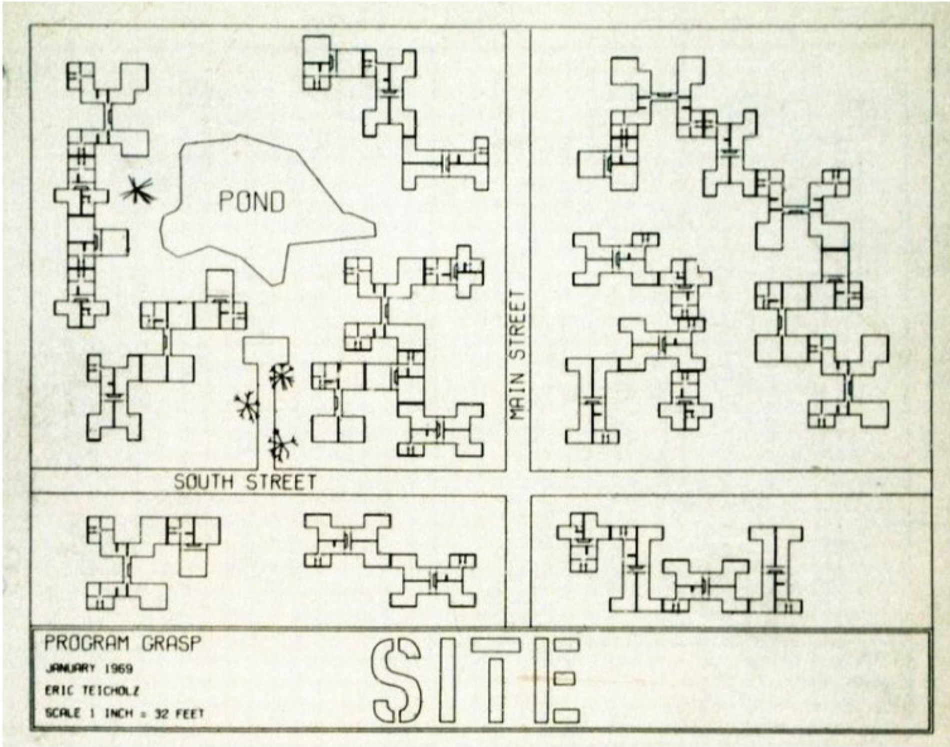


Fig. 58: Rule based design, Eric Teicholz with CS

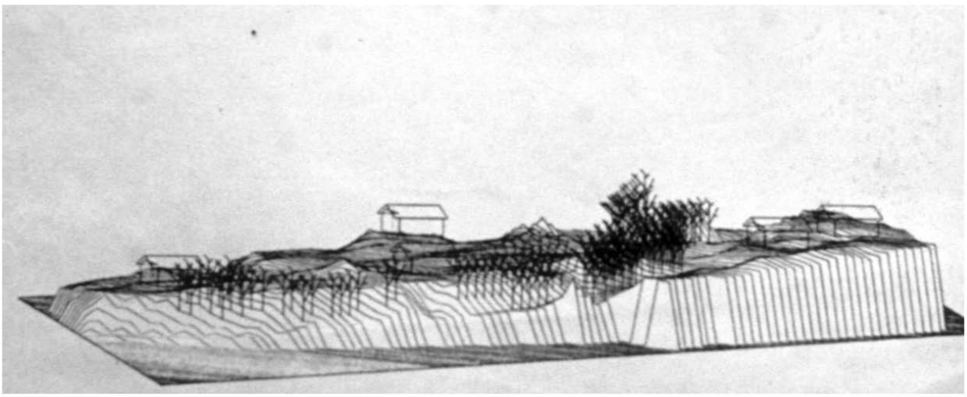


Fig. 59: Computer-allocation on 3-D terrain, CS

About two months later I figured out how to do that on 3-D terrain. We were automating the houses and the trees, and they fit on the 3-D terrain. This one computer-generated drawing in 1966 cost thirty-five dollars, the equivalent of about three hundred fifty to four hundred euros today. I didn't have that money. My salary was thirteen thousand dollars a year. So this is the only one ever made… but I knew we could do it… and also that we could move through it in an animation.

I'm now going to show you one other important project of this time. In 1956, there was a huge flood on the Connecticut River, which flows from Canada, separates Vermont from New Hampshire, and then flows through Massachusetts and Connecticut, The U. S. Army Corps of Engineers then made a plan to make about forty dams and lakes as part of a flood mitigation strategy, and in 1968 they funded us to study the Honey Hill project, one of these forty places where they wanted to temporarily store water.

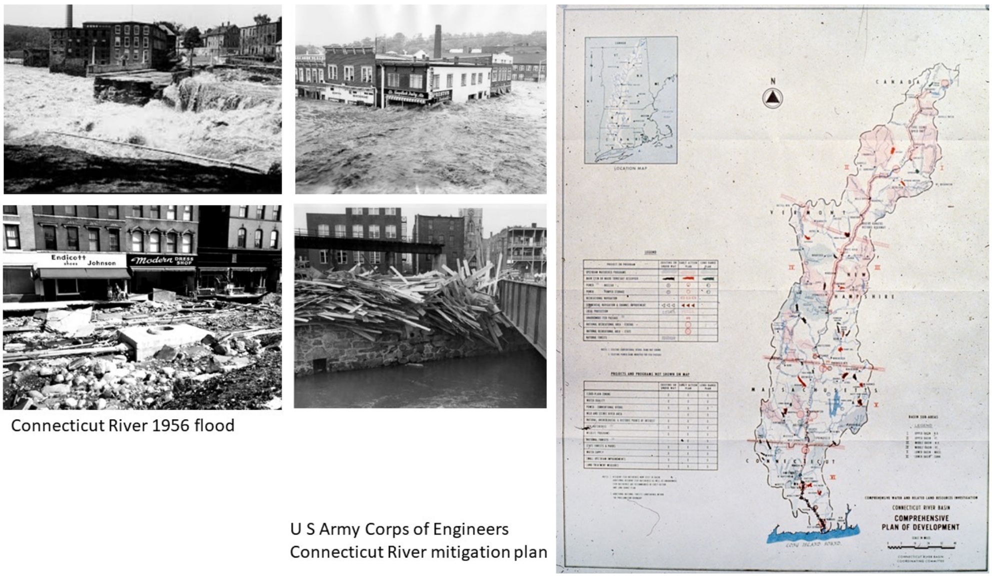


Fig. 60: The 1956 Connecticut River flood, and the mitigation plan

This is Honey Hill. The Corps of Engineers proposed to make a dam at this location and sell the surrounding impacted land to the State of New Hampshire for use as a state park. This area would occasionally be purposely flooded, but most of the time it will be a state park with different winter and summer activities, and in this case it also has to make money for the State of New Hampshire.

Fig. 61: Honey Hill, New Hampshire, USA

By that time we could make viewshed assessments in 3-D terrain. I could tell you what you can see from any spot and we could have viewpoints moving along any path. That is the visibility pattern from points along the proposed reservoir edge when full, and does take into account the pattern of surrounding trees.

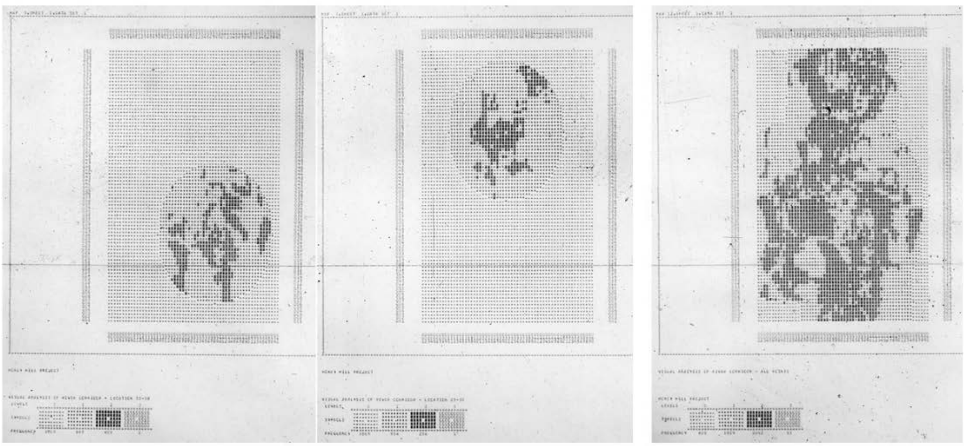


Fig. 62: Honey Hill, single and multiple points of inter-visibility assessment in 3-D terrain, CS

Four of us… Doug Way, Tim Murray, Dick Toth (who also died last year) and I… all capable designers… decided to have a competition and see what might happen with the future park's design and management. We made a shared set of digital capability and impact models. Then each of us assumed a quantitative program of requirements from a standard list, and we each made a design for winter and summer in a standard set of colors. We then gridded the designs for digital mapping and impact assessment.

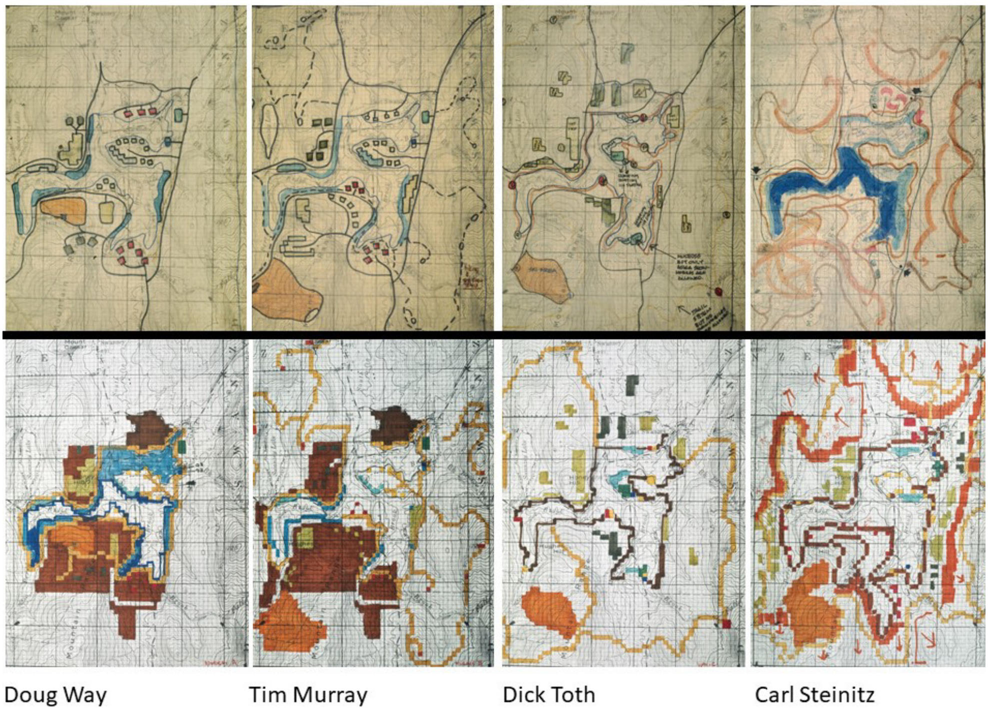
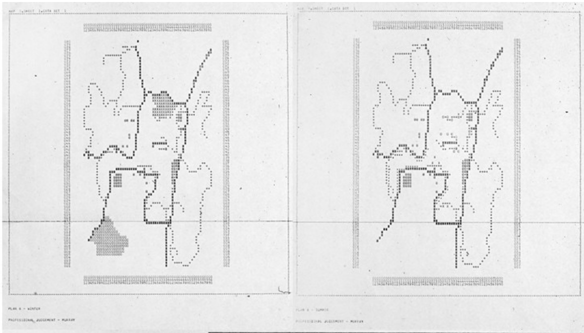


Fig. 63: Four designs for Honey Hill State Park

The designs were then assessed for the following: Attractiveness of the Locations, their Impacts, The Number of People Crowded, The Number of People Turned Away, Local Income, Regional Income, Capital Cost and Capital Cost with the Reservoir. And in several simulations for each design we had five hundred people at a time coming to the entrance and deciding where they go for their activities… and based on assumed crowding factors, at some point these facilities get too crowded and people have to go away… so income drops. So the question at the core of the design problem was: Should we put in more facilities and have more people and make more money but worsen the environment? Or should we have fewer people and keep the environment better… and what will they pay for it? And this is Tim Murray's design in the winter and in the summer.

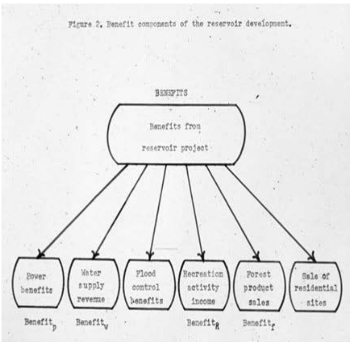
Tim Murray



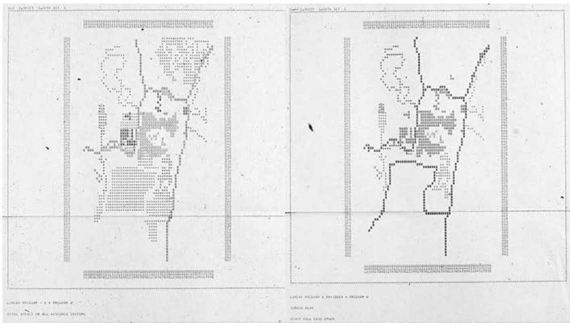
	Initial Plan	+ Impact Evaluations	+ Attractiveness Evaluations	+ Simulation Evaluations
1. SUMMER PLAN				
Attractiveness (mean mean)	36.13	32.22	42.65	44.97
Impact (mean mean)	1.314	1.373	1.298	1.261
No. of people crowded	234	0	0	0
No. of people turned away	1,084	0	0	0
$ local income	69,541	118,814	118,814	118,814
$ regional income	172,211	302,165	302,165	302.165
$ capital cost	19,784,000	17,077,098	19,934,079	20,023,072
$ capital cost w/o res.	1,184,000	1,477,098	1,334,079	1,423,072
2. WINTER PLAN				
Attractiveness (mean mean)	40.11	34.72	47.42	48.63
Impact (mean mean)	1.314	1.373	1.298	1.261
No. of people crowded	234	0	936	0
No. of people turned away	568	0	94	0
$ local income	162,336	200,760	195,613	196.764
$ regional income	430,833	536,698	535,281	538,458
$ capital cost	19,744,078	16,862,013	19,962,032	20,009,072
$ capital cost w/o res.	1,144,078	1,262,013	1,262,032	1,409,072

Fig. 64: Honey Hill State Park, Winter and Summer, Tim Murray

Meanwhile, Peter Rogers had made a linear programming model for assessment of an optimal profit strategy among the required program elements, and made a fifth design based on the resulting mix of activity facilities in the same shared analyses. An economic model was driving his design…



Peter Rogers
Design guided by a linear program



	Initial L. P. Plan	+ Program "B"	+ Simulation Evaluation
1. SUMMER PLAN			
Attractiveness (mean mean)	37.79	41.65	45.41
Impact (mean mean)	1.090	0.706	0.699
No. of people crowded	0	0	0
No. of people turned away	0	0	0
$ local income	97,349	143,661	143,661
$ regional income	266,117	370,744	370,744
$ capital cost	1,657,027	20,013,002	20,084,037
$ capital cost w/o residence	1,657,027	1,413,002	1,484,037
2. WINTER PLAN			
Attractiveness (mean mean)	42.05	62.19	63.34
Impact (mean mean)	1.090	0.706	0.699
No. of people crowded	0	0	0
No. of people turned away	0	0	0
$ local income	207,249	213,162	213,162
$ regional income	559,220	570,926	570,926
$ capital cost	1,635,017	19,935,017	20,182,017
$ capital cost w/o residence	1,635,017	1,335,017	1,582,017

Fig. 65: Honey Hill State Park, Winter and Summer, Peter Rogers

When we compared Peter's design to those by Tim Murray, Doug Way, Dick Toth and me, we all agreed that his was the best design. That experience taught me two things that I've never forgotten. First, that projects which are different in type, size or complexity may require different methods of design. And second, that regardless of type, size or complexity, you will need to organize the design process. And from that day on I always organized my Theories and Methods lecture course and my studios based on step-by-step methodology.

This early period of digital innovation at Harvard has been written about in a 2006 book by Nick Crisman, and a 1998 book on the history of GIS by Tim Foresman**,** of which the purple ones in his figure 1.1 are studies in which I participated.

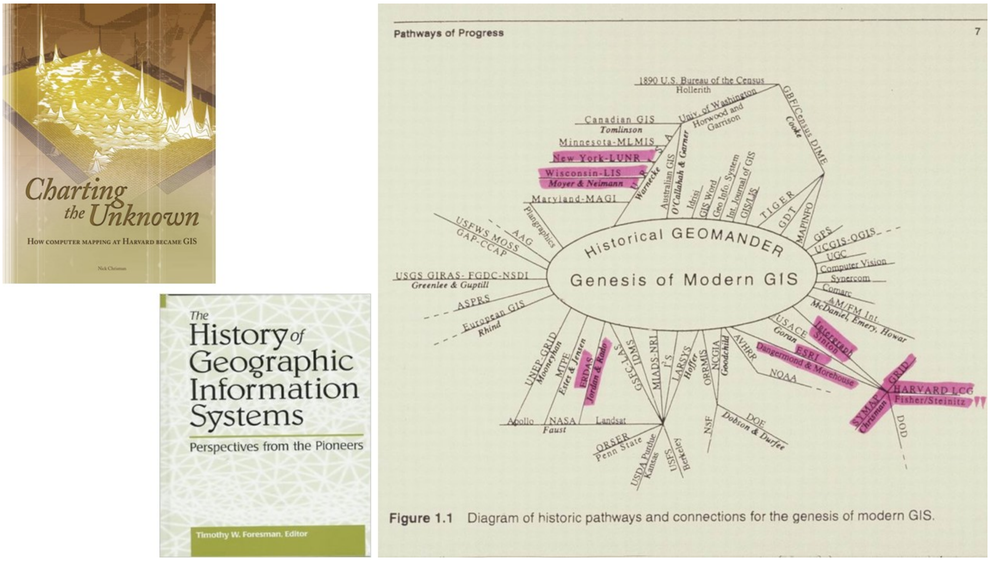


Fig. 66: Nick Crisman, and Tim Foresman, Fig.1.1

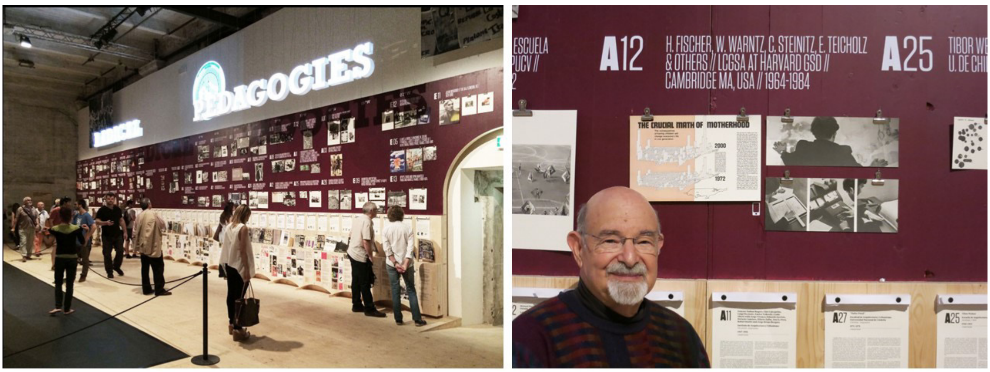


Fig. 67: 2014 Venice Biennale of Architecture, "Radical Pedagogies", COLOMINA et al.

I want to now say one more thing about the transition period in the 1960s. In 2014, Tess and I were at the Venice Biennale of Architecture. The Italian pavilion had an exhibition called “Radical Pedagogies” which showed the fifty people who had the greatest impact on Italian design education in the postwar period from 1945 to 2000 (COLOMINA et al. 2014). I was walking there… and Tess stopped me and pointed… because there we were: H. Fischer, W. Warntz, C. Steinitz, E. Teicholz… I was very surprised and very happy.

5 The Digital Future

We are now almost fully digital… and now what? Here is what I think and hope will be most important and influential developments for digital landscape architecture in the next years.

Designing will increasingly be collaborative. If a professionally oriented school isn’t teaching at least one studio course that’s collaborative across the professions the students will continue to be employees but they will unlikely be employers and leaders. The processes of negotiation and collaboration among the sciences and the arts are going to be paramount in their future practices. If they’re not doing it in school, they likely won’t do it successfully in the real world. Collaboration is central to larger projects and will also increase in smaller projects because they are getting more complicated.

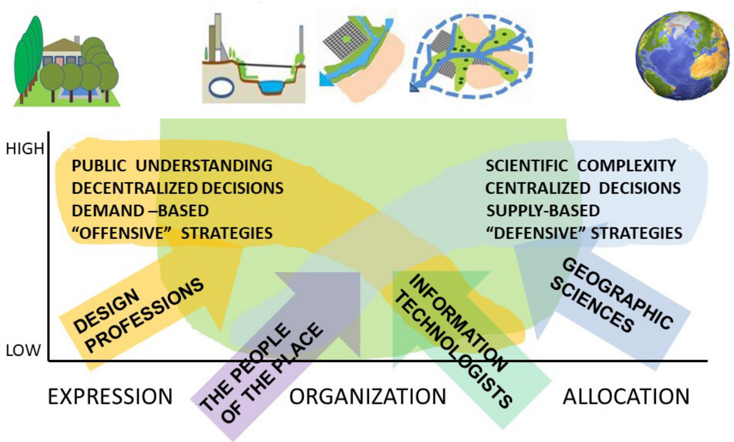


Fig. 68: Collaboration is central to larger projects

Design for increasingly large and complex areas will need a framework for organization, whether it’s mine or somebody else’s doesn’t matter (STEINITZ 1990, 2012; HOLLSTEIN, 2019). If you don’t organize it, it won’t happen well. I’m not talking about somebody’s private garden. I’m talking about anything bigger. You’re going to have to teach design under uncertainty, and maybe only knowing the rules and not knowing where and how the design is going to develop (STEINITZ 2014).

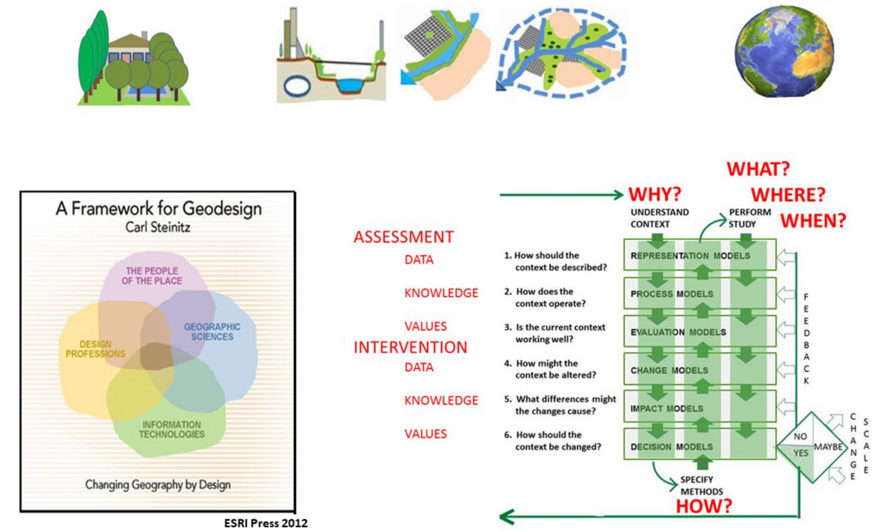


Fig. 69: Design will need a framework for organization

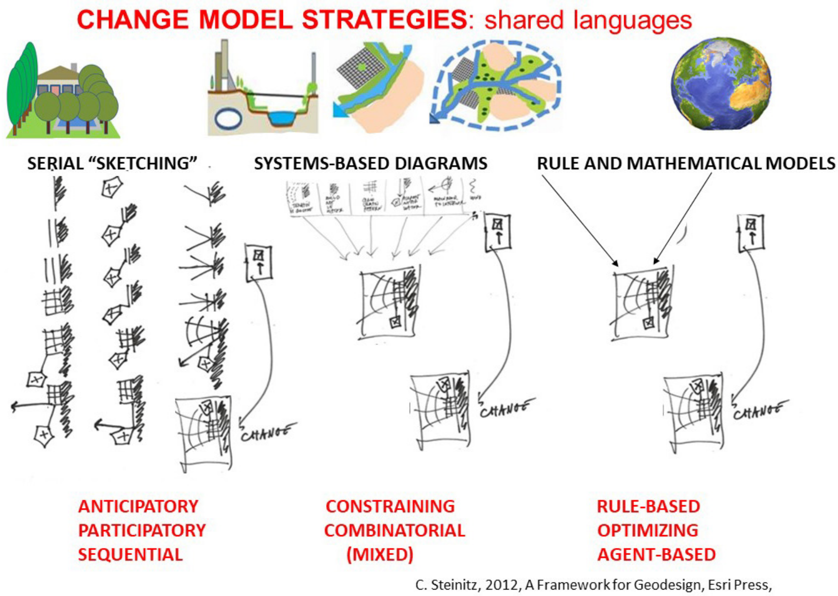


Fig. 70: Different project sizes and complexities will need different design methods

We need software that supports design workflows (STEINITZ 2016) and there already are all kinds of software that support synchronous collaboration over distance, and they will increasingly be adaptable and updateable as you (or your computers) design. They will need to support collaboration and negotiation towards agreement. They should also be easy to learn, set up, use and (most importantly) easy to understand (BALLAL & STEINITZ 2015).

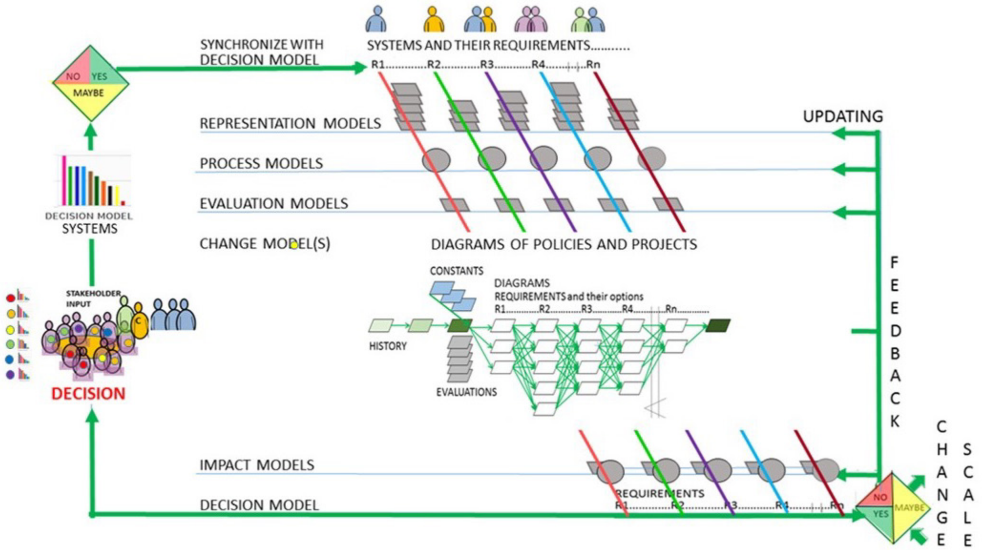


Fig. 71: A design workflow, CS

We are going to be designing in digital twins. The data will be ready for us. The problem will be making the design, and figuring out what to do and how to do it. We now are using internationally available data from anywhere in the world. Data are not the problem. We have too much data, and we need less. If you want to know to the centimeter where the flood is going to be, then you need lots of highly detailed data… but to decide whether to build in or conserve some place or not, you don't need that.

Fig. 72: Digital twin of Helsinki, Finland

Design projects will become increasingly larger and more complex. This size-complexity emphasis has had historic ebbs and flows, and I have lived through three such shifts. But global change and regional issues will increasingly dominate local ones. Design and its consequent change is going to be hierarchically and globally linked, and assessed by global to local objectives. Design assessment by the United Nations Sustainable Development Goals (SDGs) will become common (UNITED NATIONS 2015).

Fig. 73: The United Nations Sustainable Development Goals (SDGs)

Fig. 74: IGC: 150 participating university teams in 50 countries

The International Geodesign Collaboration (IGC) was organized in 2018 (ORLAND & STEINITZ 2019) as a means to compare the approaches and experiences of different geodesign teams in tackling the larger projects they would do normally, but using a common framework of guiding assumptions, project sizes, scenarios, analytical systems, workflows, assessments via the UN SDGs and presentation formats. By doing so they enable direct comparison among projects revealing insights into the different priorities and constraints of design teams working in contrasting governmental, climatic and demographic settings (FISHER, ORLAND & STEINITZ, eds. 2020). At this time of writing, IGC has 150 participating university teams in 43 countries, and 96 completed studies (INTERNATIONAL GEODESIGN COLLABORATION 2020).

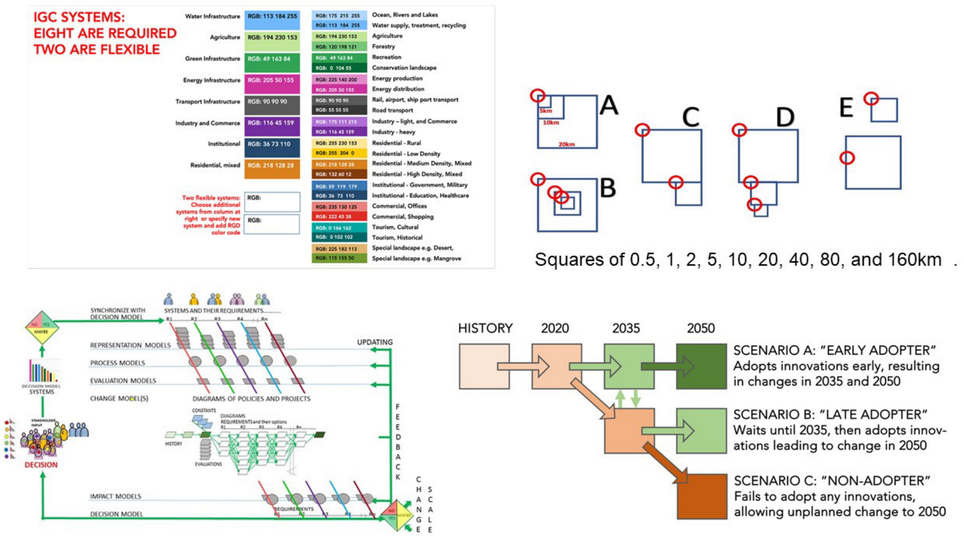


Fig. 75: IGC conventions: Systems, study area sizes, workflow and scenarios

A final thought about future digital technologies: The left figure shows the final design for the year 2050 for the CAMKOX zone outside London, England which includes Cambridge and Oxford. It was made under IGC conventions and assumptions of innovation in a two day workshop which I organized. On the right is one of Joseph Claghorn's algorithmic designs for informal housing in Medellin, Columbia (CLAGHORN 2018). The CAMKOX project is based on GIS technologies, while Joseph's project is easily capable of being moved into BIM. Both BIM AND GIS are data management technologies, and these technologies are increasingly merging. However, they are not design-support technologies. They require a design to be most useful and the question that's important is: Where is the design coming from? It's the design-support technologies and the design workflows that are the missing link. I don't want to have to go to a different technology. I want one linked technology. I want to be able to teach and design in a design support technology that goes either way: to the larger or smaller scales. And that's still missing. How should the design technologies be specified? How will we make the designs in those future technical environments? That's what we should be talking about and researching and testing. The digital technologies are what industry is going to develop. They're not going to be making the designs. We and our colleagues are the designers!

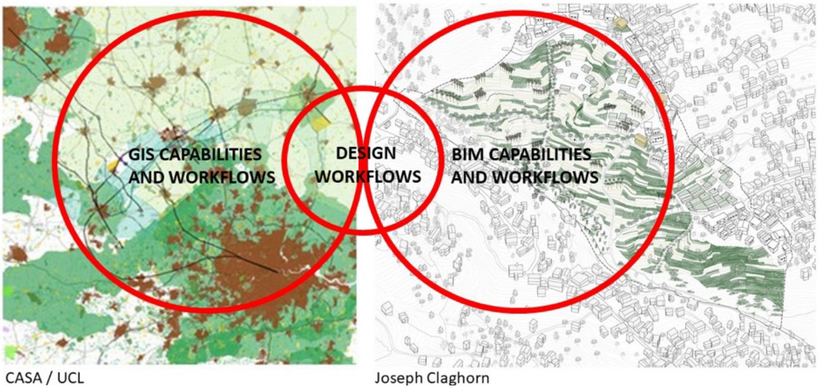


Fig. 76: CAMKOX Corridor, UK Medellin, Columbia

My opening image in the Philippines represented the pre-analog, while Joseph's Columbia study represents the digital future. Don't they seem similar? And this is the real message of my presentation: The most important things are not the methods or the technologies, but rather the "Why?" questions which initially define the context and objectives of design, and the rules which guide it. The methods and technologies change over time, often rapidly; the "Why" questions reflect basic human needs and rules that guide all of nature's systems, and these change very slowly. If we are to be part of significant designed change, we need to pay much more attention to these.

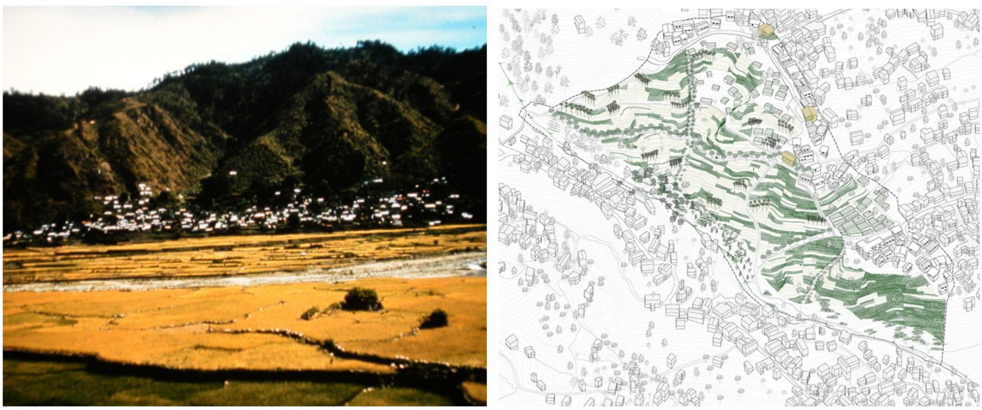


Fig. 77: "The most important things are not the technologies or the methods, but the "Why" questions and the rules." Carl Steinitz

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Carl Steinitz is the Alexander and Victoria Wiley Professor of Landscape Architecture and Planning Emeritus at Harvard Graduate School of Design, and Honorary Professor at the Centre for Advanced Spatial Analysis, University College London. He began his affiliation with the Harvard Laboratory for Computer Graphics and Spatial Analysis in 1965. In 1984, the Council of Educators in Landscape Architecture (CELA) presented Professor Steinitz with the Outstanding Educator Award for his "extraordinary contribution to environmental design education" and for his "pioneering exploration in the use of computer technology in landscape planning". He has been honored as one of Harvard University's outstanding teachers. Professor Steinitz is principal author of "Alternative Futures for Changing Landscapes", Island Press, 2003, and author of "A Framework for Geodesign", Esri Press, 2012. He has lectured and given workshops at more than 170 universities and has several honorary degrees.

On the Future of Digital Landscape Architecture

Carl Steinitz[1], Brian Orland[2]

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Keynote DLA 2020, July 2 at Harvard University

Abstract: This essay speaks to the future of landscape architecture education and practice. Digital landscape architecture enables more varied and appropriate design methods for these challenges. It urges more collaborative engagement in design for larger, more serious global challenges.

Keywords: Digital landscape architecture, collaboration, global issues, climate change, one trillion trees

At the 21st annual Digital Landscape Architecture (DLA) 2020 conference I was asked to present a keynote ending-talk about the future of digital landscape architecture. The following is a personal and editorial selection from that presentation. It follows-on the keynote lecture that I presented in 2019, "(BEFORE) **ANALOG TO** a **DIGITAL** (FUTURE): a personal perspective". The last image and text of the 2019 presentation follows.

The left photograph was taken by Charles Harris in the 1950s in Luzon in the Philippines. It represents the pre-analog, and this landscape has evolved over hundreds of years by local decisions and trial-and-error change. On the right is one of Joseph Claghorn's algorithmic designs for informal housing in Medellin, Columbia (CLAGHORN 2018). The Medellin study represents one version of the digital future. Yet, these two images are very similar.

They follow very similar rules. And this is the real message of my (2019) presentation:

Fig. 1: Old (analog) housing in the Philippines, proposed (digital) housing in Columbia

Journal of Digital Landscape Architecture, 6-2021, pp. 53-63. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-705-2, ISSN 2367-4253, doi:10.14627/537705002.

The most important things are not the methods or the technologies, but rather the "Why?" questions which initially define the context and objectives of design, and the rules which guide it. The "Why" questions reflect basic human needs, and the rules guide all of Nature's systems, and this changes very slowly. The methods and technologies change over time, often rapidly. If we are to be part of significant designed change, we need to pay much more attention to the former.

The "Why" questions are the purposes of design (as a verb), and the rules shape the design (as a noun). The methods and the technologies are the enabling means.

If the above is true, then we need to ask:

1) What are the most important "Why?" questions?
2) From where and from whom will the rules come from?
3) What are the appropriate methods and technologies?
4) And how should these influence the future of education and practice in landscape architecture?

Consider some of the founders of the profession of landscape architecture: John Claudius Loudon, Peter Joseph Lenne, Frederick Law Olmsted, Patrick Geddes and Warren Manning. They had an important thing in common. They all designed private gardens for the leaders of society of their times, and they all designed very large proposals for the general population of their times. Loudon made a design for the entire region of London. Lenne designed the expansion of Berlin. Olmsted made a management plan for one of the largest private properties in the United States and this was the beginning of multiuse forestry in America. Geddes designed the plan for the expansion of Tel Aviv, and Manning made the first design for what was then the entire United States of America.

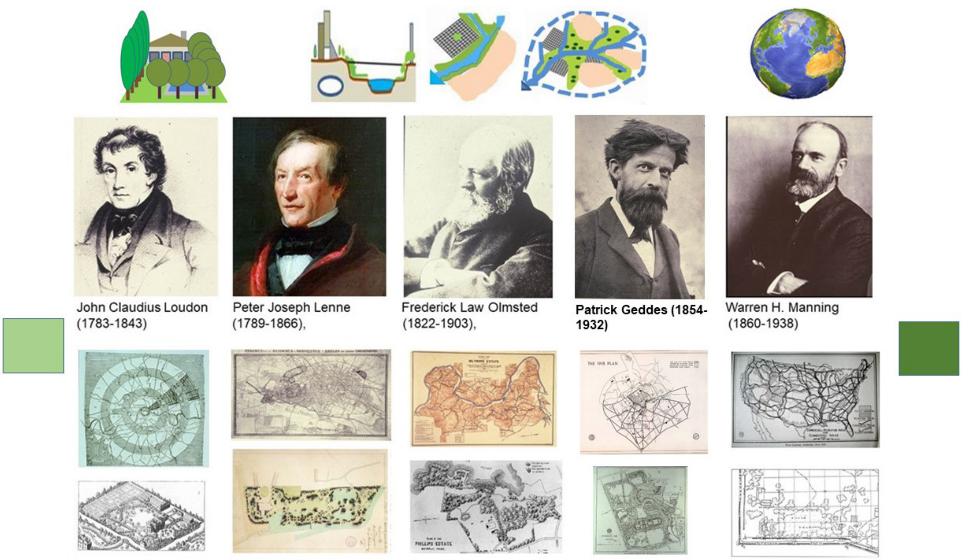

Fig. 2: Five founders of landscape architecture. The city plans in the upper row are Loudon, Berlin, the Biltmore estate, Jerusalem and USA.

These larger projects were accomplishments for which they were very proud and should be highly respected. With the exception of Manning, we don't really know how they made their designs but it is extremely likely that they did not design the same way at the garden scale and at the urban – regional scale. We can be sure that they were not digital.

Today, we are substantially digital and we would likely apply digital tools, certainly at the urban – regional scale and probably in some aspects at the garden scale.

In my opinion the real benefit of digital technology is the ability to broaden the design processes which are applicable to landscape architecture and to many other design professions. Too much of the technological innovation presented at DLA has been in support of design processes, either in their technical organization related to data or in their presentation and visualization. But they apply digital technical innovation in design methods which have been the core of pre-digital professional activity. We are still sketching serially in the digital world rather than applying iterative diagrammatic methods or rule-based experimental methods, and these are far more appropriate as projects and studies get larger in size, more long-term and necessarily uncertain. When you are trying to build a smaller project and need precise working drawings, designing individually it is not the same as when you are collaboratively designing a long-term landscape and development strategy in which the outcome "will be something like this".

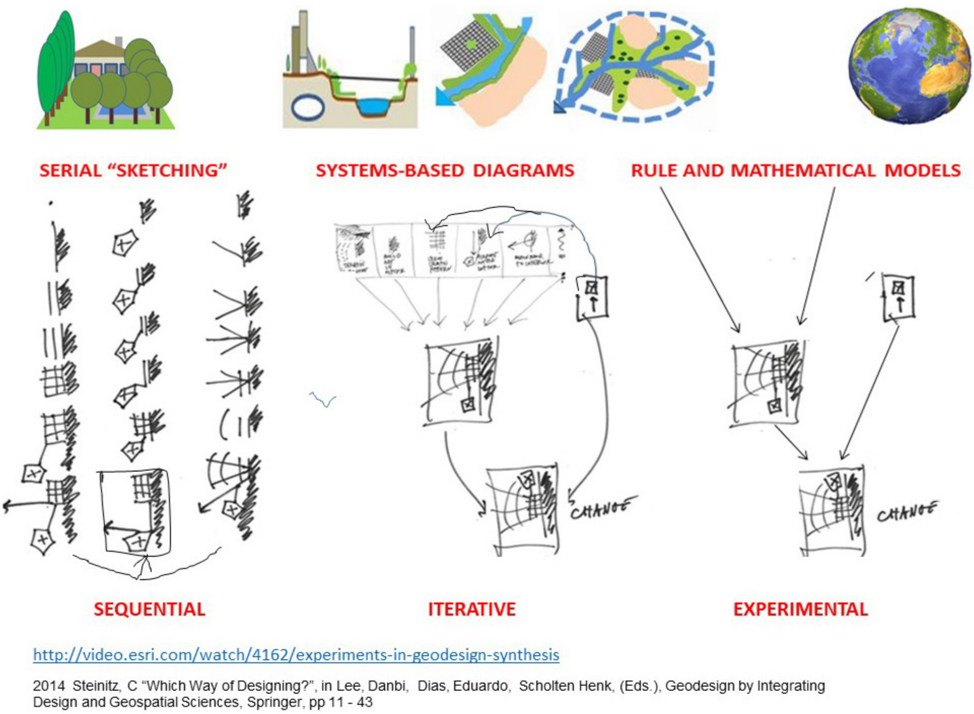

Fig. 3: Different ways of designing

The overarching theme of the DLA 2020 conference was the relationship between (digital) landscape architecture and climate change. I think that this is the single most important "Why?" question and that it will be the pervasive theme facing our academic and professional activity in the coming generations.

The two most relevant, interesting, and significant readings which I have encountered in the last months, when combined, present a sharp perspective on what I consider single most important "Why?" response. The human climate niche is an index which combines comfort for living and agricultural productivity at lower energy cost (XU et al. 2020). The figure below shows the suitability of the human climate niche in 2020 and a forecast for 2070, and it asks what the influence of change this might be on the global redistribution of population.

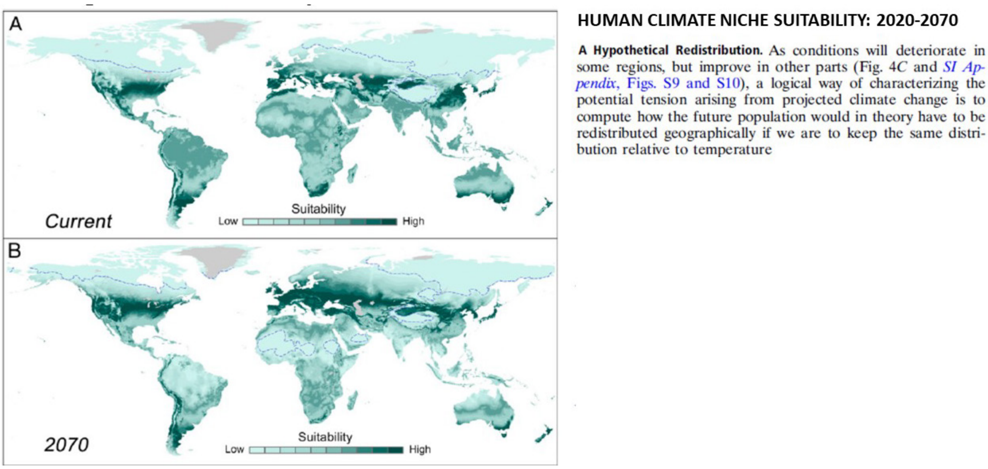

Fig. 4: The human climate niche, 2020 and 2070 (XU et al. 2020)

The figure below shows the difference in human climate niche suitability and it forecasts that people will therefore leave the areas in darkest red. What is striking is the number of people projected to migrate to more suitable human climate niches, basically migrating to the north and south. In a business-as-usual climate scenario and accounting for expected demographic developments, approximately 3.5 billion people, roughly 30% of projected global population, would move. Even with strong climate mitigation policies and projects approximately 1.5 billion people, around 13% of projected global population, would migrate. This will have the most profound impacts on absolutely everything in the world and everything that we do as professionals. If even a substantial portion of this projection occurred, it would generate enormous change on the environment and society.

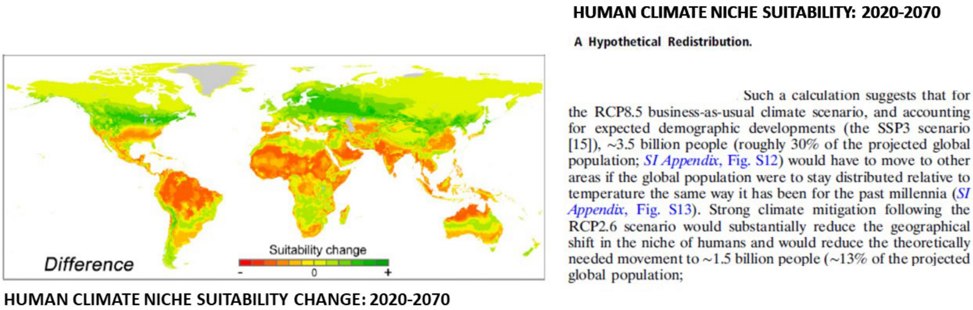

Fig. 5: Human climate niche suitability change: 2020 – 2070 (XU et al. 2020)

The second study is an assessment of forest landscape restoration opportunities which spatially indicates a significant opportunity to help fight climate change and to restore biodiversity (World Resources Institute 2020). The figure below shows existing human pressure globally, in an index defined by land-use intensity mainly caused by agriculture and population density.

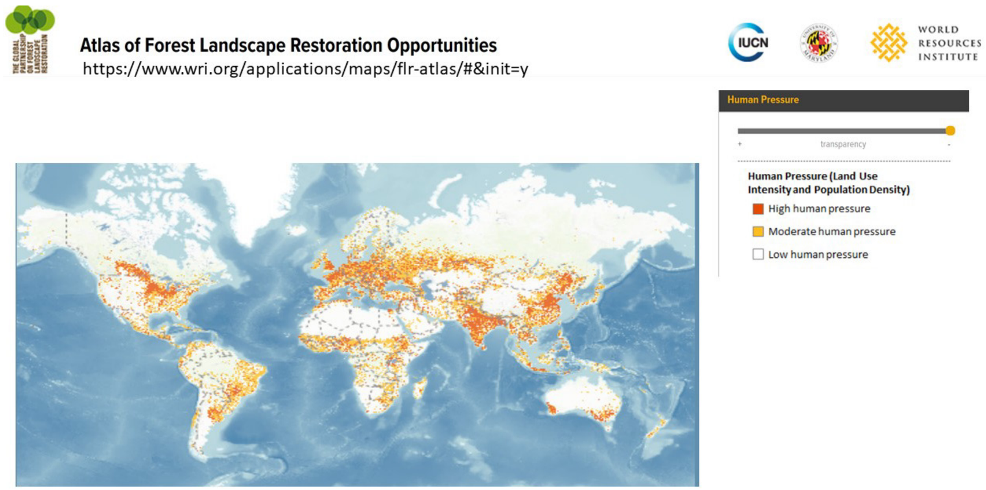

Fig. 6: Human pressure (land-use intensity and population density) (WRI 2014)

The global potential extent of forests is shown in the next figure and these are being lost to urbanization, industry and agriculture at an alarming rate. These forests need immediate enforced protection.

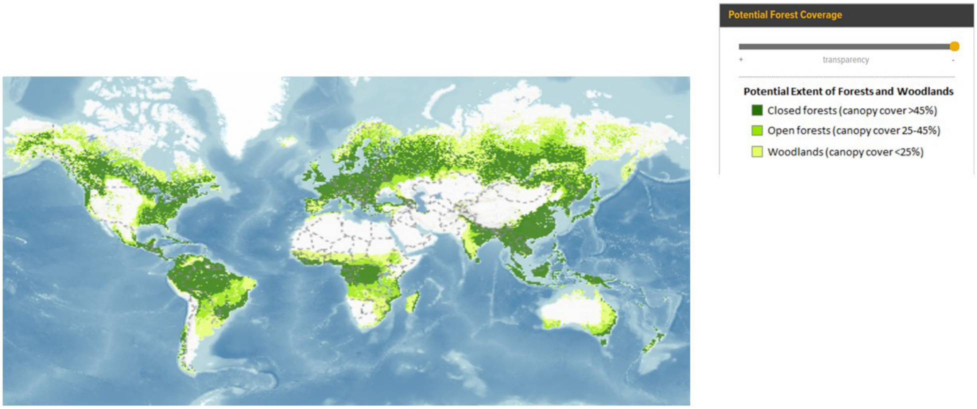

Fig. 7: Potential extent of forests and woodlands (WRI 2014)

The opportunities for several kinds of restoration are shown in the following figure. The World Economic Forum (WEF 2020) has launched a global initiative to grow, restore and conserve 1 trillion trees around the world by 2030.

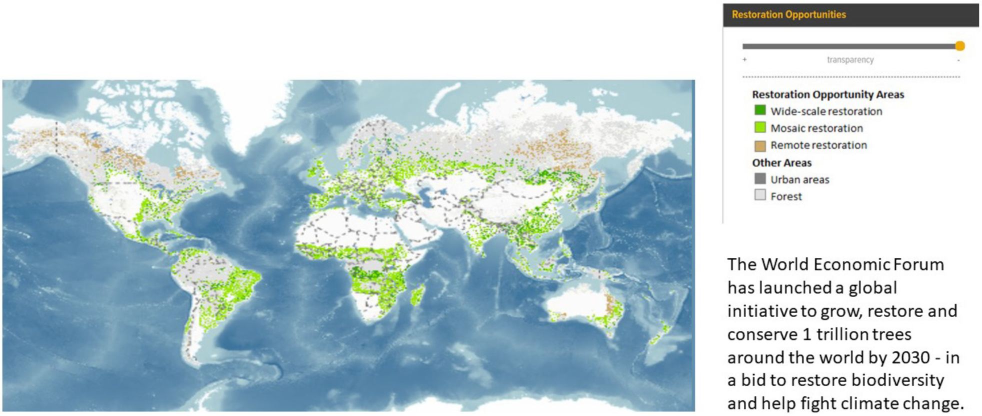

Fig. 8: Forest landscape restoration opportunity areas (WRI 2014)

Taken together, the implications of these two studies indicate a profoundly threatening set of projected changes to the environment and society and also an aspect of potential mitigation that we as landscape architects cannot ignore to consider in our teaching and practice. They require responses which range from the very local to the global in size and scale. The International Geodesign Collaboration may be part of such a mitigating strategy.

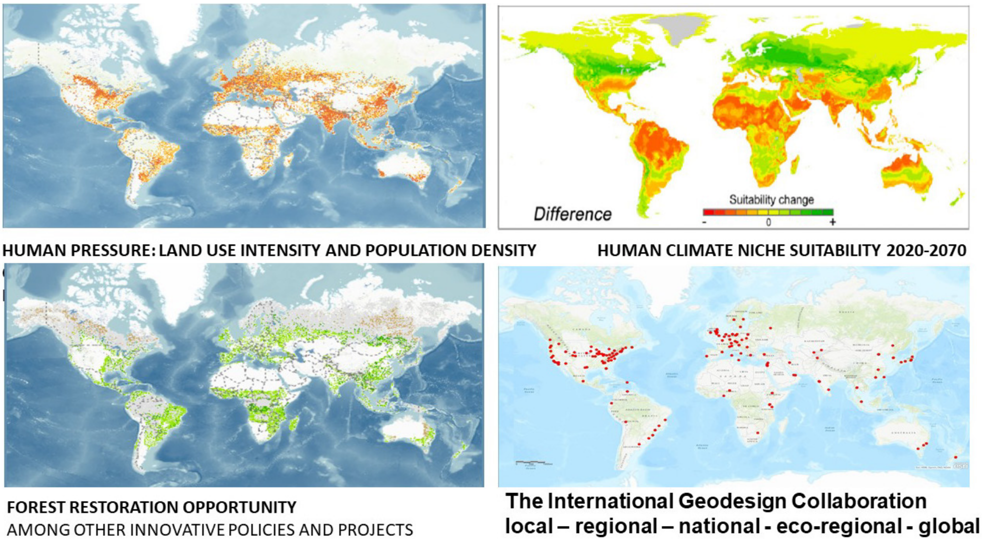

Fig. 9: What are the relationships among the prior figures? The International Geodesign Collaboration

In 2018, at the instigation of Carl Steinitz, Brian Orland and Tom Fisher, ninety global university teams agreed to collaborate to create scenario-driven designs for local-to-regional scale study areas to address future changes https://www.igc-geodesign.org/igc-overview. There are now 150-member university teams, in 50 countries, in the IGC.

Fig. 10: Membership in the International Geodesign Collaboration (2020)

The IGC strategy requires adherence to common scenario and time frames, nomenclatures and processes, and which

a) Follow a consistent and transparent workflow.
b) Address global change assumptions based on international governmental and NGO projections.
c) Adopt standard resource systems as the basis for design (e. g. water, green infrastructure, transportation, energy infrastructure, housing etc.) and innovative adaptations to those systems. Apply these on square study areas.

d) Examine scenarios for early-, late-, and non-adopters of design innovations, and assess the impacts by the UN Sustainability Development Goals (SDGs) at three time-steps, 2020 (existing), 2035, and 2050.

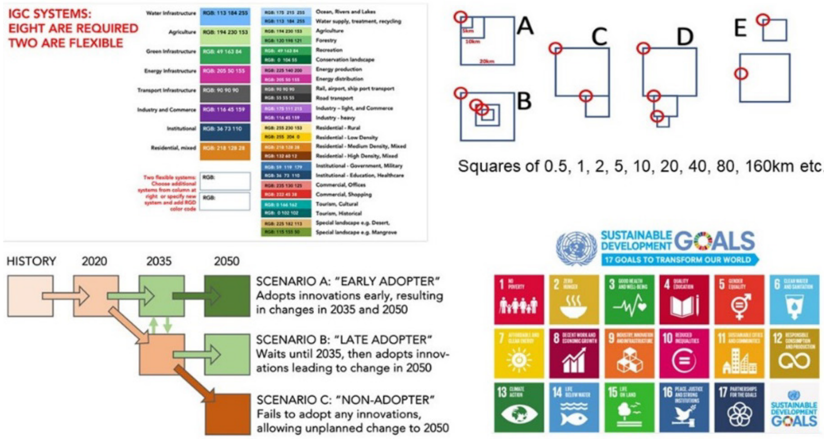

Fig. 11: Agreed conventions in the International Geodesign Collaboration

In 2020 the International Geodesign Collaboration published the book based on the 50 projects which were completed in 2019 (FISHER, ORLAND & STEINITZ 2020). These are also available in poster format on the IGC website, along with the projects completed in 2020.

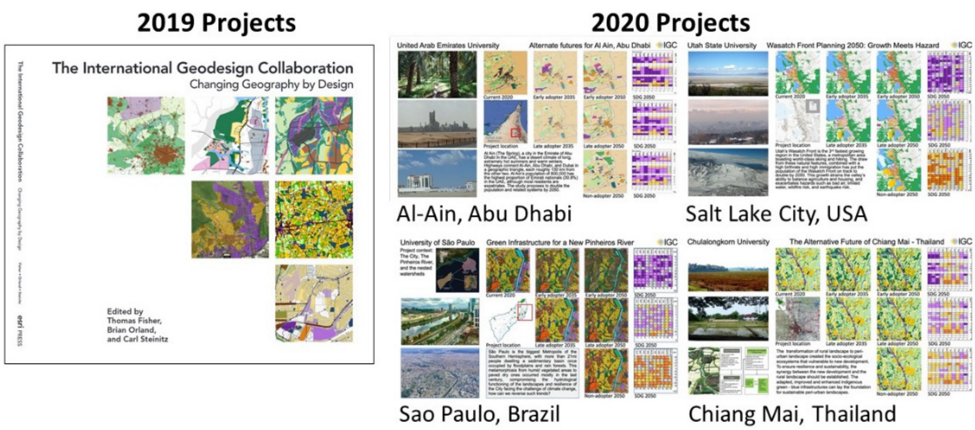

Fig. 12: The publication of the first 50 IGC projects

The 2019 projects were comparatively assessed and two of the conclusions are especially important. First, there was considerable variation in the significance of the systems included in the studies. Green Infrastructure, water infrastructure and mixed higher density housing with commerce and institutions were dominant… and these are core interests of landscape architecture. Second, the systems were considered differently as functions of climate, macrogeography and level of economic development.

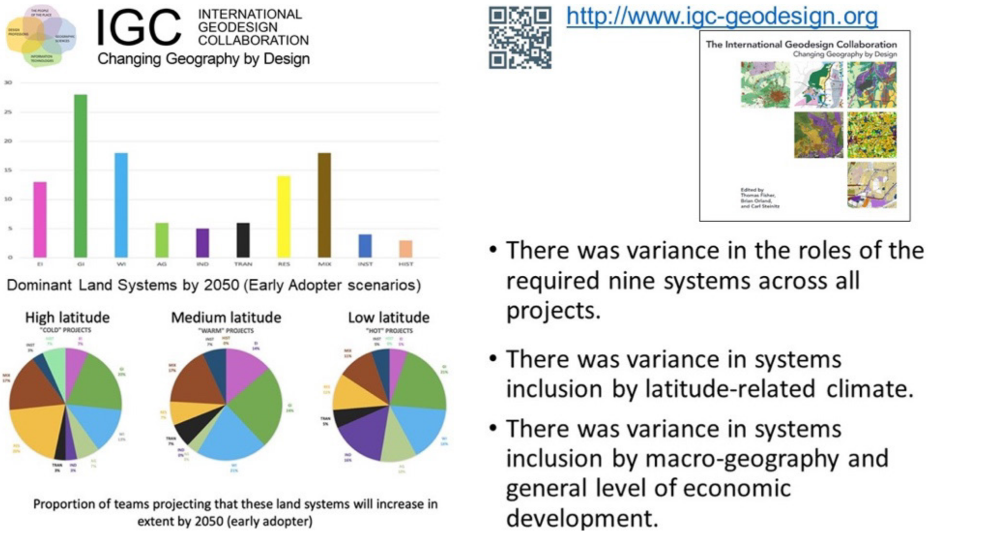

Fig. 13: Comparing the first 50 IGC projects

The implication is clear: One global design or one global set of policies and projects is not the answer to the mitigation of climate change. There must be local geodesign adaptations to systems-based policies and projects which can cumulate by negotiation into a global geodesign strategy. I think that the founders of the profession, if living today, would be important participants in the International Geodesign Collaboration and working with us in these local-to-global studies. They would likely focus on the larger studies and their work would be collaborative and fully digital.

I think that there are four reasonably clear possibilities for the future of digital landscape architecture, within a profession and an academic field only some of which is digital (and appropriately so).

The first possibility is simply a continuation of where I think we are today, in which most landscape architecture faculty, students and professionals are oriented towards immediate client-oriented projects, and working non-digitally much as the founders did.

The second possibility follows the first and assumes increasing competition for what has become "hot property"— the landscape. External competition at all scales will likely produce a narrower landscape architecture profession, far different from that imagined over 100 years ago by the founders of the profession of landscape architecture.

The third possibility is that the wrongheaded and artificial division between "planning" and "designing" (as verbs) will be continued and even reinforced, and that landscape architecture will itself choose to focus on the design of smaller projects. It will result mainly from two factors — the unfortunate caricature of landscape architecture as gardening, and the landscape architecture profession's own accredited priorities towards private project practice.

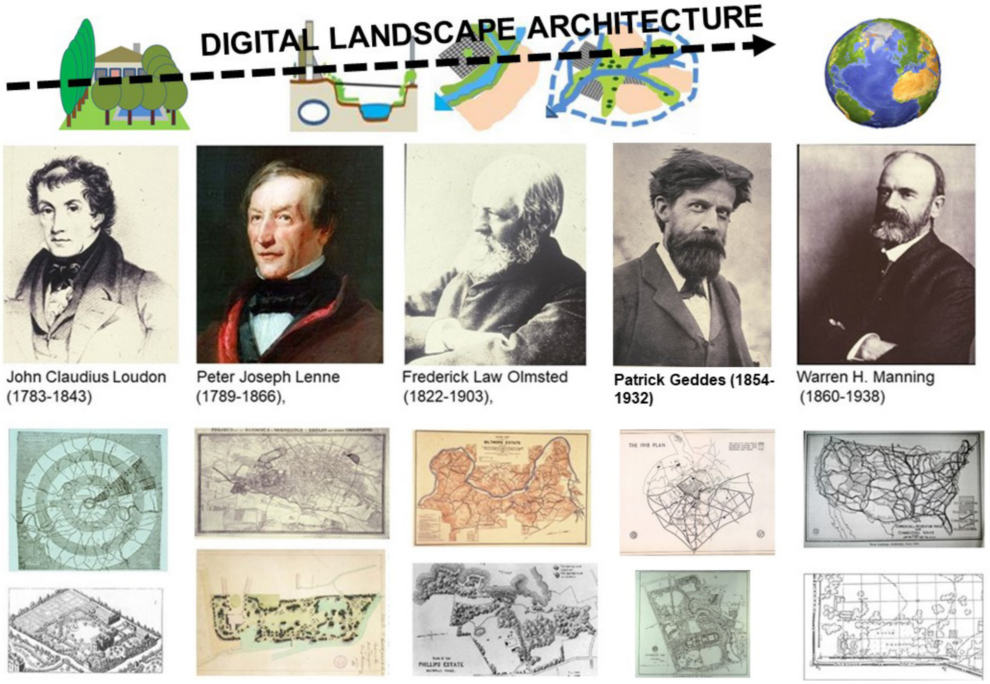

Fig. 14: Would the founders adopt digital landscape architecture? Would they participate in the International Geodesign Collaboration?

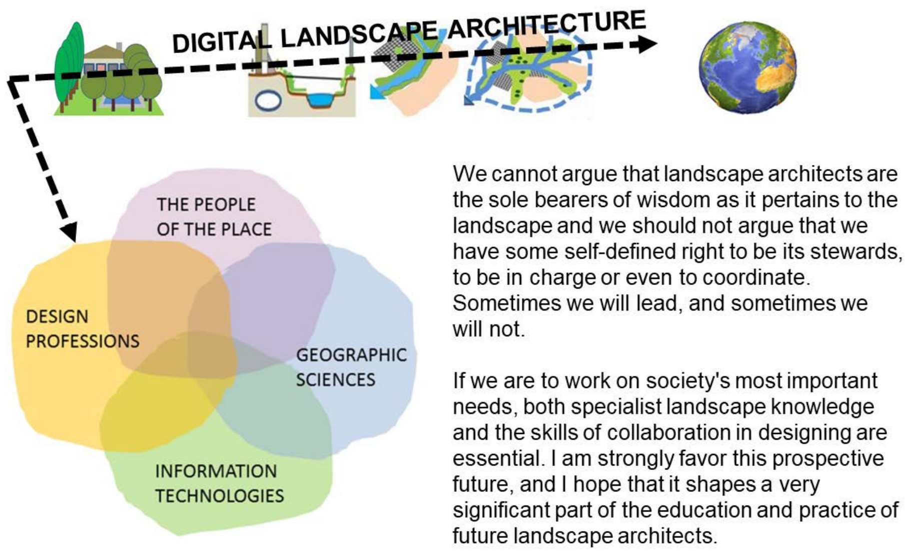

Fig. 15: A view toward the future of digital landscape architecture

The fourth possibility relies on recognizing the wisdom of the founders of the profession. First, we must know and do something that other professions do not. In our case this must be rooted in the landscape itself and at all sizes and scales: climate, geology, hydrology, ecology, perception etc… and all can be considered when designing with digital support. The digital technologies are the means… they are not the ends. Second, we must understand that almost everything we do to change the landscape requires collaboration in designing, whether with architects at the smaller size, urban designers and planners at the middle sizes, geographers at the larger sizes, with engineers at all scales, and with lawyers and bankers and government officials, and especially with many diverse stakeholders… yet with no one losing his/her personal or professional identity. This was the dominant vision at Harvard when I joined the Harvard faculty in 1965 and it is a perspective which I hold to this day.

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Resilient Landscape, Global Change and Hazard Response

Shifting Sands: Experimental Robotic Earth-Moving Strategies in Dynamic Coastal Environments

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Abstract: The increased prevalence of storm surge events that cause extreme erosion in coastal environments points to the delicate balance that exists in the perpetual formation processes of dunes. While coastal defence structures and traditional beach nourishment strategies can alleviate some of the damaging force of ongoing wave action, they don't provide a lasting solution and often produce undesirable side-effects. Design authority in this contested area of landscape transformation is often limited to engineers and shaped by reductionist economic or risk management factors. Through investigations in digital landscape fabrication techniques, this paper reconsiders the role of design in these evolving systems while demonstrating the potential for on-site, adaptive, and dynamic construction processes. By creating resilience through adaptive topographies of natural granular material, this paper proposes to establish a new equilibrium between natural processes and robotic earth-moving strategies. By combining a wave tank with natural beach sand, computational modelling and robotic beach sand manipulations, emergent topologies and open-ended design proposals are enabled under the continuous influence of water movements. The experiments were conducted in a two-week international masterclass at the School of Architecture, University of Technology, Sydney, where adaptive feedback systems for coastal remediation were studied in relation to the Northern Beaches of Sydney. As such, this paper presents a novel coastal design approach towards autonomous construction in dynamic environments, combining various technologies to generate new paths of research and design investigation.

Keywords: Coastal erosion, robotic processes, granular resilience, digital landscape fabrication, soft engineering

1 Introduction

In the summer season of 2020, up to 25 meters of the Collaroy and Narrabeen beaches in northern Sydney, Australia, were swept away by multiple storm surges. Existing rigid defence structures from wood, stone, and concrete suffered severe damage, sinking slowly into the loose granular dune area as their foundations were eroded away. While comprehensive maintenance strategies are developed to replenish the beaches with sand, Australia doesn't have the equipment, the policies, nor enough locally available sand to conduct them (SIDDEEK 2020). Instead of using conventional engineering methods, this design experiment applies robotic processes and natural processes towards continuous maintenance strategies for dynamic coastal defence structures, focusing on local material shifts and bathymetry manipulation.

This work builds upon a growing body of research into similar robotically enacted dynamic landscape tending processes (GRAMAZIO et al. 2014), (ESTRADA 2018), (BAR-SINAI et al. 2019), (HURKXKENS 2020). It also relates to work in sensor-enabled adaptive robotic fabrication in architecture (VASEY et al. 2014). The key contribution of the research described in this paper emerges from the change in context. Focusing on coastal environments provides a

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constant energy-source (the waves) that necessitates repeated action and provides the opportunity to collaborate with and productively harness an otherwise destructive process.

Here, the ultimate goal is to find topographies and intelligent adaptive maintenance processes that use the formative potential of erosion and sedimentation to minimize the mechanical manipulation required to achieve coastal remediation goals. These goals typically prioritize the protection of adjacent structures but also include a reduction of erosion and therefore the requirement to import supplementary material, the increased stability of the coastline and increased safety. The methods here described have the potential to allow for the greater fulfilment of ecological and habitat preservation goals along with the support of recreational activity, embodied energy minimization and improved aesthetics together with a reduction in the scale and consequences of unexpected side-effects.

The first step towards that goal is to establish whether sand topographies can be produced and dynamically maintained in interaction with wave motion and to assess the design potentials revealed. The second step is to begin to produce landscape formations that demonstrate positive interactions with wave and sand motion. Rather than a restrictive experimentation environment, the combination of technologies aims to reveal unexpected synergies or potentials for further investigation.

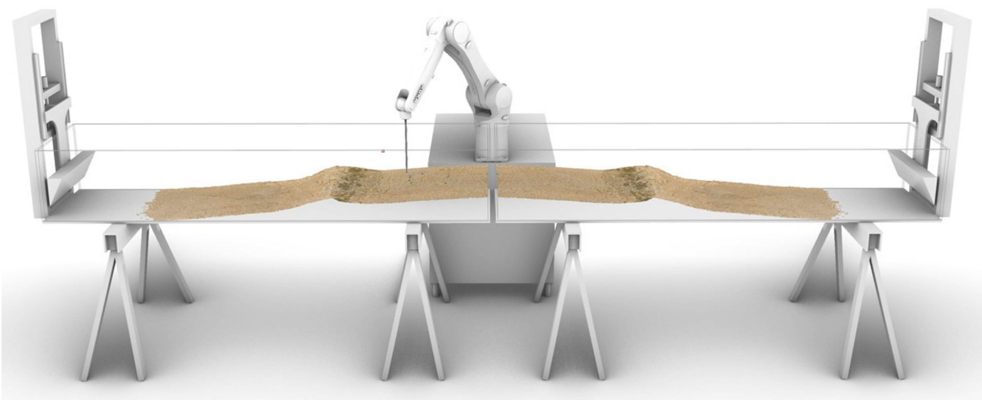

Fig. 1: Robotic Setup with wave tanks, wave actuators, beach sand and robotic manipulator

2 Robotic Wave Tank

The design experiments consisted of two phases. The first phase uncovered the object of study through five separate lenses: site, natural processes, granular material, environmental perception and robotic processes. This phase divided the tasks and methods among the participants of the masterclass and focussed simultaneously on digital craft and incremental investigation. These parallel investigations provided the groundwork for the second phase of the research, which synthesized these findings and techniques in comprehensive experiments.

To explore erosion and sedimentation processes on sloped beaches, two wave tanks were constructed (see Figure 1 and 3). Beach sand was then put into the tank to construct the berm, swash zone and surf zone (see Figure 2). The wave machines were controlled by time-interval scripts, which enabled the creation of precise wave patterns perpendicular to the beach profile to simulate storm surges. The robotic setup consisted of a six-axis robot arm, tool holder, and a 3D scanner to enable a computational response to changes in the topography by wave action. Starting from initial robotic movements designed to shift the granular material in the wave tank, the topography further informed their dimensional parameters like depth, length, and orientation. In this way, a dynamic response was created to either counter, accelerate or steer erosion and sedimentation processes depending on evolving insights during the experiments. This process was further monitored by high-res 3D scans using photogrammetry. This enabled a precise understanding of volume loss, particle transportation, and slope angles. Through an iterative feedback loop between scanning, designing and fabrication, experimental formal outcomes in continuous transformation arose (see Fig. 4). This allowed computational processes to be fine-tuned to come to resilient structures capable of withstanding multiple storm surges.

Fig. 2: Experimenting with the robotic feedback loop. Visible in the top-right is the tool holder on the robotic arm and perpendicularly attached to it the 3D scanner.

While the experiments were conducted as precisely as possible, physical processes are hard to control due to the scale of the wave tank and the mismatched scales of the 1:1 sand granules and the reduced scale of the waves and beach topography (LEMOS 2009). The difficulties and limitations facing attempts to understand complex water systems with scale models have been extensively and eloquently described in Martin Reuss' famous essay "The Art of Scientific Precision: River Research in the United States Army Corps of Engineers to 1945" (REUSS 1999). The outcomes should therefore not be seen as directly scalable and deployable techniques but rather as a first proof-of-concept of the methods and creative explorations of material and robotic processes to extract initial insights to be extended through future research.

The most obvious need is a set of experiments to establish and verify the appropriate scale-factors and coefficients necessary to extrapolation of results from scale models to the real world, along with an understanding of the limits of such extrapolation. But more importantly, the experiments change the way designers interact with the object of study: from conceiving static and final images to defining feedback systems that continuously change over time (McGee and Pigram 2011). Here, robotic processes form a natural fit to continuously evolving granular material systems under the influence of waves.

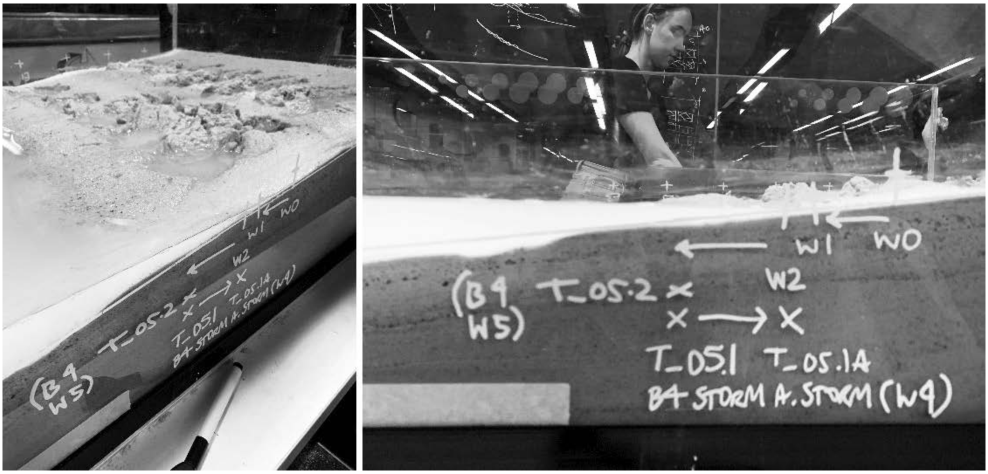

Fig. 3: Documenting a storm surge on the side of the water tank. From left to right the surf zone, swash zone, berm, and dune region in relation to the average water levels.

3 Experiments

A beach site's natural dynamic equilibrium of erosion and nourishment can maintain a safe, though continuously evolving sand dune without intervention. However, the existence of artificial constructions place limits on this possibility. The status quo requirement for current buildings and roads to stay in their current position on the beaches of Collaroy and Narrabeen, makes human intervention unavoidable. For this experiment, the natural process of wave action was calibrated to mimic the average wave height, length and frequency as well as waves during high tide combined with stormy weather found at Collaroy and Narrabeen beaches. This knowledge was combined with the material system of natural granules. Here, well rounded and sorted sand particles have only a limited formal design space, as the maximum slope angle is roughly 33 degrees. While this is true in large scale landscapes, the wet sand in the wave tank did achieve higher slope angles due to the small scale of the testing setup. Through the use of large- and small-scale photogrammetry, an understanding of the site's existing and newly proposed beach profile became possible. The robotic processes followed a clear procedure starting with a 3D scan of the sand in the wave tank, topographic analysis, the mapping of topographic transformation onto robotic movements to encode a dynamic response and finally, the execution of the robotic movements. This iterative robotic intervention adapts its patterned response based on the scan data, balancing the legibility of the original terrain geometry with an approach to an equilibrium in the system, often requiring smaller, targeted robotic interventions.

As referred to earlier, the two sequential yet complementary research phases of individual technique research and synthesis allowed for calibration of each method; the translation of these separate techniques into the synthesized experiments of phase two was a key aspect of the didactic process, requiring strategic debate.

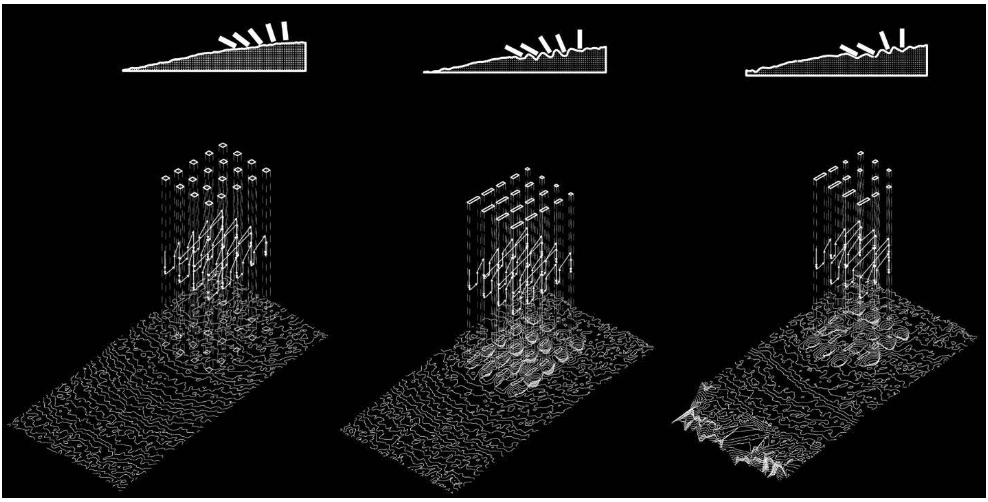

Fig. 4: Three iterations of the robotic feedback loop between scanning, computational modelling, and robotic response. Clearly visible is the change in motion from step 1, 2 and 3 which is solely due to the evolving topography of the sand in the wave tank.

Survey Technique

The scans were completed using an Intel RealSense Depth Camera and with photogrammetry. The challenge here was not resolution or frequency as in similar experiments (HURKXKENS et al. 2019), but scanning underwater topographies. During these experiments, the wave tanks were successively filled and emptied in order to scan the model's representation of the oceans floor. This is obviously not possible in the field, though other technologies are capable of scanning subaquatic landscapes (CASTILLÓN 2019).

Tool Shape

The manipulations deployed in this experiment are most closely associated with grader-style manipulations in that sand was relocated relatively close to its original location rather than deposited from elsewhere. A number of sand-manipulating tools were tried, initially by hand and then as robot end-effectors. A spatula manipulator had the characteristic of being highly directional: producing dramatically different results depending on the manipulator's angle relative to that of the motion. With its thin edge pointing in the direction of travel, the card slides effortlessly through the sand with minimal consequence. It had the benefit of being able to be used like a grader (being pushed at an angle to the direction of motion) with sand being deposited on the trailing side. A 20 mm × 20 mm square-section timber was the manipulator ultimately chosen for the final, longer robotic experiments. The primary benefit that this tool offered over others was the ability to press directly down into the sand, compressing it, and producing a stable imprint. These compressed depressions survived longer in the surf zone, or even below the water surface, then uncompressed depressions. Additionally, as the variable width markings enabled by the other tools proved to be of marginal benefit, the relatively constant width of the tool simplified the generation of robotic motion paths.

Adaptive Robotic Motion

The prevailing natural tendency during storm surges is for sand move downward on the beach and out to the sea. This is conventionally addressed through beach nourishment. We responded to this with robotic motions that begin by plunging to the low side of the beach slope and then move upwards, bringing sand back to the berm. After each scan, a map was created that identified the change in height of all areas. As mentioned above, the general tendency was for high areas to subside and for low areas to rise by being filled in, and this was accompanied by the more general tendency for all areas to subside gradually. Both of these tendencies were amplified by the increased presence of water as well as by the increased presence of wave energy. Various responses to the height deltas were tested. The first was to attempt compensation by moving sand towards the areas where height decreased and away from the areas where height increased. We expect that many of these findings regarding general tendencies would remain true for larger-scale implementations of these experiments with specific adjustments depending on the beach profile. As such, the parameters underlying the adaptive response would need to be re-discovered for each site's wave, coastline and sand characteristics, but these experiments provide a place to start.

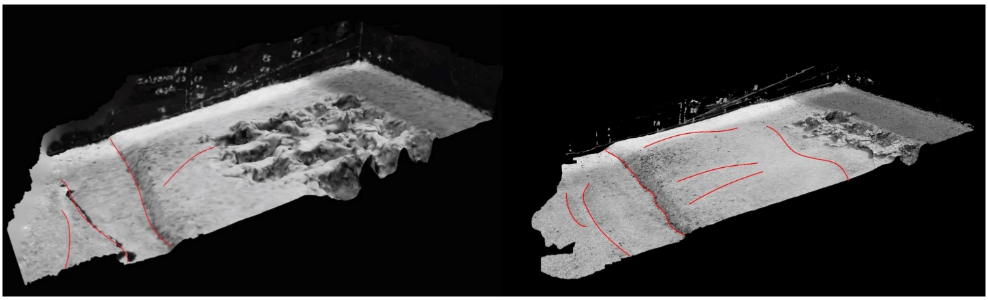

Fig. 5: High-resolution scan of two iterations between wave action and robotic manipulation. The wide dune structure does erode but keeps the sand in place, creating a large sandbank reducing wave action on the berm.

Landscape Formations

The general tendency was revealed by before and after wave-action scans: sand formations regress to the mean where high points became lower and low points became higher. This was particularly true when the sand became saturated. In order to achieve results that outperformed this general condition, specific conditions needed to be studied. In all cases, multi-layered formations were more successful than single-layered formations. Here, the first layer reduced the wave energy, which can be seen largely as a reservoir of sand that will be relocated via wave action to the lower edge of the surf zone. Formations at an angle between approximately 30 and 50 degrees to the wave motion proved successful at capturing sand. Secondary benefits such as the dissipation of wave energy through redirection could be witnessed there as well. It became apparent that while a single breakwater can withstand a storm surge for a certain time-frame, its failure would immediately create a large natural disaster. Instead, strategies that modulated a larger surface and a lower maximum height performed much better. While the wave-action started to erode the front of the defence structure, it took much longer to reach its point of failure. This was made possible by trapping sedimentation within the structure itself, creating a larger sandbank between the swash zone and the berm (see Fig. 5).

4 Conclusion

Notwithstanding the aforementioned issues around scale, the conducted experiments were able to reveal a series of behavioural tendencies and insights in the key areas of landscape formations, tool shape, adaptive robotic motion and surveying techniques. Desired performance outcomes included increased formation longevity, the wave-powered accumulation of material in desired areas typically higher up the beach; the creation or preservation of landscape structures that diminished peak wave energy; and reduced storm penetration beyond the normal shoreline. While wave tanks are often referred to as more of an art than a science (OUMERACI 1999), the value of the physical representation and the scalable accuracy of many key fluid phenomena is clear. The Collaroy beach was chosen for its specific absence of ocean phenomena such as cross-shore drift, which is difficult to simulation in a small-scale linear wave tank. Despite clear shortcomings, the many strengths of physical wave tanks are well documented (OUMERACI 1999), including observability, measurability, repeatability, input control and process control, as well as the clear didactic strengths of a physical representation of the phenomena observed; the students were able to draw resulting phenomena directly onto the sides of the tank.

The experimental setup of the wave tank and the robotic arm enabled a dynamic response to a dynamic environment. It showed how digital landscape fabrication changes the design process from envisioning a single final form to defining the parameters of a potentially continuous feedback loop between robotic manipulation and natural erosion and deposition processes. Within the iterations of the experiments, it was possible to either reach apparent equilibrium or even build-up shoreline through well-defined iterations; however, these differed from the Collaroy Beach context. The masterclass participants demonstrated sophisticated interaction with elementary material and fluid properties and of the individual techniques and their synergy by designing and implementing the final strategies in detail.

The experiments demonstrate the integration of formal, environmental, material, and topological aspects of a landscape with computational tools to come to site-specific interventions with on-site autonomous machines, opening up new coastal management strategies that leverage natural processes. At the same time, working solely with locally found materials creates potential for a resilient and sustainable construction approach. With the recent advent of autonomous earth-moving machines (VASEY AND MENGES 2020), emergent and open-ended design strategies for specific dynamic coastal environments become a possibility. While this paper uncovers some of the potentials that a dynamic model of beach maintenance may offer, further work remains to be undertaken before this model could be put into practice. Having said this, the continuous adaptive nature and the scale of intervention of the processes proposed inherently lends itself to real-world experimentation.

Fig. 6: Robotic sand formation after one manipulation cycle and a single simulated storm surge

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Conceptualizing a Model of Antifragility for Dense Urban Areas

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Abstract: Understanding how cities respond to stress can inform possible planning, design, and management changes to advance health, safety, and welfare. This paper considers antifragility, which is a property of some systems to improve when exposed to volatility, as a means to understand dynamics of dense urban areas. It presents a computational framework to assess if urban systems are becoming fragile or antifragile by tracking changes in service capacities following disruption. The Political, Military, Economic, Social, Infrastructure, and Information (PMESII) categorization is adapted to reference capabilities and extended to pose and test hypotheses about system orders for urban areas.

Keywords: Antifragility, resilience, urban systems, PMESII

1 Introduction

This paper presents a framework for a computational model of antifragility (TALEB 2012), which is a property of some systems in which they improve when exposed to volatility, for dense urban areas. The work is motivated by the increasing size and density of contemporary cities, by the vulnerability of cities to natural and anthropogenic disasters, and by the expanding roles of large cities in national and international economic, environmental, and security matters. It is done on the premise that tracking the ways urban populations develop or lose capabilities and capacities to overcome disruptions of various types, magnitudes, frequencies, and durations can provide a basis for improved planning, design, and management.

Nicholas N. Taleb coined the term *antifragile* based on the behavior of open financial markets, but he argues for its general applicability. He distinguishes antifragile systems from fragile and robust systems based on the potential effects of uncertainty including volatility, disturbance, and stress, and he uses characters from Greek mythology as introductory examples. Fragile systems, like Damocles under the sword, have great exposure to loss due to uncertainty and do not benefit from exposure to it. Robust systems, like the Phoenix that rises after death, resist harm from uncertainty, but have limited gains from it. Antifragile systems, like the Hydra, are systems that grow or otherwise benefit from exposure to damage. A non-mythic example of an antifragile system is a person who exercises regularly: the body undergoes a temporary metabolic shift as it moves faster or lifts weight. As a result, the person becomes able to run farther and lift heavier objects. Significantly, as an outcome of the temporary stress, the body becomes more generally fit and able to do some things that were not explicitly prescribed in the training regime nor necessarily anticipated, such as having improved stamina to assist in an unforeseen emergency. System qualities that contribute to antifragility include being emergent rather than resultant, risk allowing rather than risk averse, enabling small-scale rather than system-wide experiments, even rather than uneven distribution of resources, redundancy rather than efficiency, loosely rather than tightly coupled components, and variety and variability rather than uniformity.

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2 Sustainability, Resilience, and Antifragility

Urban areas can be understood as systems that are: (1) *purposeful*, because they are created to satisfy societal goals; (2) *emergent*, because the behaviour of the whole cannot be reduced to the behaviour of individual elements; (3) *complex*, because individual elements have many relationships with other elements; (4) *open*, because they exchange energy, materials, and information with their context; and, (5), *self-organizing*, because, they can modify their internal structures or functions in response to external change. Across these qualities, patterns of resource distribution and flows of people, water, food, energy, goods, waste and information emerge from processes and can be observed and measured. (BARTHELEMY 2017, BATTY 2013).

Urban systems can exhibit nonlinear dynamics, reciprocal feedback loops, time lags, heterogeneity, and surprises (JIANGUO et al. 2007). These qualities combine to create uncertainty and volatility that can allow for the emergence of both positive outcomes, such as economic growth through innovation (CHRISTIAANSE 2009), and negative outcomes, such as the disruption and degradation of basic services that could contribute to the formation of so-called "feral cities" (NORTON 2003).

It is argued here that a consideration of antifragility expands the management of uncertainty in environmental planning, design, and management through the paradigms of sustainability and resilience by foregrounding ontological uncertainty. Figure 1 provides an illustration noting the dominant consideration of uncertainty in each paradigm. Relative foci of attention are indicated on lines connecting the three terms.

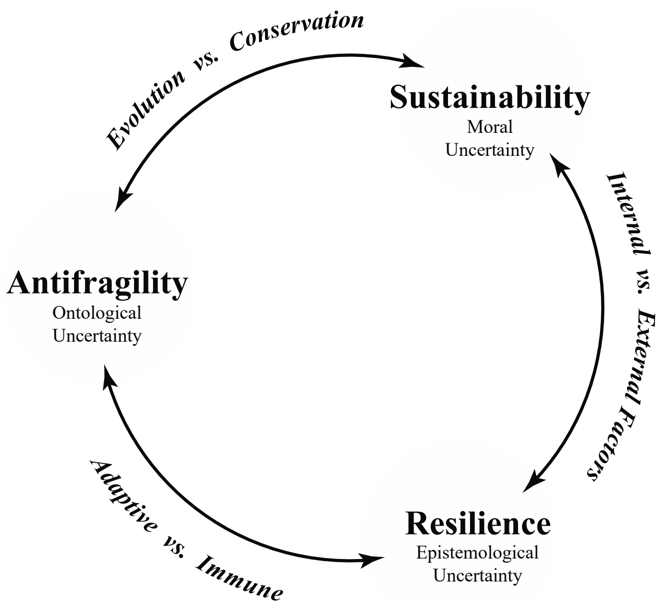

Fig. 1: Normative objectives of urban planning, design, and management and the associated predominant sources of uncertainty (Source: Authors)

The concept of sustainability can be understood as a focus on the long-term conservation of resources needed to support a system. The premise was common in texts on agriculture, forestry, and other natural resources fields since, at least, the 16th century (DIXON & FALLON 1989, WARDE 2011), but the term, itself, gained widespread attention in the late 1980s through *Our Common Future* (WORLD COMMISSION ON ENVIRONMENTAL DEVELOPMENT 1987). There is general consensus that sustainability is organized around the "triple bottom line" of environment, equity, and economics with the aim of not reducing resources or limit decisions of future generations. Determining how to define what is "right" or "just" or "best" in any one of these goals (or of any societal goal) presents moral or ethical uncertainty (HACKING & GUTHRIE 2008, MOELLENDORF 2011, VEENMAN & LEROY 2016).

The concept of resilience concerns a focus on abilities to withstand, recover, and adapt from external shocks. Consideration of it becomes increasingly important as a system's internal organization becomes more complex and as its exchanges with the system's environment become uncertain or volatile (HOLLING 1973, PICKETT et al 2004). With resilience, the moral questions emphasized under the paradigm of sustainability about which and how societal goals are prioritized are replaced by epistemological questions related to the difficult task of knowledge production about vulnerabilities and threats for purposes of governance (ARADAU 2014, CHANDLER 2014, WELSH 2014).

As noted, the concept of antifragility concerns the possibility that a system cannot only recover from disturbance, it can benefit from exposure to uncertainty and volatility by developing capabilities and capacities to manage stress, including stress that had previously not been experienced or that even imagined. This quality distinguishes antifragility from resilience and warrants emphasis. It is widely acknowledged that some understandings of resilience include the possibility of adaptation that enables the system to better withstand future shocks. The improvement, though, is an improvement to address epistemological uncertainty related to the ability to anticipate, guard against, and recover from the same kind of disruption. Medical vaccination is an example. The introduction of a harmful, but weakened or neutralized pathogen into a body allows a person to develop antigens that enable resistance to stronger doses of the same pathogen in the future. In these instances, the potential cause of harm (the specific virus) and the possible effect of harm (the specific infection) are narrowly defined. A flu shot in the autumn helps prevent contracting flu in the winter, but the same shot does not protect against measles. With antifragility, attention shifts from resilience's epistemological uncertainty to questions of ontological uncertainty related to the environment and its interaction with the composition, organization, and behavior of the system. Succinctly, becoming more antifragile is not adapting to handle the same sort of crisis better, but to better handle crises in general.

3 Application to Urban Planning and Design

Since its introduction, antifragility has been discussed within domains of knowledge and practice ranging from genetics (DACHIN et al. 2011) to athletic performance (HILL et al. 2020) to business operations (JAARON & BACKHOUSE 2014) to computer science (HOLE 2016) to homeland security (EGAN 2013). In urban and landscape planning and design literature, emphasis has been given to the adding options to respond to disruption as a way to increase antifragility (BLECIC & CECCHINI 2017, BLECIC & CECCHINI 2020, ROGGEMA 2019). Following from this premise, the initial task of moving from an aspirational model to an operational model of antifragility for urban areas becomes developing a framework to collect and relate data that indicate the gain or loss of optionality.

Figure 2 provides a diagram of the basic needs for tracking the development of a system becoming more antifragile by gaining options or, conversely, more fragile by losing options. At the top of the diagram are indicators of societal capacities, on the right hand side are kinds of change, at the bottom of the diagram are the system's responses to change, which are qualified on the left hand side. Issues related to each of these data types are discussed below. Data sources would include remotely sensed data, aggregated news resources, objects connected to the Internet-of-Things (IoT), routing options for flows, observational surveys, and interviews of personal perception. The volume of data is expected to be large. Growth of IoT sources offers the promise of increased objective measurements, but initial operational tests of the framework might focus on surveys of perceptions across an urban area to understand what how disruptions are locally recognized and managed.

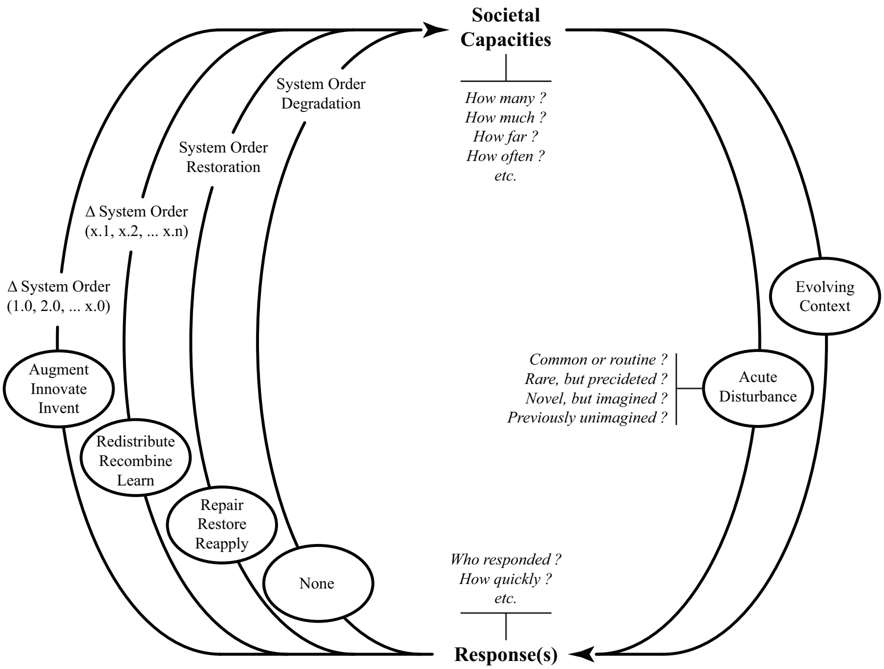

Fig. 2: Framework to observe system response to disruption (Source: Authors)

Defining classes of indicators throughout the framework can be done only provisionally for two reasons. First, epistemological uncertainty, a concern shared with efforts to improve resilience, limits ability to accurately identify and parameterize cause and effect relationships within complex urban areas. Second, ontological uncertainty limits ability to anticipate all forms of future volatility and how resources might be used to manage disruptions.

Additionally, the expected qualities of an antifragile system (being emergent, risk allowing, enabling small-scale experiments, even distribution of resources, redundancy, loosely coupling components, and variety and variability) point to the need to collect the data at multiple spatial scales over time. Figure 3 illustrates one approach to do so based on common urban administrative units: politically recognized neighbourhoods, districts, the city as a whole, and the metropolitan region around the city. An advantage of this approach is that these units may be commonly used by municipal service providers. Another approach would be to map "neighbourhoods" based on activities. An example is offered by an assessment of national districts in the United Kingdom. The authors of this study used density of telecommunication contacts and produced a map that was similar to, but not identical with long-established political jurisdictions (RATTI et al. 2010). The advantage of these units of analysis would be greater fidelity to social or socio-economic groupings. A third approach would be to use floating averages of indicators taken at different areal extents, such as 1 hectare, 10 hectares, and 100 hectares. The advantage with this approach would be to identify or track aggregate hot- and cold-spots of resource availability and system responses.

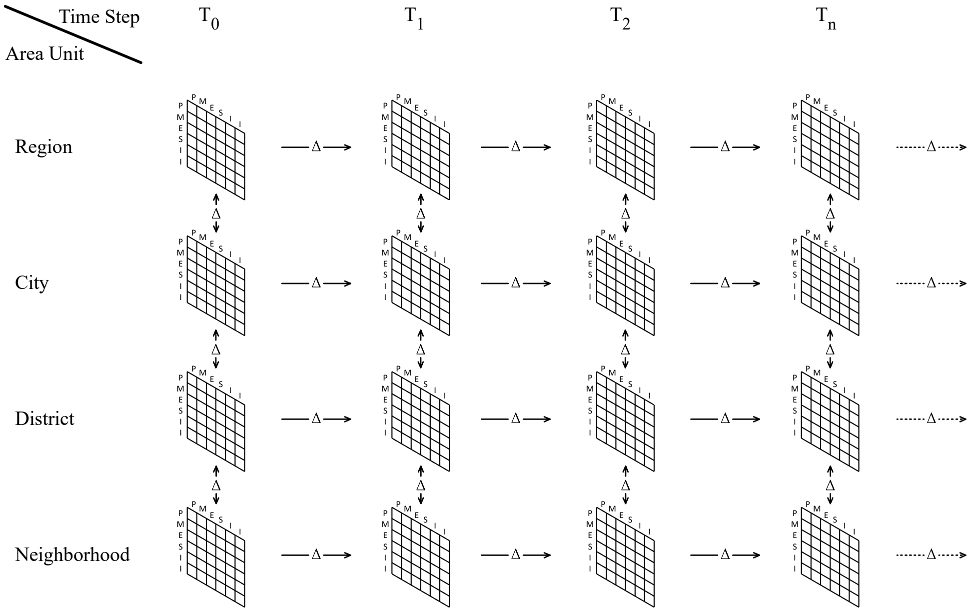

Fig. 3: Spatial scales of urban order (Source: Authors)

Tracking increases or decreases in options to overcome volatility is done through the societal capacities indicators. Four classes of indicators or proposed. The first class consists of spatially fixed resource capacities that would be recorded by number per area (neighbourhood, district, etc.) and number per population. Examples include fire and police stations and hospitals. Non-emergency fixed resources include grocery stores and schools. It would be important to inventory how things are used, not just how they are most often classified on a land use map. For example, a parking lot might sometimes be used as a market. This class of indicators also includes people who staff these resources, such as fire-fighters, which might also be distinguished by time as well as space if, say, night shifts have fewer personnel than day shifts. The second class of indicators consists of measures of diversity of spatial resources. This class is arguably the most difficult to conceptualize with regard to measures of fragility or antifragility. For basic services, having access of a variety of service providers, such as internet service providers, provides a range of options. Similarly, having a transportation network that allows more ways to travel from one point to another provides a range of options. But not all services are equally exchangeable. For example, having multiple places of worship for the same religion or sect provides a choice of providers for assembly, but does not offer the same kind of choice across religions. As such, indicators of social diversity need to be supplemented with indicators of interoperability, integration, and inclusion. The third class of indicators would be service frequency. Examples include police patrol passes per day or per week or the number of times streets are cleaned per week or month. The fourth class of indicators would be perceptions of residents about structural and functional capacities. In part, this class of indicators serves to assess if those who live in the city note or utilize available resources. Also in part, it provides a way to assess not only the use of resources, but also the trust in different service providers. For example, who might be contacted to help resolve a neighbourhood dispute?

Moving clockwise around figure 2, two kinds of volatility are noted. At the far right are relatively slowly moving contextual factors. These include trends related to politics, economics, society, and technology. On the inside are fast moving, acute disturbances or shocks. Although abrupt events are the topic of Taleb's writing, innovation and reorganization in urban areas follows from both slow and fast moving endogenous and exogenous change (BOND-FORTIER 2020, DORAC et al. 2017, TENG-CLLEJA et al. 2017). The selection of indicators for both kinds of disruption need to be connected to loads of the previously identified service capacities. As with the indicators of social capacity, it would be valuable to understand relationships between fact and perception. For example, what connections do residents draw between kinds and magnitudes of evolving change and abrupt disruptions?

At the bottom and left of the diagram are the system's responses to the disruption. There are two classes of indicators. The first is the immediate response – who responds, how quickly, with what means, etc. The second, qualified on the left hand side of the diagram, are four possibilities for remediation and recovery: the city can do nothing in response to exogenous change, it can maintain or restore capacity, it can learn, recombine, or redistribute existing resources to become more efficient, or it can innovate and fundamentally reorganize. It might be expected, but would need to be tested, the degrees to which each of these options is pursued given the dynamics of both routine conditions and crises (ROSEN 1988). Any changes made to the urban system will be reflected in revised social capacity indicators.

While it can be said that from a planning, design, and management perspective, becoming more antifragility by increasing options to respond to disruptions is beneficial, it must be recognized that antifragility is achieved by allowing failures to occur through small scale experimentation, so progress might be uneven. Further, improving antifragility of a system involves allowing some components to be fragile. That is, the survival of the whole is achieved by transferring vulnerability to some parts (see chapter 4 in TALEB 2012). This aspect of antifragility has been viewed by some as controversial (KOLERS 2016).

4 Hypotheses of Urban Order that Contribute to Antifragility

Towards the ability to move beyond descriptive statistics to a fuller science of cities (BATTY 2013), there is the need to state and test hypotheses about changes to the built environment. With regard to the framework presented here, if capacities to support societal goals are assumed to result from system order, the indicators should be framed within an understanding of urban systems organization. Such a framework would allow hypotheses for ways capabilities are created or lost through combinations of structural features and behaviours.

As an example, one approach would be to employ a modified version of the Political-Military-Economic-Social-Infrastructure-Information (PMESII) framework, which was developed by the US Army to describe operational environments – places known to be volatile. PMESII is typically used to provide a structural inventory of factors. To understand the city as a dynamic coupled human-natural system, two modifications or extensions will need to be taken. First, the structural descriptions are rewritten as "How…?" questions. For example, the conventional Military description, "Explores the military and/or paramilitary capabilities of all relevant actors (enemy, friendly, and neutral) in a given operational environment" (US ARMY 2013) is reconsidered as, "How are security issues defined, declared, engaged, and resolved?" (SHEARER 2021). Rephrased questions are given in Table 1.

Table 1: Functional PMESII questions (Source: Authors)

Variable	Defining Question
Political (P)	How is a member (typically a citizen) identified, what rights pertain to a member, and how do these rights differ from non-members?
Military (M) [Public Safety Agencies]	How are security issues defined, declared, engaged, and resolved?
Economic (E)	How do people exchange goods and services?
Social (S)	How do individuals and groups behave and why do they do what they do?
Infrastructure (Infra)	How are flows – of people, food, water, goods, power – coordinated throughout the city?
Information (Info)	How is truth recognized?

In the second modification or extension of the framework, questions related to system function are asked across the six primary topics. For example, the Political-Social interaction question is, "How is order legitimized?" In part, these questions provide a basis to deepen the analysis of the six primary areas and may reveal more nuanced issues of strength or of vulnerability. They also offer lines of inquiry to consider second- and third-order effects of change or disruption. Separate from tracking indicators of capacity, a high number of news stories from a given city related to one of these questions would signal an expectation of system change.

With respect to urban planning theory, it is offered that three triplets of PMESII interactions provide a provisional basis to hypothesize and test kinds of system order. These are shown in figure 4. The first is order established/expanded from above through the Political-Military-Infrastructure triplet (after ALLEN & COCHRANE 2010, GULDI 2012, SCOTT 1998). The second is order established/expanded from below through the Economic-Social-Information triplet (after JACOBS 1961, JACOBS 1969). Third, and in recognition of emerging smart city and cyber systems, there are two possible ways to establish/expand order from within. Social-Infrastructure-Information permits platforms such as Facebook to enable capabilities and capacities (after HELMOND et al. 2019). Political-Infrastructure-Information permits a new form of centralized ("smart") governmental influence (after CHEN & SHAN 2019, QUI 2007). While these sources of order are supported by the literature, it is possible that more influential relationships that support capacity change could be identified through longitudinal analysis of individual cities or through comparative analysis of different urban areas.

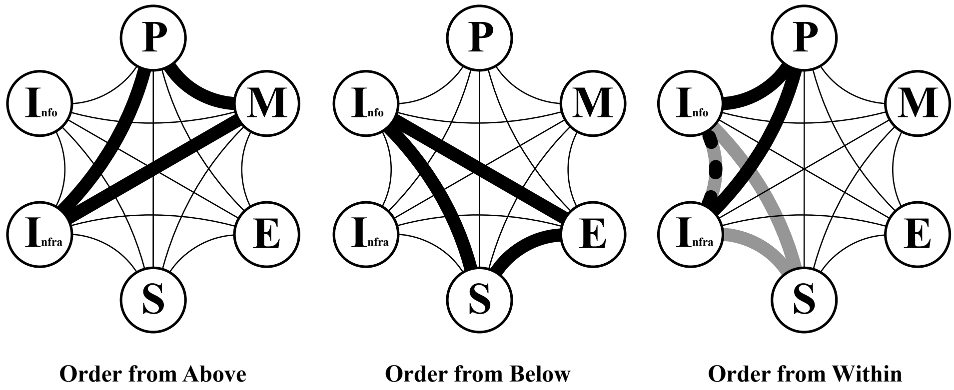

Fig. 4: Sources of urban system order (Source: Authors)

It should be emphasized that the approach outlined here does not pre-identify expected tipping points when an urban areas is considered anti-fragile or fragile. Instead it seeks changes in health, safety, and welfare capacities over time and draws attention to those changes. Hard tipping points are not provided because dense urban areas are open, complex, self-organizing, and emergent systems, so it is unlikely that abilities to manage a disturbance or to fail from it will look the same in the future as they did in the past. Related, while commonalities can be found across cities, a variety of factors including localized social expectations, level of industrial and economic development, and political organization make it seem unlikely that all urban areas would fail or succeed in the same way.

5 Conclusion and Outlook

This paper advances discussions on antifragility for urban areas by providing a framework for a computational model, categories of data, and a basis to frame and test hypotheses of evolving system order. Next steps would be to define arrays optionality indicators more precisely and begin collecting data. Given the large volume of observations that might be made, surveys and comparisons of neighborhoods within a given district may offer a step toward surveys including districts within a city and then a city within its metropolitan area.

In the last two decades of the twentieth century, the paradigm of sustainability foregrounded issues of moral uncertainty and aided the advancement of theories and practices for long-term resource management. In the first two decades of this century, the paradigm of resilience foregrounded epistemological uncertainty aided the advancement of governance for complex systems in settings with knowable even if not predictable shocks. Given unprecedented urbanization in the Anthropocene, it is increasingly necessary to consider ontological uncertainty, to look beyond identifiable threats, and to understand the functional dynamics of how cities reorganize and address previously not experienced or unknown stresses. The paradigm of antifragility can help planners, designers, and managers do so.

Acknowledgement

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Conceptualizing a Web-based 3D Decision Support System Including Urban Underground Space to Increase Urban Resiliency

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Abstract: The urban underground is increasingly recognized as a multifunctional resource important for achieving urban resilience. However, it is often neglected in planning processes. Since this can lead to undesired urban developments, approaches are required to take both the space above and below ground into account. In particular, there is a lack of visualization instruments (mainly due to available data) to foster a better understanding of the above and below ground urban system and interacting effects on urban ecosystem services. In this paper we demonstrate how urban infrastructure above and below ground can be visualized in a web-based platform using the open-source JavaScript library Cesium. Then, based on the presented prototype we illustrate its possible advancement for supporting a more comprehensive design and evaluation of possible urban developments in a collaborative planning setup. Testing and enhancing the visualizations in collaboration with stakeholders and complementing them by including 3D point clouds and 3D urban ecosystem services, the suggested platform could effectively help to explore the design of resilient urban systems and to co-develop urban transformation pathways desired by the stakeholders.

Keywords: Collaborative spatial planning, urban design, online planning platform, 3D DSS, CesiumJS, 3D underground infrastructure

1 Introduction

Increasing the resiliency of urban systems is a major objective in designing sustainable urban developments in order to ensure the well-being of the continuously growing urban population (ELMQVIST et al. 2019; MA et al. 2020). Resilience can be defined as the ability of an urban system to cope with disturbances, to reorganize itself, maintaining essentially the same functions and responses over time and evolving further along a certain path (ELMQVIST et al. 2019). Whether or not a resilient path is sustainable, however, depends on ensuring a development pathway that is also desired by stakeholders (ELMQVIST et al. 2019). The importance of achieving such desired urban development pathways is stressed in the United Nations' Sustainable Development Goal 11 (of 17) "Make cities and human settlements inclusive, safe, resilient and sustainable" (UNITED NATIONS 2015), which requires, inter alia, improving urban planning by an active management of wanted and unwanted urban resilience (ELMQVIST et al. 2019).

One important resource of the urban system for achieving urban resilience is the space below ground (PARRIAUX et al. 2004; ADMIRAAL & CORNARO 2016, 2020; VOLCHKO et al. 2020). It is increasingly recognized as a multifunctional resource, which offers physical space, water, energy, materials, an archive of historical and geological heritage, and several further ecosystem services, such as life-support systems, contributing to human well-being (PARRIAUX et al. 2004; ADMIRAAL & CORNARO 2020; VOLCHKO et al. 2020). However, the underground space is often neglected in planning processes or treated without a long-term management

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(VOLCHKO et al. 2020). Furthermore, through the deficiency of cross-sectoral planning, the underground space is used up for prevalent mono-functional uses in a "first-come-first-served" manner without taking into account possible other functions and interactions with the provision of ecosystem services – above and below ground – of the urban system (PARRIAUX et al. 2014; ADMIRAAL & CARNARO 2016; MA et al. 2020; VOLCHKO et al. 2020). This can lead to undesired developments, for example, an urban densification above ground to minimize urban sprawl can lead to an increase in the urban heat island effect, shortage of recreational area for the urban population, deteriorated storm water runoff resulting in flooding, and decreased quality of other ecosystem services due to diminishing urban green spaces (CORTINOVIS & GENELETTI 2020). Taking into account the underground space for creating built-up space, e. g., by building underground car parks combined with water retention basins, can help maintaining multiple services in a more resilient way (ADMIRAAL & CORNARO 2020). Yet, there is a lack of systematic approaches on how the underground can be integrated into spatial planning processes (VOLCHKO et al. 2020). To overcome this shortcoming, an active management of resilience in the respective urban contexts above and below ground and across scales is required, which should include experimenting with alternative solutions and knowledge co-production by involving multiple actors (ADMIRAAL & CARNARO 2016; ELMQVIST et al. 2019). Thereby, crucial issues are (1) to make the urban underground space visible, and, hence, to bring it into the decision-makers mind, and (2) to identify synergies and conflicts between urban developments above and below ground (VOLCHKO et al. 2020).

In order to facilitate a better understanding of the above and below ground urban system, 3D visualizations are regarded essential tools, which can provide a common language for heterogeneous stakeholders (MA et al. 2020; SCHOKKER et al. 2017). Yet, the 3D visualization of the urban underground space is not very common in practice and poses several challenges (SHOJAEI et al. 2013; SCHOKKER et al. 2017; MA et al. 2020). For example, required essential characteristics of the 3D model are inter alia the handling of massive data, interactivity, providing underground and cross-section views, and allowing usability and accessibility also for non-expert users (SHOJAEI et al. 2013). In addition, the 3D model needs to be able to integrate further data relevant in different urban planning contexts (SHOJAEI et al. 2013; SCHOKKER et al. 2017). In this regard, web-based 3D decision support systems offer access for multiple users without requiring special software on the user's computer (SHOJAEI et al. 2013). They can facilitate collaborative creation and analysis of spatial scenarios, whereby multiple objectives are taken into account and traded off against each other (GRÊT-REGAMEY et al. 2017; SCHITO et al. 2020).

The objective of this paper is to visualize urban infrastructure above and below ground level in a web-based 3D decision support system (3D DSS) for supporting the planning of electricity transmission lines on regional scale in central Switzerland and on local scale in the city of Zurich. The 3D DSS uses the open-source JavaScript library Cesium (CESIUM 2020a) to load diverse data sets as well as spatial modelling results on a 3D digital globe. We present the general setup of the 3D DSS for the area of Switzerland and focus then on the urban study site Zurich for details on the urban infrastructure visualization. Furthermore, we want to illustrate how such 3D DSS prototype could provide a platform for iterative loops between urban design development and evaluation. Based on recent examples from literature, we address compatible functionalities for the 3D DSS and explain how they could contribute to this end. We discuss the suggested platform concerning its current quality and provide an outlook on possible further enhancements of the visualization.

2 Method and Results: Visualizing Urban Infrastructure Above and Below Ground in a Web-based 3D DSS

2.1 Web-based 3D DSS Prototype

A recent example of a web-based 3D DSS is a platform developed for supporting the planning of electricity transmission lines in Switzerland (SCHITO et al. 2020). Users of the platform can weight relevant spatial criteria of the dimensions “nature and environment”, “spatial planning and people”, and “technical feasibility”, which are input in form of raster data (1 ha cell size) for a Multi-Criteria Decision Analysis (MCDA) that runs in Python [1]. By collaboratively discussing the weighting of the criteria and providing different settings of the weights, heterogeneous stakeholders can together create and visualize alternative scenarios of transmission line paths in short time (SCHITO et al. 2020). In the remainder, the focus is on the visualization part of this platform.

The web-interface of the 3D DSS includes a viewer for 3D visualization of data based on the digital open-source 3D globe Cesium (CESIUM 2020a). The terrain and the orthophotos of the area of Switzerland are retrieved directly from a server of the Federal Office of Topography swisstopo as Tile Map Service (TMS) [2] by applying a JavaScript code (Fig. 4). Swisstopo also offers the buildings and vegetation of Switzerland as 3D tiles via its web access service. Thus, in the 3D DSS, this above ground infrastructure is streamed directly from the swisstopo server. The modelling results of the MCDA (resistance maps, least cost path surfaces) are automatically saved on a geo-server as image files (png), which are displayed on the Cesium globe as 2D maps, and the resulting path is saved as points (csv) providing the location of 3D-objects of pylons with overhead lines in between, transition buildings, and earth cables. The latter are visualized as polyline volumes calculated directly in Cesium (CESIUM 2020b; see Fig. 1, blue tubes).

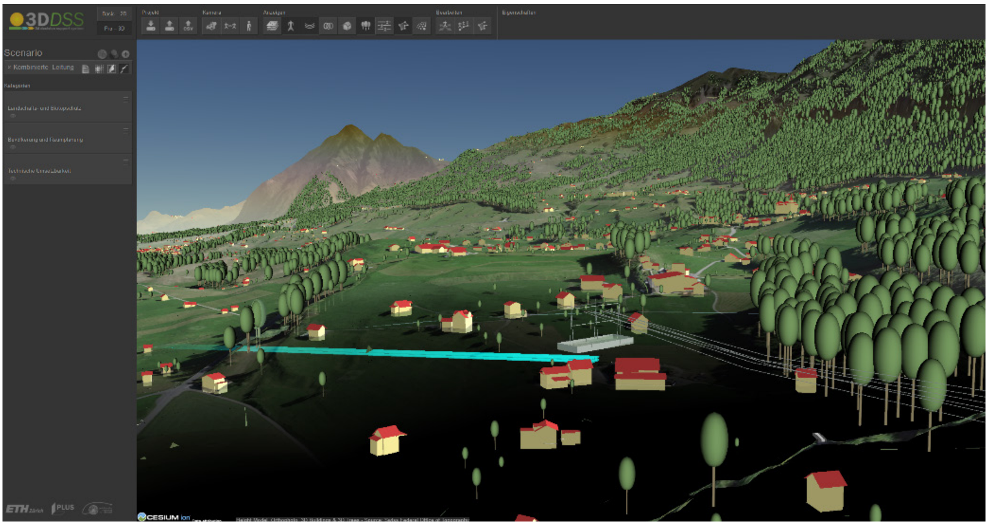

Fig. 1: 3D visualization of the modelling results in the interface of the 3D DSS: Transition building (grey) where the overhead lines change to earth cables (blue tubes)

2.2 Processing of the Urban Underground Infrastructure Data

For a perimeter with a size of 757 ha in the city of Zurich, where paths for new earth cables of electric power lines should be identified in the urban area on local scale, the transmission line planners required also the visualization of the existing infrastructure below ground. Furthermore, information on the building use, and indicators on possible conflicts with high-voltage transmission lines should be displayed. In the following, the approach for visualizing the relevant information is presented for this urban study area.

The available data of existing underground infrastructure belong to a cadastre of the city of Zurich (STADT ZÜRICH 2020). They comprise digital information on gas, water, district heating, telecommunication, and existing electric transmission lines. This data had to be processed for 3D visualization below ground in the 3D DSS. First, the width and depth of the different underground infrastructure types was identified. Therefore, the data was inspected regarding their attribute values. Most of the data contained information on the tube diameter. However, the depth of the tubes below ground and the width and depth of the pipe trenches were not provided. In an internet search, values for the dimensions of the pipe trenches commonly used in practice were determined. Thereby, inter alia, the standards for the construction of drainage systems and roads of the civil engineering and waste disposal department provided helpful information.

Although it is possible to display tubular 3D volumes in Cesium below ground (CHOW 2020), due to the size of the case study data (up to 250 MB for individual data sets) and CPU and GPU memory constraints of many potential users' computers, we decided to provide simpler representations in form of 2D polygons and 3D boxes. Therefore, the vector data (lines) was converted (e. g. from DXF /DWG or Interlis), and imported into Esri's ArcMap 10.5 for further processing (Fig. 2).

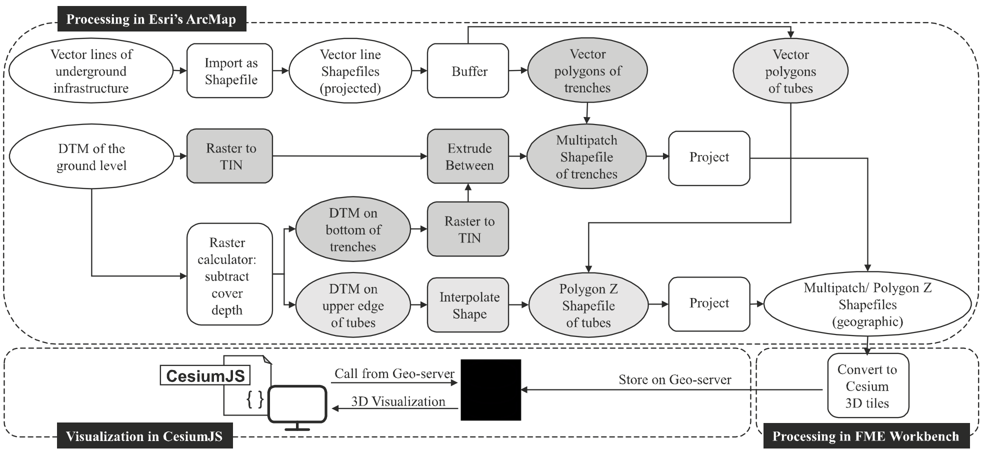

Fig. 2: Flowchart of the underground data processing for visualization in CesiumJS

First, by buffering the lines according to the attribute values of the tube diameter and the general trench width, polygons with the width of the tubes and the trenches of the respective infrastructure types were generated. In order to assign the depth of the polygon for the tubes below ground, the tool «Interpolate Shape» (ESRI 2017a) was used. «Interpolate Shape» adds a z-value from a Digital Terrain Model (DTM) to the polygon. With the tool «Raster calculator», using the DTM with the actual height of the terrain as input and subtracting the respective depth, we created surfaces, which are on the assumed depths of the upper edges of the tubes. These surfaces provided the input for interpolating the shape of the polygons of the tubes, resulting in Polygon Z-Shapefiles. For generating 3D box models of the trenches, two surfaces had to be created in the described way. Additionally, the resulting surfaces were converted to TIN Layers (tool «Raster to TIN»), the required input format for the tool «Extrude Between» (ESRI 2017b). These two TINs provided the surfaces for extruding the respective polygons between, resulting in MultiPatch-Shapefiles.

Finally, the 3D polygons processed in the described way had to be converted to Cesium 3D Tiles, the format to load data efficiently in the Cesium globe. As the Cesium globe uses the World Geodetic System WGS84 (EPSG:4326), the Polygon Z-Shapefiles and the MultiPatch-Shapefiles were projected in ArcMap into geographic coordinates (tool «Project»). Then, the shapefiles were converted with FME Workbench (Version 2020.0) [3] to the format Cesium 3D Tiles with the respective writer, whereby the coordinate system was set to "Same as the source". The resulting Cesium 3D tilesets were stored on a geo-server, from where it is called with a JavaScript code (Fig. 4) and displayed in the viewer of the 3D DSS.

In order to get an impression of the varying depth of the different tubes and trenches, the functions to display the terrain in a transparent mode (Fig. 4) and a «Clipping plane» tool for creating sections were programmed [4] When clicking on the button «Clipping plane», the tool is activated. The terrain should be displayed in the opaque mode. Then, with a first click on the ground, the beginning, and with a second click to the left side, the direction of the clipping plane is defined. As result, all features in front of this virtual clipping plane are hidden. Now, the terrain transparency can be activated to provide a view on the underground infrastructure (Fig. 3.1 and 3.2).

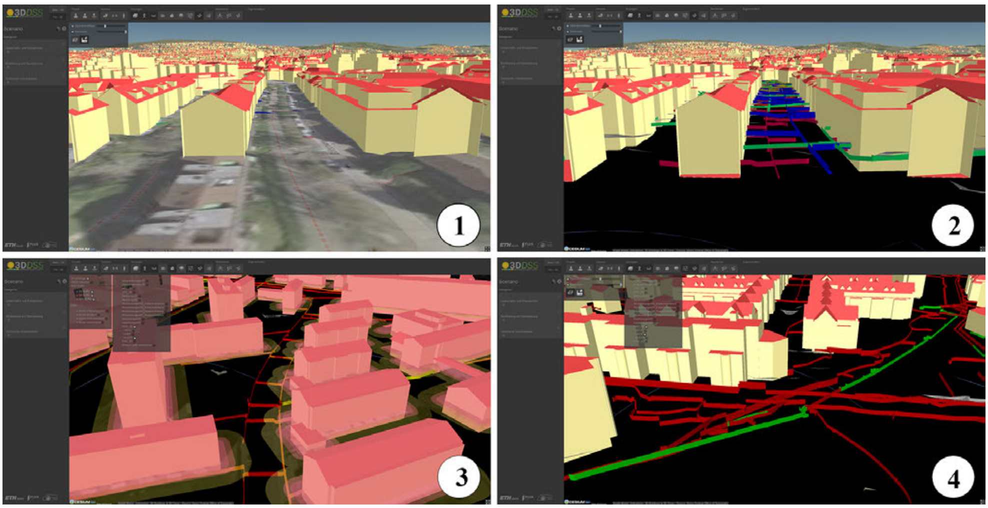

Fig. 3: (1) Section view of the urban scene with opaque terrain and (2) with transparent terrain, where the underground infrastructure is visible. (3) Information layer NISV-Buffer. (4) Colouring by attribute: green = empty pipe blocks.

2.3 Information to Support Analysis

Further information layer were added in different ways. For example, the zoning plan of the cadastre of public-law restrictions on ownership is available as web feature service (WFS) layer from the geographic information system of the Canton of Zurich. In the 3D DSS, the data including the legend is directly called from the cantonal geo-server with the function «Cesium.WebMapServiceImageryProvider». Accessing the data in this way also ensures that the data layer is always up to date.

For analysing whether there might be conflicts with the Swiss regulation on the protection against non-ionizing radiation (NISV), three different buffers (3 m, 5 m, 10 m) around the buildings were calculated and then converted to GeoJSON files using Esri's ArcMap. The polygons are loaded in the 3D DSS with the function «Cesium.GeoJsonDataSource.load». As a side effect, in areas overlapping with these polygons, 3D objects of the buildings or trenches get automatically the polygons' colour (Fig. 3.3).

Further data contained detailed information on the occupancy of the pipe blocks, e. g., whether they are empty or not. Hence, we used the function «Cesium.3DTileStyle» to colourize the respective 3D data according to these attributes (Fig. 3.4, Fig. 4) [5].

```
// Code tested in Cesium Sandcastle with Cesium 1.76.
//Sandcastle_Begin
var viewer = new Cesium.Viewer("cesiumContainer", {

// Complete the swisstopo web access inscription form for accessing the image and terrain tiles.
// Load Swisstopo Images (swissimage-product)
imageryProvider : new Cesium.UrlTemplateImageryProvider({
        url : "//<ServerName>/<Version>/ch.swisstopo.swissimage-product/<StyleName>/<Time>/
<TileMatrixSet>/<TileSetId>/<TileRow>/<TileCol>.<FormatExtension>",
        subdomains: '0123456789',
        availableLevels: [8, 10, 12, 14, 15, 16, 17, 18],
        minimumRetrievingLevel: 8,
        maximumLevel: 17,
        tilingScheme: new Cesium.GeographicTilingScheme({
            numberOfLevelZeroTilesX: 2,
            numberOfLevelZeroTilesY: 1
        }),
        defaultAlpha: 0.5,
  })}
  );

// Load Swisstopo Terrain (terrain.3d)
viewer.terrainProvider = new Cesium.CesiumTerrainProvider({
        url : 'https://<ServerName>/<Version>/ch.swisstopo.terrain.3d/<StyleName>/<Time>/
<TileMatrixSetID>/',
 });

// Globe Translucency. Set front face translucency to 0.3 when the camera is 3500 meters from the surface and 1
as the camera distance approaches 15000 meters.
viewer.scene.globe.translucency.frontFaceAlphaByDistance = new Cesium.NearFarScalar(3.5e2, 0.3, 15.0e2, 1);
viewer.scene.globe.translucency.enabled = true;

//Load the tileset "PipeBlock" and colour it FUCHSIA
var tileset = viewer.scene.primitives.add(
    new Cesium.Cesium3DTileset({
        url: 'http://localhost:8080/Specs/Data/Cesium3DTiles/Tilesets/PipeBlocks/tileset.json' ,
    }));

var defaultStyle = new Cesium.Cesium3DTileStyle({
    color : "color('#FF00FF')", //FUCHSIA
    show : true
});
tileset.style = defaultStyle;


// Load and colour a Cesium 3D tileset "PipeBlocksEMPTY" by the attribute "EMPTY".
var tileset2 = viewer.scene.primitives.add(
    new Cesium.Cesium3DTileset({
```

```
        url: 'http://localhost:8080/Specs/Data/Cesium3DTiles/Tilesets/PipeBlocksEMPTY/tileset.json' ,
    }));
function colorByEMPTY ()   {
  tileset2.style = new Cesium.Cesium3DTileStyle({
     color: {
        conditions:  [
          ["${EMPTY} === 1", "rgb(0, 245, 0)"],
          ["${EMPTY} === 0", "rgb(245, 0, 0)"],
          ["true", "rgb(245, 0, 0)"],
       ],
    },
  });
}
        tileset2.style = tileset2.style;
colorByEMPTY();
//Sandcastle_End
```

Fig. 4: Generic code example for loading the swisstopo terrain and orthophotos, enabling globe translucency, loading and colouring a Cesium 3D tileset, and colouring a tileset by an attribute

3 Aspects for Advancing the Visualization Prototype

The presented approach is suitable for 3D visualization of infrastructure above and below ground in a web-based platform on regional and local scale, including interfaces for interactive spatial development modelling. However, we did not yet evaluate how well stakeholders understand and can use this information in a planning process. Whereas transmission line planning experts rated the visualization of underground infrastructure based on a demonstration as rather to very helpful (SCHITO et al. 2020), testing these visualizations also with other stakeholders such as the general public is still required to analyse whether they are able to use this information meaningfully. Furthermore, few experts found the visualization rather not helpful or were undecided (SCHITO et al. 2020). In order to understand the further requirements regarding the visualization of underground infrastructure, hence, continued collaboration with different stakeholders is necessary. Thereby, the focus must be kept on the main purpose of the visualization platform. For fostering urban resilience, macro-level information across different spatial scales supporting strategic planning and policy decision making is required. Therefore, supporting the integration of the data above- and below ground and providing meaningful indicators to understand the relationship between 3D urban patterns and ecosystem services (ALAVIPANAH et al. 2016) is then more important, than visualizing the accurate position and diameter of the tubes. In contrast, for facilitating design on the micro-level, i.e., the building scale, a level of detail and accuracy is necessary that is "as-built", which is provided by building information models (BIM, WANG et al. 2019).

4 Discussion and Conclusion

Including the urban underground space into design and evaluation of urban development scenarios is crucial facing current trends of urban densification. The presented 3D web-platform is feasible to visualize urban infrastructures above and below ground using CesiumJS. With the suggested advancements, namely, testing the visualization platform with different stakeholders as well as complementing it with 3D urban ecosystem indicators for supporting iterative processes of designing and evaluating urban development scenarios across scales, it could become an effective digital tool, which can help to explore the design of resilient urban systems. To further improve collaborative design and evaluation in three dimensions above and below ground, new approaches using 3D point clouds are promising (URECH 2020). As recent developments already enable web-based visualization and exploration of massive 3D point clouds in CesiumJS (DISCHER et al. 2019), their integration into the visualization platform should be envisaged.

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[5] For further example codes see also https://cesium.com/docs/tutorials/quick-start (23.03.2021) for tutorials, and https://sandcastle.cesium.com (23.03.2021) for application examples.

Prototyping an Affordable and Mobile Sensor Network to Better Understand Hyperlocal Air Quality Patterns for Planning and Design

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Abstract: While there is a growing interest in employing planning and design tactics to improve air quality issues, landscape architects often rely on coarse data that may not reflect hyperlocal conditions. This paper explores how landscape architects might assemble their own sensor network to collect data on hyperlocal air quality patterns, how this data might vary spatially and temporally across a site, and how findings from this exercise might inform the site analysis process. To explore these issues, we prototyped an affordable and mobile sensor network that could be publicly deployed to capture air quality variation at the block scale. We tested the system by building units and collecting data across the University of California, Davis campus for 30 days. By analyzing the resulting data, the sensor system is capable of identifying spatial and temporal hotspots. More generally, when deployed at a larger scale, such a system could be used to improve our understanding of hyperlocal air quality patterns for planning and design.

Keywords: Sensors, landscape architecture, air quality, environmental monitoring, particulate matter

1 Introduction

The field of landscape architecture has a long history of using environmental data to help make informed decisions about planning and design. Oftentimes, though, due to the time and resource intensive nature of site-level data collection, this information tends to be secondary, coarse, and abstract with limited ties to the landscape itself. As a result, assumptions are often made about hyperlocal variations in environmental conditions. Recently, though, there has been a growing desire in the field to find new ways of understanding hyperlocal site conditions through the development and deployment of environmental sensors (CANTRELL & HOLZMAN 2015, LOKMAN 2017, CANTRELL & MEKIES 2018).

In this paper, we explore how landscape architects might assemble their own units to collect data on hyperlocal air quality patterns, how this data might vary spatially and temporally, and how findings might inform the site analysis process. To do this, the paper begins by addressing why landscape architects are increasingly interested in gathering site-level air quality data. The paper then explores how some academics and practitioners are currently experimenting with air quality monitoring in their work. The paper continues by unpacking the methodology of a recent hyperlocal air quality monitoring project with details about the site and general study design. The paper concludes with results from the study, a discussion of preliminary observations as well as potential avenues for future research.

To begin, there are a number of reasons why landscape architects are increasingly interested in gathering site-level air quality data. In a broad sense, the field of landscape architecture has experienced a shift towards evidence-based design and landscape performance metrics (DEMING & SWAFFIELD 2011). Secondly, air pollution is considered a major risk factor for

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adverse health effects and with climate change, air pollution is becoming an increasingly problematic issue (TIBBETTS 2015). Furthermore, in many parts of the world, air pollution is not equally distributed across populations, leading to environmental justice concerns. In addition, recent evidence suggests that tactics employed by landscape architects can improve air quality issues; this can happen at a master-planning scale with the careful siting of programs and site elements to minimize risk and this can also happen at a design scale with the development and incorporation of green infrastructure (BARWISE & KUMAR 2020, HEWITT, ASHWORTH & MACKENZIE 2020). Furthermore, air quality sensors are becoming more affordable and user-friendly due to a changing paradigm in environmental monitoring that is increasing the diversity of available sensor technology (SNYDER et al. 2013). Lastly, these new systems for gathering site-level air quality data are helping to fill gaps in existing knowledge, both spatially and temporally, as landscape architects have traditionally used generalized and averaged air quality information at the local or regional scale.

The potential for employing sensor-based technology in landscape architecture has become a growing topic of discussion in the field (CANTRELL & HOLZMAN 2015, LOKMAN 2017, CANTRELL & MEKIES 2018). At the same time, while some academics and practitioners in the field have experimented with hyperlocal air quality monitoring, the work has been primarily speculative or limited (CHADDERTON 2020, ERVIN 2018). On the speculative end, there are academic projects like Metabolic Forest (COX & DARDEN 2013) and The Digital & The Wild (DUKE 2016), both of which explore the role of air quality sensing in creating responsive feedback loops for design. On the implemented but limited end, there are projects like *Atmosphere InFormed* (SPERANZA et al. 2016) and *Greenscapes to Brownscapes: A Study on Impacts to Contaminant Levels in Landscapes Adjacent to Highways* (HARVEY & ADAMS 2020), both of which are real-world air quality monitoring pilot studies but are not yet scalable.

Additionally, there are a number of air quality monitoring precedents outside the field of landscape architecture that might be of use for designers interested in collecting site-level data. Two precedents of particular interest for this project come from PurpleAir and Aclima. To start, PurpleAir is a widely used air quality sensor network platform that provides real-time data on an online map. The sensors that are available for purchase through the company are relatively small and affordable – $250 at the low end – and use laser particle counters to detect PM2.5 levels in the air (PURPLEAIR 2020). Due to their stationary design, this network is dependent on a dense and geographically-dispersed series of sensors to provide a holistic overview of hyperlocal conditions. Aclima, on the other hand, has developed an air pollution monitoring platform that pulls data from both stationary and roving sensors. For one project, Aclima affixed air quality sensors onto Google Street View cars and collected data in West Oakland, California. The data from this study showed small-scale variability in air quality, even within individual city blocks, highlighting the potential benefits of a roving sensor system over the interpolation of stationary sensors (APTE et al. 2017). The lab-grade sensors used in this project were expensive and large; thus, the data collection platform cannot be easily configured into a distributed system.

The study outlined in this paper sought to merge principles from both precedent projects outlined above to prototype an affordable and roving sensor network that could be deployed to the public to capture air quality variation at the block scale. The research team was driven by three primary questions: 1) How can we design an air quality unit assembly process to be open and accessible? 2) What general conclusions can be drawn from the spatial and temporal variability in the data? And 3) How might these findings impact the site analysis portion of the design process?

2 Methods

To address these questions, an interdisciplinary team of researchers formed with expertise in landscape architecture, urban design, computer science and electrical engineering. Additionally, experts in atmospheric pollutants and climate science were consulted. Our site for the study was the main campus of the University of California, Davis, located in the Central Valley of California, roughly 24 kilometers west of Sacramento. This region of California – due to its topography, proximity to wildlands and wildfire, and agricultural land use – is a unique landscape for studying particulate matter (PM2.5) levels. Furthermore, the city of Davis has only one regulatory air quality monitor and 21 citizen science monitors; all of these are stationary and only one is located on the main campus of the university.

To study the hyperlocal PM2.5 conditions of campus and to help augment existing air quality data, the team aimed to create a mobile low-cost sensor network called "Aggie Air" to gather hyperlocal and real-time data on PM 2.5 air pollution. The first step towards developing this network was to design hardware for individual units using an Arduino platform. For the sensor itself, the team selected the PMS5003 model by Plantower which "uses laser scattering to radiate suspending particles in the air, then collects scattering light to obtain the curve of scattering light change with time. The microprocessor calculates equivalent particle diameter and the number of particles with different diameter per unit volume" (ADAFRUIT 2020). This specific model was selected because recent studies indicate that it is suitable for studying short-term spatially localized particulate matter concentrations (BULOT et al. 2019).

The alpha version of the unit featured the particulate matter concentration sensor, a GPS module for logging locations, and an SD card module for saving data. After initial testing, the team refined the prototype with a stripped-down beta version; the GPS module and SD card module were removed and replaced with a Bluetooth-enabled mobile app to log locations and transfer data to a cloud-based database (Fig. 1). This shift simplified the construction of the unit while reducing the overall cost to under $100 per unit. Ultimately, a small fleet of twenty units were built that could be affixed onto bikes and used across campus to collect data.

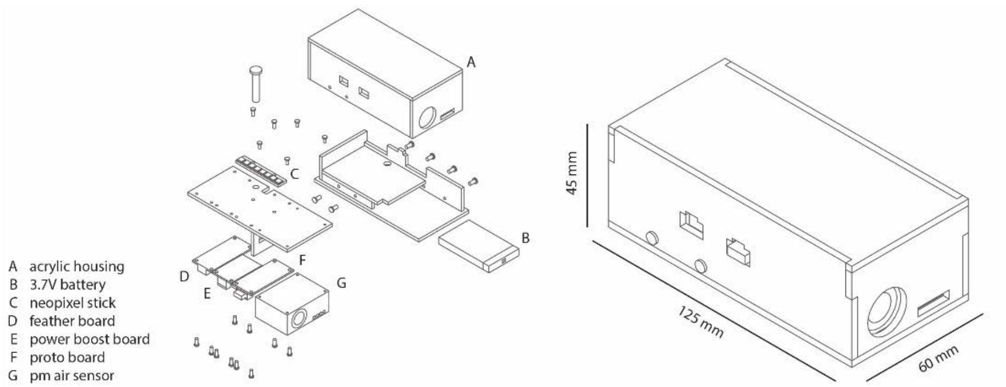

Fig. 1: Components of the final Beta unit

While the research team initially intended to recruit twenty undergraduates to collect data, health and safety concerns associated with COVID-19 precluded this from happening. Thus, one research member from the team collected data for the study. Over the course of 30 days, this research member traced the same route across campus each day following four north-to-south transects, logged air quality data, and mapped surface adjacencies along the route to better understand context (Fig. 2). For the adjacency mapping, the researcher documented the primary surface conditions twenty feet from the route on both sides of the bike. Furthermore, to better understand temporal patterns, the research member alternated the time of day data was collected – 10 days focused on morning hours from 8-11am, 10 days focused on afternoon hours from 1-4pm and 10 days focused on evening hours from 6-9pm.

Fig. 2: The data collection route and the surface adjacency mapping

During the rides, real-time PM2.5 data was expressed through a color-changing LED attached to the unit, which functioned as an actuator, and was displayed on an app displaying a digital map of campus that was searchable by date and time. Both the real-time and batched data used the standard air quality index color code ranging from green (good) to maroon (hazardous).

Lastly, for context, over the course of the 30-day data collection period, the prevailing wind primarily came from the north at an average speed of 8kph, the average temperature was 14 degrees Celsius. Furthermore, while detailed traffic data for the city blocks around campus and along State Route 113 and I-80 was unavailable for the data collection period, it is generally known that weekday mornings and Friday afternoons tend to have higher rates of traffic congestion than other times of the week.

3 Findings

The first question that drove this study focused on how the air quality unit assembly and data collection process might be designed to be open and accessible. To do this, the research team developed a step-by-step instruction manual to lead people through the process in a straightforward manner. While the research team intended to recruit a number of undergraduate students to test the manual, this was not possible due to health and safety concerns associated with COVID-19. That being said, three members of the interdisciplinary team tested the instructions for the Beta design, successfully built fully-functional units, and were able to collect data across campus using the platform.

The second question that drove this study focused on what general conclusions could be drawn from the spatial and temporal variability in the collected data. To unpack the spatial variability in the study, the research team mapped the 90th percentile of PM2.5 levels at each spatial location along the bike route for each of the thirty rides, created a color gradient from purple (fewer instances) to yellow (more instances), and visually analyzed the resulting map. Ultimately, 14 geographically-dispersed hotspots were identified based on areas that contained yellow pixels. Of those 14, three hotspots with the most yellow pixels were selected for further analysis (Fig. 3). These three areas appeared to share four general characteristics. Each areas was located on the edge of campus, close to a vehicular intersection, on a dedicated bike lane along an active road, and were adjacent to surface conditions comprised of hardscape or built-up areas. To unpack the temporal variability in the study, the research team grouped the morning, afternoon, and evening rides and plotted the PM2.5 levels (Fig. 4). The resulting data showed elevated PM2.5 levels in the evening hours followed by elevated levels in the morning hours. Rides done in the afternoon hours showed the lowest PM2.5 levels of the three sets.

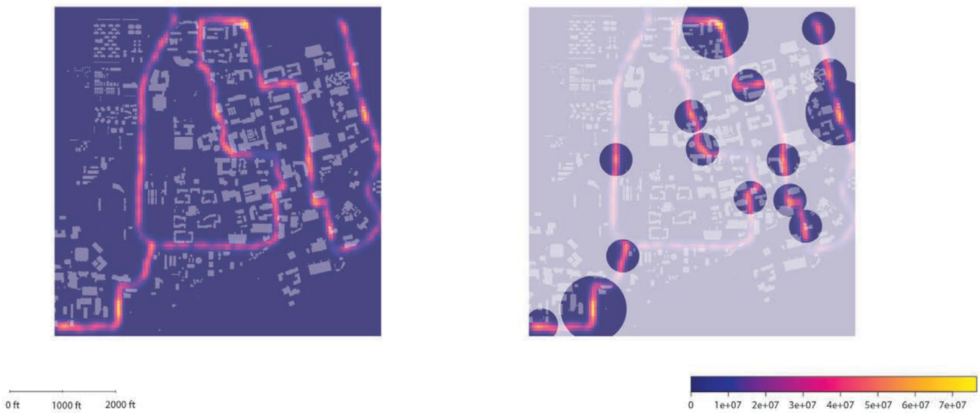

Fig. 3: Heat map showing 90th percentile PM2.5 areas for the 30 rides and the 14 hotspots

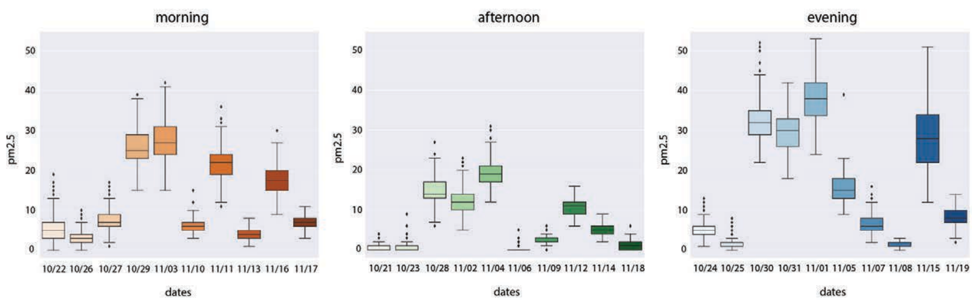

Fig. 4: PM2.5 levels grouped by morning, afternoon, and evening rides

The final question that drove this study considered how the spatial and temporal patterns observed in the data might inform the site analysis process. For this, the research team speculated about how design and planning professionals might use this data in their work and how the general conclusions from the study might raise questions about potential site interventions in the future. Based on the spatial findings from the study, two questions were developed for potential development sites located on the edge of campus, near active roads and intersections, and next to significant hardscape or built-up zones: 1) Should areas like these be reserved for certain types of campus programming to reduce long-term exposure to elevated PM2.5 levels? And 2) Might these areas benefit from increased green infrastructural interventions to reduce hyperlocal air quality issues? Based on the temporal findings from the study, one question for future research was developed: Could responsive landscape systems be designed to offer sites more protection in the evening hours?

4 Discussion and Conclusion

The potential for using an affordable and mobile sensor network, like the one outlined in this study, to better understand hyperlocal air quality patterns for planning and design is significant. This kind of system could be employed by landscape architects for site analysis to understand hyperlocal environmental risks and could also be helpful post-construction for designers to monitor the impact of built work on air quality levels in an effort to guide future management protocols and site design. The individual units developed for the project are significantly more affordable than off-the-shelf units and are easy enough to assemble with the step-by-step manual. Furthermore, the research team was able to draw general spatial and temporal conclusions from the pilot project data that might be helpful for designers.

Currently, though, the data collection process put forth in this study should only serve as a tool that can be used to generate hypotheses for further testing and exploration. To move the project forward towards specific design and planning recommendations, a number of study limitations must be addressed. To begin, more people should be recruited to test the unit assembly process to better understand the ease of construction. Secondly, more PM2.5 data should be gathered. Multiple units should collect data simultaneously to cross-validate levels, the route should be expanded to include more areas of campus, and the data collection process should extend beyond 30 days to capture multiple seasons and conditions. Furthermore, more time should be spent on analyzing site conditions to better understand potential correlations. Lastly, the following technical issues with the system should be addressed. The campus-wide WiFi network was often too weak and unreliable to use for data collection so the research team resorted to using mobile phone hotspots. The mobile app had to be physically open for the data to be logged and the app only functioned on Android devices. The mobile phone and the unit had to be charged before every ride for a reliable power supply. Lastly, while this was not an issue for the short-term study outlined in this paper, future longer-term studies should consider the potential for data drift and should plan for sensor re-calibration.

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How to Cool Down Dense Urban Environments? A Discussion on Site-Specific Urban Mitigating Strategies

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Abstract: For over a decade, the increasing effect of climate change patterns has become a global challenge to be considered and integrated on all levels into the planning of cities. Europe's extreme climate has continued to shatter heat records in the past ten years and is projected to worsen. The local heat islands in dense urban environments are affecting buildings' energy consumption and outdoor air quality, as well as increasingly influencing the health and well-being of the growing urban population, especially the elderly. Therefore, cities are a challenge when developing and adopting sustainable actions to mitigate the worsening urban thermal environment in upcoming years. The purpose of this research conducted under the supervision of Prof. Dr. Pia Fricker, Professorship for Computational Design in Landscape Architecture and Urbanism at Aalto University Finland, is to provide developed urban areas with a set of feasible and ecological outdoor thermal comfort mitigation solution strategies in respect to the changing climatic conditions of the future. The paper takes Helsinki as a pilot site, as it represents an average dense city with a high representative number of elderly citizens. Special focus is set on researching the performance of small-scale interventions which support the well-being of people living in affected urban areas. The applications fill an existing gap in urban services and infrastructure found in projected extreme climate change and engages citizens in the urban climate adaptation process.

Keywords: Heat environment, web-based application, sustainable urban design strategies, outdoor thermal comfort, dense urban environment

1 Introduction

1.1 General Introduction

Urbanization is a global trend, with 2.5 billion people expected to be residing in cities by 2050 (UN 2014). In the meantime, projected extreme weather events due to climate change will become more frequent and severe (EEA 2020). Heatwaves are the deadliest type of weather-related event, accounting for 68% of the 90,325 additional deaths throughout the whole of Europe during the period 1980 to 2017 (EEA 2020). Even in the Nordic countries, mortality rates due to heatwaves outstrip mortality rates caused by other extreme weather events (EEA 2017). Furthermore, the elderly, children, patients with pre-existing chronic illnesses, and groups in asthenic socioeconomic conditions are frequently listed as the most vulnerable communities among urban residents (KERAMITSOGLOU et al. 2017, SMID et al. 2019). In the urban context, urban structure and landcover contribute to the urban heat island (KLOK & ZWART 2012), which intensifies heat events locally. Variations in temperature range from 1 to 10 °C difference between densely urbanised areas and rural backgrounds (ULPIANI 2021), exacerbating the impact of heatwaves on human health (COFFEL 2018). Simultaneously, heatwave events increase energy consumption needed for cooling down and increases costs for construction and infrastructure maintenance (COFFEL 2018).

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Even though Helsinki is commonly regarded as a city with moderate temperature, the increasing effects of heatwaves has had a noticeable impact. According to the FINNISH METEOROLOGICAL INSTITUTE (2019), the City of Helsinki counted 25 heatwaves in 2018, with these resulting in 380 fatal casualties. Even if emissions were controlled (RCP=4.5), the maximum and average summer temperature in Helsinki in 2100 will increase by 3 degrees compared to the present (MÄKELÄ 2016). In response to climate change, Helsinki has set up several sustainable development goals by locally implementing sustainable development responsibility (CITY OF HELSINKI 2019). However, Helsinki has not carried out relevant research on how to alleviate the urban thermal environment in the field of urban design or landscape architecture.

1.2 Outdoor Thermal Comfort Indices and Models

Outdoor thermal comfort research aims to ameliorate the worse effects of a heating urban environment, while human subjective perception is the direct method to evaluate it. Although the questionnaire survey method used in the initial stage here can immediately reflect the human body's subjective sensing, it requires mass human resources and large uncertainties (TSOKA 2018, ASGHARI 2019, THORSSON 2017). The outdoor thermal comfort approach proposes establishing a relationship between the external space and the human body's thermal sensation. These indicators assess the outside climate and predict heat perceptions with potential risks (BLAZEJCZYK 2012).

Table 1: The actual thermal perception represented by various thermal comfort indices values

	WGBT	HI	Humidex	SET	PMV	PET	PST	COMFA	UTCI
Unit	°C	°C	°C	°C		°C	°C	W/m2	°C
Frosty							<-36		<-27
Very cold					<-3	<4	-36--16		-27--13
Cold					-3--2	4-8	-16--4	<-150	-13-0
Cool				<17	-2--1	8-18	4-14	-150--50	0-9
Comfortable	<18		20-30	17-30	-1-1	18-23	14-24	-50-50	9-26
Warm	18-24	27-32	30-40	30-34	1-2	23-35	24-34	50-150	26-32
Hot	24-28	32-41	40-45	34-37	2-3	35-41	34-44	>150	32-48
Very hot	28-30	41-54	45-55	>37	>3	>41	44-54		38-46
Sweltering	>30	>54	>55				>54		>46

Indices in the early stage, such as the WetBulb Globe Temperature (WBGT) and Heat Index (HI), establish heat sensation judgments grounded on the relationship between meteorological parameters, such as air temperature and humidity, without considering the heat transfer model (BLAZEJCZYK 2012). Correcting from indoor thermal indicators, the outdoor indices, such as the Physiological Equivalent Temperature (PET) and the Standard Effective Temperature (SET), import the steady heat transfer model into the heat sensation calculation, which includes the heat exchange between the human body and the environment (CHENG 2012, FANG 2019). Contrary to the steady heat transfer model's assumptions, the human thermal load continually changes in actual outdoor space. It takes a long time to reach a steady state in daily life while the human body is exposed outside for a short time (HÖPPE 2002). Thus, the current indices, such as the dynamic Physiological Equivalent Temperature (dPET) and Universal Thermal Climate Index (UTCI), are developed to describe the thermal sensation based on the dynamic heat transfer model (MAHGOUB 2019, BLAZEJCZYK 2013, FANG 2019). Despite the different calculation principles, Table 1 compares the perception interval of indices established in various stages. The PST and UTCI have a more reliable sensation calculation principle and comprehensive applicable temperature range. Therefore, PST and UTCI are adequate for outdoor thermal environment assessment.

A variety of software and platforms are certified to simulate the outdoor thermal comfort in an urban context effectively, with the most frequently used software listed as follows:

- Based on the grid level, the Envi-met computes the comfort indices through complex iterative operations of interactions between the urban context and meteorological aspects (TSOKA 2018, LATINI 2010, KÁNTOR 2018, ASGHARI 2019). On the one hand, the model includes the most comprehensive aspects, and the result can illustrate every single value in three-dimensional grids. On the other hand, it is impractical in the urban design process as elements are constructed in pixel units. Moreover, the software needs a high-capacity carrier where the process takes more than one day with a large-scale area.
- BUENO (2010) published Urban Weather Generator (UWG) on the grasshopper platform to analyse the UHI effect in urban canyon and its impact on architecture energy performance. The plugin is continuously under contribution. The UWG focus on neighbourhood-scale simulation of the urban canopy layer heat exchange produced by buildings. Unfortunately, the plugin lacks some environmental parameters, such as the effect of water evaporation.
- The Solar Longwave Environment Irradiance Geometry (SOLWEIG) model calculates radiant fluxes and MRT from Digital Surface Models (LINDBERG 2018, KÁNTOR 2018, THORSSON 2017). The model simplifies three-dimensional geometries into raster images with elevation information, which reduces the workflows and time-consumption. However, the SOLWEIG model only supports points-based PET and UTCI calculations in the newest version.
- Rayman software calculates the sunshine duration, shadow space, radiation flux, and thermal relevant indices assessment by inputting small meteorological data quantities (MATZARAKIS 2010, KÁNTOR 2018). Limitations exist due to incompatibility with low solar angles and the unexplainable shortwave radiation reflection.

For city level simulation, the Envi-met is more comprehensive, requiring a high-capacity carrier to process extensive information. The Grasshopper concentrates on building performance. The SOLWEIG model simplifies the complexity and time-consuming calculations compared to Envi-met.

1.3 A Survey of Current Urban Mitigating Strategies

Cities adopt diversiform strategies to mitigate the urban heat environment. According to action principles, research divides strategies into four categories: changing surface albedo, intercepting solar radiation, enhancing air circulation, and direct cooling devices. Albedo, which means the ratio of the reflected solar radiation and the total received radiation by an object, determines ground surfaces' thermal behaviour (HULLEY 2012). The covering materials with higher albedos contribute more to UHI. Canoga Park in California has tested that a dark asphalt road with white paint coverings can lead to the 11 °C temperature difference on its surface (RIPPE 2017). TAKEBAYASHI (2009) has also proven that different parking paving can have 40 °C surface temperature differences at maximum. Vegetation has a similar albedo as brick and stone, whereas the interception of solar energy makes the vegetation play a prior role in mitigating the thermal environment. The surface covered with vertical green has a much lower temperature than non-organic materials such as concrete and wood (SCHRÖPFER 2020). The City of Phoenix initiated the Cool Urban Space project in 2014, which compared treeless and tree canopy covered communities. It turned out that tree canopy environments lead to a 4.3 °F temperature difference, and the grass-covered surfaces led to a 0.5 °F temperature reduction (MIDDEL 2014). Moreover, many cities use wind channels to mitigate intensified urban heat environments. Currently, cities such as Stuttgart, Tokyo, and Hong Kong have formulated relevant planning and design guidelines to optimize urban ventilation. Similar to an air conditioner's principle, many cooling devices have been developed for outdoor human body cooling through heat transferring. For instance, the outdoor cooling mechanism known as the Angels in Singapore provides an artificial breeze to pedestrians through the whale tail shape device. A 550 by 50 m2 passive air conditioning system called Eco-boulevard in Madrid uses evapotranspiration to chill the nearby microclimate when the temperature is above 27 °C. Another frequently used piece of equipment is the outdoor misting system, where vents connected with water tanks or pipes spray liquid mist outside to cool the pedestrians physically. In summary, the strategies that have been implemented so far have been verified to alleviate the urban heat environment effectively. However, except for cooling devices, most strategies are investigated and targeted at cities rather than people living in cities themselves. The cooling devices usually need large space occupation to realize neighbourhood-scale air chilling, which is not suitable in the developed dense urban area.

2 Heat Environment in Helsinki

2.1 Simulation and Data Description

This current research aims to provide the developed dense urban area with a set of sustainable outdoor thermal comfort mitigation solutions directed towards the predicted severe climate situation of the future. Helsinki, as a good pilot area, represents an average dense city with a high representative number of elderly citizens. Currently, there is limited thermal environment research based on the Helsinki context which is also visible in a rather small amount of innovative data interaction (FRICKER et al. 2015). Therefore, the paper starts with an investigation of Helsinki's thermal environment and finds out the severe space.

From the city level, most of the population, including older adults (over 65 years old), are found in the city centre, which is also in poor green condition and paved with vast impermeable materials. The city centre of approximately 25 km2 was chosen as the pilot area. Considering the spatial scale and calculation duration, the SOLWEIG model is most suitable. Overlaying the digital surface models (DSM) in a specific format with input meteorological data, the model will analyse longwave and shortwave radiation fluxes individually. The summarization of fluxes density will determine the mean radiant temperature (Tmrt) as the output through the Stefan-Boltzmann law (LINDBERG 2018). The Tmrt index is the essential parameter of UTCI. The UTCI calculation in mathematical terms is as follows:

UTCI = f (Ta; Tmrt; va; vp)

= Ta + Offset (Ta; Tmrt; va; vp) (BLAZEJCZYK et al. 2013)

Currently, the latest SOLWEIG can only support the UTCI calculation in specified points. In order to overcome this, this research composes a script to calculate the UTCI in the whole region. When the Tmrt is computed, the generated raster images from the SOLWEIG will be transferred into a numerary array that records the value information. The script will read the array as a loop and do a mathematical calculation of the UTCI. Then, the calculated results will be returned as a new array and form a new raster dataset. The UTCI calculation formula refers to RAMSDEN (2015).

The input data consists of the city lidar dataset and the meteorological parameters. The research takes climate data from the Kaisaniemi weather station on the 15th July to simulate the outdoor heat environment. The lidar data is a three-dimensional point set scanned at 550m height in 2018. Dot density in the nadir was 21 points/m2, and side coverage of queues is 50%. Due to the errors, the land use information is overlayed to reclassify the point attribute and repatch the blank area. The urban geographical information and digital model are derived from the reclassified lidar dataset.

Fig. 1: The Helsinki LIDAR set in 2018 transformed to Digital Elevation Map and sky view factor for thermal simulation (Data from Helsinki Map Service 2017)

2.2 A Description of Urban Heat Environment on Specific Date

The simulation studies the outdoor thermal environment in Helsinki on the 15th July 2018. Simulations describe the Helsinki thermal environment in 2m-by-2m grids at different periods (Fig. 2). The findings illustrate thermal pressure beginning to appear in the local central area, mainly during the morning. The thermal pressure continued until 17:00 when most of the area returned to an acceptable level. At 19:00, the whole area accomplished a thermally comfortable state. In general, wharves, open arterial roads, and public open spaces, such as squares and artificial parks, are the most thermally stressed areas due to lack of shelter from trees or buildings.

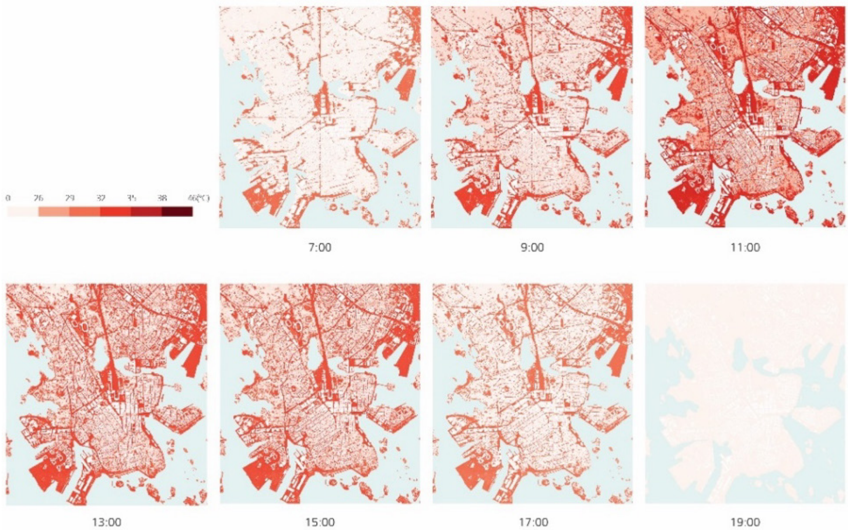

Fig. 2: Apparent temperature from 7:00 to 19:00 on 15th July 2018

Consistent with the analysis from LATINI (2010) and KÁNTOR (2018), green and construction shelters can effectively reduce heat perception. A plot under a tree or building shading can be 7 or 8 °C lower than the plot on the same landcover without shading. However, compared with other paving, grassland has an inconspicuous impact on thermal pressure relief with approximately 1 °C difference, which does not match the simulation results from LATINI (2010). Architecture is a contradiction to the thermal environment. On the one hand, the shadow of buildings reduces body temperature effectively. While, on the other hand, the space near the sunny side of the building will be about half a degree Celsius higher than the street temperature. In other words, whether the impact of the building on the ambient space is positive or negative depends on different times of the day.

Fig. 3: Apparent temperature in different spaces at 13:00 on 15th July 2018

3 Urban Cooling Strategies

3.1 Urban Cooling Strategies Based on Existing Context

It is easy to foresee that heatwaves in Finland will become more frequent in the future. Various outdoor spaces will become hazardous for citizens in these cases. To promote better outdoor quality and human well-being, multiple urban cooling strategies are conceived. Three kinds of cooling strategies for Helsinki to pursue a more resilient city were identified: adding green canopies, intelligent façades, and outdoor cooling mechanisms.

Shading is the most intuitive way to cool down pedestrian level thermal sensation, and trees have noticeable effects. Previous research and simulations have illustrated that different land coverings possess limited impacts on outdoor thermal comfort, whereas planting trees is a more efficient way. In Helsinki, there are many no tree-covered outer spaces. These areas are at high risk on heatwave occasions. The situation would be significantly improved if trees shaded these places. According to the different functions of outdoor spaces, experiments are taken to simulate woody plants' effects. The simulation areas are between 8,000 to 10,000 m2, identified as the hot zone in the previous simulation. The trees are deciduous, with 8 meters in diameters and 15 meters in height (5 meters trunk zone). As a result, a single arbor with an approximate 50 m2 canopy can produce approximately 84 m2 shaded areas at 1 pm. For instance, in Kasarmitori, 30 deciduous can shade approximately 3000 m2 squares in simulation (Fig. 4).

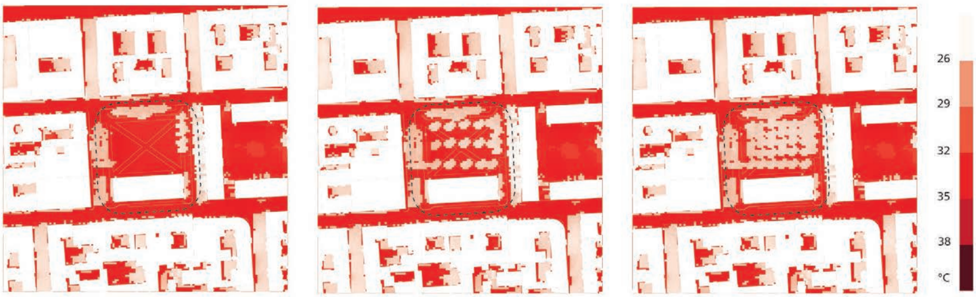

Fig. 4: Simulating the impact of 15 & 30 more trees in Kasarmitori

Façades, as the complicated interface protecting or regulating the building interior from the fluctuations of the outside environment, have an underlying impact on the surrounding microclimate (HOSSEINI 2019). Currently, intelligent façades focus on indoor ventilation and light volume. Besides enhancing the indoor ventilation, the dynamic façades can also extend the architecture's shadow range and reduce the reflected solar radiation to the sidewalk in summer, providing a delightful walking space for pedestrians.

Although there will be 2 °C temperature increase in the winter of 2050, extreme climate change means intense snowfall (> 10 cm/day) will be more common in Finland (FINNISH METEOROLOGICAL INSTITUTE 2019). Therefore, the research proposes a mechanical device that enables small area cooling in high-temperature weather. The mechanism, on the contrary, is an ecological response to the scorching climate through releasing the stored winter snow as cold air during heatwaves. The prototype of the mechanism consists of underground storage part and the above-ground device part. In the winter, people can put accumulated snow into steel spaces through coarse filtering. The insulation materials ensure the long period storage of snow. When the heatwave comes, the sensor activates the pump to release the snow water outside. The mechanism can be combined with existing urban furniture for saving space.

3.2 Interactive Platform for Residents and Governors

Climate responses are considered governmental responsibilities in many countries, such as Australia, the United Kingdom, and India (SARZYNSKI 2015). It is difficult for citizens to participate effectively because the relevant technical knowledge is hard to understand and it is difficult to explain how global changes translate into local hazards (SARZYNSKI 2015). However, expectations of collaboration between authorities and citizens in climate change adaption are rising, and scholars are pursuing more efficient public engagement (KLEIN 2018). In Helmond, the Brainport Smart District is developed to embed smart technology and service in daily life, generate knowledge from residents, and enable development simultaneously (HOOP 2019). Helsinki's city council is also committed to using smart technology to strengthen citizens' participation and collaboration abilities (HÄMÄLÄINEN 2019).

Fig. 5: Digital services provide location-based information of heat perception, outdoor activity route, and cooling mechanism nearby

Therefore, this paper advocates an interactive platform to provide citizens with substantial services in the summer, put the responsibility back in the hands of residents, and train awareness of climate change simultaneously. As a carrier of thermal environment simulations and designs, the designed web-based platform interacts with residents and urban managers in a more intuitive and visual way. The designed application, as the output of the platform, consists of four primary services: Urban Heat Map, Feedback from Citizens, Outdoor Activity Guidance, and Integration of Snow House Mechanism in the Application. According to the GPS positions, the application will send the precise heat stress data of their place and provide users with a more suitable and site-specific proposal for outdoor activities. Users can also control the mechanism to cool down nearby areas on this platform (Fig. 5). Furthermore, the application allows public decision-makers to "listen" to citizens' voices in a more focused and site-specific manner, which would prevent authorities from investing in time-intensive research. Instead, concrete measures, such as planting trees, building intelligent façades, and installing cooling mechanisms, could be taken. Through this platform, residents can participate in these actions to ameliorate the worst effects of Helsinki's thermal environment and sense the city's improvements. Governors can also selectively intervene in urban space through feedback from users.

4 Conclusions and Discussion

Using Helsinki as a test case, this paper provides dense urban areas with a set of sustainable outdoor thermal comfort mitigation solutions (Fig. 8) to address the current severe climate situation. On the one hand, the design works to fill the existing gap in urban services and infrastructure embedded within the developing extreme climate situation. On the other hand, participating in the thermal environment confrontation will popularize sustainable awareness among urban residents. Unlike the traditional urban thermal environment design or planning, which emphasizes the planning of new urban districts, this research focuses on mitigating heat sensation within existing contexts. Therefore, the strategies put particular emphasis on the performance of small-scale interventions in dense urban areas and supporting the well-being of people living in affected areas. Strategies are based on the Helsinki context, but many other countries in similar situation can refer and adapt to their own local conditions.

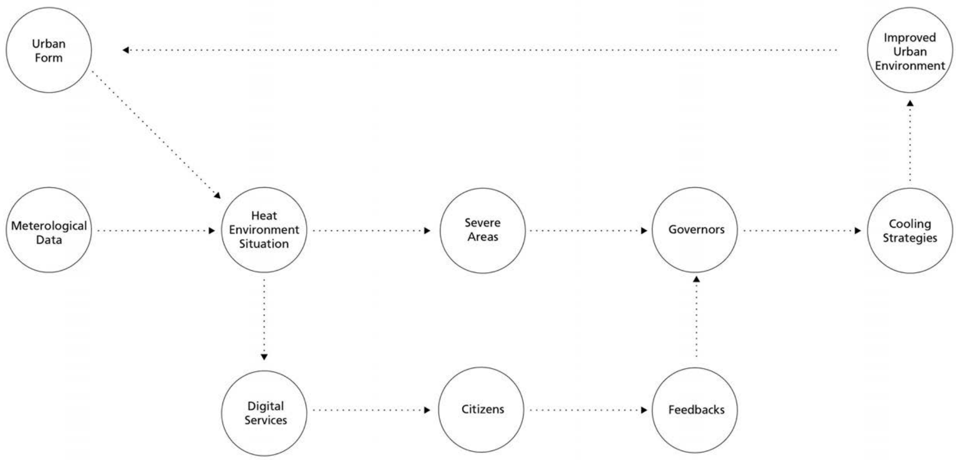

Fig. 6: Diagrammatic overview for developed heat environment mitigation model

Furthermore, the SOLWEIG model is used to evaluate the large-scale urban thermal environment effectively. As a result, shelters from trees or constructions are the most reliable urban elements to reduce thermal perceptions by 7 to 8 degrees. Different ground paving has limited contributions to the environment compared with trees. The paper also proposes that increasing the tree canopy can impact the different urban spaces positively in heatwave events. However, the SOLWEIG model currently does not consider energy consumption in the simulation, which means the influence of heat generated by human behaviour in buildings on the external environment needs to be studied.

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Beyond the Blue Blob: Salience and Perceived Legitimacy of Alternative Sea Level Rise Visualizations

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Abstract: Experts in climate communication have long understood that depictions of potential extreme events may overwhelm audiences and be discounted in favour of more salient, near-term concerns. Despite this guidance, many coastal resilience processes rely on conventional visualizations of sea level rise that combine representations of worst-case storm events with high levels of sea level rise due to expert preferences or availability of modelling. To make projections salient and relatable to existing environmental signals, we advocate for separating depictions of the effects of sea level rise from depictions of storm surge and for depicting impacts of sea level rise that are relevant to near-term adaptation decisions such as roads obstructed by astronomical high tides. We test effects on perceptions of salience of sea level scenarios, storm surge risk, and legitimacy of visualizations as a first step toward testing the hypothesis that alternative sea level rise visualizations will be more effective tools for engaging the public in coastal resilience processes.

Keywords: Resilience, realism, visualization, sea level rise, storm surge

1 Introduction

This work explores using semi-realistic 3D depictions of near-term impacts such as marsh migration and frequent road obstruction in lieu of inundation as tools to support resilience planning. We hypothesize that representing impacts related to observed experience such as septic failures and beach closures due to nutrient pollution occurring today or in the foreseeable future will be more salient to stakeholders and stimulate constructive engagement. This addresses an observed gap in the effectiveness of sea level visualizations used for engagement on coastal hazards. To develop a baseline understanding of viewer perceptions, we present a case study of visualizations of near-term sea level impacts used as part of a coastal resilience process in Portsmouth Rhode Island, USA (henceforth referred to as Portsmouth). We examine the use case for impact visualizations, explore factors affecting their utility such as the perceived salience of different scenario levels, and test the perceived legitimacy of these visualizations as a first step in addressing this hypothesis.

Sea level rise (SLR) poses an existential threat to many coastal communities. Intermittent flooding of roads due to astronomical high tides, septic system failures due to rising water tables, and marsh migration, among other impacts, create a nuisance to property owners and neighbourhoods and in some cases force abandonment long before residences are inundated. Municipalities must allocate limited adaptation resources and face the stark reality that providing services and access to all areas may not be feasible. Making policy, protocols, and incentives for retreat is politically difficult and requires earnest engagement by stakeholders. Decision makers turn to a variety of communication tools as part of the process. One such

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tool, the conventional visualization of SLR, combines the effects of SLR and storm surge, displaying levels of inundation that completely submerge the neighbourhoods that face such adaptation decisions (e. g., SPAULDING et al. 2016). These visualizations depicting communities submerged beneath "blue blobs" of flood waters can overwhelm stakeholders, reduce feelings of self-efficacy, and lead stakeholders to discount risks (O'NEILL & NICHOLSON-COLE 2009). These feelings of helplessness were expressed by a local town councillor in the subject community who said simply: "you're bumming us out".

Fig. 1: Survey images from set 1. Depictions of Island Park (bottom) highlight Marsh migration (green), and obstructed roads (red) and mean high water (blue). Similar visualizations of Common Fence Point were also presented. (authors).

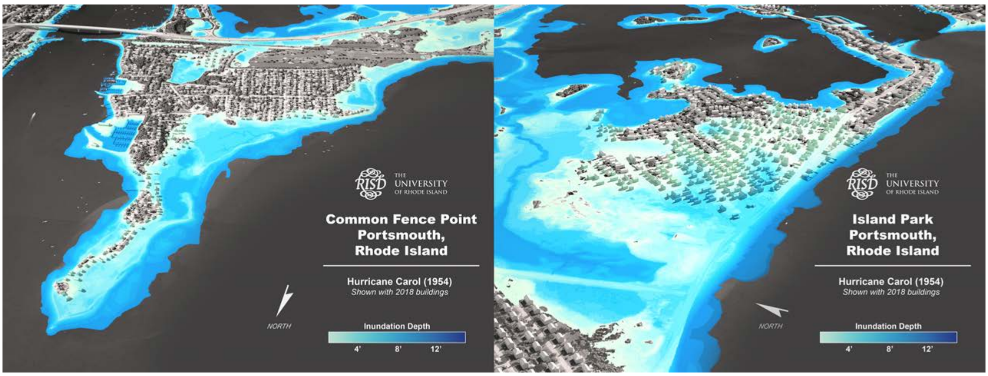

Fig. 2: Set 2 of survey images. Visualizations of Hurricane Carol's storm surge at today's sea level and buildout at Common Fence Point (left) and Island Park (right) (authors)

The localization of impacts, which has long been thought to be an effective means of increasing salience and risk perceptions of sea level impacts to inform resilience planning (RETCHLESS 2014), has been called into question by recent research that suggests localization using inundation maps might not be effective at promoting adaptive behaviour (MILDENBERGER et al. 2019, SCHULDT et al. 2018). We argue that localization, in and of itself, is insufficient to overcome other heuristics of risk perception that cause stakeholders to discount risk. The visualizations tested in this study separate depictions of storm surge from SLR so as not to conflate the inevitable effects of SLR with a low probability event (Figure 1, Figure 2). They emphasize impacts such as road obstruction and marsh migration that occur beyond mean high water and can be associated with observable environmental signals that increase the salience of projected outcomes (OLMAN and DEVASTO 2020, DEVASTO 2018) (Figure 3).

Fig. 3: An example of an environmental signal. Flooded athletic fields likely subject to marsh conversion in Common Fence Point Park, 2018 (Michael Asciola, via MyCoast)

2 Methods

An online survey was developed in collaboration with Portsmouth and the URI Coastal Resources Center (CRC). This work was incorporated into a coastal resilience initiative conducted by CRC, Portsmouth, and local organizations such as the Common Fence Point Improvement Association. Portsmouth also engaged in workshops conducted by The Nature Conservancy in collaboration with the Rhode Island State Infrastructure Bank, however the survey was not integrated into these processes.

The survey was approved by the Brown University Institutional Review Board (protocol 1908002510). It was promoted through a press release by the town leading to coverage by local newspapers and social media sites. Participation was voluntary, and all responses were anonymous. No personally identifying data was collected. The survey was administered between October 7 and October 30, 2019 and was open to Rhode Island Residents over the age of 18. There was a total of 115 respondents.

The survey included two sets of model-based visualizations of existing conditions, SLR scenarios for .30m (1’) and .91m (3’) SLR (Figure 1), and storm surge from Hurricane Carol

(Figure 2). Marsh migration projections (Figure 1) were based on the Sea Level Affecting Marsh Migration (SLAMM) Model (Boyd et al. 2015). Storm Surge projections (Figure 2) were based on the ADvanced CIRCulation (ADCIRC) model using a new Hurricane Boundary Layer Wind Model that more faithfully captures the asymmetrical nature of storms (ULLMAN et al. 2019).

2.1 Survey Instrument

Introductory text at the start of the survey defined terms and provided summary explanations of the models, procedures utilized, and criteria used to determine whether a road was obstructed. Two introductory questions addressed where respondents resided and their experience with past storms, as repeated experience with comparatively low impact events can reduce perceptions of risk (Weber 2010). The main body of questions was divided into three sections, SLR visualizations, storm surge visualizations, and summary questions. The order of SLR and storm surge sections were randomized.

2.1.1 Questions about Saliency and Concerns for SLR Visualizations Set

SLR visualizations were viewed in pairs representing the two depicted neighborhoods at .30m and .91m of SLR respectively. After viewing each pair of SLR visualizations respondents were asked the following two questions to determine how salient the stakeholder perceived the scenario to be, and what concerns the respondent had in the depicted area:

> *"Given uncertainty about the rate of sea level change, what year do you expect this level of sea level rise to be reached?"*
>
> *"What are your concerns about this level of sea level rise in these locations."*

2.1.2 Questions about Perceived Risk from Storm Surge Visualizations Set

This set of questions was designed to better understand how respondents perceived the risk of an extreme storm surge. Questions were framed to separate the perceived likelihood and severity of consequences to better understand the relationship between perceptions of probability and impacts reflecting our concern that the probability of extreme events is discounted. The timeframe is based on the typical length of a residential mortgage in the USA. After viewing the visualizations (Figure 2), respondents were asked:

> *"How likely do you think a storm of this magnitude is in the next 30 years?"*
>
> *"How severe would the impact of an event like this to be if it occurred today?"*

2.1.3 Summary Questions around Legitimacy of both Sets of Visualizations

This set of questions was designed to assess the perceived legitimacy of the visualizations given their divergence from conventional SLR visualizations. They were asked after all visualizations were presented, as follows:

> *"How trustworthy do you find the visualizations used in this survey to be?"*
>
> *"What contributes to your perception of whether or not a visualization is trustworthy?"*

The survey concluded with five demographic questions addressing gender, age, race, income and political preferences, that were utilized to determine the representativeness of the sample.

2.2 Analysis

Evaluative questions used a five-point Likert scale. Open ended questions were analyzed by seven independent coders who reviewed all responses and identified themes using inductive coding (THOMAS 2006). A shared comprehensive set of themes was developed and then applied, then revised and reapplied by all coders. The application was validated by comparing agreement among coders applying the themes independently.

3 Results

Of the 115 respondents to the survey 48 lived in the depicted neighborhoods (21 in Island Park, 27 in Common Fence Point) and 47 respondents lived in other Portsmouth neighborhoods. The remaining 20 respondents reported being from Rhode Island or did not indicate residency. 93% of respondents recognized the places being depicted in the visualizations. Although the overall sample is generally reflective of the town demographics, sample size was too small to make definitive determinations.

3.1 Perceptions of Saliency and Concerns from the SLR Visualization Set

Responses to questions regarding the SLR visualizations suggest that respondents perceive lower levels of SLR to be more salient and are less likely to dismiss or disbelieve the projections. The median expected date for realizing .30m SLR was 2031; the average expected year for .30m SLR was 2039. The median expected year for reaching .91m SLR was 2050; the average expected year for .91m SLR was 2063 (Figure 4). The median of perceptions is slightly behind the National Oceanic and Atmospheric Administration "High Curve" SLR projection adopted by the State of Rhode Island (This lag is logical given that this curve overpredicts present sea level). There are higher levels of variation in the more distant projection. There were more uncategorizable responses with the distant projection (e. g., "never"). One stakeholder stated that the .30m scenario was "here already".

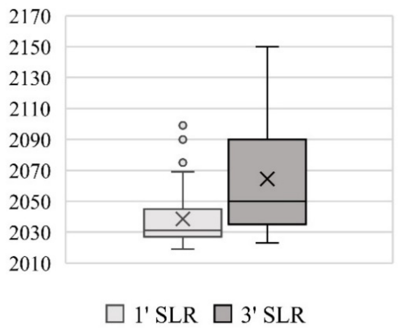

Fig. 4:
Respondent expectation as to when they expect to see the depicted level of SLR. "Given uncertainty about the rate of sea level change, what year do you expect this level of sea level rise to be reached?" "X" represents the mean, a horizontal line represents the median.

Responses to the question "What are your concerns about this level of sea level rise in these locations" were summarized into six thematic categories as described in Table 1. Responses to .30m SLR and .91m SLR were similar enough that responses were categorized together. In several cases, respondents referenced prior responses. The percentage of respondent answers falling in each category for .30m and .91m of SLR are summarized in Figure 5.

Table 1: Summary of major response themes

Theme	Description
Unconcerned or disbelieving	Unconcerned, flooding due to something other than sea level rise and/or climate change, disbelieving.
Government capabilities	Availability of resources such as current or future lack of municipal funds; the incapacity of government to respond.
Septic Failure	Issues stemming from failing septic systems.
Ecosystem Services	Impacts to salt marshes or beaches. Loss of ecosystem services (e. g., marsh is no longer a storm buffer, loss of recreation or fishing).
Property impacts	Physical damage, property devaluation or loss (e. g., abandonment) and expenses incurred (e. g., new septic systems and other expensive adaptations).

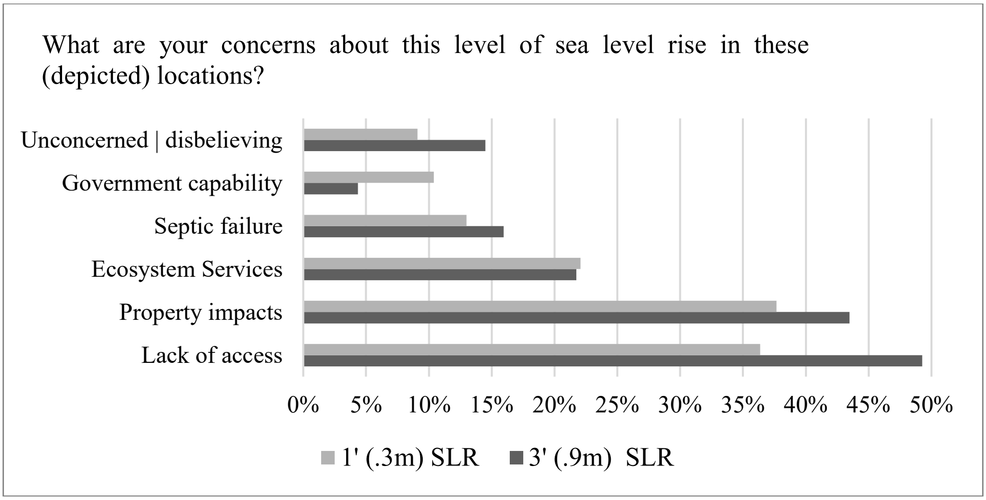

Fig. 5: Respondent answers falling into each thematic category for .30m and .91m of SLR

As with expected time horizon, the perceived saliency decreases with the higher scenario. For instance, and example of an unconcerned respondent:

> *"I own property which you show as flooded. I am not concerned; it will be 100 years before this happens if it happens at all. I will be dead."*

All categories include granular responses indicating a high degree of engagement with visualized outcomes. For instance, 'government capability' includes references to ongoing controversy over implementing sewers and the possibility they will spur gentrification. Respondents considered implications of visualized impacts beyond their own immediate risks:

> *"Impassable roads, 1/2 my neighbors' homes in the Hummocks next to the Sakonnet River bridge would be uninhabitable."*

3.2 Respondents' Risk Perceptions from Storm Surge Set

Participants were shown visualizations of Hurricane Carol (Figure 2) and asked, "How likely do you think a storm of this magnitude is in the next 30 years?" and "How severe would the impact of an event like this to be if it occurred today?" The likelihood of a storm of the magnitude of Hurricane Carol occurring today was regarded as being low (Mean 1.58 / 5). One respondent went so far as to say:

> *"Hurricanes in New England are not like down south. We've had one hurricane that amounted to anything serious, a few days without power and trees down."*

The impacts of a storm like Carol, however, were regarded as being severe (Mean 4.58 / 5). Respondents saw few options for the town beyond ensuring adequate evacuation.

3.3 Respondents' Perceptions of Visualization Legitimacy for Both Sets

Participants were asked "How trustworthy do you find the visualizations used in this survey to be?" They regarded the visualizations as being trustworthy (3.9/5). Participants were also asked "What contributes to your perception of whether or not a visualization is trustworthy?" Factors contributing to their evaluation of the visualizations are summarized in Figure 6.

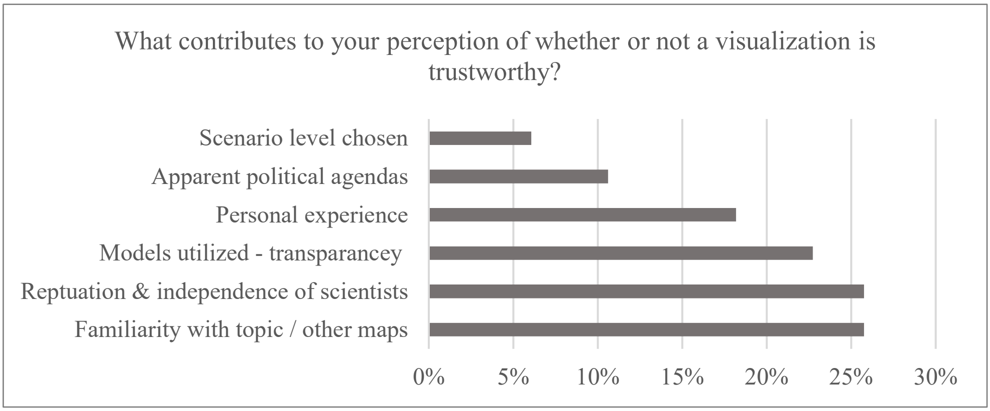

Fig. 6: Factors contributing to impressions that visualizations are trustworthy

Stakeholders view the impact visualizations presented as being like other more familiar sea level visualizations. They clearly rely upon reputation and other cues, such as transparency of methods and sources to judge the legitimacy of visualization. Moreover, they regard themselves as highly informed and familiar with SLR related visualizations and projections and are also familiar with the consequences of their vulnerability.

4 Discussion

4.1 Salience of SLR Concerns

Results suggest near term scenario levels were perceived as being more salient, and less likely to be dismissed or disbelieved. This is indicated by both the results regarding the expected time horizon, and in written answers that suggest increasing levels of being unconcerned or disbelieving of higher scenario levels. We observe that there is an inherent tension between expert-selected visualized scenarios that inform the public of worst-case inundation projections and the lesser-impact visualized scenarios that are likely to be more effective at engaging a cross section of participants and eliciting actionable concerns.

Stakeholders related projected areas of vulnerability to current issues such as failing storm drains and water table changes are already occurring in some locations. One respondent remarked that the .30m sea level scenario was "here now". These responses suggest that lower scenario levels reflecting existing environmental signals are likely effective. A comparative study will be necessary to make a definitive assessment.

Fig. 7: This realistic 3' (.91m) SLR visualization illustrates the consequence of inaction (authors)

Despite the granularity of concerns, there is no evidence that the kinds of responses derived are any different from responses that would have been offered for a SLR only visualization showing inundation. Anecdotally, this became clear to the research team when a realistic "no action" visualization was utilized outside of the survey (Figure 7) and became an article of shocked fascination as individual stakeholders came to grips with a landscape that was at once familiar and unfamiliar. A seasoned emergency manager became emotional as he looked for his own house and discovered it was not there. This visualization pointed to the capacity of still visualizations to transcend personal (effects on one's own house) and global (effects of climate change) scales, and to make future conditions tangible in a way that fostered deep reflection (OLMAN & DEVASTO 2020).

4.2 Discounting of Storm Surge Probability

Although direct observed experience enhanced perceptions of sea level risk, repeated experience with comparatively less powerful hurricanes appears to have caused some respondents to discount the likelihood of a major storm. 41% of respondents experienced a hurricane in Portsmouth. Despite these experiences, many answers minimize or dismiss the hazard (e. g., "Hurricanes in New England are not like down south. We've had one hurricane that amounted to anything serious, a few days without power and trees down."). This discounting conforms to heuristics of risk perception that suggest repeated experience with lesser storms may reduce risk perception (WEBER 2010). There is thus value in disentangling the effects of SLR and storm surge.

4.3 Perceived Legitimacy of Alternative Visualizations

As previously stated, respondents were remarkably frank about the extent to which they made judgements based upon experience with similar visualizations. Further, it does not appear that the choice to represent marsh migration and road obstruction caused stakeholders to distinguish these visualizations from others using more conventional coloration.

The high degree of trust placed in the visualizations based on reputation, emphasis on transparent peer reviewed practices, and personal heuristics comports with other research on the topic of perceived legitimacy of visualizations and computer models (FOGG and TSENG 1999, STEMPEL 2021). Although scenario level is the least frequently cited characteristic, answers elsewhere in the survey, such as the increase in disbelief of the higher level of SLR, suggest that scenario may influence the perceived legitimacy of projected outcomes, or may at least be used as a stated reason for discounting risk. Similarly, statements (e. g., "it does not seem that the visualization uses worst case scenario numbers") suggest that qualification is required to avoid undermining perceptions of legitimacy on the part of those who are concerned that the scenarios understate risk.

5 Conclusion and Next Steps

The evidence from the survey suggests that there is likely a benefit to separating storm surge and SLR visualizations because of the increase in perceived salience of SLR only visualizations and evidence of discounting of the probability of a significant event. There is, as of yet, no evidence that the semi-realistic impact visualizations that were tested offered any improvement over more conventional representational tactics. Like other innovations, more effectively depicting consequences does not in itself appear to be transformative. Based on this work, we identify the following clear needs for a comparative study. First, assessing impact depictions requires additional comparative sets such that the depiction of impacts can be disambiguated from depiction of scenario level. Moreover, in this study, different scenario levels did not yield substantially different insights, thus understanding the tradeoffs between scenario level and perceived saliency will aid in optimizing scenario selection. Second, the anecdotally observed rhetorical power of the "no action" scenario suggests expanding the range of impact visualizations tested to include inundation, semi-realistic visualizations, and realistic visualizations.

In both cases, testing perceptions of legitimacy will be essential. In the first case, disbelief and lack of concern is closely related to scenario level. Establishing whether these factors alter the perceived legitimacy of the visualizations or the scientists and visualizers behind them is thus necessary. In the second, it is unclear how realism will affect the perceived legitimacy of the visualization. Although intuition might suggest increased realism will be perceived as less legitimate, the power of attribution and reputation are significant enough that these visualizations may nonetheless be perceived as products of science if they are attributed to experts, creating complex ethical situations if these visualizations are not used in appropriate engaged processes with qualification (STEMPEL 2021).

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A Scenario and Monitoring Based Planning Approach to Strengthen the Resilience of the Cultural Landscape

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Abstract: Uncertainty is a fundamental part of planning. However, the long planning cycles of regional planning in Germany make it even more difficult to steer regional development in times of rapid change. With this case study from the Leipzig (Germany) region, we would like to explain the procedure in the research project StadtLandNavi. Based on a scenario-based approach, we want to show how decision processes can be supported. As a central tool, a monitoring system will be used to dynamically track the development of individual scenarios and to react to emerging changes. A main focus is the development and stabilization of the technical and administrative system, which is necessary to steer the process outside the planning cycles.

Keywords: Strategic planning, monitoring, indicators, landscape resilience

1 Introduction

Dynamic transformation and increasingly unpredictable processes are omnipresent and pose great challenges to landscape development in many places. Accordingly, planners and decision makers are asked by the scientific community to learn how to cope with uncertainties (BIRKMANN et al. 2016). Therefore, a flexible and adaptive approach to planning in general, as well as landscape development in particular, should be taken. In contrast, there is the requirement to create certainty in possible land uses and to be orderly (WILKINSON 2011, RAUWS et al. 2014, HILLIER 2017). This is the logic of formal regulations and the German regional plan, which is a static document developed over a period of 10-15 years.

With this background, the research project StadtLandNavi, funded by the Federal Ministry of Education and Research, develops and implements procedures to deal with uncertainties in landscape development. These procedures that are aimed at increasing resilience of the landscape are based on an approach called strategic navigation. One principle of this approach is allowing for situate orientation, viz. an iterative process conditioned by the respective situation with numerous references back and forth (HUTTER et al. 2019). We consider monitoring a prerequisite for strategic navigation as it allows for a continuous review of long-term targets in the region with regard to their achievement and, if necessary, points out necessary adjustments in planning measures.

In this paper we reflect on the establishing of the monitoring method the research project pursues. We refer to the case study region of Leipzig -West Saxony in Germany. The territory of the region complies with the regional planning unit, which adopted its regional plan in December 2020. A previous study identified increasing drought in conjunction with heavy

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rainfall events as one challenge for resilience of landscapes in the Leipzig-West Saxony region (SCHMIDT 2020). Accordingly, we focus on heavy rainfall as an example for laying out our approach.

The paper is structured as follows. Firstly, we introduce our understanding of resilience. Subsequently, we elaborate on strategic navigation. The main part of the paper describes the method we developed in order to analyze landscape's resilience as well as our approach for an ongoing monitoring. This is followed by a brief discussion, as well preliminary conclusions and outlook, due to the fact that we present first results of an ongoing research project.

2 Landscape Resilience and Strategic Navigation

2.1 Landscape Resilience

Landscape resilience can be understood as the ability of a landscape to adapt and renew itself, thus its ability to maintain, renew and strengthen its own fundamental landscape qualities despite continuous changes (see SCHMIDT 2020, RAITH et al. 2017, DAWLEY 2010, WALKER & SALT 2006). Every landscape has its own individual resilience profile. Nevertheless, case studies in SCHMIDT (2020) have shown that three principles of resilience play a decisive role in landscapes of completely different types, and with completely different types of disturbance and stress factors:

1) The principle of redundant diversity

Resilience is not promoted by diversity or redundancy alone, but by a landscape-specific balance between diversity and redundancy.

2) The principle of robust elasticity

Similarly, it is not only a question of the resistance of landscape structures, but also of a balanced ratio between elasticity and resistance or robustness appropriate to the respective landscape.

3) The principle of decentralized concentration

Landscape resilience is also promoted by a landscape-specific ratio between autarky and exchange or centrality and decentralization. The principle of decentralized concentration has long been established in regional planning. Just as a balance is needed between decentralization and centrality, a balance is also needed between autarky and interconnectedness.

The principles of landscape resilience can be found both on the level of actors and their actions in a landscape and on its physical-material level. They are of a general nature. This means, that even if each landscape possesses its own individual expression of the principles, it is important that no excessive one-sidedness arises. This is all the more important because cultural landscapes should fulfil multiple functions. Therefore, their "safety net" of landscape resilience must be all the more extensive. The decisive factor is the overall size of the network. For the following Figure 1 this means: The larger the area of the tensioned "safety net" is, the more balanced the specific resilience profile and the more resilient the landscape system are when unforeseen developments occur.

The following three criteria have proved to be helpful for a more differentiated assessment of landscape resilience:

1) Degree of provision of ecosystem services or degree of fulfilment of landscape functions

2) Degree of conservation of the landscape character

3) Speed of adaptation of the landscape system

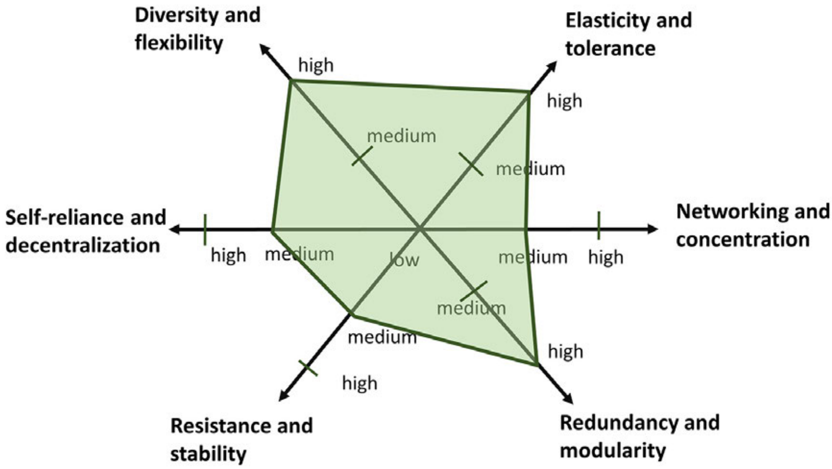

Fig. 1: Example of a safety net as an abstract visualization of landscape resilience

2.2 Strategic Navigation

Knowledge can be considered a prerequisite for developing resilient landscapes. If individuals or groups perceive a deficit of knowledge that is relevant to their intentions and actions, this is referred to as uncertainty (ABBOTT 2005). With regard to climatic phenomena, uncertainties range between the poles of predictable probability of their occurrence and intensity and their complete unpredictability. The planning discussion also points to further dimensions of missing knowledge in planning processes:

- Cause and effect relationships of planning measures and their implementation
- Goals, strategies, and actions of different actors in a region
- Value-based views by different persons (Abbott 2005)

In this way planning decisions are characterised as wicked problems (Rittel/Webber 1973), viz. developing resilient landscapes has a social dimension as well. With regard to dealing with uncertainty, this results in different approaches: 1. reduction with analyses, 2. recognition of a possible surprise by unforeseen events, and 3. creation of a common frame of reference to align views and actions of actors (KWAKKEL et al. 2010, HILLIER 2017, ZANDVOORT et al. 2018). In the following sections we focus on the first and the second category.

If there are agreed upon goals for resilient landscape design, a tentative, experimental approach can be seen as an appropriate way to deal with uncertainty. This can be characterized as an iterative learning process of testing different means for achieving goals, feeding back on achieved effects, and adjusting means for achieving goals (CHRISTENSEN 1985, BALDUCCI et al. 2011). Thus, two different levels can be distinguished for resilient landscape design: the level of long-term orientation, which enables flexible action; and its implementation with small-scale plans and projects (HILLIER 2011, RAUWS et al. 2014). Such an experimental approach is referred to below as strategic navigation. Navigation emphasizes the need to act adaptively (WILKINSON 2011). MICHEL FOUCAULT (1982 cited in (HILLIER 2011)) understands it as a journey directed towards a goal and confronted with unforeseen obstacles. The later can be overcome combining knowledge, structured procedures, and skill. Orientation of action towards a goal is also highlighted by CATHY WILKINSON (2011), who describes navigation in more detail with the adjective strategic. Against the background of emergent effects of planning and rapid change, she emphasizes the ability to pursue an intention strategically. Accordingly, a strategic plan is understood as a document that represents speculative paths for a spatial sub-area that are directed into the future (HILLIER 2017). Its function is thus to clarify pressure for action, provide orientation and record agreements (RAUWS et al. 2014).

The discussion on strategic planning highlights a transformative claim of planning as well. PATSY HEALEY (1997) defines strategic planning as a societal process in which diverse individuals from different institutions and in different positions come together to shape planning processes and develop content and strategies for managing spatial change. Such a multi-layered process is characterized by uncertainty (HUTTER et al. 2019), which can be responded to with situative orientation. This denotes an iterative process conditioned by the respective situation with numerous references back and forth (HUTTER et al. 2019). Fundamental to skillful strategy development is thus a judgment that is sensitive to the specific nature of spatio-temporal development (HEALEY 2009). Thus, resilient landscape development faces the challenge to base decisions on updated knowledge (WILKINSON 2011). The challenge of constant uncertainty of future developments can be met by a monitoring-based approach. Monitoring has the task of providing information and reflecting on goals and assessments (Jacoby 2009). Furthermore, it is the task of monitoring to provide suitable indicators to assess the achievement of objectives and the current situation of a region. For a spatial allocation it is necessary to use data with a concrete spatial reference. Additionally, suitable evaluation scales have to be developed and appropriate geo-data have to be collected and analyzed for identification. In order to meet the requirements of strategic navigation, monitoring is a dynamic process. For this reason, it is necessary to build the underlying data base on existing sources as far as possible, or to establish appropriate agreements for long-term collection and provision. Monitoring is thus very much dependent on the necessary degree of detail of the observation, the necessary cyclical updating and the suitability of the basic data sets used for target evaluation.

3 Indicator-based Approach in the Region of Leipzig to Strengthen the Resilience against Heavy Rain Events

3.1 Modelling Scenarios

The field of heavy rainfall events is to be considered as one major challenge the cultivated landscape has to face. In addition to extended dry and drought phases, heavy rainfall events in particular have increased in the past. When precipitation does fall, it is often more concentrated. Comparing the period 1991-2015 with the climate normal period, both the number of days with heavy rain events and the intensity of heavy rain per event day have increased almost across the whole planning region (FRANKE 2019). In this context, heavy rainfall can lead to increased soil erosion. This is not only problematic as an economical factor, but also in terms of cultural landscape. A lack of agricultural use in large parts of the planning region would be inconceivable, especially with regard to the uniqueness and identity of certain sub-areas. The topicality of the issue is testified by the occurrence of numerous massive heavy rainfall events in recent years. It becomes clear that the high climatic dynamics of the last decades require a continuation of data examination and analysis. In this way, trends, risks and opportunities could be recorded better and adaptation measures could be placed in a more targeted manner (SMUL 2015).

The assessment focusing the probability of occurrence of heavy rainfall events is based on a Saxony-wide study that considers heavy rainfall in detail with regard to rainfall depth, days of exceedance, mean intensity and frequency of occurrence within the period 1961-2015 (LFULG 2017). In the planning region Leipzig-West Saxony, more days with heavy rain with partly decreasing intensity could be observed than in the remaining areas of Saxony. The frequency of occurrence increases especially in summer, particularly in the second growing season (July to September).

In addition to the probability of heavy rain events, resilience depends on natural conditions: landscapes react differently to the sudden occurrence of water masses and the associated increased removal of soil substrate. Landscape resilience differs from landscape to landscape. The assessment of water erosion disposition is an integral part of a landscape planning analysis. It indicates which areas of the landscape have the greatest natural risk of increased soil substrate erosion by water. Basically, a distinction must be made between natural causes and erosion promoted by land use. The evaluation is based on the slope inclination and slope shape, the soil type, and the average precipitation amounts and intensity. An evaluation focusing on the natural risk of water erosion could be processed using a standardized official calculation procedure (ABAG according to DIN 19708).

Not only the susceptibility of the landscape to lose soil substrate through rain-impacted flows poses a risk during heavy rain events. The pronounced ability of water to seep into the soil (infiltration) should be also considered in the assessment. This indicator is largely constant and calculated for each region based on the soil type and terrain properties.

In addition to the specific soil properties mentioned above, the retention capacity is also strongly determined by the respective land use (land use-related retention capacity): the vegetation cover acts also as a relevant partial indicator but is supplemented by the respective degree of soil sealing. The applied methodology is based on a vulnerability study for the model region Leipzig-West Saxony within the framework of the model project of regional planning KlimaMORO (SCHMIDT et al. 2011).

In order to identify parts of the landscape that are particularly vulnerable to heavy rainfall events, water erosion disposition and retention capacity are considered together. Both indicators are directly linked to each other: for example, the damage caused by water erosion increases if the soil substrate does not absorb surface water quickly enough – it consequently has a low retention capacity. Avoidance capacities could only be considered to a limited extent within the scope of the analysis. The reason for this is, among other things, the uncertain data and information situation considering the agricultural management methods and details of the crop cultivation on a regional level. Furthermore, it is foreseeable that these are data that can hardly be estimated for the future so that a considerable degree of uncertainty remains (SCHMIDT et al. 2011). In contrast, agricultural land represents by far the largest share of land use of the region's area (SCHMIDT et al. 2019).

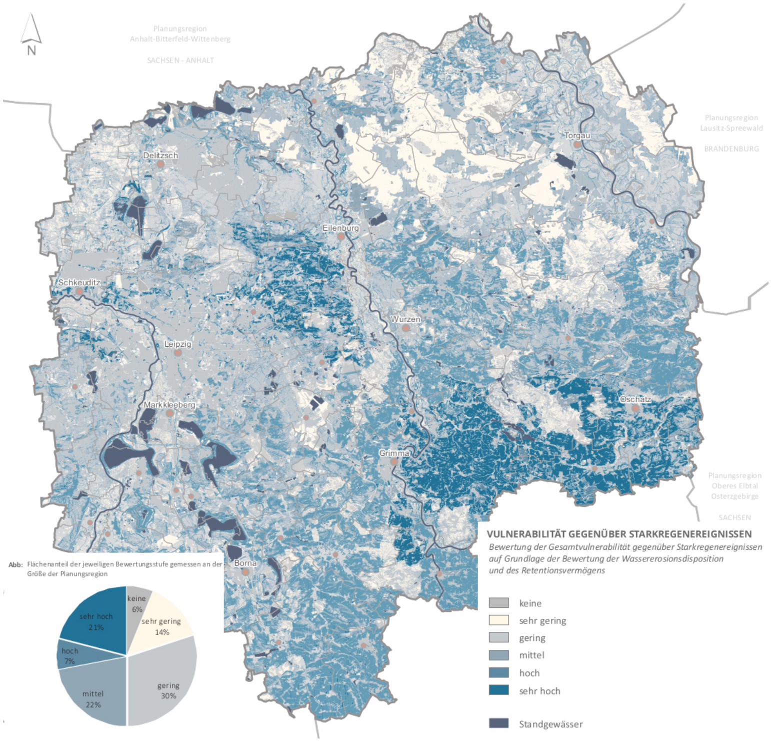

Fig. 2: Assessment of the vulnerability of the landscape in case of heavy rainfall events depending on the water erosion disposition as well as the retention capacity. Areas with a dark coloration (with the exception of flowing and standing waters) show an increased risk towards the impacts of heavy rain events (SCHMIDT et al. 2019).

The natural indicators, such as water storage capacity, soil type and relief, form the basis of the analysis. For a monitoring system in the sense of strategic navigation, however, those sub-indicators are of particular interest that, on the one hand, could be change, and on the other hand, would influence the analyses. With regard to the example just explained, this includes in particular the land use data, which are extraordinarily well suited for a spatially comprehensive monitoring tool due to the nationwide uniform and available basic landscape model. If the land use in particularly endangered areas is changed, e. g. by a year-round land cover, this can be mapped by re-processing with updated geodata and enables a possible necessary planning reaction. Additionally, the updating, combination, detailing and stabilization of the data sets of the natural sub-indicators lead to a significant improvement concerning the data basis over time. As a result, this increases the precision of the model-based indicator as well and the indicator gets closer and closer concerning landscape reality. The more the analysis fits reality, the better the basis for decision-making for resource-conserving and sustainable land management in the sense of strategic navigation.

Another factor that can be taken into account when assessing potential risk areas during heavy rain events is the mapping of runoff paths. They document recurrent erosion processes and thus highlight the areas with the greatest soil substrate losses. The individual trajectories differ in length and intensity and also represent suitable starting points for counteracting water erosion in agriculturally dominated areas.

The natural factors determining the sensitivity of the cultural landscape are known in the Leipzig region and are hardly subject to change. The uncertainty here is accordingly low. However, the natural factors define the framework within which the variable, use-related factors must be regularly monitored. The typical planning periods at the regional level of 10 – 15 years are too long to react appropriately to possible undesirable developments with adapted measures.

Other scenarios and indicators that will be developed for the region consider landscape resilience to drought stress, dust storms, and flood events in agriculture and forestry. Furthermore, the changes of the cultural landscape with regard to technogenic overprinting, landscape image and recreational effectiveness of open spaces in the region are to be monitored. After the necessary methodology has been developed by the research project, it is currently being coordinated and adapted with experts from regional, district and urban planning. Subsequently, the monitoring tool will be established and released for use by all actors in the region and the public.

3.2 Monitoring

When applied to monitoring resilience of a landscape to heavy rain events, one has to take into account that the indicator exposure to water erosion is composed of fixed and dynamic factors. For monitoring, it is crucial to look at the highly variable sub-indicators on a regular basis. There are several sources of information that allow an assessment of the hazard or the reduced hazard through implemented measures. In the area of agricultural management, this is, on the one hand, the crop type composition. On the other hand, the percentage of land that is cultivated with soil-conserving techniques as well as currently fallow land or temporary conversions of erosion-prone land into grassland. In the area of the biotope equipment of the cultivated landscape, these can be hedges and embankments or compensation areas with erosion-reducing management objectives.

Our work shows that necessary data for monitoring is available from a wide variety of authorities. However, these information flows are not established at the planning level. Neither are there agreements on the provision of data, nor are the data available for a one-time analysis of the current situation. This is the main challenge in establishing a monitoring system. The aim of the StadtLandNavi project is therefore, after the analysis of the demand situation, to take the first steps for long-term safeguarding of data flows in the region. This safeguarding is based on the creation of automatic mechanisms for the provision of data. If individual basic data for the indicators are updated, the data stock in the monitoring system is updated by automatic processes and the indicators, the degree of target achievement and threats are recalculated. The actuality should always be based on the most current initial data set. This makes it possible to monitor the achievement of objectives or the threats to the scenarios outside of planning cycles and with little personnel effort.

In addition to the purely preparatory observation, several exemplary measures will be implemented in the landscape, such as increasing resilience. By means of monitoring, the effects of the measures implemented in practice will become visible and evaluable. This should lay the first foundations for monitoring to support decisions as to when measures are necessary and how they work. At the same time, individual examples already provide a first catalog of what can be implemented to improve or achieve the goals of the individual scenarios.

Since monitoring is an ongoing and continuous process, it is not sufficient to develop the methodological basis. Successful establishment requires anchoring the system on a technical basis as well as on an administrative level in the region. In a first step, an actor in the region has to be found who takes over the maintenance of a monitoring system. This includes the maintenance of the technical basis and access rights of a service- and WebGIS-based system as well as any necessary adjustments of data sources during operation, support requests and governance tasks. During the ongoing operation of a monitoring system, it is to be expected that adjustments in the area of governance will become necessary. This can be the extension of the user group or contractual adjustments in the procurement of basic data or license models. The challenge here is to find an actor, or several actors, in the region where both the personnel basis is anchored and the necessary accepted authority is available to curate the contents of the monitoring system. Such an actor can be an already existing structure such as a regional planning association, a county, a well-staffed municipality or a metropolitan region in addition to a newly founded company. Contracts then ensure the provision of data, the provision of specific information for the internal use of individual actors and the public, and the financing of personnel and ongoing technical maintenance on the part of the curator.

4 Discussion

We propose that the outlined monitoring procedures may support planning actors in the Leipzig region to connect the overarching goal of resilience with down to earth implementation measures. The evolving knowledge base may allow for strategic navigation in landscape development.

The combination of analysis of the cultural landscape, derivation of necessary data flows for institutionalization of monitoring, creation of a technical basis in the region and finally exemplary implementation of measures is costly, but at the same time promising. The pure theoretical analysis and indicator development cannot lead to an implementation by the actors on site by their own resources. Therefore, StadtLandNavi processes tasks that are independent and superordinate of everyday work. Based on our preliminary results, we propose that the biggest challenges for ongoing monitoring required for strategic navigation are establishing data provision and defining responsibilities for the ongoing monitoring procedures. This requires agreements with the responsible body of the monitoring with regard to the type of provision (data standards, services, rights and visibility rules) with all management entities of the necessary source data sets. In addition, from a methodological point of view, it is sometimes necessary to extend existing data collections or even create new ones in order to achieve the necessary level of detail. The first examples, which have been developed in the research project and will be further developed in the next two years, are a signal for the necessity and feasibility on a political level.

5 Conclusion and Outlook

An important aspect of monitoring cultural landscape development is institutionalization. Discussions with actors in the region have already produced several expressions of intent. Currently it is being decided with which actor the technological basis will be implemented. Start-up financing for the adaptation of the monitoring system, which is currently still anchored in the research project, is available. The operation is thus secured for the duration of the project until 2022. Subsequently, the operation and further development based on the current experience and suitability of the system can continue to serve as planning support. Further topics besides the cultural landscape are planned and already in the first evaluation regarding suitability. These are sustainable land management, securing of recreational functions and housing demand analyses.

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Development of a Combined Typology to Co-Assess Urban Sprawl and Habitat Network Structure

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Abstract: This contribution combines, based on dispersion metric DIS, urban sprawl metrics with considerations on landscape connectivity. The motivation to do so comes from the question of ecological impacts from urban sprawl. Based on calculations of DIS-based metrics for both settlement and habitat-network structures a land typology is introduced which helps to identify different situations of co-existence of sprawl and habitat-network.

Keywords: Urban sprawl, habitat networks, landscape connectivity

1 Introduction

Urban sprawl is a complex phenomenon, covered by different theories and described by various indicators. The term addresses a process as well as a pattern, and both are subject to demographical, socioeconomic, economic and physical planning related studies. From a landscape point of view, visual appearance and physical structure of land patterns resulting from urban sprawl are of special concern. In general, we have to state that urban sprawl changes social-ecological balances by changing land-use and land-cover systems. Growth of scattered settlements, densification of transportation networks, displacement, intensification and loss of agricultural land, deforestation, but also the need of land for recreation purposes are key examples for such transformative and often conflicting processes related to urban sprawl, which mainly takes place at the fringes of urban centres and development axes.

We must discuss urban sprawl also concerning its environmental and ecological consequences. Water balance, thermal pollution, air pollution caused by traffic and visual/recreational landscape quality are closely linked to patterns of urban sprawl. Above all, however, in particular habitat disturbance and habitat loss caused by urban sprawl must be brought to the fore. At the fringes of our cities, a lot cite specific habitat structures and biodiversity patterns exist that get under pressure if urban sprawl is in process.

This contribution deals with the effects of urban sprawl on habitat connectivity. We know that in a biotope or habitat network connectivity is a key parameter for successfully establishing exchange of individuals and genes, for accessibility of resources and for enabling migration and dispersal. Settlement and transportation infrastructures and thus patterns and dynamics of urban sprawl directly affect permeability of landscape and its bio-connectivity. Hence, landscape pattern assessment concerning conflicts between settlement patterns and habitat networks is a tool to proactively prevent or to mitigate serious impacts on biota from urban sprawl.

JAEGER et al. (2010) have presented a concept for measuring urban sprawl. They use metrics that analyse the neighbourhood of an urban location. This metrics can also be – but up to now was not – applied to basic questions regarding bio-connectivity. Appropriate adjustments of them can be used to describe form (e. g. mainland type, patchy type, linearity) and, when

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considered in a combined analysis, they can answer questions like: which pattern of urban sprawl restrict permeability? How did urban sprawl and permeability develop in settlement history? Where do bottlenecks exist, and which patterns do cause them?

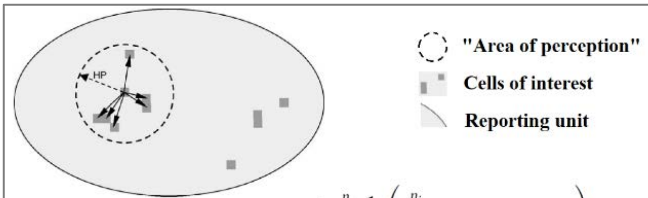
The objectives of this contribution is to apply the concept of JAEGER et al. (2010) in parallel both to the settlement patterns and to grassland habitat network patterns which can be found in the federal state of Baden-Württemberg, and then to combine the results for a comprehensive typology of land structures. The paper discusses the resulting types with regard to its ecological and planning related implications and suggests further steps in co-assessing urban and habitat structures.

2 Material and Methods

The study uses data from the grassland habitat network provided by the Environmental Agency of the State of Baden-Württemberg (LUBW 2014) and OpenStreetMap[1] data on settlement, both covering the complete territory of Baden-Württemberg. Grassland habitat network addresses a species guild, whose habitat requirements are linked to extensively used grassland types such as dry grasslands or orchard meadows. Settlement data include groundcover by buildings.

For the study, a geographical land model is defined which regards a landscape as a data driven simplification, such as presented in Fig. 2. Connectivity area consists of habitat core-areas and habitat linkage-area and lies embedded in a configuration of settlement barrier and matrix barrier, both not further differentiated.

The concept of urban sprawl metrics as introduced by JAEGER et al. (2010) starts with the calculation of dispersion *DIS*. The calculation sums up the weighted distances between cells covered by settlement. A brief summary gives Fig. 1, for a deeper discussion of *DIS* calculation and its linkage to urban sprawl refer to JAEGER et al. (2010).



$$DIS(b) = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{n_i}\left(\sum_{j=1}^{n_i} f(d_{ij}) + WCC(b)\right)$$

$$f(d_{ij}) = \left(\sqrt{2|\vec{x} - \vec{y}| + 1} - 1\right)$$

where n_i denotes the number of urban cells that are closer to cell i than the horizon of perception, d_{ij} is the distance between (the centers of) cell i and cell j, and $WCC(b)$ is the within-cell contribution.

Fig. 1: Calculation of Dispersion DIS by JAEGER et al. (2010)

1 https://download.geofabrik.de/

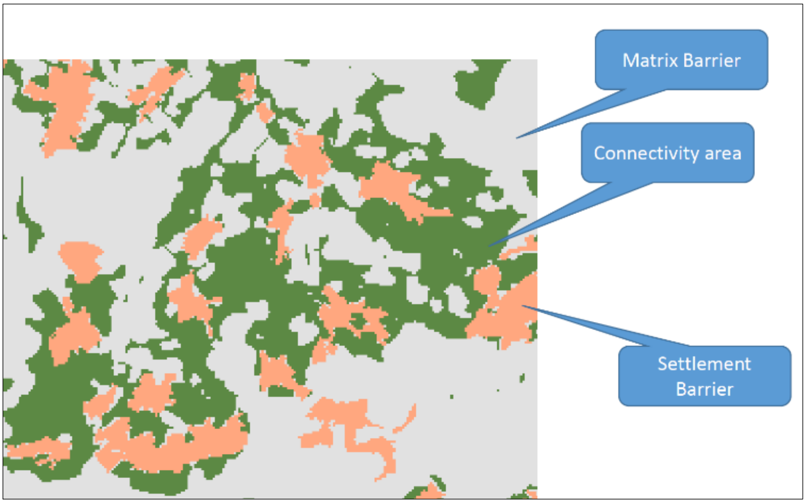


Fig. 2: System of considered land mosaic

Dispersion metrics *DIS*^{u} is calculated for buildings and in parallel *DIS*^{h} is calculated for the habitat core-areas in the Habitat-network. Both is calculated for hexagonal reporting units (Fig. 5). When calculating *DIS*^{h} "Area of perception" in the *DIS* concept can be interpreted for an (species) individual radius of being able to identify habitat quality. The concept of summarizing distances between habitat network cells indicates the total effort to access "good habitat quality" cells from a "good habitat quality" cell.

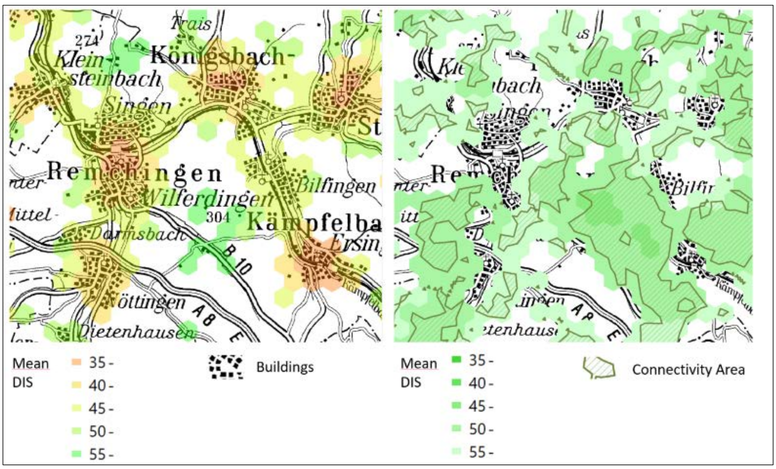


Fig. 3: Dispersion of buildings *DIS*^{u} (left) and habitat network *DIS*^{h} (right)

JAEGER et al. (2010) derive from *DIS* metric *UP* which quantifies "urban permeation". This metric describes for a study region the degree of being interspersed by settlement bodies and twins the two components 'amount of settlement' and 'dispersion of settlement' by multiplying it, and thereafter relates the product to the size of the study region (*UP* = *DIS* × urban area /size of the study region). So, in this paper we correspondingly calculate as

"urban permeation": $UP = DIS^u \times$ settlement area /size of hexagon

"habitat permeation": $HP = DIS^h \times$ habitat network area / size of hexagon

To combine *UP* and *HP*, a land typology is introduced. *UP* and *HP* values are classified into 3 classes each by a mixture of considering standard interval and tertile intervals. This leads to 9 combinations called "permeation type" (PT) (Fig. 4), which are coded by combination of digits 1,…,3 and which can be assigned to the hexagonal cover of state of Baden-Württemberg.

Fig. 4 illustrates the different permeation types. PT11 represents a configuration of sparsely scattered settlements and habitat. PT13 shows a land configuration highly permeated by habitat and PT31 is highly permeated by urban structures. Finally, PT33 is characterized by a high degree of coexistence of habitat structures and urban structures. We can simplify the classification by considering PT21, PT31 and PT32 as "urban dominated", PT12, PT13 and PT23 as "habitat dominated" and PT11, PT22 and PT33 as being in "parity".

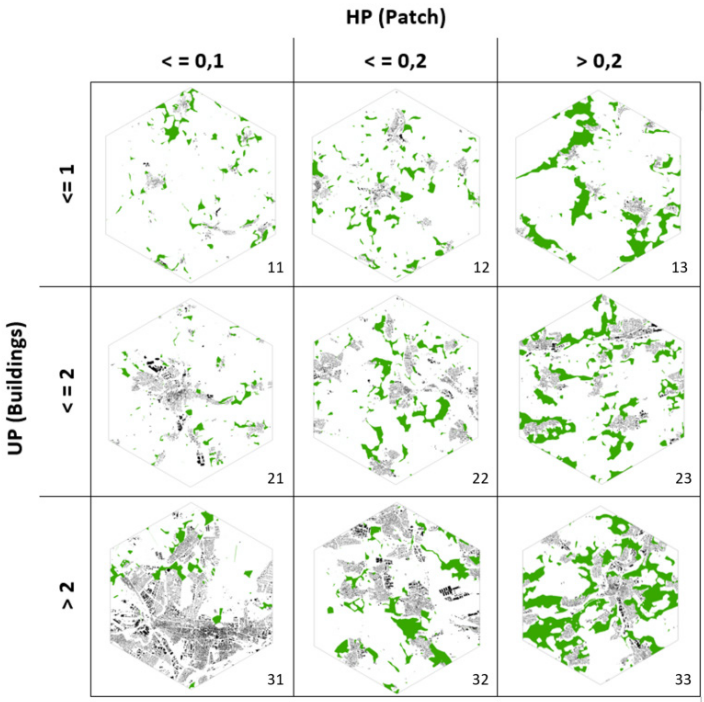


Fig. 4: Classification of dimensionless *UP* and *HP*; examples for land configuration in the resulting 9 combinations of *UP* / *HP* classes called "permeation types" (green = habitat core-area, black = buildings)

In a PT33 landscape, nature conservation collides with significant disturbance from the urban fabric. Here secondary landscape services from habitat networks – like recreation or ventilation – get an important issue in ensuring urban residential comfort. Those landscapes are at a climax of urban development. PT31 landscapes are in the situation of being over-urbanized when considering the chance to establish coherent habitat structures. PT11 land is not of concern in planning related considerations – no conflicts, no development options, and so, no problems to solve. And finally, PT13 points to landscapes where significant habitat network exists and can be easily be developed

For habitat-network management the most challenging type is PT31 and the best opportunities can be found in PT13. PT12 and PT32 can be considered as "good to be managed" and in PT12 or PT23 strong challenges must be tackled.

3 Result and Outlook

Fig. 5 shows territory of state of Baden-Württemberg covered by hexagons, which indicate the type of land configuration according to the typology.

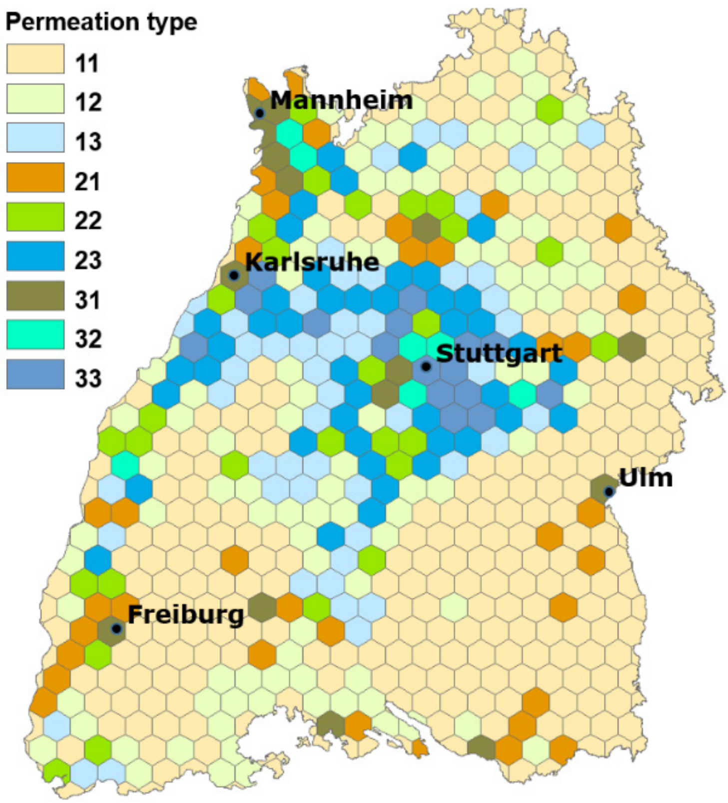


Fig. 5: Permeation types in Baden-Württemberg

PT11 is covering rural areas. A mixture of permeation types on the other hand covers the urbanized area. The centres of urbanized areas have different permeation types in their neighbouring periphery. Ulm is a rural centre, whereas urban dominated types surround Mannheim. Stuttgart (centre and periphery) and Karlsruhe show a more parity typed periphery. Freiburg is a mixture between Ulm and Mannheim.

There are a lot habitat dominated landscapes in the wider periphery of Stuttgart and Karlsruhe and in the urbanized axis in between. According to the permeation types assigned here, good and very good opportunities for enhancing and successfully fostering habitat-network development can be stated.

It is shown that *DIS* based metrics *UP* and *HP* help to characterize land configuration concerning both urban area and habitat network. Permeation types as suggested provide an appropriate method to separate different land structures, which clearly indicate different situations concerning urban sprawl pattern und habitat-network coherence, and which address fundamentally different planning arena and agenda. It is promising to run the proposed method in analyses of existing land configurations. The identification of permeation type is a helpful outcome, which helps in Green Infrastructure development control.

In a next step, permeability studies must be carried out to identify the specific permeability characteristics of each permeation type. Such analyses have the potential to identify optimal patterns of landscapes in terms of being both sprawled and bio-connective.

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Visualization, Animation and Mixed Reality Landscapes (VR, AR)

Where the Wild Things Will Be: Adaptive Visualisation with Spatial Computing

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Abstract: Augmented Reality is increasingly being used as a tool for education and communication. However, applications tend to be limited to a single-use case, due to the complexity of adapting in-situ visualisations to different environments and topographies. In this paper we propose a novel adaptive visualisation workflow designed to embed large-scale visualisations with temporal dynamics within arbitrary environments, using dynamic spatial mapping. We build a generic parameterised method to create interactive, explorable visualisations of progressive environmental augmentations. We demonstrate how this system could be used to simulate a simplified rewilding visualisation for use in education and stakeholder participation, allowing participants to explore potential ecological changes in-situ.

Keywords: Augmented Reality, visualisation, spatial computing, occlusion, rewilding

1 Introduction

The United Nations General Assembly has recently declared 2021-2030 the decade of ecosystems restoration (UNITED NATIONS 2019). Rewilding has been proposed as one path to achieving the ambitious vision of a restored level of biodiversity by 2050. Rewilding is a progressive approach towards nature restoration, which aims to restore complex ecosystems while minimising human interventions (LORIMER et al. 2015). The widespread acceptance of afforestation efforts will need innovative public policy solutions, backed by public understanding and support (SANDOM & WYNNE-JONES 2019). This is achieved by a communication strategy that involves affected communities in decision making as well as outreach activities that inform the wider public about the outcomes of interventions, potentially including opportunities for nature experiences such as guided tours through the area in question.

Visualisation plays an important role in stakeholder participation (LANGE 2011). Since the early before-and-after visualisations of Humphry Repton (REPTON 1980), we have used developments in visualisation technology to improve the communication of the effects of proposed landscape interventions. Augmented reality (AR) has been used since its inception, as a method to enrich visualisation and communication techniques. Recent developments in AR hardware has led to a resurgence of AR applications in landscape architecture (GOUDARZNIA, PIETSCH & KRUG 2017, HAYNES, HEHL-LANGE & LANGE 2018, SORIA & ROTH 2018, TOMKINS & LANGE 2019), however realistic occlusion has been a barrier to the effectiveness of on-site visualisation (LI et al. 2018).

Realistic occlusion without environmental understanding is a difficult task in AR application development. Marker-based AR is one widespread technique, which requires detailed modelling and laborious spatial calibration ahead of time to get convincing results, leading to either site-specific single-use applications without environmental occlusion (GOUDARZNIA et al. 2017, SORIA & ROTH 2018), or more generic applications with no interaction with the surrounding environment (TOMKINS & LANGE 2019, 2020).

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Haynes et al. (2018) have demonstrated an innovative, yet time-consuming manual approach to roughly mapping the spatial profile of an area using primitive shapes to create simple occlusion geometries (HAYNES et al. 2018). While this approach is feasible for small areas, its application would be problematic for complex or larger natural environments, and entirely unsuited to free exploration. These limitations pose a problem in harnessing the immersive power of Augmented Reality visualisation to affect change in large scale projects, such as the Rewilding Britain Initiative (SANDOM & WYNNE-JONES 2019), which are spread across many sites, or in projects with undefined sites, such as you find in outreach and education programs.

Site-specific outcomes are heavily influential in the acceptance and success of rewilding endeavours (CEAUSU et al. 2019), severely limiting the transformational role of single-use applications across multi-site projects. If AR is to play a role in large scale projects, we need an approach which can be applied to sites in which the environment is unknown in advance. The development of spatial mapping in wireless AR headsets may offer the chance to develop applications which work with the local topography, without prior knowledge, applicable across multiple sites without spatial recalibration.

To assess the ability of the latest AR hardware to address these limitations, we must adapt the way we build AR experiences, moving away from the visualisation of specific interventions, to building adaptive visualisations through procedural generation reactive to the immediate environment. We introduce the Adaptive Visualisation Workflow to dynamically visualise landscape augmentations, through a user-guided exploration process, constrained by pre-defined parameterized stages, which adapt to the local topography. By defining a set of simplified temporal stages to approximate the progression through the natural succession of plant recolonization of human-dominated landscapes (BILLINGS 1938), we show an example of how this generic visualisation engine could be used to explore a phenomenological visualisation of the rewilding process in-situ. With this work, we aim to let people experience the evolution of their wild spaces, learning not in a lab, but upon the very land concerned.

2 Methods

For this project, we have created a new Augmented Reality application for the wireless Microsoft HoloLens 2 headset. We built our application within the Unity Game Engine, using the Mixed Reality Toolkit (MRTK) Spatial Mapping library to build and interact with a continuously maintained spatial mesh of the world around the user. The dynamic mapping process ensures that no prior knowledge of topography, nor prior modelling of the intervention is required. To maintain a generic application, our experiences are designed by configuring a set of independent visualisation stages akin to snapshots in time, which are incorporated into the Adaptive Visualisation Workflow, as explained in section 2.1.

2.1 The Adaptive Visualisation Workflow

To create our AR experiences, we follow an adaptive visualisation workflow, driven by the interplay of user exploration, local topography and a configuration based scenario, shown in figure 1. The adaptive visualisation workflow aims to frame how we build AR experiences which explore procedurally generated scenarios in response to the immediate environment, using the on-site dynamic mapping process shown in figure 2. We create experiences which can be used across sites, yet capture the underlying traits determined by pre-configured parameterisations, such as species variety, prevalence, density and dynamics.

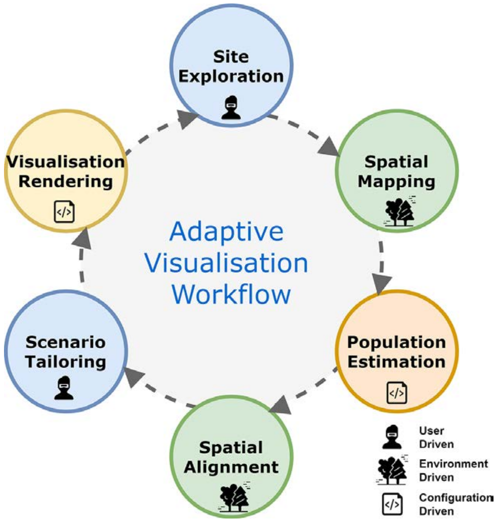

Fig. 1:
The continuous loop of the Adaptive Visualisation Workflow, driven by the interactions of the user, the immediate environment and the pre-defined scenario configuration parameters

During the experience, while wearing the headset, we begin the cyclic workflow. As the user explores, through walking and casting their gaze around, we build up a spatial mesh of the environment, as shown in figure 2. The spatial mapping is restricted to approximately 3 meters range from the participant, ensuring exploration is a key process to create larger-scale visualisations. With all newly mapped areas, we use a set of the pre-defined stages, to calculate how many new assets (for example, tree species) should be visualised, and of which types. We then spatially align the new visualisations such that they are embedded in the natural undulations of the generated mesh, as shown in figure 3. With each stage calculated, the scenario is then pruned to show only the assets required in the current stage. Finally, the results are visualised with the headset. This is an autonomous process, with the only user input being exploration, and the explicit commands to change the currently displayed stage.

Fig. 2: On-Site Dynamic Spatial Mapping Process. (A) A multi-layered urban green space with complex geometry. (B) The dynamic mapping process visualised as seen through the HoloLens 2. (C) A snapshot of the 3D spatial mapping mesh of the urban green space captured during a short walk, exported and rendered after the session.

2.2 Defining a Visualisation Stage

The Adaptive Visualisation Workflow is a procedurally generated process, which is adapted to a specific scenario through the configuration of distinct stages. Stages consist of a user-defined set of groups, or layers, which interact through their average density. Each associated item within a group contains a 3D representation, and their associated relative prevalence within the group, as shown in figure 3. All assets within a group share an average density estimation, as such, stages which combine species with different dynamics, such as pioneer trees and undergrowth, should be represented as different groups within a stage. In our example, stages represent the temporal progression of natural plant succession seen in the re-colonization of unmanaged land (BILLINGS 1938), with each stage including distinct tree groups, and undergrowth groups.

The spatial distribution of items within a group is determined by iteratively adding models as the space is mapped, ensuring the global density of items within one layer remains consistent with the average density configured for the group. Individual items within a group are picked at random, with respect to their respective prevalence. For example, varying the density and prevalence of species across succession stages can approximate the changing underlying make-up of forest biomass through time. An example configuration, as shown in figure 4, demonstrates a simplified progression of plant succession which can be adapted for specific sites and stages as required. Each stage after the first contains two groups, one for the undergrowth (annual, perennial and shrub dynamics), and one for the tree species dynamics.

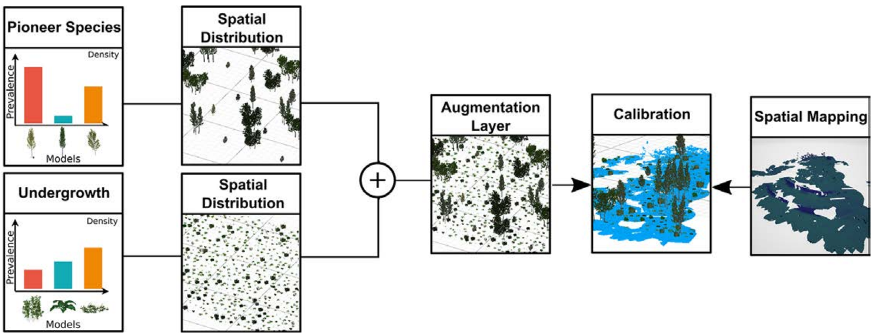

Fig. 3: Procedural generation of augmentations for a single-stage, build from two distinct groups configured with different species, prevalence and group-level densities

As stages are defined by a probability distribution through asset prevalence, each run of the experience will create different variations on the scenario. Choosing to represent the distribution in terms of prevalence and density of species groups enables a flexible way to configure experience to approximate group dynamics. Parameters could be taken from theoretical model predictions or site-specific measurements. Assets are free to be any set of objects which can be rendered in Unity, including 3D models, billboard models and animated models such as wildlife. In this example, we use the highly detailed European Vegetation resource pack, from the Unity Asset Store. Stages can be progressed using a simple set of voice commands giving audio feedback, which are less prone to environmental interference than holographic user interfaces. As such, the only interface to the participant is the augmentations themselves.

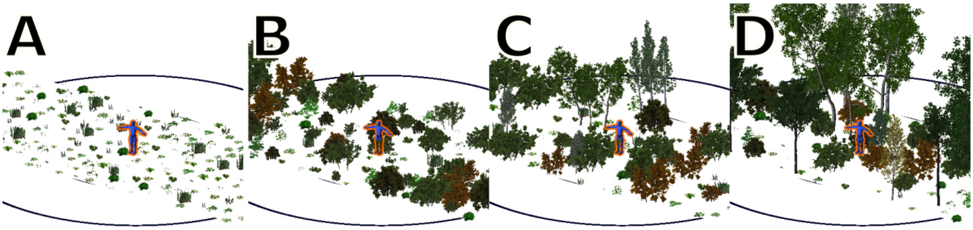

Fig. 4: An example configuration of stages to approximate plant successional stages. (A) annual & perennial plants and grasses, (B) shrubs, (C) Early pioneer and (D) Mature Pioneer species.

3 Results: Visualising Passive Rewilding for Education

Rewilding in the European context often emphasises a passive ecological approach to rewilding (SANDOM & WYNNE-JONES 2019), relying on the natural process of ecological succession for land management. Rewilding can occur in a variety of settings, and spatial scales, from urban green spaces to abandoned agricultural landscapes (PRIOR & BRADY 2017). Here we apply the Adaptive Visualisation Workflow to develop a proof-of-concept application to determine the applicability of our approach to enhancing educational opportunities for nature experiences, such as guided site tours in outreach. To achieve this, we use our procedural visualisation engine to visualise a phenomenological configuration of plausible local outcomes of natural plant succession, reminiscent of the unguided afforestation seen in the passive approach to rewilding.

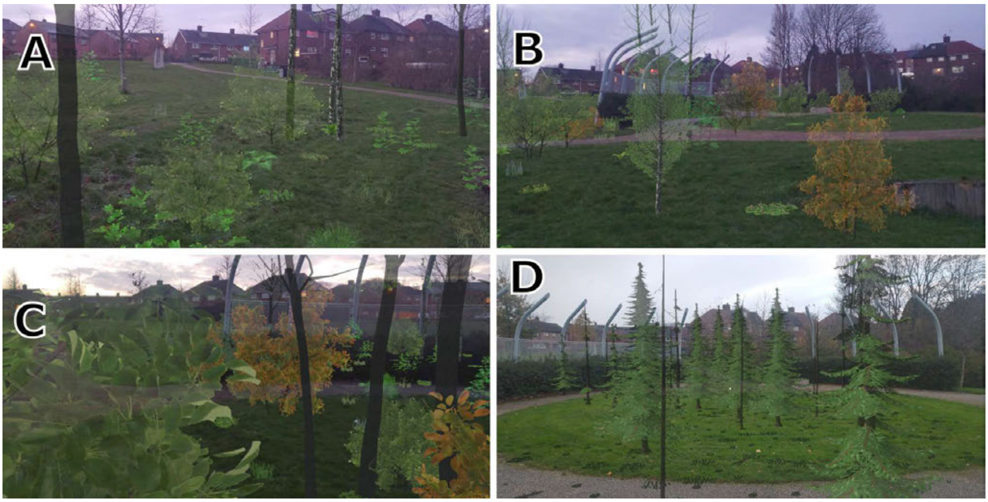

Fig. 5: Examples of successional visualisations in an urban green space, taken through the HoloLens headset. (A) Augmented mature pioneer Birch trees and shrubs alongside established real trees, (B) Early pioneer species and shrubs, (C) Close up experience of the shrub augmentations, (D) Alternative Pine dominated configuration.

We define a simplified 4 stage progression, annuals and perennials and grasses, shrubs, early pioneers and established pioneers inspired by the natural progressions found in BILLINGS, (1938), shown in figure 4. We represent the stages of pioneer succession as two separate stages, to smoothly capture the growth of the pioneer species from early colonisation to maturity. Each stage contains primary species, and residual species, such as undergrowth, showing the gradual reduction in species prevalence as the habitat becomes less favourable.

In this configuration, we focus on a section of European grasses, shrubs and tree species based on what is present in the local area, mainly birch, oak and maple. Indicatively, we included the locally prevalent perennials, horsetail (*Equisetum arvense*) and dandelion (*Taraxacum)*. Each simulation will result in a different experience, reflecting the spatially stochastic, but generally predictable stages of natural succession (BILLINGS 1938). Each outcome is shaped by the profile of the land itself, the path the participant has taken to explore the area, and how they have chosen to experience the progression of stages.

Figure 5 shows 4 examples of the visualisations created by the HoloLens, with figures 5A, 5B and 5C showing the primary configuration based on a Birch dominated succession progression. Figure 5A shows a possible pioneer stage, in conjunction with a small area of exploration. We see the addition of several larger Birch trees, with smaller shrubs, and newly established maple saplings interspersed. Areas near the boundary of exploration can leave an abrupt gap in the augmentations. In contrast, figure 5B shows the early stages of pioneer growth, with augmentations present for ~30 meters in advance of the user. Figure 5C shows the visual effect of walking through the dense shrubbery, including the level of detail available with close up inspection. Unfortunately, we found that the visual efficacy of the HoloLens is strongly affected by direct sunlight, as such these pictures were taken in the late afternoon.

To create visually appealing tree models, leaves are generally created with translucent materials, allowing the light behind to subtly influence the appearance of the leaves. While this produces excellent visualisations in general, when capturing the images from the HoloLens, this results in reduced visual definition. In contrast to this, Figure 5D shows a configuration using more rudimentary models of pine trees. In this case, the materials are solid and non-transparent, leading to a clearer image, but less realism. In all cases, due to the additive nature of the HoloLens, there will always be some degree of transparency, with 100% occlusion of the environment impossible.

4 Discussion

In this paper we aimed to explore the applicability of an untethered headset based Augmented Reality for displaying, exploring, and interacting with changes in the immediate environment, to address the drawback of single-use site-specific AR applications which are unsuited to larger project goals. We have proposed a new Adaptive Visualisation Workflow, which enables us to formulate the visualisation process in terms of the continuous interactions between the user and the environment using a procedural visualisation engine. This approach avoids many site-specific requirements, such as mapping and calibration in advance, while remaining generic enough configure the engine to produce a large range of desired scenarios.

The visualisation engine is model-independent, designed to spatially contextualise the predictions of theoretical models, real-world measurements, or tailored scenarios (KUULUVAI-

NEN 2016). This allows users to visually experience representations of various scenarios in-situ, a key benefit for communication of complex and widespread interventions (CEAUSU et al. 2019).

As the visualisation engine is constrained by the parameterization of the experience, the accuracy and rigour of the visualisations are largely dependent on the initial configuration. This allows for experiences which range from general-purpose scenarios designed to visually communicate the general principles and ideas of complex subjects, such as in our Rewilding use-case, to more rigorous site-specific visualisations which would require detailed knowledge about the ecosystem (soil, plants, animals, localization, climate, etc.), which would be encoded in the parameterisations of the stages, species, prevalence, density and progressions of the stages, a simple example of which is shown in figure 3.

In section 3, we demonstrate the capability of creating spatially widespread and complex visualisations which arise entirely in a closed loop of interactions between the participant, and the environment. In order to assess the applicability of the Adaptive approach to visualisation in communication exercises, we built a proof-of-concept application aimed at communicating the phenomenological process of natural species succession associated with the passive rewilding process, to illustrate the conceptual afforestation process of an urban green space using locally prevalent species. For this paper, we have presented results from an urban green space, however, this approach is equally applicable to larger open areas. We show that the dynamic spatial mapping can successfully augment an environment, without prior knowledge of site topography. This workflow could largely eliminate the barrier of dynamic occlusion found in other spatial communication tasks, such as small-scale flood visualisation, and support novel applications of in-situ visualisation. With the initial technological barriers of generic in-situ visualisations in place, further investigations will be continued to capture specific data-driven model predictions in a spatial visualisation.

We found that the HoloLens creates an effective medium for free exploration of augmented natural landscapes. However, in its current iteration, the hardware does present some significant limitations. Primarily, effective use of the hardware is hampered by bright sunny days, as the over-saturation of natural light limits the ability to see visualisations clearly. This is not an issue with hand-held AR devices, and as such an effective communication strategy may still require both hand-held and headset AR until the hardware improves.

5 Conclusion

Augmented reality has been used as a tool to enhance communication and education since its inception, focusing on handheld AR devices in recent years. However, in this instance, we demonstrated a headset-based experience that is both embedded in the natural world and, like rewilding, applicable to a large range of sites, from small urban green spaces, to open abandoned farmlands, without prior topographical knowledge.

We have proposed a new Adaptive Visualisation Workflow designed to support generalised AR applications, with the widespread applicability required for large, multi-site projects and educational applications. We find that while the HoloLens 2 hardware is extremely capable in terms of mapping environments in real-time, and has the necessary computing power to perform such experiments, the environmental requirements, such as low light levels pose the biggest issues in creating an effective and widely applicable experience in this current device.

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Assessing Visual Landscape Sensitivity towards Wind Turbines with a Distance Decay Effect: An Exploration of Different GIS Approaches

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Abstract: The German energy transition has come to a halt in terms of on-shore wind turbine deployment. This is to a large extent due to public opposition. Sensitive siting of wind farm locations in the landscape early in the planning process might help to overcome this problem. In our paper, we investigate different methods for visual landscape sensitivity analysis towards wind turbines that can be used as one input into spatial planning at the federal state or regional level, where strategic decisions for wind farm locations are mainly taken. Statistically comparing different methodological approaches, different distance decay effects with different distance weights and different GIS algorithms, we conclude that (a) large-area visual sensitivity analyses are possible, (b) the distance decay effect has a negligible influence on the spatial distribution of visual sensitivity and (c) that there are more methodological questions that should be empirically investigated in order to base strategic wind farm siting decisions on a valid information basis.

Keywords: Visual landscape sensitivity, wind turbines, assessment, GIS, distance decay effect

1 Introduction

An increasing share for renewable energy sources is not only a target of the European 2030 Climate and Energy Framework (EUROPEAN COMMISSION n.d.) but also of the German Climate Protection Program (BMU 2019). In order to realize the targets, existing potentials need to be utilized with solar and wind power being the most important ones in Germany (BFN 2019). Therefore, German spatial planning authorities have the legal task to designate areas for possible wind energy use in a substantial share of their administrative area (FA WIND 2016). After a continuously rising number of newly installed wind turbines since the early 2000s, wind power deployment came to a halt in Germany in 2017 (FA WIND 2020).

Despite the set political goals, selecting concrete sites for wind power development and ensuring public acceptance for these new landscape elements remains a major difficulty in spatial planning. Residents often perceive the process of change critically. Wind turbines in particular change the visual landscape by their sheer dominance. This happens due to their height (200 m and above), their technical design and the moving blades (BREUER 2001). LIMA et al. (2013) briefly summarize additional imposed impacts of wind turbines. The subsequent landscape transformation might even lead to a shift from a (more or less) traditional cultural landscape into an energy landscape. Consequently, wind turbines impair visual landscape functions like the scenic landscape quality or the recreation potential (NOHL 1993).

Yet, the impact on landscape aesthetics is not uniform. Perception varies depending on the landscape configuration and personal attitude (ZUBE et al. 1982, NOHL 2001). It is commonly accepted that the perceived visual impact caused by a wind turbine decreases with distance

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from the observer (e. g. BREUER 2001, BISHOP & MILLER 2007, DE VRIES et al. 2012, MOLNAROVA et al. 2012, BETAKOVA et al. 2015). This is called distance decay effect.

The visual impact is inter alia characterized by visual sensitivity (BACHFISCHER 1978). Visual sensitivity is less often investigated and has no universal definition. For example, STORE et al. (2015) took visibility, potential users and visual landscape quality into account. While GERHARDS (2003: 97) found landscape character to be important for visual sensitivity as well, he also pointed to visual vulnerability/visibility to be important especially for regional planning.

We understand visual landscape sensitivity as an indicator that describes the potentially impacted area if a project is realized at a certain location. This indicator is – at first – independent of specific locations of viewers, the landscape quality and character in the area and existing impacts from other structures. Nevertheless, in a complete visual impact assessment our sensitivity indicator can – and should be – combined with the three mentioned other aspects. We focused our study on visual sensitivity solely on visibility: Visual vulnerability can be analyzed using visibility analyses. We investigated five different approaches to calculate a visibility index as a proxy for visual landscape sensitivity. Low visual landscape sensitivity is the ability of a landscape to cloak negatively affecting objects (ROTH & BRUNS 2016: 52f.).

Of particular interest is how the distance decay effect affects visual landscape sensitivity. Distant wind turbines are perceived as less intrusive as close ones. However, little research has been done to assess how the generally accepted distance decay effect of visual impacts influences sensitivity results.

BRUGHMANS et al. (2018) and HILDEBRANDT (2015) differentiate three approaches to work with distance weights for the inclusion of the distance decay effect in sensitivity analyses:

- No distance weight (no distance decay effect)
- Stepwise discrete distance weights (zonal distance decay effect)
- Continuous distance weight (continuous distance decay effect)

Figure 1 visualizes the distance decay effect for these approaches. A uniform distance weight corresponds to no distance decay effect and no distance weights. A stepwise approach uses distance zones (bands) as visual impact thresholds with specific distance weights. Lastly, with a continuous distance decay effect the distance weight changes continuously.

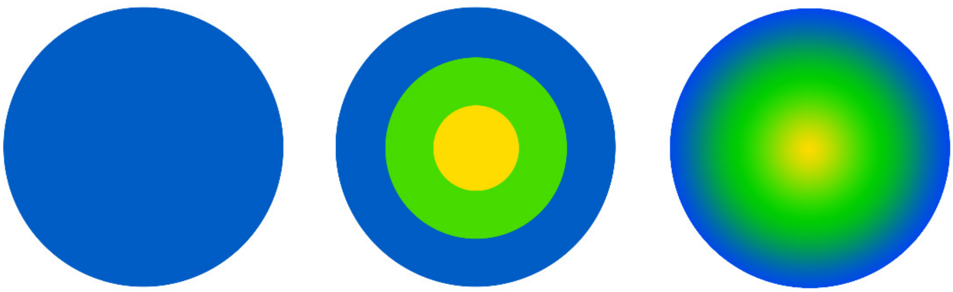

Fig. 1: Visual representation of approaches to model the distance decay effect; adapted from BRUGHMANS et al. (2018, 16)

Even though a theoretic basis exists, there is no large-scale application for visual landscape sensitivity assessments with a distance weight. Distance weights were only integrated into a few methods with purposes other than visual landscape sensitivity (e. g. WAGTENDONK & VERMAAT 2014, GIBBONS 2015, BRUGHMANS et al. 2018). Our aim is to close this gap by investigating the implementation of a distance weight into large-area sensitivity calculations for wind turbines. Specifically, our objectives are (a) to develop Geographic Information System (GIS) procedures to cover each of the three approaches of a distance decay effect, (b) to compare the resulting visual sensitivity and (c) to suggest the most efficient methodology based on performance. For the explorative study of visual landscape sensitivity with a distance weight, we used parts of the federal German state of Thuringia.

Knowledge of visual landscape sensitivity prior to specific wind energy projects is essential to inform spatial planning authorities. Consequently, different sites for wind power development are identifiable and comparable. This allows the inclusion of landscape aspects into earlier stages of planning, when specific locations for wind turbines are not yet determined. Well-founded, responsible siting decisions help to avoid or minimize negative visual impacts of wind turbines and to protect sensitive areas. This could also contribute to higher public acceptance of well-sited new energy infrastructure.

2 Methods

Our main research aim was to develop GIS procedures to include a distance weight into visual landscape sensitivity assessment for wind turbines. These should be applicable for large-area analyses. We also wanted to know, how visual landscape sensitivity differs between these approaches and the corresponding implications. We solely focused on visibility and therefore used different modifications of visibility analyses.

It is important to recognize the difference between visibility and viewshed analyses. Using a GIS for viewshed analyses is state of the art to quantify a project's visual impact (e. g. PAUL et al. 2004, MÖLLER 2006, WRÓŻYŃSKI et al. 2016). In this case, location and dimension of a turbine are known. The field of view is calculated from the turbine tip while a potential viewer is placed on each cell to quantify the impact. However, the deployment for visibility analyses to quantify visual sensitivity is also possible (e. g. FISCHER & ROTH 2020). Therefore, the setting of the viewshed analysis is inversed. We do not look from a wind turbine at viewers but from viewers to a wind turbine. The visibility analysis assesses the visual landscape sensitivity against potential wind turbines' impacts. Here the location of the wind turbine is not known. Hypothetical observer points (persons) are placed in a landscape. The visibility analysis places a potential turbine tip over each raster cell and calculates the number of observer points from which the tip is visible. Using this approach it is possible to compare the visual sensitivity of different areas to potential energy infrastructure development.

We hypothesized that using a uniform distance weight is the fastest and simplest approach. Furthermore, we believed that visual landscape sensitivity to wind turbines differs depending on applied coefficients and thresholds.

We used five GIS procedures to assess visual sensitivity to potential wind turbines with 200 m tip height. Table 1 summarizes the approaches. We gave meaningful names to all approaches to indicate the main concept of each method. They cover all distance decay approaches and calculate a visibility index.

We integrated understandings of NOHL (1993) and BREUER (2001) into the method by FISCHER & ROTH (2020). Both primarily focused on offering a method to calculate the necessary area of compensation measures for impacted landscape aesthetics. Even though NOHL's (1993) approach is almost 30 years old, the method itself or modifications are still part of German planning practice. Our integration of a continuous distance decay effect for visibility analyses is new in the field of landscape planning. All results were reclassified using seven levels of sensitivity and a quantile distribution. This simplifies spatial comparison.

Table 1: Methodologies to integrate a distance weight and GIS procedure

	Approach of distance weight integration		
	Uniform distance decay effect	**Stepwise distance decay effect**	**Continuous distance decay effect**
Underlying methodology	1. Uniform analysis (3 km) after BREUER (2001) 2. Uniform analysis (10 km) after FISCHER & ROTH (2020)	Stepwise analysis after NOHL (1993)	1. Observer viewshed 2. QGIS Interpolation
GIS procedure	1. Adapted from FISCHER & ROTH (2020) 2. Adopted from FISCHER & ROTH (2020)	Adapted from FISCHER & ROTH (2020)	1. Summarized viewshed based on hypothetical observers 2. Lines of sight and interpolation

We conducted the analyses for a 20 × 20 km tile of the German federal state of Thuringia (shown in Figure 2). The state is in the heart of Germany, which prevents boundary effects due to abrupt end of data. Furthermore, it contains diverse landscapes with gradients in relief, anthropogenic dominance and a varied land use. Additionally, FISCHER & ROTH (2020) developed their original method for this state and their results are available for comparisons.

We used ArcMap (Version 10.6.1) and its "Viewshed 1" to calculate the visibility indices for all selected methodologies except the QGIS interpolation. We deployed QGIS (Version 3.10.1) for the QGIS interpolation and R (R CORE TEAM 2020) for further statistical analyses. We calculated Pearson's correlation coefficients to compare the resulting visibility indices.

Fig. 2: Location of the investigation area within Germany.
The map shows the federal state of Thuringia (red contour; ATKIS, © GDI-Th, Date: 30.06.2020) and the 20 × 20 km tile of the investigation.

2.1 General Assumptions of Visibility Analyses

Visibility analyses calculate for each cell how many hypothetical observers (persons) within a fixed distance are able to see the tip of a potential wind turbine if the tip is located above the center of the raster cell. In our case, the obtained frequency quantifies the visibility of a 200 m high wind turbine when erected on a cell based on set observer points. This frequency value equals the visibility index and is our proxy for the visual landscape sensitivity. A higher value equals a higher sensitivity. Assigning a decreasing distance weight to each observer reflects the declining visual impact with distance.

Observer points, representing fictive persons with an average German eye height of 1.57 m (JÜRGENS 2004), are the basis for a visibility analysis. They are spread in a regular grid (500 × 500 m) throughout the study area. Points that are located within land use types with a vertical extent permanently higher than eye height (namely forest and settlement) are excluded from the visibility analyses, as their field of vision is restricted. Additionally earth curvature correction was always applied. A Digital Surface Model with a resolution of 10 m (based on DSM2 © GDI-Th: 2010-2013, adjusted by FISCHER & ROTH 2020) was the basis for all methods. It determined the resulting sensitivity resolution. We used the data in all methodologies. Figure 3 shows the topographic characteristics of the investigated area.

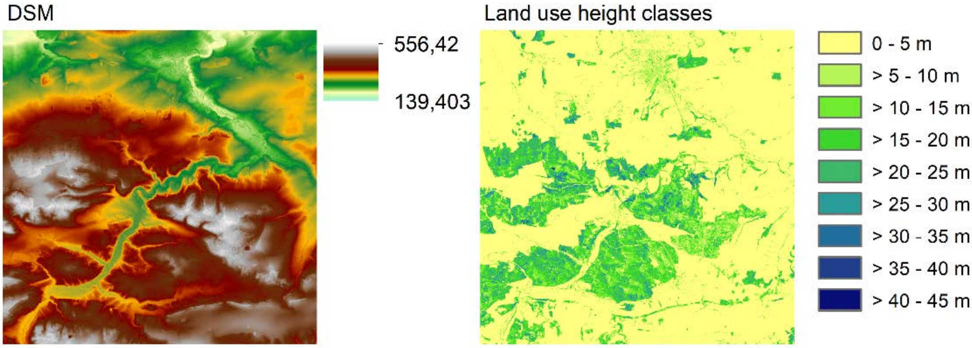

Fig. 3: Digital Surface Model and land use height classes of the investigated area

Another important parameter for visibility analyses is the maximum analysis distance. This corresponds to the maximum viewing distance. Visibility is examined only within this boundary. After this threshold, the assumption of a visual impact caused by a wind turbine is neglected. A visibility range of 10 km is typically applied in Germany (TÄUBER & ROTH 2011) and is used within all methodologies except in the uniform analysis (3 km). The maximum viewing distance also acts as a buffer enlarging the analyzed area to exclude boundary effects. Otherwise, visual sensitivity is underestimated closer to the border, as less observers exist. The area with results, the 20 × 20 km tile respectively, remains the same for all approaches.

Furthermore, the application of the distance decay effect needs to be set. The selected methodologies correspond to different distance decay effects and apply diverging distance weights as shown in Table 2 and Figure 4. The latter allows for a visual comparison of the applied distance weights for each distance from the turbine to the observer. The continuous distance decay effect is modelled with a linear decrease in distance weight from 1 (observer close to turbine) to 0 (observer at maximum viewing distance).

Table 2: Applied distance weights per visual zone

	Method	**Zone**	**Distance weight (coefficient)**
Uniform distance decay effect	Uniform analysis (3 km) after BREUER (2001)	0 – 3,000 m	1
	Uniform analysis (10 km) after FISCHER & ROTH (2020)	0 – 10,000 m	1
Stepwise distance decay effect	Stepwise analysis after NOHL (1993)	0 – 200 m	0.6
		200 – 1,500	0.3
		1,500 – 10,000 m	0.04
Continuous distance decay effect	Observer viewshed	0 – 10,000 m	Linear decrease from 1 to 0
	QGIS Interpolation	0 – 10,000 m	Linear decrease from 1 to 0

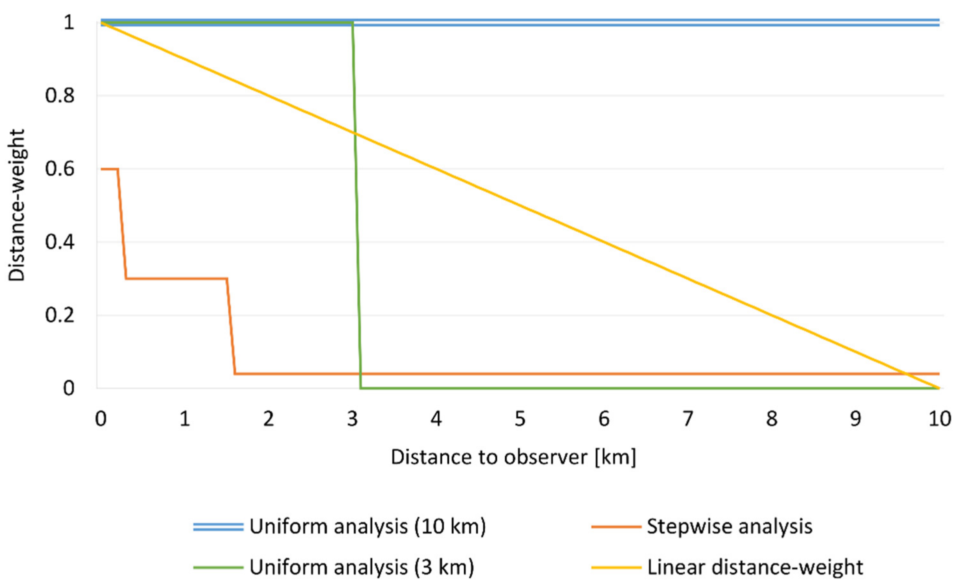

Fig. 4: Visualization of the applied distance weights; adapted from HILDEBRANDT (2015, 67), modified

The uniform analysis (3 km) as well as the uniform analysis (10 km) follow an all-or-nothing approach with no distance decay effect (uniform). Here every observer, who is able to see the turbine tip, is weighted equally. The stepwise analysis differentiates between three zones of distance between an observer and a turbine. For each zone, NOHL (1993) selected a distance weight to classify the strength of the visual impact as integrated in the stepwise analysis.

2.2 GIS Procedures in the Uniform Analysis (10 km) after FISCHER & ROTH (2020)

FISCHER & ROTH (2020) developed a workflow to assess visual landscape sensitivity for large areas using a visibility analysis. The methodology and the results are our baseline within the uniform analysis (10 km). We explain their GIS procedure below. The authors calculated a visibility index with high resolution. They developed the workflow around the ArcMap tool "viewshed 1" which allows several specifications as summarized in Table 3.

Table 3: Parameter settings used by FISCHER & ROTH (2020) and within the uniform analysis (10 km)

Parameter name	Representation of	Value [m]
OFFSETA	Hypothetical observer / person eye height	1.57
OFFSETB	Height of potential turbine	200
RADIUS2	Maximum viewing distance	10,000

The tool "Viewshed 1" adds the OFFSETB value to every cell of the DSM. This leads to errors if a cell has a permanent land use height (forest and settlement) as the sum implies higher turbines. To cope with this problem, FISCHER & ROTH (2020) classified land use height in classes with 5 m intervals (see Figure 3). The value of each land use height class is subtracted from the 200 m original turbine height. For each of the resulting heights (adjusted OFFSETB) visibility analyses covering the investigated area completely were conducted. The final visibility index is the combination of the interim-results, where the value corresponds to the land use height class of each cell.

2.3 Adaptations for the Uniform Analysis (3 km) after BREUER (2001)

To obtain visual landscape sensitivity for the constant effect within the uniform 3 km analysis, we adjusted the uniform analysis (10 km) to the understanding of the maximum viewing distance by BREUER (2001). He believes that a considerable visual impact only occurs within a radius 15-times the turbine height. The maximum viewing distance was thus reduced to 3,000 m. This value acted as the visual threshold for the visibility analysis. All other parameter settings match the ones of the uniform analysis (10 km) to calculate the visibility index.

2.4 Adaptations for the Stepwise Analysis after NOHL (1993)

For integrating the stepwise distance decay effect, we calculated the visibility index per distance zone. NOHL (1993) defined the thresholds. We selected the zones by using a minimum (RADIUS1) and a maximum distance (RADIUS2) as corresponding thresholds. As a result, the frequency of observers within the specific zones who are able to see the potential wind turbine was calculated. We integrated the distance weights by NOHL (1993) by multiplying the frequency per zone with the corresponding distance weight coefficient. Then, all results were summed up.

Since the first zone ends at 200 m distance from the observer but observers are arranged with 500 m between them, no values were calculated for some cells. However, tests showed that observers are able to see a wind turbine within a 200 m radius with almost no exception. We consequently assumed that an observer in this zone would always see a wind turbine and consequently set the interim-result to one. With this setting, we were able to work with area-wide values. In areas with a land use height, visibility was assumed to be nil.

2.5 GIS Procedures Based on Methodology Observer Viewshed

For the representation of a continuous distance decay effect, we developed a new workflow using the ArcMap ModelBuilder. It is a summarized viewshed analysis of all primarily selected observer points (see Section 2.1). Within the model, each observer is selected separately. Then a viewshed analysis (tool "Viewshed 1") integrating the DSM starts. The settings match the ones made in the uniform analysis (10 km) in Table 3. The results show all cells where a potentially installed turbine tip is visible for this one observer. Additionally, the Euclidean distance is calculated with a radius of 10,000 m (matching maximum viewing distance) starting from the selected observer (hypothetical person) and a resolution of 10 m (matching DSM resolution). These values are inversed and normalized to values from zero (far from the observer) to one (close to the observer) to represent distance weights with a continuous distance decay effect. Next, we intersected the area of visibility and the inversed Euclidean distance. Only areas, which are visible from the observer, maintain their weight value. All other cells are set to zero. Subsequently, all distance weighted raster datasets are summed up to create the visibility index for one fixed height.

As the same parameters as used in the uniform analysis (10 km) are applied, errors as described in Section 2.2 occur likewise from only using one fixed height as OFFSETB. Consequently, the previously described procedure was repeated for all adjusted heights (OFFSETB) used in the uniform analysis (10 km). Finally, the visibility index of each cell is selected by taking the calculated value following the land use height class of the cell.

2.6 GIS Procedures Based on Methodology QGIS Interpolation

We developed an additional GIS approach independent of ArcGIS and a viewshed tool. Instead, we used the tool "Intervisibility network" by CUCKOVIC (2016) in QGIS. The tool creates lines of sight between two sets of points. One set acts as the observers and one as the targets. This calculation is based on the DSM.

The previously described methods calculate the visual landscape sensitivity for each cell of the DSM. This is not possible using the tool "Intervisibility network". Instead, we created a point-feature class arranged uniformly in a grid with 100 m distance between points. These points represent the wind turbines that are potentially placed on the cells. As their height value is also added to the land use height, we subtracted the land use height class from the 200 m object height to receive the right height. This dataset worked as source dataset in the tool. The tool draws lines of sight to each point of our observer dataset that lies within maximum viewing distance of 10,000 m and is visible.

Each resulting line characterizes a visual relation between a potential turbine and an observer. We calculated the length of the line. After inversing and normalizing, a distance weight was obtained. Next, we summed up all distance weights (originating from lines) per source point (representing a turbine). Thereby, the distance weighted frequency of observers who were able to see the tip of the potential wind turbine (visibility index) resulted. These values were interpolated (Natural Neighbor) to create an area-wide grid with 10 m resolution.

3 Results

Table 4 summarizes the needed computing time to calculate the visibility index in the investigated area for each selected methodology using one workstation. Time needed to prepare the relevant datasets, as well as additional steps like the conversion into a sensitivity assessment are not included.

Table 4: Time for calculation of visibility frequency in the investigated area using one workstation

Method	Time (hh:mm:ss)
Stepwise analysis	Ca. 40:00:00
Uniform analysis (3 km)	Ca. 12:00:00
Uniform analysis (10 km)	Ca. 28:00:00
Observer viewshed	Ca. 177:00:00 (> 7 days)
QGIS Interpolation	Ca. 13:00:00

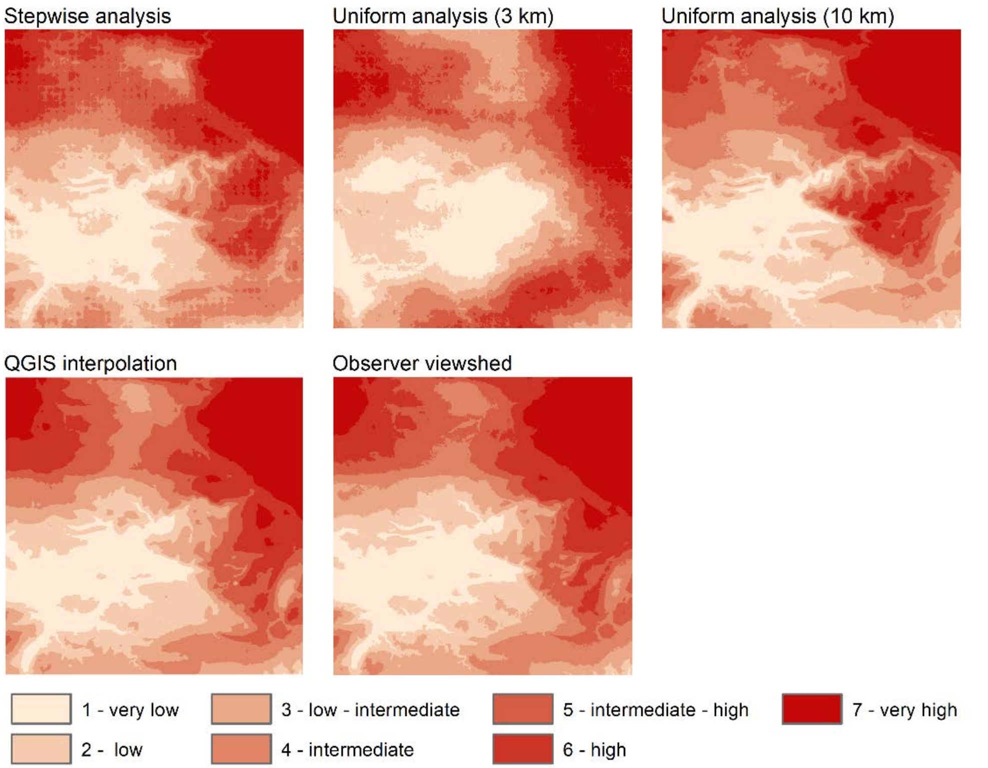

Fig. 5: Spatial comparison of the visual sensitivity as predicted by all approaches using a quantile distribution

Absolute values of the visibility indices differ substantially. However, values based on the observer viewshed and the QGIS interpolation are very similar. The visual sensitivity is comparable using classes based on a quantile distribution as illustrated in Figure 5.

The results based on the stepwise and uniform analyses 10 km, as well as the ones based on the QGIS interpolation and the observer viewshed, are particularly similar and spatially comparable with slight deviations. These four partly resemble the topography. Open areas with less undulating terrain tend to higher sensitivity. Meanwhile valleys and mountainous regions possess a lower visual sensitivity.

Results based on the stepwise analysis are coarser. Sensitivity, after the uniform analysis (3 km), differs from all others with contrasting sensitivity especially in the east and southeast. This result also seems to be stronger influenced by land use height classes with larger areas of the lowest height class having high sensitivity.

Table 5 summarizes the calculated correlation coefficients for all pairwise comparisons. All pairs correlated positively and statistically highly significant. The visibility index based on the uniform analysis (10 km) correlated strongly with all other values except the one based on the uniform analysis (3 km). Here correlation was moderate. All other pairs show strong correlations. The results by the observer viewshed and the QGIS interpolation correlated almost perfectly.

Table 5: Pearson's correlation coefficients of the visibility indices

	Stepwise analysis	**Uniform analysis (3 km)**	**QGIS interpolation**	**Observer viewshed**
Uniform analysis (10 km)	$r = 0.97$ $p \leq 0.001$	$r = 0.67$ $p \leq 0.001$	$r = 0.94$ $p \leq 0.001$	$r = 0.95$ $p \leq 0.001$
Stepwise analysis		$r = 0.80$ $p \leq 0.001$	$r = 0.97$ $p \leq 0.001$	$r = 0.97$ $p \leq 0.001$
Uniform analysis (3 km)			$r = 0.84$ $p \leq 0.001$	$r = 0.84$ $p \leq 0.001$
QGIS interpolation				$r = 0.99$ $p \leq 0.001$

4 Discussion

This study investigated different approaches to integrate the distance decay effect into visual sensitivity assessment towards wind turbines. Therefore, we conducted a variety of visibility analyses with distance weights. The innovative part was the development of new GIS-based models to assess the continuous distance decay effect. We expected to find diverse results.

We showed that it is possible to model a stepwise and a continuous distance decay effect into visual landscape sensitivity assessments for wind turbines: A uniform distance decay effect as well as stepwise one can be calculated by adopting the methodology by FISCHER & ROTH (2020). Both of our new GIS approaches are suitable to model a continuous distance decay effect.

The absolute values of the visibility indices are a direct consequence of hypothetical observer density and the applied maximum viewing distance. The latter determines the number of hypothetical observers included in the analysis. Consequently, the mere visibility index has little meaning. The main aim of a visual sensitivity analysis is to identify areas that are not as sensitive towards wind turbines compared to others. This is true for mountainous regions. For once observer density is lower as the land use type often is forest. Moreover, while far views are possible from the edge of mountainous regions, the relief restricts the view within. Often one can see only to the next mountain. This is amplified in valleys. Consequently, visual landscape sensitivity is low there.

We found that the visual sensitivity results differ stronger between varying maximum viewing distances than between different distance decay effects. Spatial areas of different visual landscape sensitivity (classified by a quantile distribution) match mostly between methods as long as the maximum viewing distance is the same. Changes in the applied maximum viewing distance lead to broader deviations in sensitivity assessment. This is due to the very different number of included observers. The reasoning, that maximum viewing distance is more influential than the distance decay effect is also supported by the very strong correlation between all approaches with 10,000 m maximum viewing distance.

Our results suggest that the distance decay effect has a negligible influence on the spatial distribution of visual sensitivity. Hence, applying a uniform distance decay effect while setting the maximum viewing distance to 10,000 m (uniform analysis (10 km)) is adequate to assess visual landscape sensitivity to wind turbines. This is the simplest approach with a moderate calculation time and a simultaneously high accuracy. The even faster QGIS interpolation does not assess every cell uniquely but interpolates values. This saves time but is not as accurate. The observer viewshed took a vast amount of time as viewshed analyses were conducted for each observer point. This procedure is repeated nine times with nine adjusted height values. Nevertheless, as correlation values of the stepwise analysis are high in comparison to the approaches for the uniform and the continuous distance decay effect alike, an analysis with distance zones may contribute to results that match the real perception even more. We conclude that the uniform analysis (10 km) is the most efficient methodology to assess visual sensitivity.

Our explorative approach focused on an investigation area measuring 20 × 20 km. Nevertheless, all investigated GIS approaches are transferrable to large areas by deploying a parallel calculating computer network. FISCHER & ROTH (2020) already demonstrated that for the whole federal state of Thuringia.

Visibility analyses offer a valid quantitative approach to assess visual landscape sensitivity towards wind turbines or other structures. Our results contribute to the prevention of extensive visual impacts, as different sites for wind power development and their sensitivity are comparable. This supports siting decisions concerning wind turbines, as aesthetic impacts are included into the decision-making, which in turn might increase public acceptance. Still additional aspects like political interest, other environmental impacts for example on species and economic feasibility need to be included as well.

However, sensitivity of the landscape as predicted by visibility analyses can only be approximated. Still, maximum viewing distance and the distance weights influence the results strongly. Which of the five investigated understandings of the distance decay effect and the predicted visual impact is the most fitting one in reality is not part of this study and needs investigation by a ground-truthing approach. An online survey based on photographs of existing wind parks would be meaningful to obtain empirical results. Knowledge on the realistic perception of visual landscape sensitivity could found a generally accepted method.

Even though the usually applied maximum viewing distance for viewshed analyses is set at 10 km in Germany (TÄUBER & ROTH 2011), ROTH & GRUEHN (2014) believe that 10 km is a minimum threshold. The 10 km value was chosen for turbines with a maximum height of 100 m in the 1990s and early 2000s (e. g. NOHL 1993, BISHOP 2002 as cited in BETAKOVA et al. 2015). This threshold still has not been changed with current turbine heights of 200 m and above. It also varies depending on the method (brief overview given by IOANNIDIS & KOUTSOYIANNIS 2020). So far, no scientifically proven visual threshold for wind turbines exists (BETAKOVA et al. 2015). At the same time, the SCOTTISH NATURAL HERITAGE (2017) stated in its guidance document for the siting of wind farms that generic distances are no longer suitable. This is justified by varying viewing distances due to turbine design, site aspects and weather conditions. Still, one threshold, which is valid for the German landscape configuration and atmospheric composition, would be desirable. Reinvestigation into this topic is overdue. HILDEBRANDT (2015) suggests a range of 15-16 km with significant visual impacts, based on studies from other countries (e. g. SULLIVAN et al. 2012). Whether the situations of these studies are comparable to German landscapes has to be further examined.

Another topic that needs to be challenged is the zoning of visual thresholds to model a step-wise distance decay effect. BETAKOVA et al. (2015) found thresholds at comparable distances as NOHL (1993). A perceived impact reduction occurred at thresholds of 1,500 m, 7,500 m and 10,000 m distance from the observer (150 m wind turbine height). However, several thresholds were preliminary fixed in their study. It is furthermore unclear, how NOHL (1993) drew the distance weights. Their validity is thus questionable. If there are thresholds with differing visual sensitivity and which values are appropriate in reality is uncertain and a task for future research.

Additionally, landscape aesthetic quality influences landscape sensitivity (GERHARDS 2003: 97, BETAKOVA et al. 2015, STORE et al. 2015). As the visual impact is stronger in highly aesthetic landscapes so is the perception of the decreasing impact with distance. Simultaneously, the distance decay effect is not as pronounced in landscapes with a lower aesthetic quality (BETAKOVA et al. 2015). How this is applicable in practice needs investigation.

We modelled the continuous distance decay effect as a linear function. However, other types of mathematical functions may be useful. Alternatives include a fraction (WAGTENDONK & VERMAAT 2014), the logarithmic function or the exponential function (e. g. SHANG & BISHOP 2000). As long as no empirical study enables a deeper understanding of the distance decay effect for 200 m and above turbines, all functions are equally suitable.

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Using Tree Modeling Applications and Game Design Software to Simulate Tree Growth, Mortality, and Community Interaction

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Abstract: This research involves the use of tree growth software and landscape visualization tools to explore future landscape management possibilities at the Flight 93 National Memorial tree grove in Stoystown, PA. The site's trees have experienced significant problems over the 10-year existence due to compacted and degraded soils, leading to stunted tree growth and in many cases high rates of tree mortality. Using a combination of a tree growth 3D modeling plugin and computer game development software, we visualized several tree mortality scenarios which were used to inform landscape grove management over the course of a 25-year maintenance plan. A pilot grove of 40 trees was selected for initial growth simulation, with each tree modeled individually to represent species and documented health characteristics. Real-time rendering game design software was used to develop photorealistic renderings in order to visualize the changes in character that occurred as a result of various growth and mortality scenarios.

Keywords: Growth, simulation, canopy, mortality, interaction

1 Introduction

The creation of three-dimensional landscape rendering typically relies on prefabricated tree models to visualize trees in the landscape. These models sufficiently communicate the general character of the tree, even incorporating differently-modeled instances of the same species to give the appearance of natural variation. However, these tree models should not be confused with simulations, those which integrate architectural and self-organizing components of tree growth to create scientifically-informed tree models (PALUBICKI et al. 2009). When attempting to manage a landscape to achieve an intended design character, and especially when a site-specific management strategy needs to be developed in response to site conditions, a data-informed method to create vegetation that is faithful to botanical structure and development is critical (DE REFFYE et al. 1988).

This research involves the use of tree growth software and landscape visualization tools to explore future landscape management possibilities at the Flight 93 National Memorial in Stoystown, PA. The memorial is located at the site of the crash of United Airlines Flight 93, one of the hijacked flights in the September 11, 2001 attacks. The memorial was made to honor the passengers and crew of Flight 93, who prevented the plane from reaching its intended target by overtaking the hijackers. The memorial consists of a visitors center, Wall of Names, Tower of Voices, and a memorial grove consisting of 40 individual groves which contain 40 trees each, one tree for every victim of the plane crash (THOMPSON 2017). The groves have experienced significant problems over the 10-year existence due to compacted

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and degraded soils, leading to stunted tree growth and in many cases high rates of tree mortality. This grove restoration and visualization project is interdisciplinary and collaborative, with partnership between the National Parks Service Olmsted Center for Landscape Preservation and the Center for Cultural Landscape Preservation at SUNY College of Environmental Science and Forestry. This research aims to visualize the visual impacts of tree mortality, tree replacement, and ongoing maintenance on the intended design character of the memorial groves in order to develop a tree management plan for the site.

2 Methods

Using a combination of a tree growth 3D modeling plugin and computer game development software, we visualized several tree mortality scenarios which were used to inform landscape grove management over the course of a 25-year maintenance plan. Many of the trees on the site were dead or in extremely poor health due to poor soil and drainage on the site, which was previously an active mine (EMILI et al. 2016). The severity of the tree health issues throughout the site prohibit the use of standard tree 3D models to explore the stunted or missing trees' impact on the landscape character. In order to simulate interaction and competition between trees, we needed to be able to grow 3D trees whose growth would respond to sun and shade, compete for light with their neighbors, lose branches over time, and simulate a range of other tree growth factors (BELLA 1971). To accomplish this we used The Grove, a Blender tree growing add-on, to simulate the growth behavior of each memorial grove of 40 trees upon a base terrain developed using contours in AutoCAD and Rhino (Fig. 1). The initial use of the model heavily focused on the location and orientation of the 40 groves and the 40 individual trees within each grove. Each grove of 40 trees followed a triangular planting pattern consisting of 5 columns of 8 trees. Trees were spaced 30' apart in each column, and 23' apart diagonally between rows. The circular orientation of the 40 groves allows for a 32' interior spacing along the inner pedestrian edge and 37' spacing along the vehicular approach road.

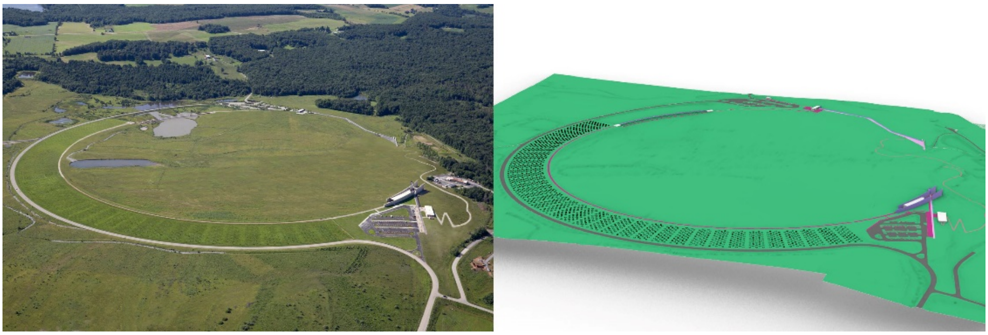

Fig. 1: Flight 93 National Memorial Aerial Photo (left) and 3D Model (right)

A test grove of 40 trees was developed for the pilot study. The goal for this test was to determine the methods for affecting tree growth on a per-species level based on the existing health of each individual tree in a species group. There were 7 total species planted throughout the 40 groves. Four distinct health conditions were identified in research for this project, which was conducted by Cornell (BASSUK et al. 2020). While the criteria used to identify the four health conditions were not outlined in the provided document, representative images of the baseline conditions were present and used as a comparison. Currently, The Grove is unable to translate traditional field measurements such as diameter at breast height (DBH) and growth rate to the digital visualization of the tree. Therefore, the images provided in the Cornell research were sufficient to begin this test. To achieve the most accurate visual appearance of each health condition, manual adjustments were made to The Grove growth characteristics. It is important to note that we did not find any information about whether the methods used in the Cornell report are characteristic of a typical forest assessment.

To begin the growing process, the tree is selected from the pre-set list of available species in The Grove. Each tree contains unique growth characteristics to best match the species selected. These growth characteristics are present under 14 different categories that range in the trees ability to add or drop branches to manipulating branch flexibility and leaf shading area. A trial and error process was used to determine which of the 14 factors best reflected the desired visual qualities.

Each growth characteristic is dependent on its own relative scale. A growth template was developed to demonstrate the effects of the single growth characteristic at a time. For this test, each individual tree was grown to the same age, and all other pre-set conditions remained, except for the variable growth condition being tested. For each variable, 6 trees were individually grown to test the minimum and maximum value, as well as 4 evenly spaced values in between. This process was started for the five categories which we believed could reach the desired effect based on the description text available through the program. These included Canopy Density, Favor Bright, Favor Rising, Age Limit and Favor End.

Once the visual qualities were understood through this process, only three of the five previously selected characteristics were needed to reach the desired effect. These software controls modified for this test were:

- Canopy Density: Determined the addition or subtraction of side twigs to all branches that were grown. A higher number in this category results in increased density tree foliage.
- Favor Bright: Only maintained leaves that received the most direct sunlight. A higher number in this category results in an exaggerated death of shaded leaves and exaggerated growth of leaves in direct sun.
- Favor Rising: Created a dense upright canopy that limited any outward spreading of branches. A higher number in this category results in no horizontal competition for growing branches resulting in increasingly perpendicular growth.

The final combined values for these three characteristics were determined through a secondary trial and error process. Each iteration of the modified tree growth test was compared to site photos and the sample images provided through the Cornell assessment until the combination of values matched the site conditions.

Initial experimentation was conducted to understand the impact of each of these conditions on the resulting tree model, resulting in a baseline set of values that effectively generate the 4 distinct health conditions outlined by Cornell. This process was then used to generate a model of a single grove, with each of the 40 trees modeled individually to represent each species and documented health (Fig. 2).

Fig. 2: Software settings for each individual tree within one modelled memorial grove

Each modification was recorded so that all instances of the same species-health interaction in all groves could be replicated with the same configuration. The single grove modeling was completed with all tree species represented at their current health, allowing us to determine the abilities of the software to visually capture healthy as well as unhealthy trees across several species (Fig. 3).

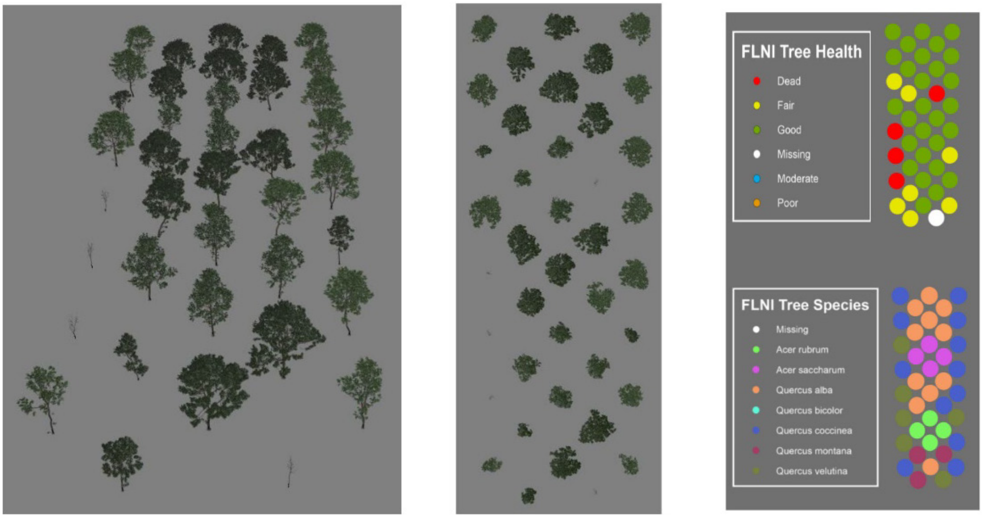

Fig. 3: Completed model of existing grove conditions, perspective view (left), top view (mid) and documented tree health and species from field study (right)

The next step was to develop a mortality threshold study. The mortality threshold study was necessary in order to determine the extent to which tree mortality would negatively impact the character and identity of each of the 40 groves. Although the loss of a single tree in a grove of 40 trees would be unlikely to cause visual fragmentation, our team theorized that the loss of several trees could potentially disturb the visual cohesiveness of the grove. To create the mortality study, 4 groves were selected. The timescales to be visualized were 10, 20, and 30 years, with the goal being to represent various moments during and slightly beyond a 25-year management plan. Using a randomized mortality pattern, five scenarios were developed per grove; 0, 3, 6, 9, and 12 tree deaths. These represent a maximum of 30% tree mortality per grove, a high mortality rate for a healthy tree community (HILBERT et al. 2019, MORIN et al. 2015, NOWAK et al. 2004). Each grove was divided into three sections, with each section receiving a varied proportion of tree mortality. The sections included: Viewshed Edge, containing trees that interact with adjacent groves; Movement Edge, trees that face the vehicular approach road or the inner pedestrian path; and Interior, all remaining trees with no edge condition. Each mortality scenario was randomized per grove, per mortality scenario and diagrammed in 2D in order to evaluate the study design (Fig. 4).

The Grove currently does not allow for the growth of different species within a single run sequence. Each species much be grown independently of the other resulting in no generated interaction between sets of grown trees. This was not particularly important for the health study, as the goal was to demonstrate the varied health conditions on trees that are already stunted and not physically interacting with the surrounding tree canopies. However, in visualizing future growth conditions for the mortality study, in this case up to 30-year growths, alterations were made to the growing process to allow The Grove to respond to interacting tree canopies.

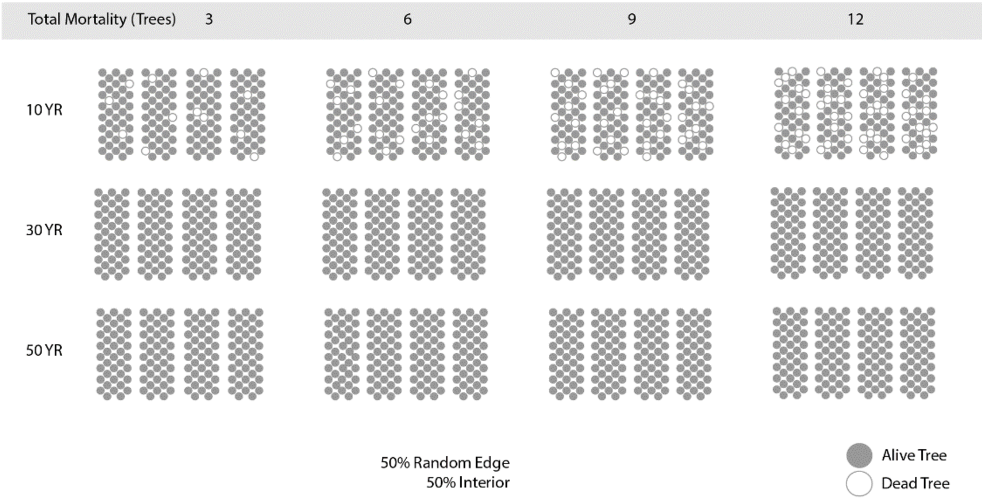

Fig. 4: Mortality study scenarios showing numbers of dead trees and percentage of dead trees on edges + interior

For each mortality scenario, a single tree species was selected to represent the quantity of trees needed for each mortality study. All pre-set growth characteristics were maintained to best represent an ideal growth condition. The entire grove, up to 40 trees, were then grown as a single sequence to the desired timescale. This process was repeated for each of the groves independently as the individual groves did not yet interact with the adjacent grove.

After completing the mortality studies, we used photorealistic real-time rendering to visualize the changes in character that occurred within each. Immersive realism was critical to the project's success, as it provided the highest level of precision (KULLMAN 2014). The ability to differentiate both large and small-scale vegetation elements was essential to providing the level of realism necessary to understand the visual impact of any changes to these elements (KINGERY-PAGE & HAHN 2012). This level of realism would allow us to visually communicate subtle changes in detail within the tree canopy in order to note the changes in landscape character that occurred in each study. Although Blender and the Grove offered significant computational power in simulating tree growth models, they lacked suitable environmental rendering characteristics such as particle-driven atmospherics and real-time vegetation rendering. Just as importantly, they lacked the ability to handle thousands of polygons necessary to create a large-scale realistic site model. We exported each Blender model as an FBX file and imported them into Unity as scene assets.

A primary visualization goal of ours was to achieve fast real-time rendering with a high degree of realism, a challenging task given the large site dimensions and number of trees to be modeled (BAO et al. 2011, COLDITZ et al. 2005). In order to accomplish this goal, we elected to use Unity 3D, a game design and virtual reality platform. Unity's ability to continually adjust each scene object's Level of Detail (LOD) proximal to the viewpoint allowed us to develop the site's meadow condition along with enabling us to quickly place each Blender tree model and quickly apply bark and leaf materials specific to each species. The completed grove models were then exported as still image renders (Fig. 5). Unity's ability to create standalone scene packages also allowed us to create walkthrough models that could be controlled by the user, allowing project partners to self-navigate through the groves and explore changes to the canopy. This was a critical factor in making decisions about tree canopy threshold, as we could understand the impact of missing trees from both a fixed and moving point of view.

Fig. 5: Still image render of Grove mortality study in Unity 3D

3 Discussion and Conclusion

The ability of Blender and the Grove to simulate tree growth characteristics and environmental interaction provided a valuable tool for confidently attempting to visualize a future condition. The ability of Unity3D to create fast, highly realistic real-time renderings and WALK-THROUGH STUDIES OF TREE MORTALITY ENABLED US TO IMMERSIVELY STUDY AND EVALUATE THE IMpacts of tree mortality rates on the character of the groves as a whole. It is crucial to acknowledge that these tools do not provide us with absolute certainty about future tree growth and loss. Rather, they provide a method of testing a range of possibilities with the understanding that the outcome is likely to exist somewhere within that range. Acknowledging this fundamental truth will enable us to use these tools to communicate potential landscape futures, with visualizations which provide data-informed input for management and design decision making.

Within the geodesign framework established by CARL STEINITZ (2012), this represents a way of working that has the potential for vast growth. Algorithmic approaches to geodesign have the potential to analyze the complexity of ecological relationships within the landscape (ROLF & PETERS 2020). As adaptive, performance-driven ecological landscape approaches become increasingly complex, this ability to computationally play out future vegetation growth scenarios can offer new forms of visual feedback and design iteration.

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Hanging Gardens: A City Crown for Halle by Walter Gropius in Virtual Reality

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Abstract: As part of the project "Hanging Gardens – A City Crown for Halle by Walter Gropius in Virtual Reality", a central building project of Classical Modernism can be experienced and walked through for the first time, which – had it actually been built – would have made the city of Halle known worldwide as a centre of Bauhaus architecture. The article provides insights into the development, design and implementation of the interactive VR installations. The basis is formed by 15 preserved original drawings and years of research work. Over several steps, the topography of the area was built up, the 92-year-old drawings interpreted and digitally recreated, and 3D models developed and visualised.

Keywords: Virtual and Augmented Reality, simulation, georeferencing

1 Introduction

The impressive architectural design by Walter Gropius for the city of Halle (Saale) was made tangible for the first time in the interactive exhibition project "Hanging Gardens – A City Crown for Halle", shown from 15 September 2019 to 19 January 2020. The exhibition takes the form of a walk-in VR-installation. After years of research and an elaborate digital reconstruction, visitors could experience the spectacular, although never carried out, architectural design on the Lehmannsfelsen in Halle. The interdisciplinary research and exhibition project thus makes the design virtually visible 92 years after its becoming, and not far from the originally intended location.

The exhibition gives an insight into how the Hanging Gardens would have looked. Architect and founder of the Bauhaus Walter Gropius (1883-1969) submitted this design to a competition for a so-called city crown for Halle with a city hall, a museum and a sports forum in 1927 (FUHRMANN 2019). With a graphic 3D-interface, the visitors could view the complete area in miniature; they could teleport from one position to another or move freely within the digital model via controllers. Multiple VR-stations and a large-screen projection offered insights. The exhibition "Hanging Gardens – a City Crown for Halle" offers the three-dimensional and impressive virtual experience of the design. Special attention was given to the room concept of the concert hall.

The base for the realization of the project were 15 original drawings as well as long-lasting research. The topography of the location was constructed in several steps, then interpreted in 2D-models, and finally digitalized and transferred into 3D-models. The positioning and dimensions of the design were made fathomable during site visits with augmented-reality applications and 360-degree-videos. There are images and 360-degrees panoramas for particularly compelling locations. An extensive accompanying program with guided tours, lectures and workshops deepened and expanded the topics of the presentation. The results from the discussion forums and workshops became part of the exhibition and constantly changed its content and form.

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Fig. 1: Exhibition project "Hanging Gardens – A City Crown for Halle from Walter Gropius in virtual reality"

2 New Design and Content Accents in Landscape Architecture

It's obvious: The open space design that Gropius designed for the contribution Hanging Gardens lies outside the classical appearance of 1920s landscape architecture. With this design, he sets new accents in open space planning in terms of content[1] and design.

For Gropius, the Hanging Gardens above the river Saale represent a new landmark for the city of Halle (GROPIUS 1928). The competition area was already connected to a grown urban quarter and thus close to the city center. And yet the still undeveloped Lehmannsfelsen is in the midst of nature. Gropius places an urban master plan in this idyll, which at first glance embodies above all the ideas of architecture and technology discussed at the Bauhaus in Dessau.

The plan graphics don't show the great natural scenery above the Saale floodplains. Instead, Gropius develops the concept out of the traffic plan, describes access and exit routes for cars, puts bus traffic on the promenade on the banks of the Saale and creates one hundred parking spaces. Gropius deliberately refrains from drawing gardens and landscapes in order not to "interfere with the clear assessment of architectural bodies" (GROPIUS 1928). Only rows of trees, not shown in green but in blue, serve as local boundaries for the entire ensemble or form the transition from architecture to landscape. The design is characterized by different levels of open space design, described by Gropius himself in 1930: "the use of accessible roof gardens with plants is an effective means of incorporating nature into the stony deserts of large cities. The cities of the future with their gardens on terraces and roofs – seen from the air – will give the impression of a large garden" (GROPIUS 1974).

Among the contribution submitted for the competition, Walter Gropius' large-format design drawings entitled "Hanging Gardens" stand out both conceptually and in their radical formal language. The partially colored blueprints submitted in Halle are now kept in the estate of Walter Gropius at the Busch-Reisinger Museum in Cambridge, USA. They were given a logo in the upper left corner consisting of three circles in the Bauhaus colors yellow, red and blue

[1] The competition and Walter Gropius' contribution were extensively studied and analysed for the first time as part of a research project by the author. Cf. Christine Fuhrmann: Eine Stadtkrone für Halle a. d. Saale by Walter Gropius, (Dissertationsschrift) Bauhaus-Universitätsverlag Weimar 2019.

and the motto Hanging Gardens. The original drawings were severely damaged when they returned to the Bauhaus Archive Berlin after the death of Walter Gropius. Here they were rediscovered, documented and scientifically interpreted as part of the research work in 2007.

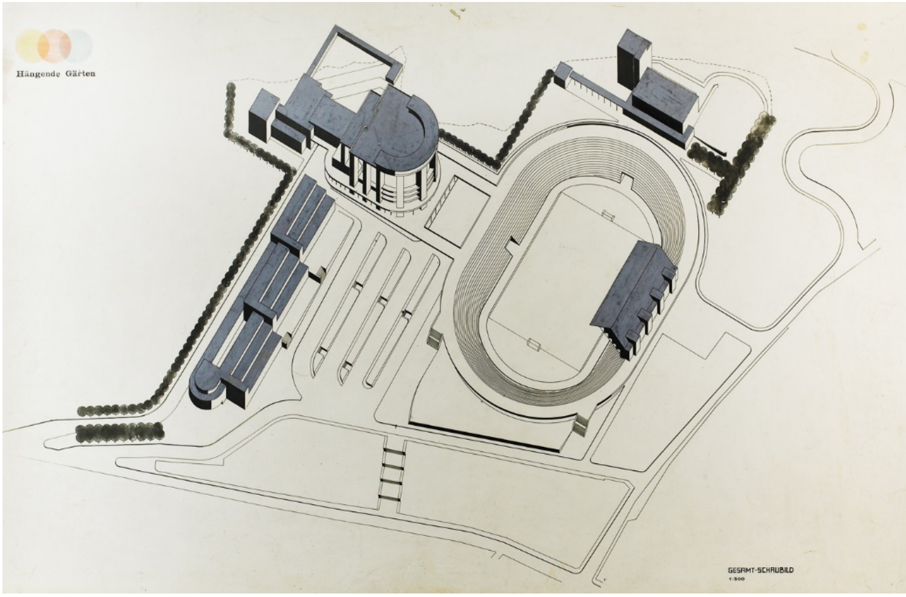

Fig. 2: Walter Gropius: A citycrown for Halle 1927/28, isometry, 1:500, blueprint, ink, washed, gouache (Harvard Art Museums/Busch-Reisinger Museum) © VG Bild+Kunst Bonn 20203 (From drawing to digital model)

2.1 2D Vector Graphics

The site plan and the floor plans, views and sections of the buildings were first converted into 2D vector graphics. On this basis, the first rough 3D data of the outer cubature of the buildings were created. At the same time, the Lehmannsfelsen area was verified based on georeferenced 2D data provided by the city of Halle. The contour line information was transformed into a dense three-dimensional polygon mesh and the adjoining buildings, streets and paths as well as the banks of the Saale were transferred to it and the first 3D model of the existing topography was modelled.

The next step was to merge the information contained in the original drawings on the elevation profile, the building cubatures and the road and path routing from the traffic plan into a coherent open space model and to compare it with the topography model. This confirmed that the special features of the rocky area had already been taken into account in the design.

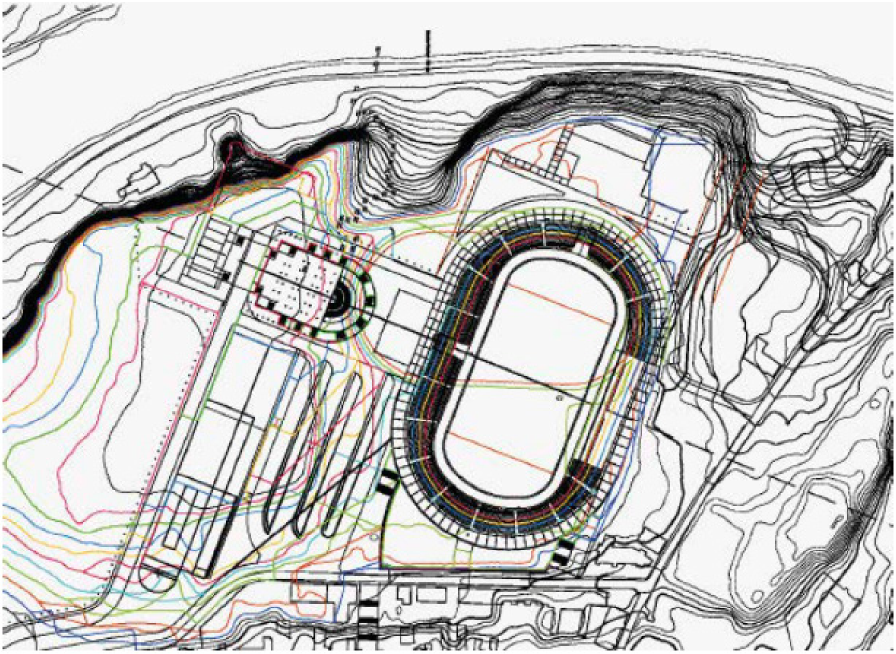

Fig. 3: The Site plan according to original drawing with elevation map, 2008

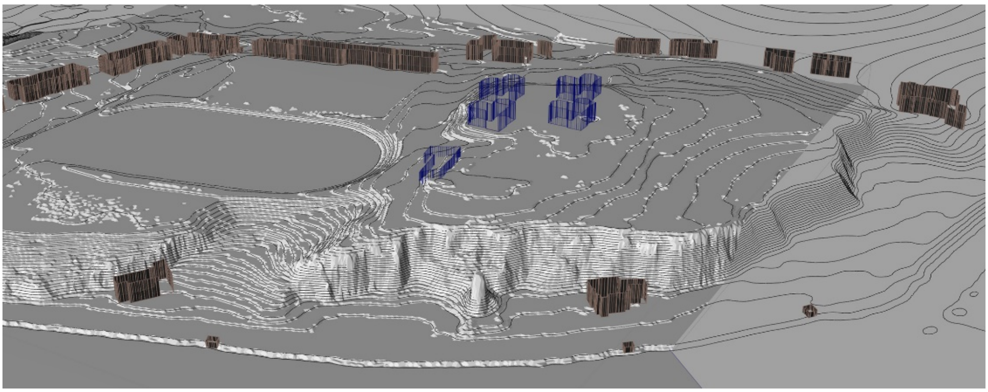

Fig. 4: First 3D model of the existing topography, 2008

The still sketch-like digital model structure was subsequently concretized over several steps to a model character, in which the degree of detail, the color scheme and the materiality are based on scale models. For public presentations, a guided camera flight was created based on the 3D visualization. Starting with the isometric overall view, the guided camera flight shows the overall ensemble and the exterior views of the buildings. This video was shown as part of the exhibition “Eine Stadtkrone für Halle. Walter Gropius in Competition” 2011/12 at the Kunstmuseum Moritzburg Halle and at the Bauhaus Archive in Berlin.

3 Processing of geoscientific data of the Lehmannsfelsen in Halle/Saale

3.1 Georeferencing

Georeferencing is primarily used to compare geographical cartographies (ACKERMANN 2009). It is necessary to compare reliable data from older records and plans with up-to-date and much more accurate representations, correcting older material if necessary. Programs such as Arc-View or Arc-Gis, which meet the high demands for accuracy during a referencing process, are employed for these processes.

3.2 The Terrain Model

In general, a digital terrain model (DTM) or elevation model (DEM) in geography and land surveying does not contain objects on the earth's surface (houses, animals, trees etc.). We used two data sets from grid models for the project "Lehmannsfelsen". The advantage of grid models is the equal division of the measuring points on x- and y-direction. We added the height to every single grid point in the z-direction. Common grid spacings are GDM5 (10m grid), DGM25 (25m grid) and DGM50 (50m grid). The vector format is another possibility, which already contains triangular data with x, y and z coordinates. These coordinates, however, do not necessarily have to lie on a grid.

3.3 Data Review and Reduction (Stripping)

The separation of important and unimportant data takes places while reviewing the geographical data. An elevation file of the project (geographical laser survey in a 1m grid) had a much larger extent than requested (requested was 500×500m, we received 700×800m) and a data format that our CAD software could not read.

In response to the second point, we formatted the data format (here: Gauss-Krüger coordinates) with each point in the form of x,y,z coordinates (example of a coordinate: 4 496 261. 50; 5 707 359. 50; 90. 20) into a point cloud readable by us (x,y,z coordinates in relation to newly defined points for the visualization, example: 0.5; 0.5; 90.2). We formatted all 629 090 points in the batch procedure.

Following, the point cloud be visualized three-dimensionally in the CAD software without having a distance of more than 4496km to the coordinate source in the x-direction. We removed excessive points and reduced the object to a size of 500×500×50m. The advantage of the result was the smaller file size, making the navigation of the entire object much more comfortable. We repeated this process for the model of the Land Survey Office (10m), which was much lower-resolved, but larger in relation to the area of the Lehmannsfelsen.

The resulting point clouds are the starting point for all further conversions and referencing. We, therefore, had to ensure that:

- no descaling takes place, for this purpose, objects are set up in the CAD software (so-called bounding boxes), within which the processed model must remain.
- the units of measurement (mm, cm, km) do not get changed. Each measure of length has determined application-related accuracies.
- all CAD programs within the project reflect the same units of measurement.

- each geometry entering further processing is checked for dimensional accuracy and location (a 10×10×10m cube as reference for size comparisons within the import files).

Another problem is the size of the grid pattern of data from different suppliers. The DGM grid of the data delivery of the City Survey Office was 1m. The DGM grid of the data of the Land Survey Office, however, was 10m. We had to reconcile the data.

3.4 Converting to Polygonal Geometry (Meshing)

When converting to polygonal geometry, a polygon with two triangles is created between 4 points (vertexes). The geometry thus received 17 250 polygons with twice the number of triangles, which later had to be calculated by the graphics. This polygon number is no longer a challenge for modern hardware. However, the number is already too large for 3D online presentations because the terrain takes several seconds or minutes to transmit. Here we had to keep an eye on the target medium and, if necessary, draw attention to the fact that the loading process of such a project takes some time. To keep the amount of data as small as possible we only used the high accuracy of the 1m terrain model in a limited area: in a visual focus of the project. Furthermore, the 10m grid was going to extend to a total size of 800×800m.

Later, a so-called "multiple stitchable terrain engine" can be used within the 3D authoring system to prepare the 3D visualization (ACKERMANN 2009). It allows the user to view the scene while terrain data is still being loaded in the background, and to split terrain information. There are different technical approaches for such systems, the explanation of which will not be included in this text.

3.5 Optimization and Reduction of Data

The optimization of the polygon number of the 3D model makes sense for further processing of the terrain data in the visualization project or the model construction. For this process, we created a combination of the 1m and the 10m grid model. Afterwards, the CAD program (here 3DsMax) corrects polygon errors and reduces the number of polygons of the overall model. An algorithm takes the changes in the height within the predefined terrain section into account. Without having to discard visually vital details, the number of polygons can be up to approximately 10 000.

3.6 Projection of Elevation Lines (Isoline-extraction)

For the Lehmannsfelsen project, we drew the elevation or elevation contour lines at a distance of one meter from sea level, starting from the highest point. How the elevation lines are established is primarily determined by the purpose they are intended to serve.

There are two methods of creating elevation lines. You can either connect all the obvious points of a point cloud on a common plane or project a line structure on the side of the polygonal model in x- or y-direction with the desired height spacing (ACKERMANN 2009). In the first case, the display of the elevation lines is very curved. The disadvantage of this method is that you can only use the elevation data of the point cloud. In the second case, the result is much "softer" due to polygonization, the advantage being the possibility of generating an elevation line at any height. However, a disadvantage is a chance of only obtaining interpolated elevation data between the points. Both methods can be drawn with softer curves later, by rebuilding the geometry and converting the curve types from 1-degree to 3-degree curves.

4 Virtual Reality

Virtual reality (VR) is a real-time three-dimensional simulation of an artificial environment created by using digital techniques. The use of VR-glasses creates a stereoscopic spatial effect, completely decoupling the sense of vision from the real environment. The experience is very immersive, as users act in the digital space through their head and body movements and interact independently with the application. Drawings, images and videos cannot generate such effects. VR-applications enable us to experience non-existent or invisible realities, just like in this exhibition (HANISCH 2021).

Through the interpretation of the two-dimensional design drawing into a three-dimensional model and the use of VR technology, the size and uniqueness of the architectural concepts – in relation to the time of its creation – can be experienced by everyone. The abstract style and representation of the VR-visualization are deliberately not photorealistic to meet the status of a design that has never been realized. The navigation and interaction systems are devised to suit users without any previous VR-experience. Visitors are able to use the application intuitively.

During the period of the exhibition, the VR-model has constantly been refined and enhanced. In addition to many details that were continually amended and revised, there were two significant milestones: The city hall was completely redesigned to make the concert hall visually and interactively tangible. Also, the accompanying program included workshops where participants could discuss and plan ideas for the open space. A few of these designs were subsequently implemented into the VR-model to give an impression of how the architectural ensemble with planting and green space might have looked like. Both enhancements have left a great impression on the visitors[2].

The visual immersion of the VR-scenario really does seduce the user to move in the model. Typically, the radius for physical actions in virtual reality is limited. For the exhibition, however, the designers found a technical solution that allowed the visitors to walk a few steps despite the unavoidable cable connection. Thus they were able to decide themselves how close to walk to the railings of the roof terraces to enjoy the view.

[2] The research project “Stadtkrone.VR” was realized with different programs for modelling and visualization and the program unity3D for the realization of the VR-application. The team chose the VR-headset Samsung Odyssey+ for uncomplicated set-up and cleaning as well as a high image resolution. The headset uses Microsoft’s Mixed Reality Tracking System.

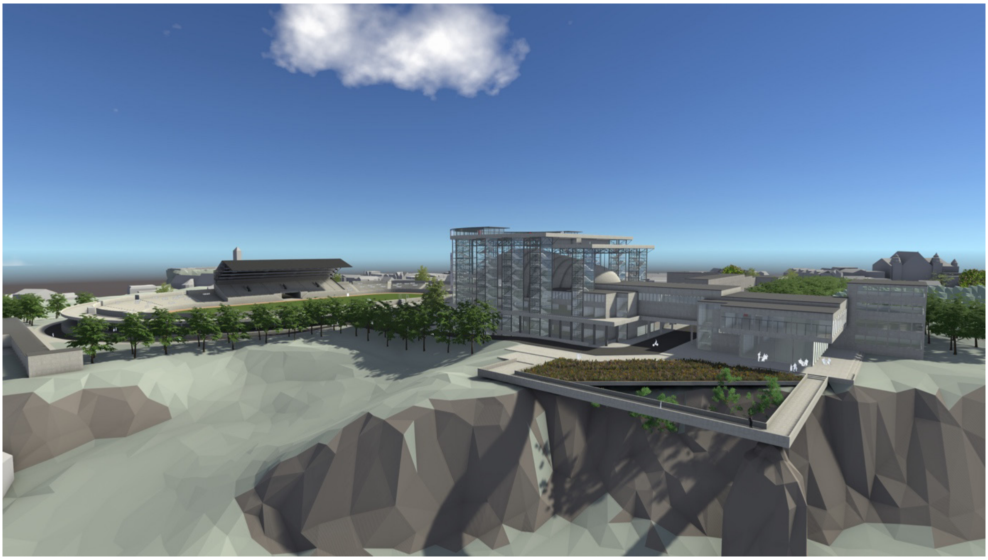

Fig. 5: Virtual view of the "Hanging Gardens – a city crown for Halle", 2019

4.1 Navigation and Interaction

The team developed the navigation and interaction systems under the premise that the vast majority of visitors would be using a virtual reality application for the first time or at best would be beginners in the usage of VR-glasses. Of course, there would also be users who were familiar with the technology. Therefore, the team came up with two different scenarios. Firstly, there is a method for the inexperienced, who would mainly use their head and body movements to interact inside the VR-model. Additionally, there are controllers for those who are already well versed. Since the functionality of the controller is much harder to implement, the focus was mainly on developing an intuitive solution. At this stage, it was of great benefit that experiences and results from previous VR-projects on comparable scenarios already existed. The team developed several concrete concepts and evaluated them.

To be able to change locations quickly and comprehensively on the large area, the use of a miniature map was most promising. The map gives an overview of the site and allows the user to teleport to any location. There are 20 selected points in the form of large pins, which the visitor aims at and activates by aligning their head.

5 Green Space in Virtual Reality – Milestone "Hanging Gardens "

Since the beginning of the project, the team discussed whether to include the hanging gardens in the virtual design. Gropius had renounced the drawing of gardens and landscape in the original plans in order to "not impair the clear assessment of the architectural bodies" (GROPIUS 1928). Thus, a virtual greening could only represent an interpretation, making the subject more vivid to the visitors.

In a workshop, tutors and students sketched ideas and suggestions for possible plants. The challenges were to implement them in the VR-application. While there are a number of plant models for VR-functions, only a few of them are models of real plants. In the search for suitable material, the team involved specialized companies. It soon turned out that their models were only limited suited for VR real-time rendering. Ultimately, most models had to be built manually with a plant generator. However, trees of the same kind never look the same in reality; each grows individually differently. As the viewer would have immediately noticed, there could not be rows of basic models of lime trees (guide models). In consequence, each tree and each bush had to be individualized and positioned separately. At a distance, these tree models work very well, but if the viewer gets closer, it becomes apparent that the image quality is still far from reality.

Due to the numerous trees, bushes, grasses and flowers, the number of polygons in the VR-application increased enormously. Only a few exemplary partial areas were grassed in order to lower the risk of slowing down the refresh rate when turning the head. The team chose lime trees to represent all trees in the design, Gropius also had this tree species planted at the Bauhaus building in Dessau in 1926 (FISCHER-LEONHARDT 2005). As another example for the hanging gardens, the terraces on the rocky edge towards the banks of the river Saale were grassed with wild shrubs. The planting enriches the model, improves the clearness of proportions through more details and conveys the theme of the "hanging gardens" to the visitor.

Fig. 6: Workshop "Hanging Gardens" in November 2019

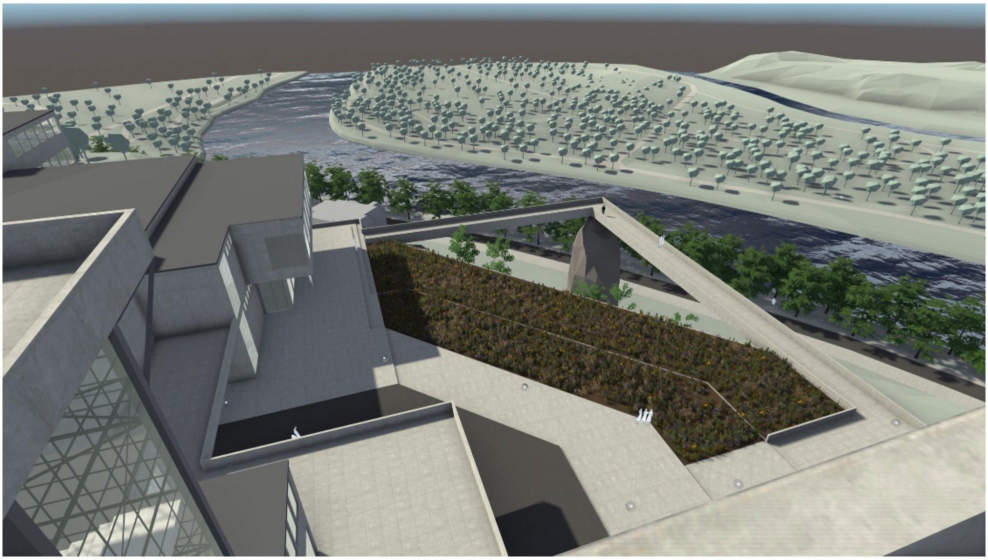

Fig. 7: View from the roof terrace of the 32 meter high town hall to the test area with wild flowers

Fig. 8: Visitor of the AR-guided tour

5.1 Augmented Reality

There already exists technology for visualizing limited areas such as interiors and individual objects. There are numerous applications like smartphones with depth-sensing cameras that enable a true to scale overlay of a piece of furniture in a live-camera image. In contrast, realizing complex scenarios, like the 3D-visualization of the design “Hanging Gardens“ using augmented reality technology in the original area, is a lot harder to accomplish.

There are a number of aspects to be taken into account, such as the exact positioning of the 3D-model, the positioning of the user and the optical characteristics and computing capacity of the devices. On the Lehmansfelsen in Halle, the elevation profile changes considerably, which means that users take a different vertical position every few meters. In addition, the current construction and the stock of trees and bushes limit the possibilities of suitable locations where participants can experience the architectural dimensions and impressive views. Due to the technical feasibility and the specificities of the area, the AR-project was above all an experiment.

After the testing of different prototype solutions and also the use of a mobile VR-station, the team chose the version which enabled on-site guided tours for interested citizens. Each participant received a tablet that visualized the 3D-model in the scope of its intended position. For this, the VR-model was enormously simplified and optimized for the AR-application. Among other things, the team removed components like streets to show the visitor the positioning of the design on the Lehmannsfelsen as comprehensively as possible. The use of high-performance tablets is a compromise because AR-glasses that can display the digital extensions in a high-resolution are not yet available. These mobile devices will then also master an exact positioning determination outdoors.

6 Discussion

The drawings of the original plans are draft drawings and not finalised. Thus, there are areas for which no statements were made in terms of drawings and content, such as the surfaces, materials, stairs and vegetation areas. Within the framework of the research project, an attempt was made to connect all spaces and open spaces and to give them a structure, so interpretations often had to be made. Another topic was the representation of the trees, but Walter Gropius did not specify which type of tree should be used. During the implementation in the VR model, questions arose again and again in this context. One of the main reasons why the small-leaved lime was used as the lead tree in the VR application was the interpretation that Gropius also used this type of tree for the outdoor facilities of the Bauhaus building in Dessau in 1926. The fact that there was already a young avenue of lime trees on the banks of the Saale at the time of the competition was also obvious.

Since in the VR application the user can step right up to the tree trunk and at the same time also look into the distance while turning, the trees had to be modelled both in detail (bark, leaves) and overall (habitus, colour). All trees are interactive in the sense of real time and can thus be interacted with in VR. A digitisation of the trees with the help of image scanning was discarded, as this could not achieve a satisfactory combination of model quality and texturing. Optimal solutions were to be achieved using photogrammetry.

The lime tree used in the VR model was finally modelled, copied and supplemented with interactions. The aim was not to display the models exactly to scale. The decisive factor was that the user should recognise the object to a high degree. The students involved had to be able to visually control the models to not reduce them too much and at the same time have an eye for the textures. The aim was for the photo and the model to look as identical as possible without visual loss.

The figurines in the model are very good for creating proportions. The best proportion reference model is the human being itself. Trees, on the other hand, can be large or small and therefore work only to a limited extent for this purpose.

The minimap has proven to be very beneficial to use. It allows an overview of the entire architectural ensemble in the VR model.

7 Conclusion and Outlook

The exhibition was the result of a year-long research project with the aim of making Walter Gropius' visionary design Hanging Gardens tangible and accessible to visitors and experts using VR and AR technology. This made it possible to reach users who are not normally interested in history, architecture and landscape architecture.

During the project, the following were realised:

- An interactive large-screen projection of the design: self-running 3D visualisation in real time (VR) that could also be individually controlled by visitors via touchscreen.
- Interactive VR stations: walk-through immersive presentation of the design available to visitors in stereo view using VR technology.
- A 3D mini-map and an action space measuring approx. 6 x 6 metres each enabled users among other things, to teleport around the digital site and to move actively to approach the parapets (roof terraces).
- A balloon position also provided an overview.

The user-friendly intuitive interaction model, controlled by the head and body posture, was refined several times and, for alternative use, a controller-supported control for free navigation and teleportation via keyboard inputs were integrated. In the course of the exhibition, the model was detailed and the VR application was expanded. In addition, a new model of the city hall was integrated. After the workshop on the topic of "Hanging Gardens", the greening of the area took place (with mainly specially created models).

The exhibition met with a positive response from visitors. As a result of the visitor statistics, approx. 4000 visitors were counted. Within the framework of the accompanying programme, guided tours for school classes and administration were requested and carried out. The VR application can be borrowed and used for study purposes[3].

[3] stadtkrone-halle.de

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The Color Analysis of Building Façades: Based on the Panoramic Street View Images

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Abstract: The color scheme of the building façades is a critical visual impression of the city's context and characteristics. Analyzing the building colors can provide a way to get an objective and holistic view of the city and a foundation to enact regulations and ordinances on the building color and texture. Traditional color analytical processes are usually carried out by manual survey and sampling, which can take a lot of time and be high-cost in large-scale urban areas, and are limited by the number of color samples and accidental factors of the environment. To this end, we proposed an automated color sampling and analysis method by using street view images as the data source. The images were semantically segmented to extract the façade areas with a convolutional neural network. The dominant colors of the building façades were then identified and transformed to the Munsell color system for further analysis and comparison between different districts. The research can provide a repeatable and objective urban building color analysis method and a low-cost, high-efficiency tool for urban color surveys.

Keywords: Building façades, street view images, convolutional neural network, Munsell color system

1 Introduction

The color scheme of a city is an essential element of the urban landscape and is related to the first impression of the city. It is also a reflection of the city's historical context. By analyzing the colors of the buildings, we can get a more objective and holistic view of the city and can provide a foundation for the regulations and ordinances for the color and texture usage of building construction.

Research on building colors has a long history that dates back to the 1st century. Vitruvius, the Roman architect has described the natural color materials in his book "De Architectura Libri Decem", known today as "The Ten Books on Architecture" (CAIVANO 2006). In recent years, the harmony of building color has been widely applied in urban color plans in a number of cities around the world (WANG et al. 2020, XU et al. 2020). Traditional research methods for urban color analysis include color card comparison, instrument color measurement and photograph recording (LI et al. 2020). These methods are usually carried out by manual survey and sampling, which is limited by the number of color samples and the environment's accidental factors. Moreover, because the color sampling process is operated manually, it could take a lot of time and be high-cost.

Due to the limitations of current color analysis methods, most studies of urban building colors are focused on a part of the urban area such as the historical area or downtown area, while large-scale studies on the city scale are seldom carried out (LUAN & JACQUES 2017). As urban color planning has received much more attention in urban planning, current research tools cannot meet the need for color analysis.

With the development of street view services by Google, Bing, Baidu, and other map service providers, the access to the realistic views of the urban buildings in most cities around the world has become available for everyone. The panoramic images collected by the data re-

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cording vehicles could provide an intact and continuous illustration of building façade along the street. Compared to traditional sampling methods, using the large-scale street view images as the data source could significantly reduce the time costs, and is suitable for large-scale urban problems the study.

To this end, we used a large scale of Baidu street view images as a data source and semantically segmented them to extract the façade areas with the help of a convolutional neural network. Then, the dominant colors of the building façades were identified and transformed to the Munsell color system for the analysis and composition between different districts. This can provide a repeatable and objective urban building color analysis method and offers a low-cost, high-efficiency analysis tool for urban color surveys.

2 Study Area

Wuhan is a city located in the central part of China. The city's central urban area (678 km^2) was selected as the research area. Since 2014, Wuhan Natural Resources and Planning Bureau has initiated a research project on the building color and material planning and management in response to the goal of "improving the living environment and creating a charming Wuhan." Based on the city's historical context, the city government released the "Regulations on the Usage of Building Colors and Materials in the Main Urban Area of Wuhan" in January 2016. The regulation adopts the Munsell color system to describe the colors and requires that the façades of the new, rebuilt, and expanded buildings must meet the regulations by adopting one or several colors listed by different color regulated districts. The listed colors are determined by a systematic field study and a public questionnaire survey. The corresponding color regulated districts and each district's acceptable colors are shown in the figure below (Figure 1 & Figure 2).

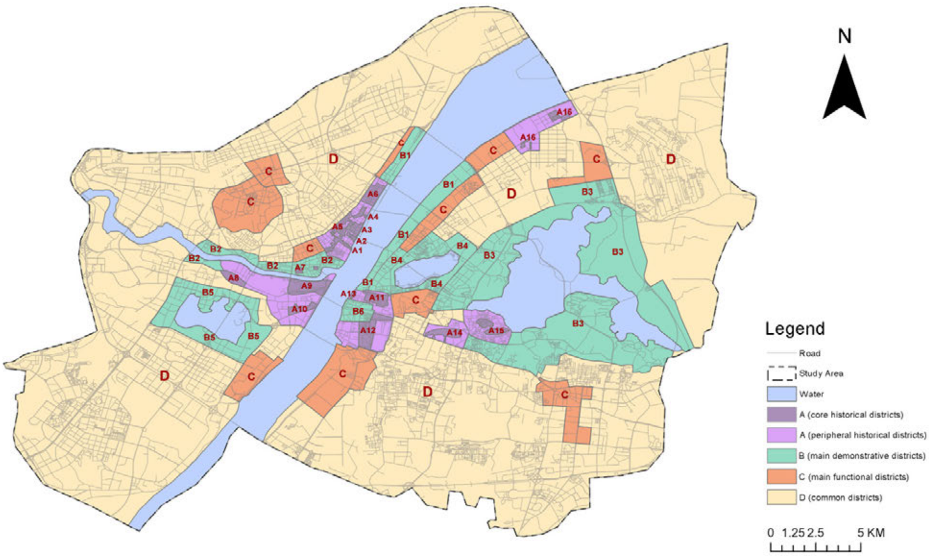


Fig. 1: Districts listed in the "Regulations on the Usage of Building Colors and Materials in the Main Urban Area of Wuhan"

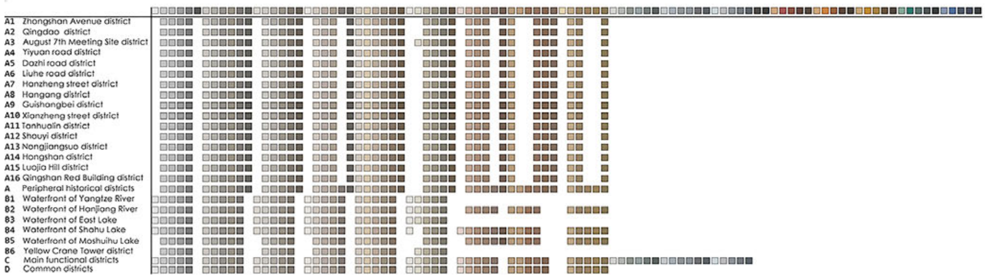


Fig. 2: The acceptable colors of the building façades in different districts in the regulation

3 Methods

3.1 Acquiring Panoramic Images

The street vector data in the area are downloaded from OpenStreetMap (OPENSTREETMAP CONTRIBUTORS 2020). The roads and streets located on the ground were screened out by removing the viaducts, underground tunnels, and bridges based on the attributes of the vector data. Then the streets were divided into equal distances with 200m intervals to find the sampling points to acquire the panoramic images (Figure 3).

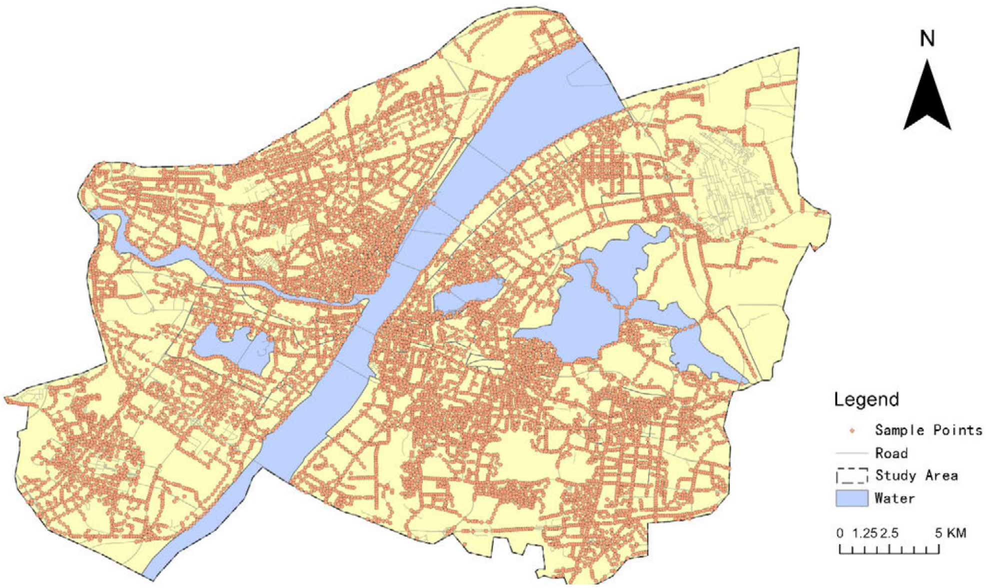


Fig. 3: Sampling points of panoramic images in the main urban area of Wuhan

The panoramic street view images were obtained by a web crawler with Baidu API (BAIDU LBS 2020). Each image downloaded was a 2:1 equidistant cylindrical projected image with a resolution of 1024×512. 10294 valid panoramic images were finally obtained.

3.2 Projection Transformation

As different areas are not proportional on an equidistant cylindrical projected image, the equidistant cylindrical projected image was transformed to a cylindrical equal-area projected one with the following equations (Figure 4):

$$x_2 = \frac{\pi x_1}{2} \quad (1)$$

$$y_2 = y_0 \quad (2)$$

y_0 is the pixel height of the cylindrical equal-area projected image, x_1, x_2 are the corresponding x, y pixel coordinate of the equirectangular projected image, y_1, y_2 are the corresponding x, y pixel coordinate of the cylindrical equal-area projected image (ZHANG et al. 2020).

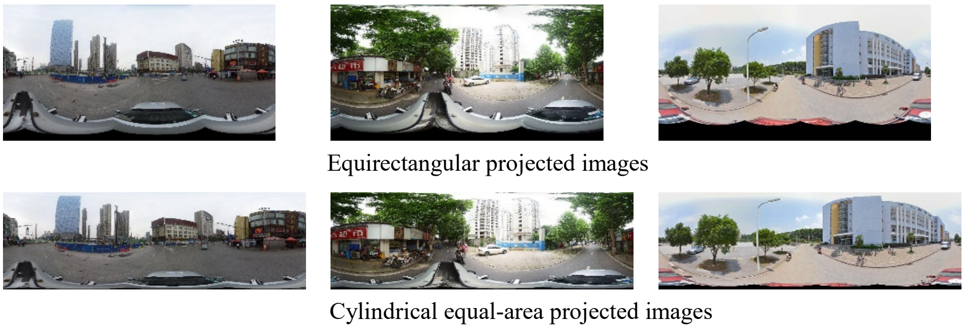


Fig. 4: The transformation from equirectangular projection to cylindrical equal-area projection

3.3 Recognize and Extract Building Façade by Semantic Segmentation

The convolutional neural network Dilated ResNet-105 was used to identify and extract the building façade area in the cylindrical equal-area projected image. The training data is from the Cityscapes Dataset. The accuracy of semantic segmentation is measured by Mean Intersection-Over-Union (mIoU), which first computes the IOU for each semantic class and then computes the average over classes (QUAKNINE 2019). IoU is defined as follows: IoU = true positive / (true positive + false positive + false negative). Dilated ResNet-105 achieves an mIoU of 75.6% on the Cityscapes dataset. After removing 917 images that did not contain building façade areas, the remaining 9377 images were binarized to the building façade areas and other areas. The binarized images were then used as masks to extract the building façade areas on the panoramic images (Figure 5).

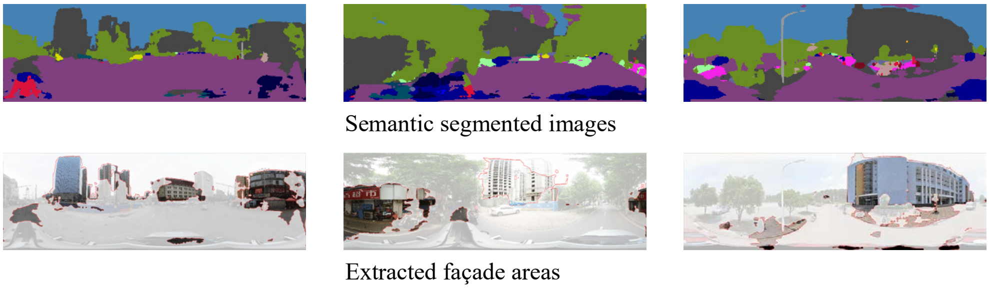


Fig. 5: Semantic segmented images and extracted façade areas

3.4 Extracting the Dominant Façade Colors

To reduce the influence of different lighting conditions and shadows cast on the façades, the façade areas which were excessively light or dark were removed before further analysis with the following RGB value calculation:

$$++< 1.1 \quad (3)$$

$$- \vee + -\vee + -\vee \; 0.4 \quad (4)$$

To analyze the dominant colors of the building façades, the color that covers the largest proportion on each image was extracted as the dominant color of the building.

3.5 Conversion to the Munsell Color System

The Munsell color system is a color space system proposed by the American painter and art educator Albert H. Munsell in 1898. This color system expresses the color relationship between Value, Color, and Chroma in a three-dimensional sphere (Figure 6). It is based on human visual perception of uniform marking colors, making it a reliable scientific basis (GONG & SHENG 2019, SALLY 2014). Color in the Munsell color system is divided into five dominant colors and five intermediate colors formed by mutual mix: red (R), red-yellow (YR), yellow (Y), yellow-green (GY), green (G), green-blue (BG), blue (B), blue-purple (PB), purple (P), purple-red (RP), and divide the changes between two adjacent colors into ten parts, a total of 100 kinds of color. The middle axis of the sphere is Value, which is divided into 11 levels, from all-black (N0) to all-gray (N5) to all-white (N10). The radiation extending from the center of the central axis is Chroma, and its value increases from 0 near the central axis as the distance from the central axis increases. The composition of its color expression is Color + Value/Chroma; for example, 5GY4/6 is Color 5GY with Value N4 and Chroma 6 (Figure 7).

The Munsell color system is based on psychology and is formulated according to the visual characteristics of different colors. It is widely used in color representation and management, and also used as a standard and tool to define color relationships, evaluate color matching effects, and record color forms.

As the "Regulations on the Usage of Building Colors and Materials in the Main Urban Area of Wuhan" was based on the Munsell color system. The RGB colors of the façades were then transformed to the Munsell colors based on ASTM D1535 tables with the Illuminat C Observer (AKEN 2020).

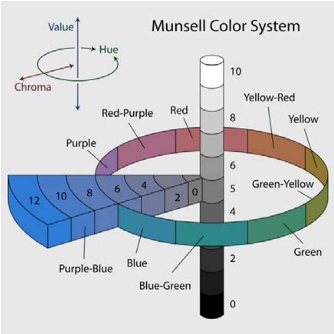


Fig. 6: Munsell color system

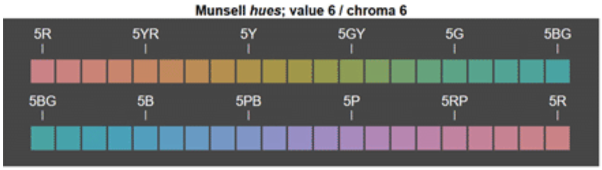


Fig. 7: Munsell color system distribution band of Color

4 Results and Discussion

It can be seen that the dominant colors of the building façades are mainly pale white, slate grey, and light brown (Figure 8). The dominant colors in different districts are generally similar, and the color characteristics of different areas are not very prominent.

Fig. 8: Distribution map of dominant colors of buildings in the main urban area of Wuhan

A comparison between the 98 Munsell colors recommended in the "Regulations on the Usage of Building Colors and Materials in the Main Urban Area of Wuhan" and the actual dominant colors of the city are illustrated in CIE-XYZ color space (Figure 9). It can be seen that the colors of the building façades are mostly consistent with the regulations, and there are a few colors such as dark blue, medium green, dark orange, and saddle brown listed outside the regulated color area.

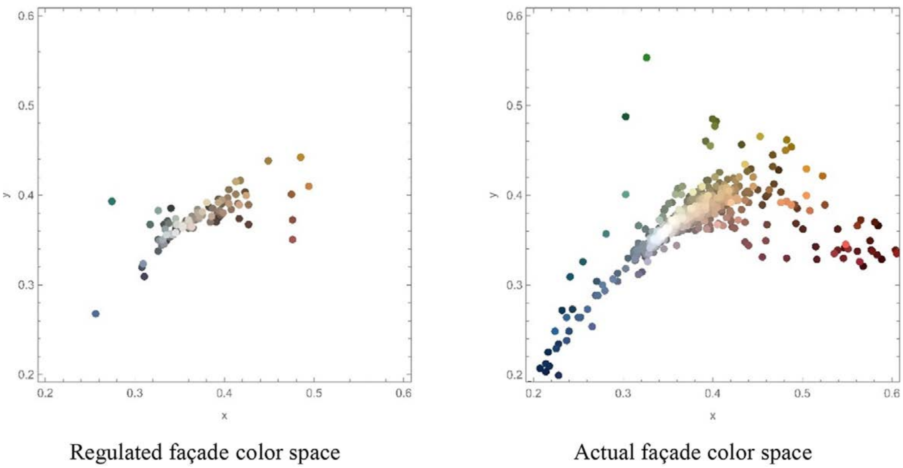


Fig. 9: Comparison of regulated and actual façade colors in CIE-XYZ color space

In the "Regulations on the Usage of Building Colors and Materials in the Main Urban Area of Wuhan," the main urban area of Wuhan is divided into 4 different districts: A (historical districts); B (main demonstrative districts); C (main functional districts) and D (common districts).

To reduce the complexity and visualize the hue distribution of the dominant colors, the Value and Chroma of each color were unified to 6, and the colors without a hue (pure white to grey) were dropped out. The color distribution of dominant colors in each region are shown in Figure 10. It can be seen that the colors in different districts are mainly distributed between 5YR-5Y with 2 other peaks at 5P and 5PB, which shows that the warm orange and blue-purple are in dominance.

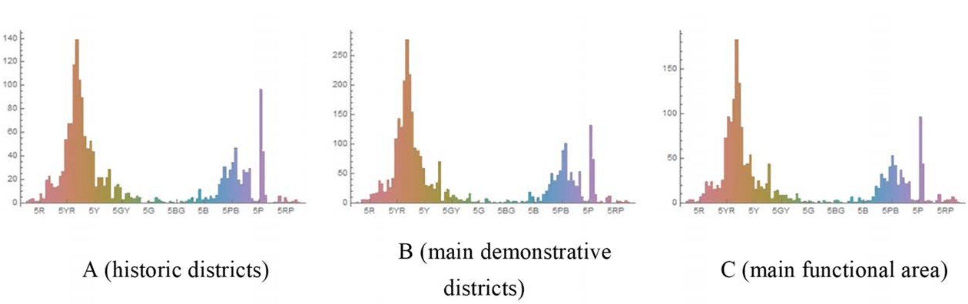
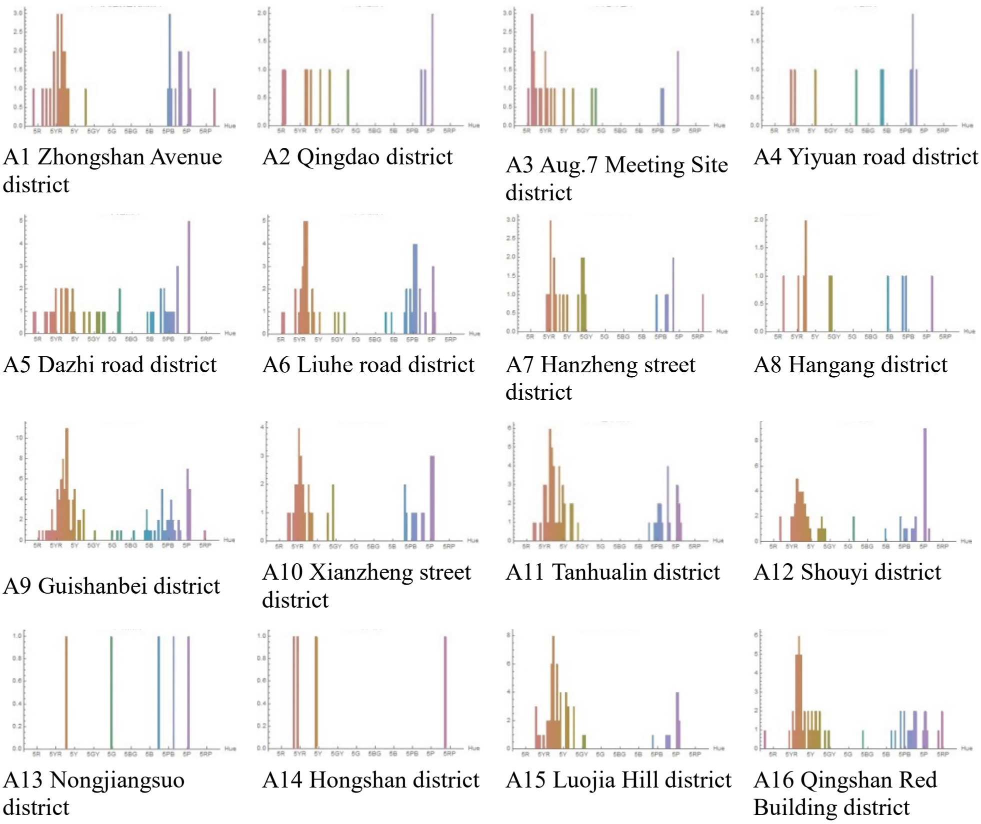


Fig. 10: Color distribution of the façades in different districts

The city of Wuhan has a history of 3500 years. The historical districts of Wuhan contain a number of traditional Chinese and western buildings. The color distribution of each historical district is shown in the figure below (Figure 11).



A1 Zhongshan Avenue district

A2 Qingdao district

A3 Aug.7 Meeting Site district

A4 Yiyuan road district

A5 Dazhi road district

A6 Liuhe road district

A7 Hanzheng street district

A8 Hangang district

A9 Guishanbei district

A10 Xianzheng street district

A11 Tanhualin district

A12 Shouyi district

A13 Nongjiangsuo district

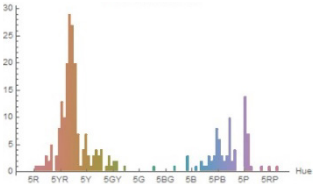
A14 Hongshan district

A15 Luojia Hill district

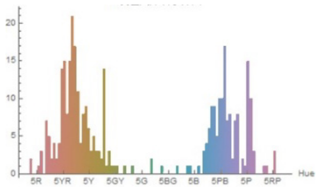
A16 Qingshan Red Building district

Fig. 11: The color distribution of each historical district

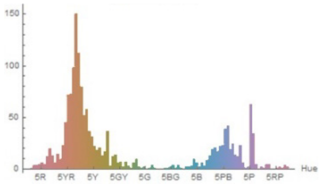
Although the recommended colors in the regulation are almost the same in A1 – A16 districts (Figure 2), the hue distribution in different historical districts show that colors are variant. Districts such as A5, A9 and A16 have a wider hue distribution than other districts. And in most districts the warm colors are in the majority.



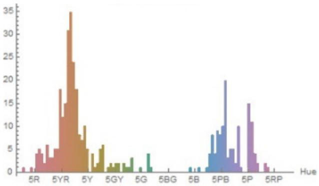
B1 Waterfront of Yangtze River



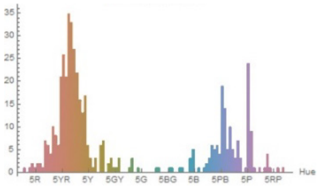
B2 Waterfront of Hanjiang River



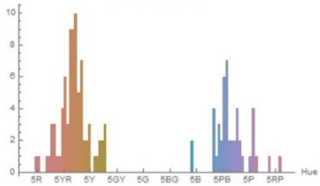
B3 Waterfront of East Lake



B4 Waterfront of Shahu Lake



B5 Waterfront of Moshuihu Lake



B6 Yellow Crane Tower district

Fig. 12: The color distribution of each main demonstrative district

The color distribution of each main demonstrative district is shown in Figure 12. The B1 – B6 districts are the waterfront areas of Wuhan. Some of the districts such as B2 have a wide distribution of cold colors from blue to purple while the warm colors are also significant. However, compared to A or C districts, the color difference is not very prominent.

5 Conclusion and Outlook

Focusing on the building façade colors of Wuhan's central urban area, we used panoramic images downloaded from Baidu Map, and extracted the façade areas by semantic segmentation to conduct color analysis based on the Munsell color system. The result shows that the dominant colors of the main demonstrative districts, the historical districts, and the waterfront districts are mainly warm. And the typical colors are pale white, slate gray and light brown. Compared with requisite colors listed in the "Regulation on the Management of Building Colors and Materials in the Main Urban Area of Wuhan", the difference of façade colors between each district is not very significant, further coordination is still needed to highlight the characteristics of different districts in the city.

5.1 Potential Applications

As the number of cities which adopt the color management regulations is continuing to increase, the establishment of a holistic building color database has become valuable as the foundation of further analysis. The research proposed a method to automatically identify building dominant façade colors by recognizing and extracting the façade areas on the panoramic street view images. First, the semantically segmented images are binarized and transformed to the cylindrical equal-area projected images to extract the façade areas. Then the color composition of façade areas is calculated to obtain its dominant colors. It is suitable for analyzing building façade colors in large-scale areas. Compared with traditional manual color sampling and recognition, it can shorten the analysis time, reduce the labor cost, and improve the accuracy of color analysis. Moreover, with the regularly updated panoramic images collected by vehicles, the dynamic change of building colors could be monitored, and the particularly popular/unpopular colors could be found. The regulation could be more flexible and adaptive to different developments (e. g. the maximum deviation from the given colors could be regulated by percentage, or the allowed colors would be updated cyclically based on the dominant city colors).

5.2 Limitations and Future Research

The accuracy of color recognition is influenced by a number of environmental factors. The street trees and street furniture may block some part of the building façades and will affect the color recognition. The colors on the panoramic image may deviate from the actual color for some factors such as the time difference of the panoramic street view images were taken and illumination conditions. And the accuracy of the neural network model's semantic segmentation limits the accuracy of the recognition results. At present, there are still some other elements such as cars or pavement that could be misidentified as the building façade area. Moreover, casted shadows or light reflection may also affect the accuracy of color recognition. More refinement is still needed to make the color analysis process more precise and adaptable to different urban areas.

Acknowledgements

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The Effectiveness of Virtual Reality Simulation on the Qualitative Analysis of Lighting Design

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Abstract: This research explored the effectiveness of virtual reality (VR) simulation on the qualitative analysis of landscape lighting design. An urban plaza in Seoul was selected as the study site. After constructing the existing and proposed lighting models in Unreal Engine, an experiment with VR simulation was conducted. The experiment provided an immersive experience, presenting the plaza model with a lighting-design proposal and assessing the experience with a set of survey questions. The survey results demonstrated that the night environment of the improvement plan was superior in all categories to the existing lighting.

Keywords: Digital twin, outdoor lighting, Unreal Engine 4, Virtual Reality, Gwanghwamun Plaza

1 Introduction

Recently, the number of nighttime activities by urban residents has increased rapidly, and the importance of the night environment quality has increased considerably (KIM 2005). Lighting is an essential factor in the creation of a nightscape that contributes significantly to the safety and comfort of nocturnal city life (PAEK 2007). In the lighting-design process, both quantitative and qualitative analyses are important to assess the proposed design. However, current lighting simulation tools focus primarily on quantitative assessments, producing computational analyses of the physical environment using photometric data inputs and outputs.

There are several programs that enable quantitative analyses by providing 3-dimensional assessment of a proposed design. Relux and DIALux evo are the two most popular applications used for the lighting design of indoor and outdoor environments (SCORPIO et al. 2020). Both software tools generate quantitative analysis of average luminance values using 3-dimensional simulations. The programs report numerical, quantitative results that contribute to lighting-design proposals and to designers' communication with clients or contractors (HONG 2011).

In interior spaces where the architectural elements are solid objects that contain light sources, these analyses are effective tools for the quantitative assessment of the proposed design. However, there are critical limitations when the existing analysis programs are used for the qualitative assessment of outdoor lighting design. First, it is challenging to simulate accurate lighting effects for landscapes with plantings. Second, the continuity of illumination through space cannot be assessed from individual views. Third, the rendered images are low in resolution and lack details; they can only provide limited visual analyses of the design. Programs such as Relux or DIALux evo cannot obtain qualitative assessments, which are often substituted for by rendered model views or photoshopped images.

Virtual reality (VR) technology is used in architectural and landscape design as an efficient simulation technique with interaction, immersion, realism, and behavioral subjectivity. Among many VR systems, game engines can model virtual environments that the user can

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interact with fully. The user can explore the virtual environment through the game engine, making changes and viewing the effects of those changes in real time (SCORPIO et al. 2020). Unreal Engine 4 (UE4) by Epic Games supports an immersive experience and provides real-time renderings that enable instant visualization. The user can walk through the virtual space, look around, and change position with control devices in order to experience the space with illumination continuity. UE4 can generate high-resolution rendered images of lighting design results that can be analyzed instantly. Moreover, the engine can implement changes in different weather, seasons, or times, which is a strong advantage in the accurate assessment of outdoor lighting over time.

Relux (Gu et al. 2012)	DIALux evo (https://www.dial.de/en/online-course-dialux-evo-for-outdoor-lighting 2020)	Unreal Engine 4 (Scorpio et al. 2020)

Fig. 1: Comparison of 3-dimensional simulation views

This research explored the effectiveness of VR simulation on the qualitative evaluation of landscape lighting design. An urban plaza in Seoul's central business district was selected as the study site. The experiment provided an immersive experience, presenting the plaza based on a lighting-design proposal and assessing subjects' experiences with a set of survey questions. The goal was to test the utility of VR simulation as a new qualitative analysis tool for lighting design.

2 Simulation Models

Gwanghwamun Plaza is located in the central business district of Seoul. The plaza is a symbolic open space with historical value and statues of strong national characters. Despite the large number of people using the square at night, the plaza's illumination level is very low with only a few spot-lighting fixtures that are focused on statues. There is heavy daily traffic on the boulevard located on both sides of the plaza, creating unpleasant glare and shadows. The current lighting condition of the Gwanghwamun Plaza affects the safety of the users and undermines visual comfort of the plaza.

Fig. 2: Existing night environment conditions at Gwanghwamun Plaza

For the study's model, we utilized a preconstructed 3-dimensional model of Gwanghwamun Plaza. We obtained accurate information about the quantity and specifications of the lighting fixtures in the plaza from the Seoul Metropolitan Government. A series of field surveys were conducted to confirm that the specifications of the lighting fixtures matched the conditions of the actual site. UE4 was used to demonstrate the night environment of the current site and that of the improvement plan.

In UE4, there are two methods of generating lighting. The first is to create lighting fixtures within the software. The second method is to import Illuminating Engineering Society (IES) files to UE4. IES files are photometric data generated from the photometric standard of the Society of Illumination, also used in Relux and DIALux. We could not obtain an accurate IES file of the existing lighting fixtures at the study site, so we generated lighting fixtures directly in UE4.

UE4 allows the creation of point, spot, and rear lights using lumen (lm). Lumen is a measure of the luminous flux emitted at a one-steradian angle. In photometric measurements, the perceived force of light and the total amount of energy emitted are the same regardless of the light distribution (wide or narrow). Based on provided information, we were able to check the lumen values of the lighting fixture installed at the site to replicate that lighting in UE4 and reflect the nighttime status of the target site.

Existing lighting model: overview

Improved lighting model: overview

Existing lighting: eye-level

Improved lighting: eye-level

Fig. 3: UE4 simulation of the existing nightscape and the improvement nightscape of Gwanghwamun Plaza

For the improvement plan, we referred to the open space lighting guidelines in the Seoul Metropolitan Government's Nightscape Design Guidelines (2018). We applied three rules to the lighting-design proposal:

1. The lighting design of the plaza should not interfere with the view during the day or night.
2. The lighting fixtures in the plaza adjacent to the road should not result in glare to drivers.
3. Illuminance should be secured using pedestrian lights, bollards, etc.

Following these rules, we minimized the lighting equipment installed in the plaza to avoid inconvenience to the users of the plaza. In addition, we avoided using down-lighting fixtures such as pole lights in order to avoid any glare for drivers on the adjacent boulevard.

3 Experiment and Survey

After constructing the existing and the proposed lighting models in UE4, we conducted a VR simulation experiment. To start, we implemented a third-person character in UE4 to allow study subjects to experience the night environment by changing their point of view. Before conducting the simulations, we trained subjects so that they were familiar with the VR simulation controls, including specific keys that could move characters or change existing plans and improvements.

We turned the experimental environment into a darkroom and instructed subjects to sit in front of a large monitor. The experiment was conducted with one person at a time, and a total of 11 people participated in the experiment. The subjects first experienced the existing lighting condition and then compared it with the proposed lighting condition. We provided the subject ample time to freely explore both conditions and to experience the night environment in real time.

Fig. 4: Set-up of VR experiment

After the VR experience, the subjects evaluated the existing lighting and the proposed lighting plan through a survey questionnaire. For items that assessed the outdoor night environment, we referred to the Introduction to Lighting Design (NAKAJIMA et al. 1997), which classifies landscape lighting elements into the categories of safety, direction, security, promotion, identity, and attraction. Because "safety" and "security" can be interpreted similarly, we converted "safety" to "visual comfort" to avoid potential confusion in this experiment (VAN DEN WYMELENBERG & INANICI 2014). The survey question responses were made using a 7-point Likert scale (7=agree very strongly, 1=disagree very strongly).

Table 1: Survey Questions

<table>
<tr><th>Category</th><th>Question</th><th>Response</th></tr>
<tr><td>Visual Comfort</td><td>The space is visually comfortable.</td><td rowspan="6">7 = agree very strongly
6 = agree strongly
5 = agree
4 = neither agree nor disagree
3 = disagree
2 = disagree strongly
1 = disagree very strongly</td></tr>
<tr><td>Direction</td><td>The lighting helps determine where to go in the space.</td></tr>
<tr><td>Security</td><td>Space is a safe environment from crime.</td></tr>
<tr><td>Promotion</td><td>The lighting in the space will improve the image of the city.</td></tr>
<tr><td>Identity</td><td>The lighting in the space illustrates the identity of Gwanghwamun Plaza.</td></tr>
<tr><td>Attraction</td><td>The lighting in the space is attractive.</td></tr>
</table>

Survey results related to the existing model are shown in Figure 5. In the category of "visual comfort," 50% of the subjects chose negative responses (scale 1, 2, and 3), while 25% of the responses were positive (scale 5, 6, and 7). The "direction" and "identity" categories exhibited the most negative responses, as high as 75 – 80% and with little positive response. In terms of "security" and "promotion," the results were similar, as 60% of responses were negative. In the "attraction" category, 50% of responses were neutral (scale 4, neither agree nor disagree). Overall, 61% of the responses to the existing lighting model were negative and 17% were positive. In follow-up interviews, we found that the low illumination level caused by the lack of lighting fixtures significantly influenced the results of the survey. It was the primary reason given by subjects for low scores.

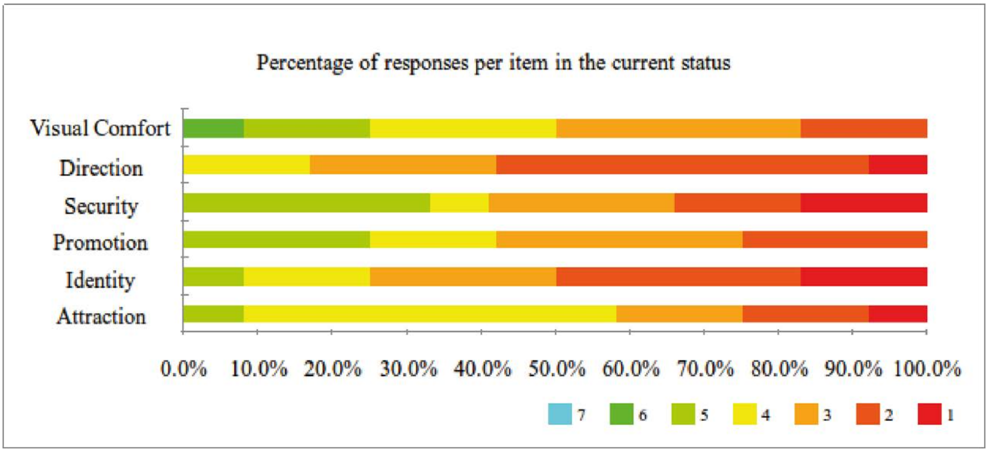

Fig. 5: Percentage of responses per category for the existing lighting

Survey results for the improvement plan are shown in Figure 6. In the "visual comfort" category, 75% of responses were positive (scale 5, 6, and 7) and 25% were neutral (scale 4). The "direction," "security," "promotion," and "attraction" categories showed over 90% of positive responses (scale 5, 6, and 7). The "promotion" category yielded only positive responses while the "identity" was the only category with negative response. Overall, the survey results showed more than 80% positive responses. We found that increasing the intensity of the illumination by adding a lighting fixture had a positive impact on the qualitative analysis.

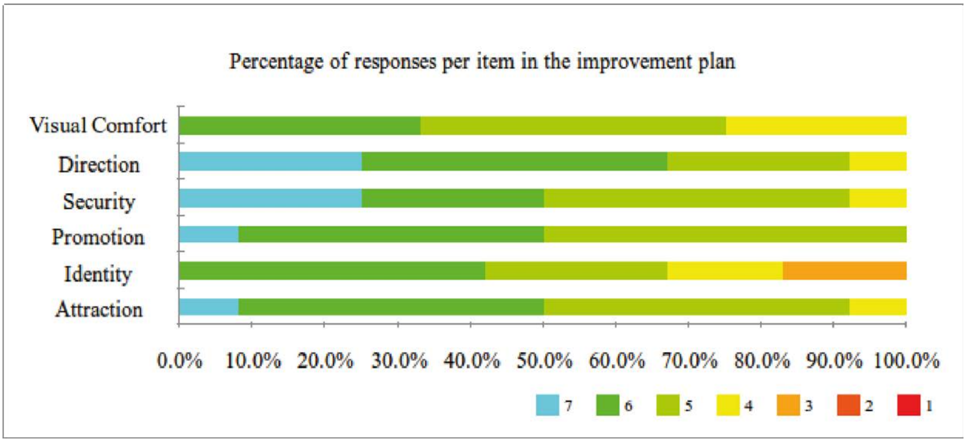

Fig. 6: Percentage of responses per category for the improvement plan

The dramatic differences between the results in Figure 5 (existing lighting) and Figure 6 (proposed lighting) are presented in Figure 7. Comparing the results, we see that the scores were lower for the existing lighting than for the improvement plan in all categories. The score for the direction item showed the most significant increase in the improvement plan, indicating that the lighting elements added by the improvement plan were the most helpful in reading the orientation of the space. In contrast, the visual comfort item score rose by the lowest margin. In sum, the survey results demonstrated that the night environment of the improvement plan was superior in all categories to the night environment with the existing lighting.

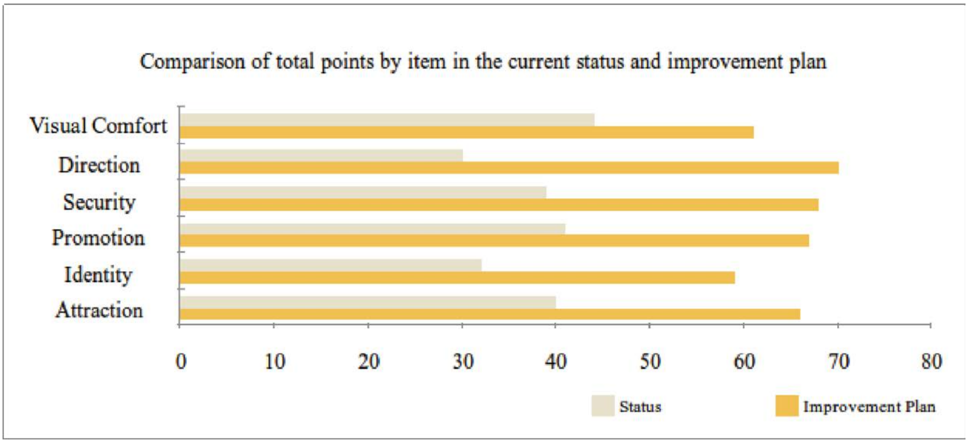

Fig. 7: Total point comparison: existing lighting and improvement plan

4 Conclusion and Outlook

This research explored the utility of VR simulation as a qualitative analysis tool for lighting design. When designers include immersive and realistic VR simulations in the lighting-design process, results show that the VR tool can help recognize a safer and more comfortable nightscape. Ultimately, lighting design using VR simulation can create more pleasant and safer night environments.

This study has several limitations. First, the experiment utilized a large-screen monitor instead of a head-mounted display (HMD), so the user experience is less immersive. Second, nighttime simulations are particularly difficult because there is no accounting for ambient lighting in the VR models. Therefore, the viewing environment needs to match this condition and the subjects must be given an appropriate length of time for their eyes to adjust to that condition. Third, a monitor does not produce enough light to cause the viewer to experience glare. Fourth, the absence of specific IES files that represented the installed lighting of the target site meant that we could not create an identical reproduction of the current lighting environment of the site. A more accurate qualitative assessment of the lighting environment would be possible if researchers utilize the IES file for lighting creation in UE4 and HMD in future, subsequent studies. We believe that the visualization of realistic lighting environments on UE4 and the resulting quantitative data can be sufficiently replaced by the existing lighting design simulation software.

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Long-term Perspectives of Stakeholders' Perceptions of Visualisation Media in Participatory Planning: The Case of Sanguan Temple Square in Guangzhou

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Abstract: Despite recent developments in the field of visualisation technology and evaluation studies, little research has been carried out on how stakeholders perceive different visualisation tools over the longitudinal development of planning projects. Using questionnaires and semi-structured interviews, this study examines the effectiveness of analog tools (sticky notes, photographs, paper maps, 3D physical models), digital visualisations (2D digital images, 3D modelling) and news coverage throughout a community micro-regeneration process. 3D physical models and 3D modelling were considered the most useful in terms of aiding comprehension and discussion. The longitudinal impacts of different visualisations were observed, ranging from information and communication to social, cultural and political influences on public awareness, cultural rehabilitation and political attitudes. The findings suggest using a combination of analog and digital visualisations overall suits stakeholders' needs best.

Keywords: Longitudinal, visualisation, analog, digital, perception

1 Introduction

The advantages of using analog and digital visualisation tools to support participatory planning have long been recognised (AL-KODMANY 2002, BISHOP 2013, LANGE & BISHOP 2005). Studies have demonstrated the effectiveness of visualisation tools in cognitive, affective, and behavioural dimensions, such as information and motivation (WISSEN HAYEK 2011, HEHL-LANGE & LANGE 2017), communication and interaction (AL-KODMANY 2002, LANGE & HEHL-LANGE 2010), changes in public awareness and action (LU et al. 2020, SHEPPARD 2005), and informing policy development and adjustment (PETTIT et al. 2011, SCHROTH et al. 2015). Most usability evaluations of visualisation tools have been conducted in controlled workshop environments. Their application in real-world planning practices, however, has hardly been investigated (BILLGER et al. 2017)

A typical planning project undergoes inventory, planning and design, evaluation and decision-making processes before its final implementation. Many evaluation studies of visualisations concentrate on a particular point in time during the process. Although they effectively determine the potential or limitation of different tools, they fail to take into account the long-term perspective in the overall process (BISHOP 2013, SCHROTH et al. 2015). A longitudinal study offers a way to look back at past events and collect data showing the impact such events have had over a long period (ELLIOTT et al. 2008). Using a longitudinal examination of a community micro-renewal project, this study explores how stakeholders perceive different visualisation tools used at various planning phases and the impact of these tools over time.

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2 Methods

2.1 Study Context

Sanguan Temple Square in the Puntoon Wuyue Village, Guangzhou serves as a crucial node for local people to gather and pursue cultural activities. Since 2017, local people's needs were identified by the community planners through various focus groups as part of an overall renewal project. A number of improvements have been proposed and further illustrated in the design stage through exhibitions and workshops. Special attention was given to the reinstating of a gatehouse in the square. Using a range of media and with the help of a 1:1 physical model construction and a gate design competition, the final decision was approved in expert meetings. At the time of writing, the major part of the project has been implemented, while the gatehouse construction remains on hold.

2.2 Presentation Format

Seven types of visualisation tools were adopted during the participatory process. These encompass analog as well as digital media. Examples as used during the entire process are presented in Figure 1.

a) An A0 board with sticky notes to solicit opinions about the site;
b) A series of A5 photographs presenting the history of the square;
c) A series of A4 paper maps showing the historical evolution of the site;
d) An A2 digital plan of the square design with detailed illustrations of key landmarks;
e) A 1:1 physical model (approximately 4 x 5 x 1 m) of the proposed gatehouse;
f) 3D renderings showing the proposed gatehouse in the square for the design competition;
g) TV news informing the on-going implementation of the project.

The photographs and maps (Fig. 1-b, 1-c, 1-g) were prepared using museum archives and private collections. The plan in Figure 1-d was created by designers using Photoshop and CAD. 3D renderings as represented in Figure 1-f were exported from selective perspectives (eye-level and bird's-eye view) of gatehouse SketchUp models by different competition participants. Some visualisation tools allowed people to interact with them. For instance, the large 1:1 physical model was pre-cut and arranged jointly by local people and planners (Fig. 1-e). The sticky notes enabled participants to express their concerns (Fig. 1-a) and vote for their favourite design (Fig. 1-f).

Fig. 1: Examples of visualisation media used during the participatory process

2.3 Data Collection and Analysis

Drawing on BISHOP (2013), triangulation methods combining interviews and questionnaires were conducted with five stakeholder groups: villagers, tenants and other residents (V), planners, designers and competition participants (P), news media (N), construction teams (C) and government officials (G). Through ethnographic observations and interviews with stakeholder representatives (V=10, P=3, N=2, C=1, G=1) between 2018 and 2020 the effects of visualisations were investigated. Interviews were transcribed and analysed using NVivo 12 software.

To get an overall picture of the performance of different visualisation tools and to support the qualitative interviews, surveys were conducted with 57 stakeholders (V=38, P=8, N=3, C=3, G=5), who have been involved in various planning phases (Inventory=28, Design=43, Decision-making=10, Implementation=16). Their demographic information is as follows: 42 were male and 15 were female; 12 were aged 18-30, 16 were aged 31-45, 16 were aged 46-60 and 13 were aged 61 or above; 13 held an education level of middle school or below, 19 people were educated to high school level, 18 had an undergraduate degree, and 7 were educated at master's level or above. They were asked to evaluate the visualisation tools they have used concerning their easiness to comprehend and helpfulness for discussion and state their ideal tools for each of the planning phases they participated in. Descriptive statistical analysis using SPSS 25.0 was used to show similarities or differences of the stakeholder groups.

3 Results

3.1 Perceived Effects of Visualisations throughout the Process

Suffering from long periods of housing demolition in their district, Group V was initially opposed to the renewal project when approached. Analog visualisations helped to build trust between Groups V and P. P1 recalled: "We made a physical model of the ancestral hall, [The villagers] pointed at it and advised on renovation using sticky notes. Later, they were much more open to us." The old photographs (Fig. 1-b) and paper maps (Fig. 1-c) have invoked the hidden history of the village especially for many younger-generations (noted by V3, V5, V7, V9). One example is illustrated by V3: "I was not aware that there was a river winding through the village, nor did I know about the cultivation of Puntoon Wuxiu (five kinds of water crops) in this area." These have aroused their sense of cultural belonging, which later became the inspiration for the design, according to P3, "to restore local culture through different design elements, such as pavements, stone lion sculptures, rebuilding the ancient bridge, and levelling the square for cultural activities."

During the design and evaluation stage, visualisation created an active environment for social engagement and communication of design. To promote the local culture, an exhibition showing the history and future of the site was initiated by some people from Groups V and P. Visitors of the exhibition commented on the 2D plans (Fig. 1-d) and physical models as "it was direct to see the past and forthcoming future of the area through which we could suggest our needs" (V4, V6, V8, V10). The reinstating of the historical gatehouse involves several government sectors, and its associated management problems have hindered its development. A 1:1 physical model was jointly made by Groups V and P, taking a half-day to build (Fig. 1-e). According to V1, V2, P1, P2 and N1, the aims were two-folded: "compare design alternatives and attract social attention through news reports and the on-site exhibition."

Visualisations have effectively shifted political attitudes and decision-making. In the initial stages the project failed to achieve approval due to disagreements between Groups G and P over the gate's location. A design competition was subsequently conducted using SketchUp renderings in which people were invited to vote for their favourite design (Fig. 1-f). This was in effect, attracting a large audience. One design competition participant (P5) recalled: "Many passers-by dropped into our exhibition and looked at different proposals; several journalists reported the event, one of whom even participated as a designer." The social impacts have greatly influenced the decision-making process. "The winning projects were against my proposal and I have to compromise," said G1. P1 and P2 also noted changes of political behaviours after the competition: "G1 assisted us with the administrative process" and "Group G in the second-round evaluation approved our design and praised the competition voting as a collaboration example between designers and the general public".

Along with ongoing implementation, visualisation has had a wider socio-cultural impact. Many people visiting the square will stop and look at the photo exhibition (Fig. 1-b). This was reinforced by villagers" spontaneous behaviours and different forms of publicity by news media (Fig. 1-g). N2: "I hope to make more people aware of the site, and promote the local culture and the place's identity. This also has implications for other community renewal projects in Guangzhou." V5 explained his intention to initiate the village-based WeChat platform: "We hope to attract more attention to the village and disseminate our local culture… Several blogs went viral, much more reads than our account followers…"

3.2 Utility Evaluation of Visualisation Tools

Tab.1 illustrates different tools used during the participatory process. Analog tools were mostly adopted at the inventory stage. The design period saw use of a combination of both types of tools, whereas more digital visualisations were utilised during the decision-making process. In the implementation and maintenance phase a combination of both tools was used. Of the seven types of visualisation tools, 3D physical model, photographs, and 3D digital modelling were seen by most participants, with sticky notes and news media being less frequently seen. Stakeholders' evaluation of the ease of comprehension of the visualisation tools was generally positively linked to their helpfulness for discussion. 3D physical models were regarded as the most helpful for comprehension and discussion, followed by 3D digital modelling. Paper maps were ranked the least useful in both metrics.

In relation to inter-group comparisons, groups P and V vary significantly in perceiving 2D digital images and 3D modelling. Among those who evaluated both tools with high ease of comprehension, the scores by Group P (75%, 78%) were twice that of Group V (35%, 36%). Age differences were also a factor in the perception of digital imagery. More than 60% people aged 18–30 considered them to be easy to comprehend and helpful for discussion while the rating for the 61+ group was 20%. Education level was observed to affect the perception of digital visualisation tools. Those holding an undergraduate degree or above felt more comfortable with digital tools compared to those who were at junior-school level or below. Gender did not impact stakeholders' perceptions of the digital visualisations. There were also no significant proportional differences between various stakeholder characteristics (stakeholder category, age, gender, and education level) in perceiving analog tools and news media.

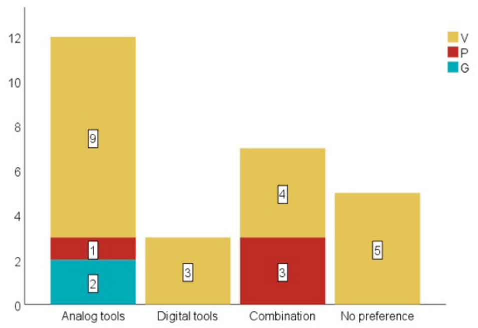
Table 1: Utility evaluation of visualisation tools

Availability during planning phases					**Number of people have seen**	**Ease of comprehension**			**Helpfulness for discussion**		
Category	PP1	PP2	PP3	PP4	Number	Low	Medium	High	Low	Medium	High
Sketch and sticky notes	X	X			22	9%	41%	50%	9%	32%	59%
Paper map	X	X			31	6%	61%	32%	10%	45%	45%
photo	X	X		X	34	0%	50%	50%	0%	44%	56%
Physical model	X	X	X		42	0%	26%	74%	0%	26%	74%
2D image		X	X	X	29	3%	48%	48%	3%	31%	66%
3D modelling		X	X		34	3%	38%	59%	3%	26%	71%
News media		X	X	X	27	0%	56%	44%	0%	33%	67%

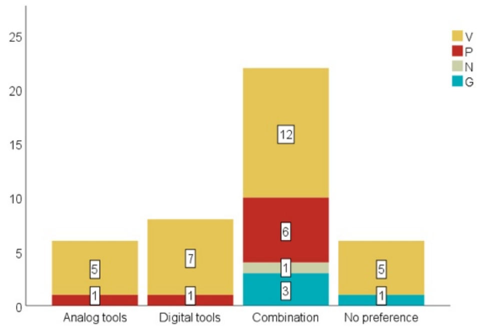
0-25% 26-50% 51-100%

Note: PP1= inventory, PP2=design, PP3= decision-making, PP4=implementation and maintenance; Light grey to dark grey indicates an increasingly stronger view regarding ease of comprehension or helpfulness for discussion.

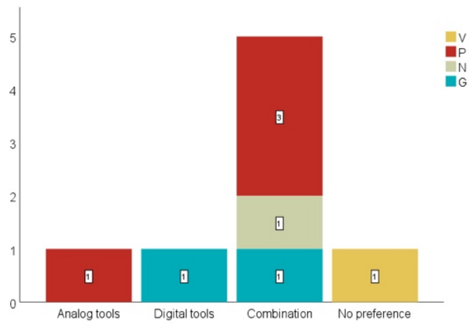
Stakeholders were asked to indicate their ideal visualisation tools for planning communication at each phase they had been engaged in. Figure 3 suggests that the preferences of major stakeholders (Group V, NM and G) moved from using analog tools in the inventory stage to combining analog and digital devices as the project progressed, which were in line with the observed use patterns (Table 1). Group P preferred combining both tools throughout the process. Figure 4-a shows that most stakeholders prefer using 3D physical models among the analog tools. Concerning digital visualisation tools, 3D and more advanced technology were most popular with stakeholders (Fig. 4-b), particularly in the younger generations and those with a higher education degree.



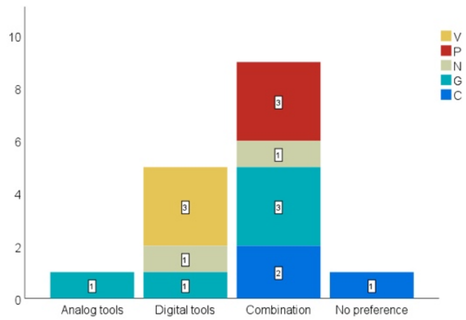
(a) Inventory



(b) Planning and Design

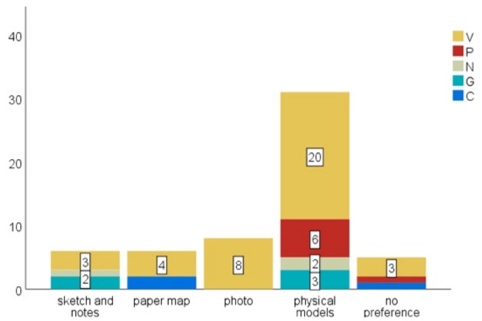


(c) Decision-making

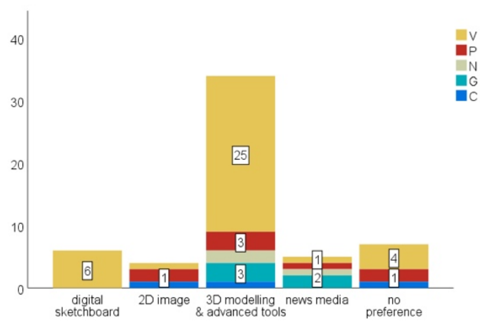


(d) Implementation and Maintenance

Fig. 3: Stacked bar count of stakeholders' preferences for visualisation tools at different planning phases. (a) inventory; (b) design; (c) decision-making; (d) implementation and maintenance



(a) Favourite Analog Tools



(b) Favourite Digital Tools

Fig. 4: Stacked bar count of stakeholders' preferences for visualisation tools: (a) analog tools; (b) digital tools

4 Discussion

The interviews have demonstrated the effectiveness of visualisations in terms of information and communication during the planning process, which corresponds to previous work (HEHL-LANGE & LANGE 2017, WISSEN HAYEK 2011). Visualisation tools with larger dimensions, such as photo exhibitions, design competitions and a 1:1 physical model (Fig. 1-b, e and f), were observed to trigger wider social attention. This confirms Lu et al. (2020) 's findings that landscape visualisations with larger dimensions are more likely to attract and sustain people's attention. This increase in social awareness further contributed to the shift of political attitudes. The findings align with SCHROTH et al. (2015) where governmental policy and operational changes occurred after exposure to visualisations.

Notably, the effects of visualisation related to cultural identity were consistent at various stages, indicating that analog and digital tools could serve as bridges to increase cultural awareness through both intangible elements and material forms. The results reflect those of HEHL-LANGE & LANGE (2017) who also found that participants related their memories and experiences to visualisations. A limitation of longitudinal studies is that some compounding variables (e. g. policy or environment) may also affect the project beyond the roles of visualisation tools. Triangulation methods are needed to complement participants' statements and examine the findings in different contexts.

Both analog or digital 3D visualisation has demonstrated superiority over 2D representation in usability evaluations and preferred items. This has been confirmed by the participants' ratings of various visualisation tools in the workshop experiment by GILL et al. (2013), which could be explained by the fact that 3D visualisations allow viewing the proposed design from multiple perspectives (LANGE & BISHOP 2005). Generally, differences were found in the evaluation of digital images and 3D modelling in terms of aiding comprehension and discussion. These were evident between lay people and experts, the highly educated and less educated, and the young and the old. Studies have shown that experts differ from novices or lay persons in processing image contents (DUPONT et al. 2015). SCHROTH et al. (2015) have also noted the difficulty of the older generation in understanding digital devices.

5 Conclusion

This study has highlighted the effects of analog and digital visualisation tools in the various stages of a planning and design project. It provides implications regarding when and how various tools could be tailored to meet different purposes in various participatory settings. The results indicate that a combination of analog and digital visualisation throughout the participatory process would best suit diverse stakeholders' needs and could potentially cater to a wider audience. It could be used as a basis to develop more detailed visualisation guidelines. We expect advanced visualisation techniques permitting on-site visualisation (e. g. HAYNES & LANGE 2016, HAYNES et al. 2018) to play an increasingly important role in visualisation and stakeholder involvement in the future.

Acknowledgement

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Holographic Construction of Generative Landscape Design Using Augmented Reality Technology

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Abstract: The Augmented Landscapes project is a workshop exploring the making of landscape solely with 3d models and AR devices without any processed drawings. The workshop promoted generative landscape design by inserting landscape elements by utilizing a multi-agent system based on the Boids algorithm. Microsoft HoloLens with the Fologram plugin allowed for a direct and real-time connection between Rhino and HoloLens. This paper documents the process, methods, and findings of the workshop with the holographic construction experience through AR technology.

Keywords: Augmented Reality, Mixed Reality, HoloLens, algorithmic design, smart construction technology

1 Introduction

In recent years, digital manufacturing technology has rapidly developed in the fields of architecture and engineering. Research is being actively conducted on automated construction using 3D printers and robots. However, digital manufacturing technology is often found to be limited when dealing with sophisticated and complex processes. It still relies on human labor owing to the complexity of operations and the fragility of materials (HAHM 2019).

The dependency on human labor is even stronger in the case of landscape architecture, which involves topographical features and planting materials as the main design elements. In the field of landscape architecture, construction technology automation has proceeded extremely gradually, owing to the fragility of the materials held by soil and plants. Automation has been applied mainly to design and documentation processes. It is thus essential to ensure efficient transition from design to construction phases. In this regard, introducing augmented reality (AR) technologies into design and construction processes will prove to be a vital breakthrough for landscape architectural practice.

Although AR is not a new concept, this technology has become mainstream only in the last three years, owing to the development of consumer AR devices (COPPENS 2017). The release of Microsoft HoloLens in 2016 made this technology more accessible to the general public. In particular, its development kit opened this technology up for amateur developers. Since then, architectural researchers and practitioners have increasingly started investigating AR. The examples of the use of AR in physical construction are projects such as Steampunk (Steampunk Pavilion 2019) and the projects from a research cluster – Augmented Craftsmanship – at the Bartlett (HAHM 2019).

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2 Precedent Study

Designers and researchers have used AR construction methods. An exemplary project is the Steampunk pavilion in 2019, designed and built by a team of architectural designers and AR software developers. This project introduced a traditional crafting technique of the steam-bending process. This process has existed for thousands of years but is generally constrained by certain mold shapes, as the process requires timbers to be mounted during the drying process, which usually requires many hours. Conventionally, steam bending has always been performed on fixed molds, as it takes a lot of time to build one mold; however, Steampunk pavilion invented a customized molding system using simple custom-angled racks. These custom racks were placed and manually fixed by professionals wearing AR devices in order to create molds without any blueprints, robotics, or machines. This helped speed up the mold-making process, allowing each timber board to assume different shapes. This project allowed us to understand better how human intelligence and computational accuracy can perform collaboratively.

AR devices are especially useful for providing and guiding accurate spatial locations in large 3-dimensional (3D) spaces. If there exists a precise virtual 3D model, projecting it for human eyes would be easy. However, the physical world is distinctly different from the digital; hence, during the construction process, multiple errors and differences would be encountered when compared to the original digital model. Although AR devices can scan existing physical environments in real-time, the scan is still inaccurate. Accurate scans of the physical world require an additional process in order to feed to digital models for any interaction. In the Steampunk pavilion project, the design team custom scanned physically produced timber boards into a digital model using custom tools (i. e., by digitizing the physical model) only for some areas, as it requires additional customized joints. The project also utilized a design language that allows a high degree of tolerance in design accuracy.

3 Experiment: The Augmented Landscapes Workshop

This paper documents the process, methods, and results of the workshop with the holographic construction experience through AR technology. A workshop was conducted with 12 Masters students as a part of the Augmented Landscapes project. The workshop began by introducing smart construction technology via virtual reality (VR) and AR and sharing the convergent cases in architectural design later. Participants were grouped into three teams. Approximately 30% of the participants did not have prior experience with digital design tools, whereas the rest could perform basic computational techniques. The experiment was designed to test the holographic construction of complex design elements. A circular disc was set as the target site in the Rhino software. The Boids algorithm was used as a generative design tool in order to introduce complexity in the design (REYNOLDS 1987).

3.1 Dealing with Absolute Position vs. Relative Position

From a few AR construction projects, including Steampunk, we learned that augmented methods work exceptionally well when dealing with processes that require digital models to guide to an absolute position (instead of relative position) in 3D spaces. Before explaining further, it is necessary to clarify the difference between absolute and relative positions of parts. For example, an actual world coordinate is an absolute position, but a relative position is the position of a part relative to its adjacent parts. Naturally, in the physical world, and especially in 3D structures, when parts accumulate in the direction normal to the ground, the relative positions of the parts are more important indicators than the initially designated absolute position.

For example, if the construction material/components perform relatively precisely to the actual digital model (such as brick structure), then absolute position stays constant for the entire process. However, if the material is very flexible, the assembly process typically requires a clear understanding of part-to-part relationships instead of their absolute position or orientation. Steampunk pavilion worked out well, having the combination of fixed ground position with the accumulative assembly process between parts, which showed synergy between AR assistance and human intelligence. Furthermore, we also learned that this process has excellent benefits when dealing with groundwork, which usually requires an absolute position in spaces. AR technology has no limitations in scale, and it works better for projecting or scanning larger objects than smaller objects. Therefore, we see much potential of this system used in Landscape design.

Landscape construction typically requires delicate planting processes, which require manual labor; hence, there is considerable benefit in introducing this method to landscape construction. Compared to conventional methods, this method will prove to be more precise in communicating design ideas with creators. Moreover, it will eliminate any complex robotic processes that generally require highly skilled technicians and a long preparation time.

3.2 Generative Design with the Boids Algorithm and C# Library

As the AR construction process is beneficial for combining computer intelligence with human intuition, we have been extremely interested in building and constructing forms that cannot be conceived by the analogue methods. When used as a multi-agent system, computers can often generate geometries that are highly complex yet highly controllable, which usually is difficult or even impossible to be designed or sketched manually. As our proposed

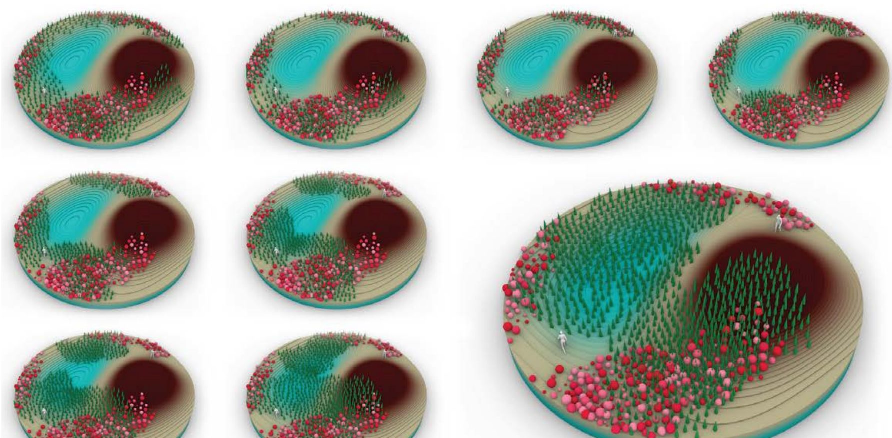

Fig. 1: Design alternatives using Boids algorithm

construction method is already manual, we consider that manual designing is not the best way of applying this method. This is because herein, the computer performs merely as a representative tool (i. e., as a projection tool).

We introduce the Boids algorithms in this workshop for educational purposes in order to elucidate generative modeling methods during the initial design process. This algorithm is widely used for design applications such as wayfinding for crowd simulation. Moreover, it is widely employed by designers who utilize a generative design method to create forms and shapes that cannot be manually designed in conventional practice. The algorithm is controlled by three simple principles: separation, alignment, and cohesion. Furthermore, it is set up such that the overall behavior can be intuitively controlled in real-time.

A grasshopper file with the Boids algorithm was provided as a generative design tool to perform computational design. The grasshopper file's parameter allowed for the generation of infinite design iterations that could be applied to the design of terrain and vegetation. The tools were developed specifically to design nonmanual/computer-generated patterns, shapes, and geometries. A device was used to insert a large number of landscape elements, which reduced the requirement for manual control and increased agent-based control. This is referred to as multi-agent modeling using object-oriented programming.

Although we used the Boids algorithm to mimic crowd behavior and populate a large number of elements, we noted the more significant potential of extending this tool, as there are various ways of translating this algorithm to manifest different types of geometries. It is also possible to translate the resulting data sets into a collection of useful information for the future design process.

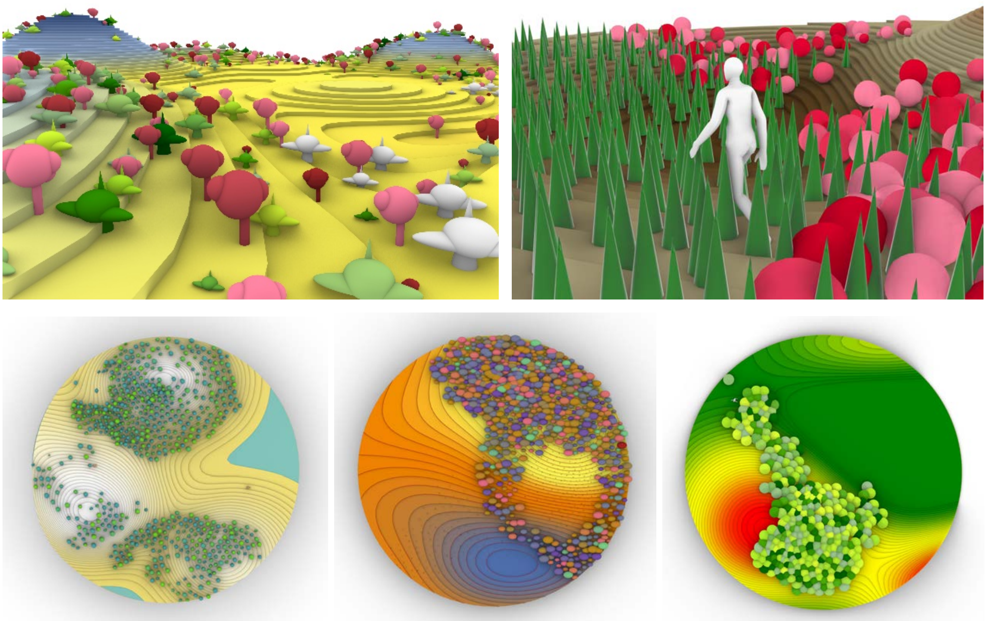

Fig. 2: Perspective views and plans of 3D model

C# was used as the primary coding language. It was compiled with the RhinoCommon and Grasshopper APIs and organized as a Rhino Grasshopper library to enable complex text-based coding that can be easily accessed and used by nonexperts. Even though C# is programmed in a text-based coding platform, it can be used within the Rhino Grasshopper platform because it is compiled as a library. The entire process from designing to fabrication could be performed within the same software environment as generative design, and AR communications were controlled within the Rhino software. This process provided a designer-friendly interface and a fluid design for production workflow.

3.3 Microsoft HoloLens and Fologram

We used Microsoft HoloLens as the primary hardware device and Fologram as the leading software to project a holographic template to be experienced in the real world at a 1:1 scale. Fologram is a plugin that was mainly developed to simplify the link between Hololens and 3D modeling software, as most of the AR operating software are game engines such as Unity3D or Unreal. This game-making software is often potent in dealing with interaction, interface, and simulation. However, they usually are not very good at dealing with modeling. Fologram enables designers to rapidly and efficiently deploy virtual models to Microsoft HoloLens. Users can make real-time changes; this allows for quick review. This experimental setup, involving Microsoft HoloLens with Fologram plugin in the Rhino Grasshopper environment, has the same tools as those used in the Steampunk Pavilion.

Introducing Fologram allows us to manipulate geometries in our typical design environment while being able to add AR functionality simply. Fologram currently only operates in Rhinoceros; therefore, it became our chosen software platform for our design exercise. Also, this platform has great potential in developing custom tools using scripting. It became a perfect environment to start exploring our research agenda.

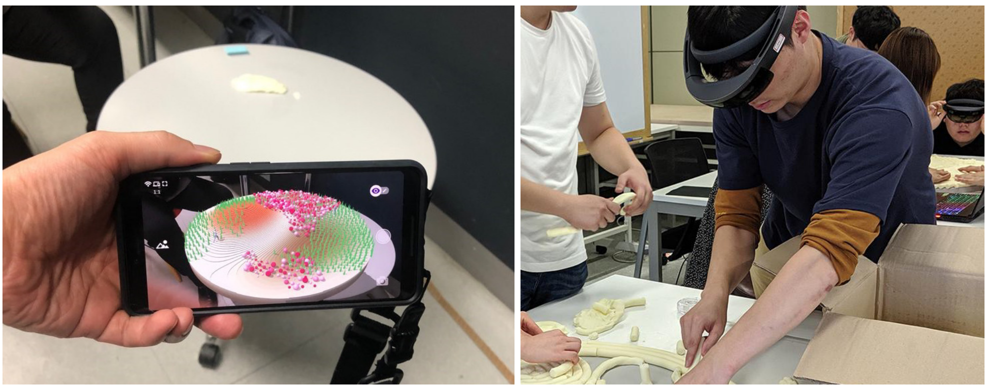

Fig. 3: Augmented reality by Fologram and model making with Microsoft HoloLens

Holographic lenses were used as the primary design communication tool for creating physical models. Using Microsoft HoloLens, the result of the generative design was virtually floated over a wooden disc with a diameter of 70 cm to create a stereoscopic model. A set of HoloLens was provided to each team. The holographic leader of the team reviewed the design as an augmented instruction for the on-site construction of a physical model. A topography was created using ivory-colored modeling clay by adjusting the height to match the holographic model.

3.4 Results

The results of the workshop were evaluated via exhibitions and reviews. Participants indicated positive responses to intuitive instructions and immediate communication. The most acknowledged advantage was that the process of creating stereoscopic models using HoloLens did not require a large amount of processed data and that it printed base drawings, or sketches.

Program tutorials with algorithm design and model creation using AR technology required five hours, which was perceived as a reasonably short duration compared to the conventional design and model-creation processes using drawings and sketches. The limitation was that the narrow viewing range of HoloLens reduced the impact of immersive experiences, and the requirement for efficient communication methods between holographic leaders and general users was discussed.

Fig. 4: Final presentation and 3D projection

4 Conclusion and Discussion

This research contributes as one of the first experiments that use mixed reality in landscape architectural design and construction processes. The workshop promoted generative landscape design by inserting landscape elements by utilizing a multi-agent system based on the Boids algorithm. Microsoft HoloLens with the Fologram plugin allowed for a direct and real-time connection between Rhino and HoloLens. Therefore, we could execute real-time generative design elements by constructing virtual models in physical materials directly from designs without any printed drawings.

AR/VR technology is being mainly developed and used in the entertainment industry. Most hardware/software is developed for gaming purposes. In the architecture and landscape fields, AR is still mainly utilized as a representative tool. However, we consider that this technology has potential beyond being a virtual experience provider or representational tool. We consider that this technology can help us shape our physical reality instead of remaining in the virtual world. For this reason, Fologram is an excellent example for AR/VR developers to consider the out-of-the-box application of this technology and actively develop more creative and insightful methods of applying this technology in different fields (JAHN et al. 2019).

There are still numerous technical limitations, mainly owing to the amateur use of the hardware device, the limitations of viewport size, the resolution of projected images, the weight of headsets, and the sensitivity of the device in a bright environment. The second generation of Microsoft HoloLens appeared to overcome the majority of current limitations. We believe that advanced development in this technology will flourish.

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UAV Imagery and Remote Sensing in Landscape Architecture

UAV Photogrammetry, Lidar or WebGL? A Comparison of Spatial Data Sources for Landscape Architecture

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Abstract: This article deals with a comparison of spatial data from different sources for the needs of landscape architecture. These include data acquired from public providers, the government (geoportals) and commercial map servers utilising WebGL (Mapy.cz, Google), and data obtained using UAV (drone) photogrammetry. The motivation for this is that the development of UAVs has allowed us to get new data very quickly and cheaply. However, in order to clearly justify the need for their use in landscape architecture projects, we need to compare them to other commonly available and used data sources. Emphasising the possibilities and appropriateness of using UAV data is important, but it is equally important to know when other data sources are more appropriate.

Keywords: UAV photogrammetry, WebGL, spatial data

1 Introduction

This article deals with a comparison of publicly available spatial data with UAV (Unmanned Aerial Vehicle) data obtained by the photogrammetry method. In the beginning, we asked the following questions: What spatial data are available to us? How do they compare to the data acquired from a UAV?

We currently use a variety of digital technologies that allow us to improve workflow in landscape architecture. One of them is UAVs – drones that offer us a variety of different options. These options are often unexplored, and so there is an effort to look into them more deeply. This gives us a literally new perspective, especially in relation to digital landscape modelling.

The basis for all landscape planning is spatial data. Spatial data from the perspective of this article are those that capture real space in exact XYZ coordinates from which a surface (mesh) can be generated and/or directly provided data in the form of a surface model. Such data allow us to analyse the surface differently, to measure accurately and perhaps even to create visualisations of the landscape. There are a number of possible ways to obtain spatial data. We can divide the methods of acquiring these data into direct and indirect. The aim of this article is not to describe and compare all known methods, just the most accessible and most frequently used ones. The difference between these methods is shown in Table 1. Price data provided in the table are relative and should be seen in the context of area size and level of accuracy (the larger the area – the higher the price, the greater the accuracy – the higher the price). All data are based on the conditions present in the Czech Republic. € represents very cheap acquisitions, €€ and more represents higher prices.

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Table 1: A table comparing direct and indirect data acquisition methods

Data acquisition:	Method:	Precision(m):	Acquisition speed:	Price:	Area size:
Direct methods	Theodolite	0.01-0.05	**	€€€	O
	RTK GPS	0,.02-0.1	**	€€€	OO
	Laser scanning	0.01-0.1	***	€€€€	O
	UAV Photogrammetry	0.03-0.1	****	€€	OOO
Direct methods/indirect methods	Airborne laser scanning	0.1-1	*****	€€€€€€	OOOO
	Airborne photogrammetry	0.1-1	*****	€€€€€€	OOOO
Indirect methods	Spaceborne (Remote sensing)	1-20	**	0-€	Any size
	Digital cadastre	0.1-0.2	*	0	Any size
	DTM/DSM	0.2-1	*	€	Any size
	Map source	By Map Scale	By sourse	0-€	Any size

Direct methods are those methods whose parameters we can directly influence. The form of influence can either be that we directly choose when and how the data are acquired, or we obtain such data by taking hand measurements. The conditions we can directly influence include acquisition time (day, time of day, time of year), the level of precision of the technique or method used, prioritisation of capturing certain elements or properties more precisely, and others. Examples of these methods are theodolite, GPS RTK, laser scanning, and UAV photogrammetry. Aerial laser scanning and aerial photogrammetry are at the frontier of both direct and indirect data acquisition methods. Such data can often already be bought pre-made for a specific territory, or we can have them processed – flown, but this solution is very expensive. Indirect methods are those that do not allow us to directly define our requirements. We need to be satisfied with the quality and form of processing that the provider has designated.

2 Spatial Data Acquisition

It should be said at the outset that we focused on the size of objects and on the scale of the landscape. For the purposes of this article, this scale was set to range from hundreds of square meters to the low tens of hectares. For objects within a few hundred meters, other methods, such as precise GPS measurements, would more often be appropriate, and for the needs of higher tens to hundreds of hectares, UAV use no longer makes any sense. This paper is focused on the use of 3D models, therefore the term spatial data is used for elevation (digital surface and digital terrain models) and orthophotomaps.

The potential of UAV use and the current possibilities associated with it have been addressed by a wide range of authors such as Rekittke (REKITTKE, NINSALAM & PAAR 2015), Girot (LIN & GIROT 2014), Gerke (GERKE 2018), Siebert (SIEBERT 2014), Yazici (YAZICI 2018) and many others. The authors of this article sampled dozens of sites across hundreds of images in several examples, and so can compare these methods with various other methods, such as geodetic measurements, laser scanning, and others. To evaluate the potential, we used and modified a chart published by Eisenbeiß (EISENBEIß 2009).

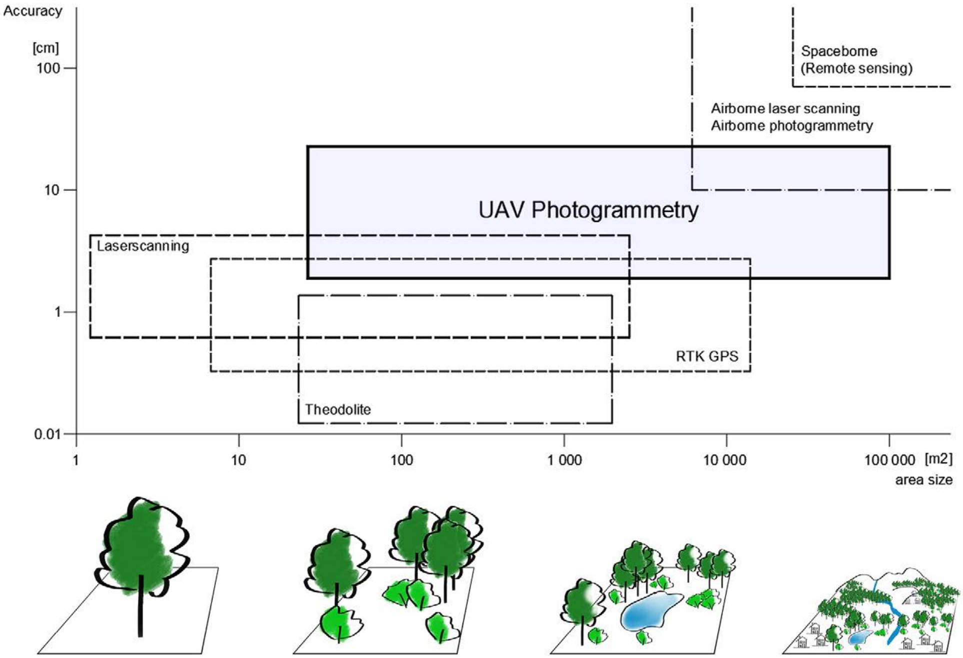

Fig. 1: The potential to use UAV in terms of precision and scale of object solutions. Modified and updated after Eisenbeiß (EISENBEIß 2009)

2.1 The Potential Use of UAV Photogrammetry as a Direct Method

UAV photogrammetry as a method for accurately capturing space is well established in the field of landscape architecture (CURETON 2016, KULLMANN 2018). This method consists of an automated viewing of the area under consideration along a pre-defined route at a specific height and by providing an overlay of individual images. We can use both classic RGB cameras and various special cameras such as multispectral and thermal cameras. Subsequently, such images are processed by specialised photogrammetry software using the structure obtained from motion (SFM) and multi-view stereo methods. Although all current UAVs write GPS coordinates onto each individual image, this information is not accurate enough for precise processing and subsequent use for taking accurate measurements or making designs. Either ground control points (GCPs), or precisely targeted points identifiable in images taken by GPS RTK (real-time kinematic positioning), or if the drone itself already possesses GPS RTK, need to be used for those activities that require precision.

The UAV photogrammetry method has a number of advantages, such as the timeliness of the data (both the imaging and processing are very fast), the easy repeatability of the imaging, its relative cheapness, high degree of accuracy (about 5 cm vertically and approximately 5-10 cm horizontally) and the primary data source itself – the point cloud is composed of tens of millions of points (depending on the technique and settings chosen). We can thus obtain good evidence useable for various design processes (concept, design, studies, project, presentation). One of the main drawbacks, or rather characteristics of the method, is that only the surface is captured in the images. It is therefore not possible, for example, to capture undergrowth, other objects under trees, an individual tree within a group, the terrain when vegetation overlaps, etc. Other disadvantages are their limited or problematic use in certain locations such as in cities or legislatively protected natural areas. There are also limits in the processing of vegetation (great simplification of complex structures) and this method uses sophisticated techniques that quickly become obsolete (drones, cameras, batteries).

2.2 Data from Public Providers or the Government

The first source used for making a data comparison with UAV data is that obtained from public providers. In Europe, there are a variety of local services, both public and private, that provide such data, but whether they are available, at what level of accuracy and under what conditions (free or paid) varies from one country to another. This article primarily addresses the situation in the Czech Republic. In respect of elevation data, the most prevalent method used for obtaining such spatial data is aerial imaging using Lidar. The resulting data types are a digital terrain model (DTM) and digital surface model (DSM). The accuracy is determined both by the parameters of the method chosen and by the resolution provided (points per $1m^2$). Standard accuracy is from 10-30 cm or more depending on land cover at a resolution 2×2 meters to one point. These data are most often aggregated into Geoportals that allow us to view these data online. We can often work with these using GIS via connecting WMS (Web Map Service) services in preview quality, or buying them in full quality. One great advantage is that they are often available in preview quality for free, and even this allows for making complex analyses in GIS. Another advantage is their coverage across the entire landscape. Drawbacks include the fact that they are updated only every few years, they have no surface texture and their level of accuracy is too low for some needs such as visualisations.

2.3 Data from Web GL

The second potential public resource is from publicly available map portals that provide a 3D view. Examples of such a resource include Google 3D Maps, Google Earth, Mapy.cz and Apple’s 3D Maps. These data can be viewed using the WebGL, JavaScript API for rendering interactive 2D and 3D graphics within any compatible web browser without the need to use any plug-ins.

Their acquisition and further use is possible thanks to this type of web view. For the purposes of this article, we used a process created by Élie Michel and available via github (ÉLIE 2020). The process consists of creating a screen shot using RenderDoc and then importing it into Blender, where we can directly work with it or export it for use in other 3D programs such as Sketchup, 3DS Max, Rhino and others. To be able to import into Blender, Elie Michel has created the MapsModelsImporter plugin (ÉLIE 2020), which transforms data captured as print screens using RenderDoc. The main drawback of these data sources is that they are not georeferenced and need to be manually georeferenced. So the level of accuracy is always lower. Another drawback is that these data are currently available primarily for large cities, and their updates, like DTM/DSM, occur only every few years. Their greatest advantage is their very high level of quality and easy accessibility (compliance with the licensing conditions of each provider).

3 Methods for Making Comparisons of Spatial Data Sources

As general criteria for making comparisons, we chose their suitability for each design phase (concept, design, studies, project and presentation), their free availability, and above all, their level of accuracy. As mentioned earlier, the article looks at the size of objects on a landscape scale that is hundreds of square meters to the low tens of hectares. Planning and designing projects on this scale generally does not require very high spatial data accuracy for the whole territory. The requisite level of precision is very different depending on the type of project and intent (adjusting the surfaces x creating new structures), but in general it can be said that the requested level of precision will be in units of 10-20 cm so that we can work with these data appropriately. The level of accuracy itself is determined by the measurement error and by the number of points per square metre.

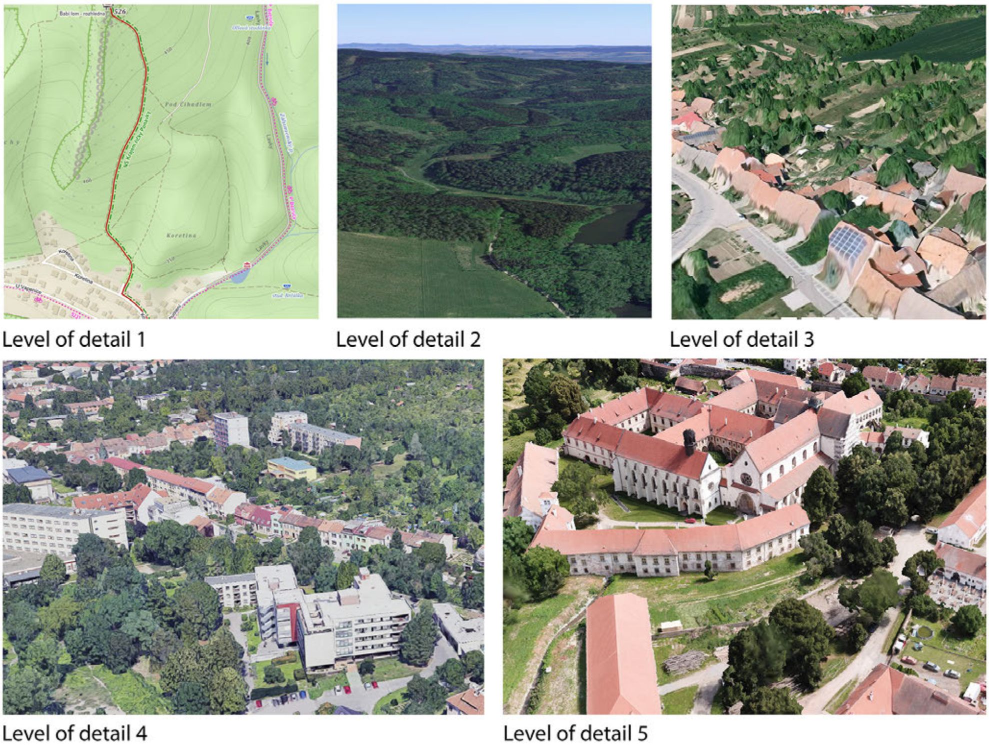

Fig. 2: Examples of models according to LOD 1-5
LOD 1: 2D data only, spatial data only as contour and shadow terrain
LOD 2: Basic 3D view – An orthophotomap on the surface from contour lines
LOD 3: DSM covered by an orthophotomap (Low detail, problematic vegetation display)
LOD 4: Processed by photogrammetry, high level of detail, low geometric precision
LOD 5: Very precise and a high level detail, comparable to photography

This determination of accuracy (deviation and resolution) is not appropriate when assessing WebGL data, where the accuracy itself is determined by the georeferencing method and will therefore always be very small relative to other types of data. However, these data are often very valuable for their "appeal" because they often contain very good texture. Similarly, data obtained by Lidar (DMT, DSM) can be very accurate, but if they do not contain texture, for example, they are unsuitable for visualisation.

As a result, to make a comprehensive comparison we chose a modified method – level of detail (LOD) according to CityGML. This method was published by the Karlsruhe Institute of Technology (KIT) and can be considered the standard (Vo 2019, Agugiaro 2015). We adapted this method for our needs primarily from the perspective of "appeal" precision and type of data.

4 Case Study

The selection of the area was based on criteria such as the significance of the object from the perspective of landscape architecture, the fact that it contains different types of compositional elements (structures, trees, shrubs, roads, etc.), there are data available for making a comparison and the object has not been renovated, so its current state needs to be captured well.

Porta Coeli Convent

The selected area is located in the city of Předklášteří, approximately 25 km from the city of Brno, in the Southern Moravian Region in the Czech Republic. It is a historic monastic compound that was established in the 13th century. The current state of public spaces is not good and they need to be revitalised. For this purpose, it was necessary to prepare a study that incorporated the requirements of various institutions and users of the area (monument protection, the Cistercian Order, the forest administration, a museum and a brewery). As a result, to process the study, it was necessary to have basic spatial data of the current state. Due to the size of the area, a solution was sought that could be more efficient and cheaper than a detailed classical geodetic survey. The question was asked whether or not it was possible to use commonly available spatial data from public providers if it was necessary to use the acquisition of spatial data using UAVs. A capture using UAV photogrammetry was primarily to examine the use of such data for the design stage Design-study and presentation using visualisations.

Data Acquisition

From freely available data, we used data obtained from the Czech Geodetic and Cadastral Office (CUZK [online]). They provide a variety of mapping materials such as a digital cadastre, digital and raster maps, orthophotomaps, archival imagery and, for our purposes, primarily DSM referred to as DMP 1G (Fig. 3 part A) and DTM referred to as DMR 5G (Fig. 3 part B). For DMP 1G, the reported data deviation is 0.4-0.6 m for DMR 5G, and the reported data deviation is 0.18-0.3 m. The available resolution via WMS in ArcGIS is 5 x 5 meters to one point, and after purchasing full quality (10 euros for a 2.5x2 km map sheet), this resolution is 3-5 points per meter. The quality of this data from the LOD point of view is LOD 3 for DMP 1G and LOD 2 DMR 5G (if we texturise them using an orthophotomap).

The second source of data used for making a comparison was data from WebGL. For this area, they are available from the map portals Google Maps (Fig. 3 part C) and Mapy.cz (Fig. 3 part D), but only the data from Mapy.cz have good quality LOD 4. Google only has a quality LOD 2. For the obtained data, we used the Élie Michel (ÉLIE 2020) method mentioned above. For georeferencing, we used data obtained from DSM DMP 1G.

Fig. 3: (A) Digital surface model DMP 1G – LOD 3 maps, (B) digital terrain model DMR 5G – LOD 2 maps, (C) Google Maps 3D view, (D) Mapy.cz 3D view

To obtain data from a UAV, we used a DJI Matrice 210 with an X4S camera. In general, if you want to fly in this type of territory, a license to fly is required (it is a "specific" category according to EU rules), and you need to have a permit from the facility administrator to operate the flight. The Pix4D capture planning application was used for the flight planning, which enables users to precisely set flight parameters for automated flying. Flight altitudes of 60 and 80 meters was chosen. The camera angle was chosen to be 70 °, and the overlap of individual images was 80% forward and 70% sideways. The flight was planned in a double grid. Ground control points were targeted using GPS Trimble Catalyst D1. The acquired images were processed using Reality Capture. One great advantage of this program, in addition to having good calculation results, is the good possibilities it offers for editing the data obtained in this way. For example, you can delete trees, smoothen areas, reduce the number of polygons, and then have them re-textured again. The output we get is relatively good quality, but not a large mesh with very good texture. Of course, we can also work with an original point cloud, such as choosing individual points, generating contour lines and otherwise analysing and measuring them. Furthermore, we can also export this data to AutoCad, GIS, Sketchup and other commonly used design software.

Fig. 4: Mesh created with Reality Capture

5 Results

In our case study, Porta Coeli Convent, we verified what data are freely accessible and also acquired data from a drone using DJI Matrice 210.

Further work with the data after their acquisition consisted in modifying the data with AutoCad, on the basis of which a proposal was prepared. For this purpose, a combination of data from the digital cadastre, a contour generated from DSM – DMP 1G and orthophotomaps obtained by UAV photogrammetry was used. The contour lines generated from the UAV point cloud are much more accurate, but they do not cover the terrain under the trees, which is unsuitable for design purposes. After removing the vegetation, we get DTM, but it is very inaccurate compared to DMP 1G. The orthophotomap obtained from the UAV was used to redraw the edges of surfaces, draw the positions of trees and specify the boundaries of buildings (more accurate than the digital cadastre).

Based on the data acquired in this way, a design was prepared and was transferred to a 3D model. A modified mesh model from the UAV was used as the basis of the model. This model was first modified and simplified in Reality Capture and then the design in Sketchup was modelled into it. By comparison, the WebGL model had very few polygons and a much worse surface texture. However, for some purposes, such as having a simple concept or a basic bird's-eye view, this method would be sufficient.

In general, we can say that for the chosen location there is a variety of data available such as the digital cadastre, DMT, DSM, Google 3D Maps, and the Mapy.cz 3D view. But because the data had to be much more accurate for the chosen purpose, UAV photogrammetry proved to be the appropriate solution. An overall comparison of the publicly available data with the data captured by the UAV is shown in Table 2. This table shows that other data are suitable or sufficient for different uses. It can therefore be concluded that for some uses where it is not necessary to have accurate background, we have a plethora of other sources available. However, for obtaining a more accurate background, a method using UAV photogrammetry may be appropriate.

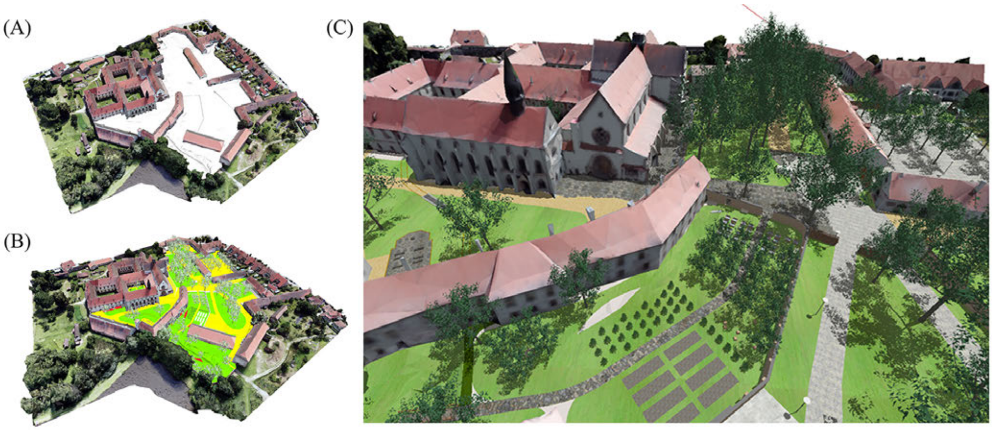

Fig. 5: (A) A cleaned 3D model before adding the design, (B) a 3D model with added surfaces, vegetation and outdoor furniture, (C) the final 3D model with texture

Table 2: A comparison of spatial data sources according to given criteria
* The accuracy depends on the georeferencing method
** According to the resolution provided by the map server
*** The usual accuracy is hundreds to thousands of points depending on the selected processing method, shooting distance and resolution of the camera used
ø symbols represent the usability scale, where ø represents poor, øø represents okay, and øøø represents good

	Free availability	Precision (LOD)	Accuracy (m)	Accuracy - number of points per m2	Usability for concept	Usability for design	Usability for studies	Usability for project	Usability for landscape visualization
3D maps (WebGL)	•	1-4	*	**	øøø	ø	ø	ø	øø
DSM/DTM	•	3	from 0.2	3-5	ø	ø	ø	øøø	ø
UAV		4-5	from 0.05	***	øøø	øø	øø	øø	øøø

6 Discussion

To conclude, it may be problematic to transfer the results and workflow we used to another model territory, and more importantly, to another country. In the country where this study was performed, there is generally a large amount of available data and mapping material of a sufficient quality. As for the WebGL method itself, it is particularly suitable for use in large cities, which are mainly available on Google with a good level of quality, and it can be expected that this trend will continue to expand as individual methods improve. One advantage of the country in which this study was performed, Czech Republic, is that it is completely covered by a 3D view in Mapy.cz in LOD 3-4, so it is often possible to choose a better quality map table. Regarding the use of UAV photogrammetry, this method can be problematic in many countries depending on the local legislative rules. Another problem associated with the use of UAVs in populated and built-up areas is the potential for high hazards. This should also be kept in mind when choosing a suitable method for obtaining spatial data.

Acknowledgements

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Ecological Connectivity Networks for Multi-dispersal Scenarios Using UNICOR Analysis in Luohe Region, China

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Abstract: Habitat loss and fragmentation are increasingly disrupting natural ecosystems across the world, especially in areas that have experienced extensive recent anthropogenic land use change. Evaluating multi-dispersal scenarios of ecological connectivity networks provides an important means to evaluate how dispersal ability influences the prediction of optimal ecological networks. Few examples exist of the dependence of connectivity networks on the scale of dispersal ability used in the analysis. In this study, we performed supervised classification to map land use types using Landsat 8 imagery, then used Morphological Spatial Pattern Analysis and Conefor to identify important core areas for biodiversity, and finally used UNICOR to simulate the resistant kernel and factorial least-cost path connectivity networks. Our main results show: (1) Species with dispersal abilities of ≤ 2 km showed generally low connectivity in most areas, with core areas of high connectivity mainly in Luohe central area, Linying county and Wuyang county, and major corridors were restricted within the Luohe central area, Linying county and Wuyang county. Species with dispersal abilities of 4 km and 8 km showed a network of connectivity with multiple pathways connecting the interior of the study area. Finally, species with dispersal abilities of ≥ 16 km showed high connectivity levels and appeared fairly insensitive to current configurations of human development in the study area. (2) Intensely developed areas may be obstructing species movements into the southeastern and northeastern parts of the region. The green space along roads and rivers may facilitate movement and promote connectivity. In future planning, planners should consider ways to enhance ecological connectivity networks, such as identified in this study, for conserving species with limited dispersal range.

Keywords: Ecological network, dispersal ability, resistant kernel, factorial least-cost path

1 Introduction

With the rapid increase of industrialization and urbanization, natural ecosystems and ecosystem services in China are experiencing landscape fragmentation and degradation due to urban sprawl (PENG et al. 2018, UPADHYAY et al. 2017). In effect, landscape fragmentation and degradation cause habitat loss and impact the movement of species (CLOSSET-KOPP et al. 2016). Thus, maintaining landscape connectivity and mitigating the fragmentation of habitat may be critical for ecological processes such as gene flow, dispersal and migration (RUDNICK et al. 2012). Ecological Networks (ENs) can provide conservation solutions to mitigate the damage caused by intensified land use (JONGMAN 2008) by promoting landscape connectivity and reducing landscape fragmentation (UPADHYAY et al. 2017) through facilitating gene

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flow, migration, dispersal of species (RICOTTA et al. 2000). Therefore, an optimized ecological network (EN) spatial pattern is of great significance for the sustainable development of urban and rural ecosystems (RUIZ-GONZÁLEZ et al. 2014).

While several studies have assessed ecological network connectivity for species of conservation concern in many parts of the world (e. g., CUSHMAN et al. 2014 and 2016, KASZTA et al. 2019 and 2020, ASHRAFZADEH et al. 2020), relatively few have explicitly evaluated the sensitivity of these network predictions to the dispersal ability of focal organisms. This is particularly important, as dispersal ability has been shown to be the most important factor affecting functional connectivity in several taxonomic groups (e. g., CUSHMAN et al. 2010a, ASH et al. 2020). The few ecological network assessments that have explicitly assessed the effects of dispersal ability have found strong influences on predictions and conclusions regarding conservation recommendations (e. g., CUSHMAN et al. 2010a, 2013a and 2016, RIORDAN et al. 2016, MACDONALD et al. 2018).

Despite being one of the largest nations in the world, with the world's largest population and one of the fastest-growing economies, there have been relatively few landscape-scale assessments of the structure, function and optimality of ecological networks completed in China. In 1979, Three-North Shelterbelt was the first exploration of ecological construction to improve the desert environment in China. After the 1990s, the Chinese government announced a set of urbanization policies which resulted in the creation of vast urban development, but also the first coordinated efforts to enhance green areas for health, aesthetic and biodiversity values. These included initiatives such as Landscape Garden City, Forest City, Ecological Garden City and City in the Park. In recent years, national planning in China has increasingly considered the security and health of ecological processes to protect ecosystems systematically (PENG et al. 2018).

Luohe city was designated a National Landscape Garden City in 2002 and National Forest City in 2010, which have directed development to enhance green open space for the physical and mental health of residents. Its developments of ecological connectivity networks and green urbanization represent an example of a national focus on green development. While Luhoe is a focus of green development, there has been relatively little quantitative and analytical work to assess the effectiveness and optimize the future development of green infrastructure in the region. Little is known about how multi-dispersal scenarios can influence the ecological connectivity network in the Luohe region. To provide this critical information, we applied the UNIversal CORridor and network simulation model (UNICOR) (LANDGUTH et al. 2012) to map the ecological connectivity networks for multi-dispersal scenarios in Luohe region, China, where intensive construction activities over the past several decades have resulted in massive and rapid land use change and reduction in natural ecosystems and habitats. We have three goals: (1) to map and compare resistant kernel maps at multi-dispersal scenarios, (2) to map and compare factorial least-cost paths at multi-dispersal scenarios, and (3) to rank conservation orders of ecological connectivity network.

2 Study Area

Luohe region is located in central Henan province (113º27′ – 114º16′E, 33º24′ – 33º59′N) and is characterized by varied topography of plateau and hills in the west and lower riverine valleys in the east. The total municipal territory of Luohe region is 2617 km^2, including

Yuanhui district, Yancheng district, Shaoling district, Wuyang county and Linying county (Figure 1), spanning 76 km from east to west and 64 km from north to south. Luohe city is developed along Sha and Li rivers which meet in the central area.

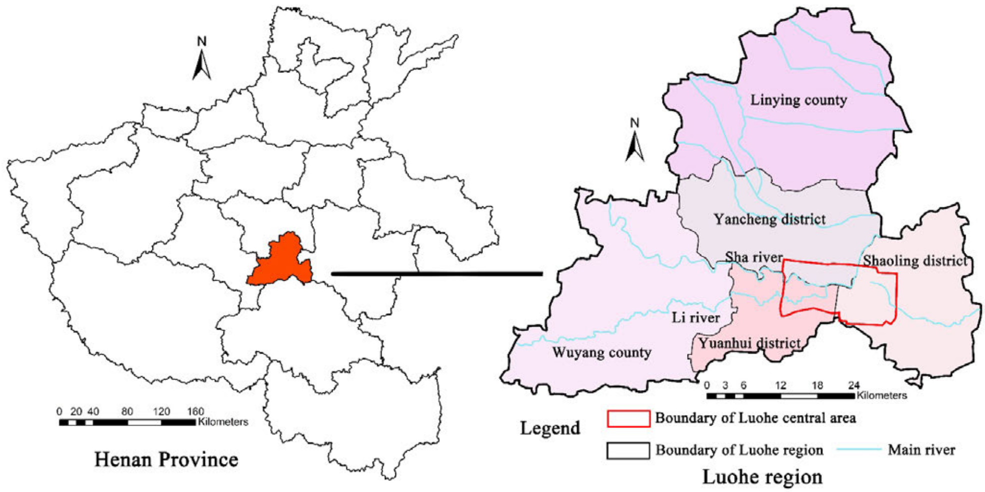

Fig. 1: Location of Luohe region within Henan Province

3 Methods

3.1 Multi-dispersal Scenarios and Ecological Source Selection

We evaluated connectivity network predictions across seven dispersal thresholds, including 1 km, 2 km, 4 km, 8 km, 16 km, 32 km, 64 km (MATEO SANCHEZ et al. 2013), which follows power two scaling to span the scale of the study area and the potential dispersal ability of most native species. In this way, we evaluated a general sensitivity of ecological network predictions to dispersal for species associated with green space.

3.2 Remotely Sensed Image Acquisition and Preprocessing

1) **Image acquisition.** We downloaded two Landsat 8 images on June 14, 2019 and July 7, 2019 (Resolution: 30 m; Coordinate system: WGS_1984_UTM_zone_50N and WGS_1984_UTM_zone_49N respectively) from EarthExplorer – USGS (INTERNET 1. 2021). At that time the wheat in Henan province was fully mature, with a distinctive yellow color, and as green space is characterized by high reflectance in the green wavelengths, it is possible to distinguish green space and farmland spectrally with great accuracy.

2) **Image preprocessing.** In ENVI 5.3, we used Radiometric Calibration and FLAASH Atmospheric Correction functions to produce two maps, then clipped them using the boundary of the Luohe region. Because the whole Luohe region involves two images, classification accuracy was not high at the edge of the maps when we mosaicked them. Classifying them first then mosaicking them solved the problem.

3) **Classification.** We selected five types of the land cover of interest – green space (e. g. forest, grassland, shrubland, orchard, urban green area), farmland, water surface, road and built-up area (AQSIQ, SAC. 2017), and performed a supervised classification to prepare land use/land cover (LULC) map using Support Vector Machine Classification in ENVI, then we input two classification maps into ArcGIS to mosaic them using Mosaic To New Raster function (Figure 2).

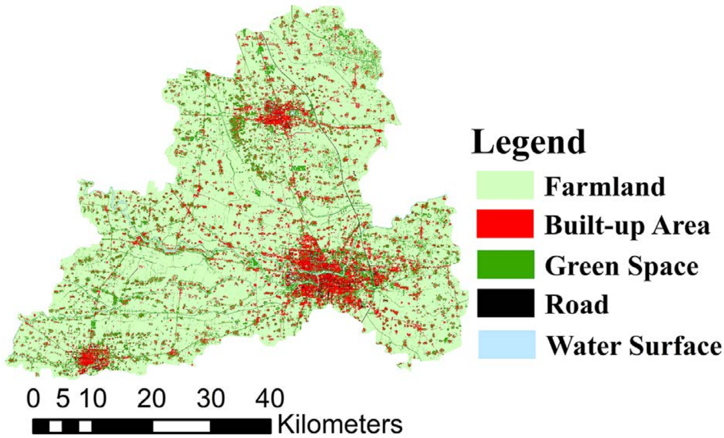

Fig. 2: LULC classification of Luohe region

4) **Accuracy assessment.** We chose 100 ground truth points on a Sentinel-2 image (Resolution: 10 m) on September 30, 2019, to test the accuracy of classification using the Confusion Matrix Using Ground Truth ROIs function in ENVI.

5) **Fragmentation analysis.** Calculated five class metrics including Patch Density (PD), Percentage of Landscape (PLAND), Radius of Gyration_Area-Weighted Mean (GYRATE_AM), Edge Density (ED), and Aggregation Index (AI) in Fragstats (MCGARIGAL et al. 2002 and 2012) to quantify the structure and composition of the land use mosaic. These metrics were chosen given past research that demonstrated their utility in species environment relationship modeling (GRAND et al. 2004, CHAMBERS et al. 2016), and connectivity and gene flow modeling (CUSHMAN et al. 2013b and 2012b). The ecological meaning of these metrics can be found in (CUSHMAN & MCGARIGAL 2008, CUSHMAN et al. 2008, CUSHMAN & MCGARIGAL 2019).

3.3 Identifying and Ranking Core Areas

We used two criteria to evaluate the importance of core areas of green habitat.

1) The size of green space, since species often have minimum patch area requirements to occupy and persist in a habitat patch. To accomplish this, we reclassified the land use types in ArcGIS. We set the value of green space is two as foreground, the value of other land use types is one as background, then input the data into GuidosToolbox and conducted Morphological Spatial Pattern Analysis (MSPA) (SOILLE & VOGT 2009). The green space was divided into seven classes – core, branch, edge, islet, bridge, loop and

perforation. The core is defined as areas of large extent of green space, the islet is defined isolated pixels unconnected any other pixels, the bridge and loop are connectors linking core areas, edge and perforation are the outer and inner boundaries of habitat patches, the branch is connector linking one end to a habitat patch (SOILLE & VOGT 2009, CARLIER & MORAN 2019). Then we chose class metrics of PD, PLAND, GYRATE_AM, ED, AI to measure the spatial pattern of each type of green space. Among them, we extracted Core as core areas, then we selected all core with areas greater than 50,000 m^2 for inclusion in the next analysis.

2) Degree of Probability of Connectivity (dPC), representing habitat availability and connectivity (HOFMAN et al. 2018). We used Conefor 2.6 to identify the important nodes, and chose core areas whose dPC is larger than 1 to represent the important nodes for the connectivity network across the Luohe region. Then we calculated landscape metrics of PD, GYRATE_AM, ED, AI to measure the landscape pattern of important nodes.

3.4 Ecological Connectivity Network Mapping and Evaluating

The UNIversal CORridor and network simulation model (UNICOR) (LANDGUTH et al. 2012) includes two approaches for quantifying landscape connectivity. The first approach is resistant kernel modeling (COMPTON et al. 2007). Resistant kernel modeling predicts the incidence function of the rate of expected movement from a defined set of source locations cumulatively through a landscape (CUSHMAN et al. 2012a) for every pixel in the study area, rather than only for a few selected "linkage zones" (COMPTON et al. 2007). The second approach is factorial least-cost path modeling (CUSHMAN et al. 2009). Factorial least-cost path modeling predicts movement corridors and corridor strength (CUSHMAN et al. 2013c) for species with multi-dispersal abilities.

1) Resistance Surface. Based on the literature review (YIN et al. 2011, JIANG et al. 2016) and the purposes of this study, we set the resistance values of green space, water surface, farmland, road, built-up area is 1, 10, 30, 90, and 100 respectively.

2) Source points. We extracted centroids of the important nodes from Conefor to be the source points.

3) Resistant kernel modeling and factorial least-cost path modeling. We input resistance surface and points location in UNICOR and predicted resistant kernel and factorial least-cost path networks for each dispersal ability threshold.

4) Ecological connectivity network evaluation. We used the function of Raster Calculator in ArcGIS to standardize values of resistant kernels in order to compare the differences of multi-dispersal scenarios. We overlapped the resistant kernel & factorial least-cost path and main road & main river to show the location of the paths.

4 Results

4.1 Land Use Classification

Accuracy assessment (Table 1) showed the overall accuracy is 92.1478%, with a Kappa Coefficient of 0.8806. This shows the classification is highly successful and robust for use as the basis of the rest of the analysis.

4.2 Definition and Rank of Core Areas

MSPA analysis (Figure 3) indicated that Core is 1.4%, islet is 4.65%, perforation is 0.01%, Edge is 2.85%, loop is 0.37%, bridge is 1.18%, branch is 2.77% of the extent of the analysis area. The highest ratio of islet showed that 4,65% of green space is isolated. The core ratio showed that 1.4% of the area is core areas. The bridge and the loop ratio showed that 0.37% + 1.18% of area connect the core area. The edge and the perforation ratio showed that 2.85% + 0.01% of green space are the outer and inner boundaries of habitat patches. The branch ratio showed that 2.77% of green space only connect one end to a habitat patch.

Conefor analysis showed there are 80 core areas which a value of dPC greater than 1, which were chosen for the first protection order. Through MSPA analysis we chose 96 core areas which have areas larger than 50,000 m^2. Based on these two criteria, there were 96 – 80 =16 core areas to be the second protection order. Most of the core areas are located in Luohe central area, Linying county and Wuyang county (Figure 4).

Table 1: Accuracy assessment of land use classification (Overall Accuracy = 92.1478%, Kappa Coefficient = 0.8806)

Class	Commission (Percent)	Omission (Percent)	Prod. Acc. (Percent)	User Acc. (Percent)
Farmland	3.88	0	100	96.12
Built-up Area	16.07	7.84	92.16	83.93
Green Space	26.47	28.57	71.43	73.53
Road	4.55	46.15	53.85	95.45
Water Surface	6.74	2.35	97.65	93.26

4.3 Fragmentation Analysis

Fragmentation analysis of land use types is reported in Table 2. The PLAND revealed that the proportion of land use types in descending order of extent is: farmland > green space > built-up area > water surface > road. This showed that the Luohe region has farmland-dominated land use. The PD and ED of green space are 12.3583 and 70.1397 respectively, showing that green space in the region is highly fragmented. AI of green space is larger than road and water surface, showing that green space is more aggregated than these highly heterogeneous cover types.

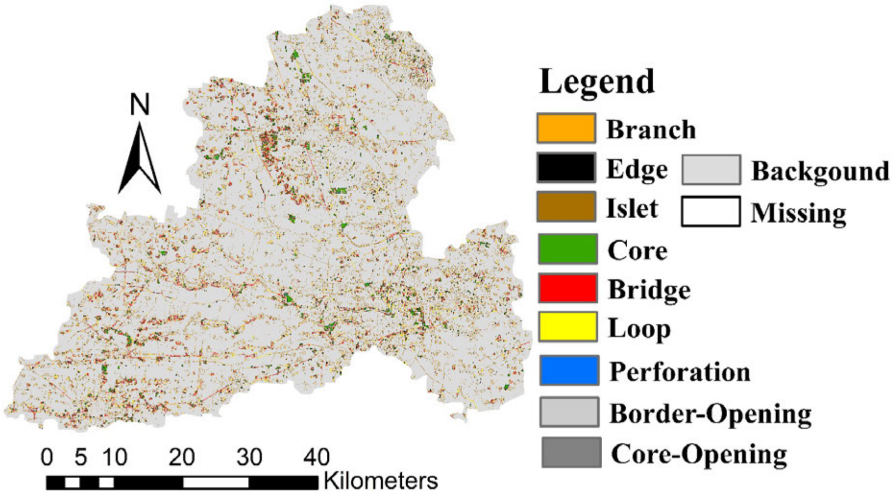

Fig. 3: MSPA results of Luohe region

After selecting green space core areas using Conefor, we reanalyzed fragmentation on this subset (Tables 3 and 4). The PD and ED decreased, the GYRATE_AM and AI increased for the core area green space subset compared to the full green space mosaic. This shows that raw green space has many more and smaller patches of a higher diversity of types, and that the final core areas have more homogeneous patches of larger size. This shows our selection was successful in identifying the largest and most aggregated patches of green space for conservation and management focus.

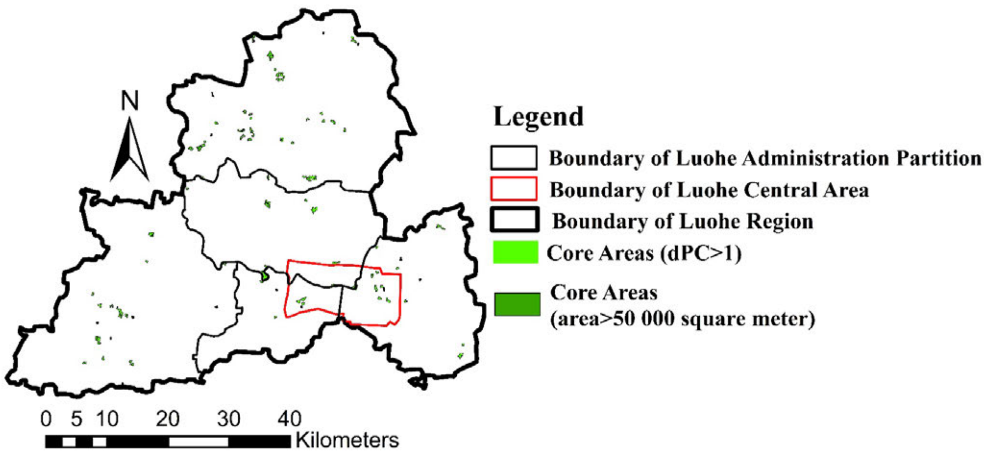

Fig. 4: Location of core areas of Luohe region

Table 2: Fragmentation analysis of land use types (class metrics)

Class	PLAND	PD	ED	GYRATE_AM	AI
Farmland	75.2578	4.3621	70.2955	8906.892	92.9359
Built-up Area	9.3464	4.807	36.0924	600.3523	71.152
Green Space	13.2222	12.3583	70.1397	280.5806	60.2107
Road	0.768	1.9858	6.1258	118.3107	40.3934
Water Surface	1.4057	2.2244	7.3363	3327.675	59.9499

Table 3: Fragmentation analysis of MSPA results (class metrics)

TYPE	PLAND	PD	ED	GYRATE_AM	AI
Loop	3.5063	3.0822	10.2066	101.7828	42.4706
Islet	35.137	86.1615	0	63.0258	41.3329
Branch	20.9781	52.6468	33.3189	68.7404	40.739
Edge	17.4077	22.713	76.018	75.5529	43.0736
Core	10.5946	15.7893	53.9287	101.939	61.986
Bridge	12.3253	6.9406	39.3989	154.3613	45.8415
Perforation	0.0509	0.0504	0.253	56.3837	51.2

Table 4: Fragmentation analysis of core areas (landscape metrics)

TYPE	PD	ED	GYRATE_AM	AI
Core Areas	7.9146	0	225.3534	84.2022

4.4 Resistant Kernel Evaluation

Resistant kernel (Figure 5) values are the spatial incidence function of the expected density of movement through each cell in the landscape by dispersing organisms with the specified dispersal ability, moving from the specified source cells, and responding to the specified resistance surface (Cushman et al. 2012a). Generally speaking, the resistant kernel increased with the dispersal threshold increased. The values of the resistant kernel (Figure 5) and standardized value (Figure 6) changed dramatically with dispersal thresholds of ≤ 2 km; species with dispersal abilities of ≤ 2 km showed generally low connectivity in most of areas (Figure 5 and 6), with core areas of high connectivity mainly in Luohe central area, Linying county and Wuyang county. That means species with dispersal abilities ≤ 2 km, and which are dependent on greenspace for habitat, will experience fragmentation of their populations across the Luohe region. In future planning in the Luohe region, planners should consider species of short dispersal abilities and build stepping stones strategically across the region to enable linkage among the green space network to meet their biodiversity requirements.

The values of the resistant kernel (Figure 5) and standardized value (Figure 6) have a moderate increase with dispersal thresholds of 4 km and 8 km. Species with dispersal abilities of 4 km and 8 km showed a network of connectivity with multiple pathways connecting the interior of the study area. That means species whose dispersal or migration distance is between 4 km and 8 km and which are dependent on greenspace for habitat would be affected intermediately with strong connectivity in the core network of central green space but limited longer distance connectivity, particularly to the northeast and southwest corners of the study region. Planners should build parks or gardens in the areas where linkage is most limited between the core areas to protect medium dispersal abilities' species in future planning.

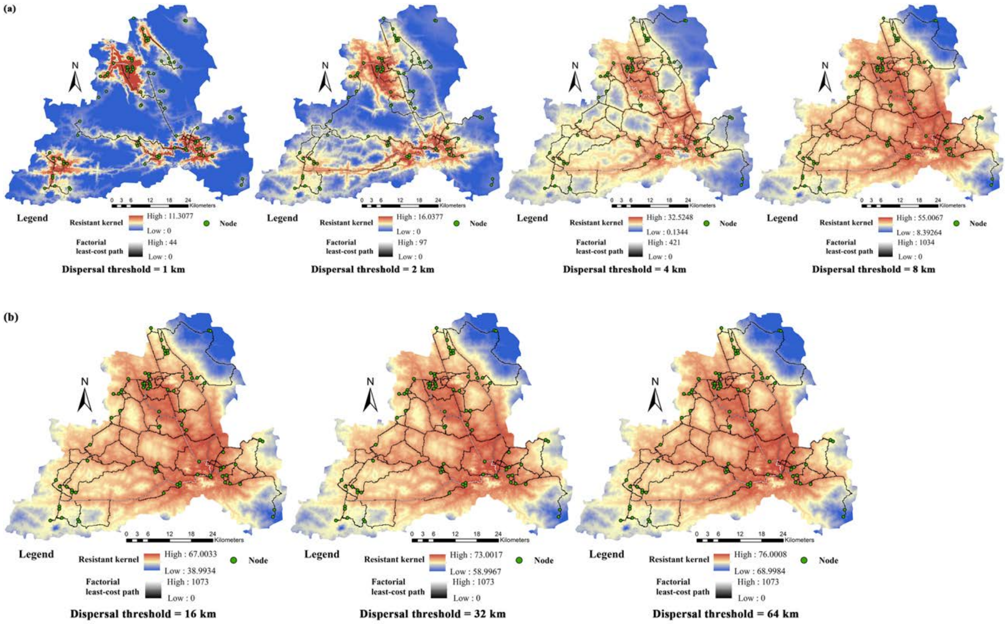

Fig. 5: Comparison of resistant kernel and factorial least-cost path

Finally, the value of the resistant kernel (Figure 5) increased slowly and the standardized value (Figure 6) almost did not change with dispersal thresholds ≥ 16 km. Species with dispersal abilities of ≥ 16 km showed high connectivity levels and appeared fairly insensitive to current configurations of human development in the study area. That means species whose dispersal abilities are ≥ 16 km which are dependent on greenspace for habitat would be affected slightly by the location and configuration of green space patches given their ability to integrate and move between patches through high dispersal. Planners could choose a few conservation areas with complete ecosystem functionality to conserve long distance dispersal species. Species with large dispersal ability, however, generally also have larger body sizes and lower population densities, so their ability to persist is likely limited by the small extent and generally small size of green space patches. For these species with high vagility but large habitat area requirements conservation strategies should focus on increasing the extent of green space as much as possible with less concern about where it is located.

In the southeastern and the northeastern parts of the region, the connectivity is the lowest at all dispersal scenarios (Figure 5), because of limited green space in these intensively agricultural areas, and because built-up areas of Luohe central area and Linying county may act as movement barriers inhibiting species to move to the southeast and northeast. Planners should consider more about how to increase the connectivity in intense built-up areas. In the central area, there is still high connectivity even if there is the most intense built-up area, the plenty of green space along the Sha-Li river in the central area results in the consequences.

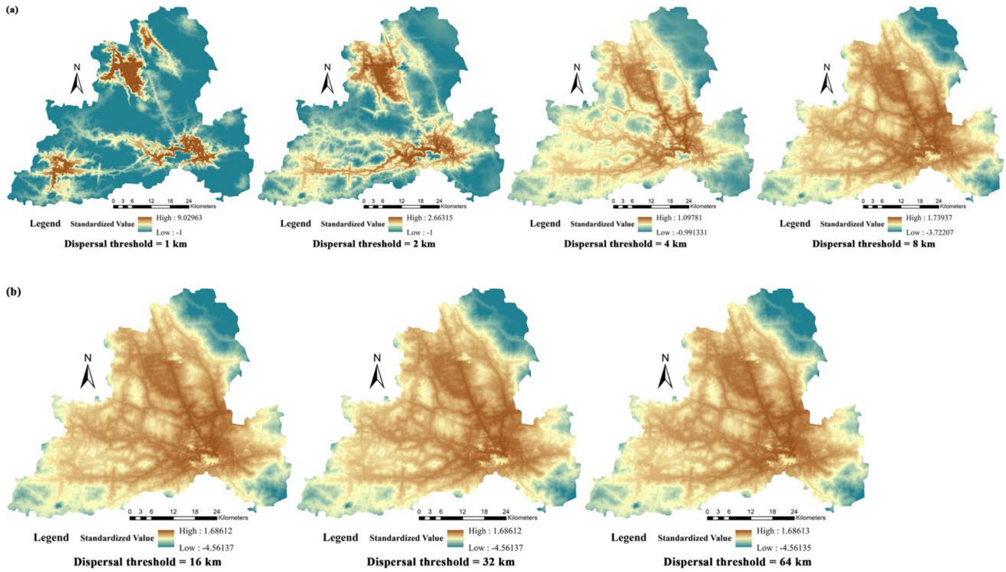

Fig. 6: Comparison of the standardized value of the resistant kernel

4.5 Factorial Least-Cost Path Evaluation

Multi-dispersal scenarios have the same corridor patterns, but very different network extents and linkage (Figure 5). This means that different dispersal abilities do not influence the corridor patterns, but strongly affect how extensive and interlinked the corridor network is. The pattern is primarily driven by the source points and the resistance layer, which are consistent among scenarios. The strength, extent and connectivity of the network are primarily driven by dispersal ability. The number and strength of paths changed dramatically with dispersal thresholds of ≤ 2 km, with the network highly limited and localized around clusters of core patches. The number and strength of paths stayed approximately the same at dispersal thresholds of 4 km and 8 km. The number and strength of paths changed relatively little as well at dispersal thresholds of ≥ 16 km. This means species with short dispersal ability are very sensitive to network breakage and fragmentation, and planners must carefully plan networks of stepping stone green space patches along the routes of most important connectivity among core areas of green space.

4.6 Overlapping Map Evaluation

Main roads and rivers passed through high connectivity areas, and most Factorial least-cost paths are aligned with main roads and rivers (Figure 7). This reflects past urban design applications in which planners concentrated on the creation of green space along roads and rivers based on national policies. This showed that not only land use type influences the species' dispersal, but also national policies about the green space construction. It reminds planners to build more green space combined with other landscape elements, for instance, river corridors and transport corridors.

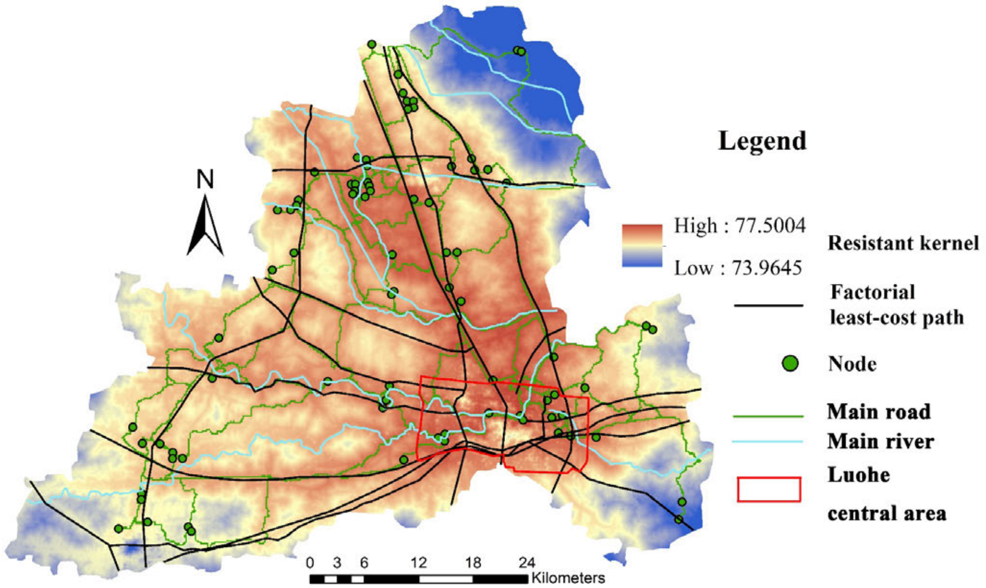

Fig. 7: Overlapping map of main road & main river and resistant kernel & factorial least-cost path

5 Discussion

Our overall goal in this study was to assess the pattern of green network connectivity in the Luhoe region across a range of dispersal abilities. Our main result is that connectivity, assessed both by the factorial least-cost path and resistant kernel methods, was highly sensitive to dispersal ability, with strong threshold effects below 4 km dispersal distance at which the connectivity of the system broke down dramatically. Conversely, above 8 km dispersal ability, the network appeared highly connected across the full region. Moreover, we identified three hypotheses to discuss.

1) **Hypothesis 1: Kernel connectivity will increase with dispersal ability.** Kernel connectivity represents the predicted spatially-explicit dispersal rates across the study area extent (CUSHMAN et al. 2010b). As expected, species with small dispersal abilities of ≤ 2 km have low kernel connectivity, which changed dramatically from the larger dispersal abilities. Species with large dispersal abilities are predicted to have high kernel connectivity and the value of that stayed stable above dispersal ability of 16 km. These results suggest that planners should rank the conservation order based on the study results: species with dispersal abilities of ≤ 2 km are the first protection order, species with dispersal abilities of 4 km and 8 km are the second protection order, species with dispersal abilities of ≥ 16 km are the third protection order in Luohe region.

2) **Hypothesis 2: Symmetry of thresholds of kernel connectivity and factorial least-cost path connectivity.** Factorial least-cost path analysis showed the optimal routes of potential corridors across all combinations of source points, and reflected the relative strength of linkage across the landscape (CUSHMAN et al. 2018). Our analysis showed

that the number and strength of paths changed dramatically with dispersal abilities of ≤ 2 km, and the number and strength of paths stayed stable with large dispersal abilities, showing the same dispersal threshold sensitivity as the kernel connectivity analysis. That means the change of the factorial least-cost path is synchronous with the change of the kernel connectivity. These results remind planners to improve connectivity through building more green space concentrated in areas predicted to be important linkages based on both kernel and factorial least-cost path methods, across the full range of dispersal abilities.

3) **Hypothesis 3: Most ecological connectivity networks are along with roads and rivers.** After 1990, the Chinese government launched policies to improve ecosystem management and conservation, resulting in the creation of extensive green space along transportation corridors and riparian corridors (PENG et al. 2017). Luohe city reflects this characteristic; most ecological connectivity networks are along roads and rivers. It reminds planners that future green space should be created in other landscape contexts, particularly in areas of the landscape with low human activity levels and disturbance to promote the existence and movement of species sensitive to human disturbance.

4) **Scope and limitations.** The resolution of Landsat 8 images is low, which might affect the results of the land use classification and MSPA analysis. In future research, we should use high-resolution images to compare how the resolution of images affects the results. We defined five classes of land use for general species, we will specify the green space types (e. g. forest, grassland, shrubland, orchard, urban green area) based on the exact species in the future deep research. There might be some errors because of the number of ground points we chose, we should choose more points in the next study.

6 Conclusion and Outlook

In UNICOR analysis, we had three conclusions based on the results and goals:

1) Resistant kernel analysis predicted the density of dispersal movement across the landscape, and showed that the extensiveness of kernel connectivity was highly dependent on dispersal ability. At small dispersal abilities of ≤ 2 km there were high levels of fragmentation, and as dispersal ability increased kernel connectivity produced broader extents of interconnected habitat.

2) Factorial least-cost paths predicted the routes of highest potential connectivity linking all pairs of source points. This shows the optimal network of linkages among the source locations. Different dispersal abilities have the same pattern of corridors, but the extent and connectivity of the network are highly sensitive to dispersal ability. Depending on dispersal ability, least-cost paths do not connect all the ecological nodes because of the high density of built-up areas, but the paths pass through the central area thanks to the green space along the rivers.

3) Conservation order based on the results. We recommend planners should build plenty of stepping stones located in breakages in our predicted connectivity network of additional roadside green spaces, residential area green spaces, transport corridor, river corridor to protect species with dispersal ability of ≤ 2 km, which is the first conservation order. Planners should build some parks or gardens with city features to protect species with

dispersal ability of 4 km and 8 km, which the second conservation order. Planners should build fewer but larger conservation areas in areas of low human activity and disturbance to protect species with dispersal ability of ≥ 16 km, which is the third conservation order.

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Mapping Invasive Giant Goldenrod (*Solidago gigantea*) with Multispectral Images Acquired by Unmanned Aerial Vehicle

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Abstract: Invasive alien species are one of the main threats to worldwide biodiversity loss. Unmanned aerial vehicles with multispectral sensors offer a cost-effective alternative to monitor invasive plant species at a centimetre scale. Giant Goldenrod (*Solidago gigantea*) is one of the most problematic invasive alien plant species in Switzerland and controlling this species – especially in nature protection areas – is a priority. In this study, a methodology is developed to detect the Giant Goldenrod coverage via unmanned aerial vehicle (UAV) equipped with multispectral sensors. Very high resolution maps (6.5 cm) are produced and high accuracy is achieved for the classification of the Giant Goldenrod coverage with a kappa coefficient of 0.902 and an overall accuracy of 92.12%. These results indicate that UAV equipped with multispectral sensors is a valuable tool in monitoring and combatting invasive alien species.

Keywords: Invasive Alien Species (IAS), invasive neophytes, Unmanned Aerial Vehicles (UAV), multispectral sensors, remote sensing

1 Introduction

Global biodiversity loss is alarming with current extinction rates likely to be 1000 times the background extinction rates (PIMM et al. 2014). The IPBES 2019 report states that around one million species are threatened with extinction with the underlying reasons for this biodiversity crisis being land-use changes, pollution, climate change, over-harvesting, and invasive alien species (IPBES 2019, DASGUPTA 2020). Invasive alien species (IAS) are defined as non-native species with dispersal potential extending their natural range to new ecosystems, survive and reproduce in these new ecosystems, and subsequently becoming a threat to native species (IUCN 2000). Hence, IAS are species that have been translocated beyond their natural biogeographical range by humans and that are causing economical, ecological, and human health damage or at least have the potential to cause harm (GIGON & WEBER 2005). IAS are found in every taxonomic group from viruses to mammals and their impacts are observed in every ecosystem type on Earth causing hundreds of extinctions in native species (IUCN 2000).

Since the arrival of Christopher Columbus in the Americas in October 1492, the pace of the world-wide translocation of non-native species has continuously increased with 37% of all first records on non-native species reported in the most recent decades (1970-2014; SEEBENS et al. 2017). Worldwide, 3.7% of the taxa in the global flora are now known to be naturalized (VAN KLEUNEN et al. 2020). Even though only a fraction of the naturalized species introduced by humans from other biogeographical regions becomes invasive (MACK et al. 2000), the collapse of biogeographical barriers due to global trade, new technologies, and transport is a

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major threat to biodiversity and ecosystem services (KUEFFER 2017), has implications for human health, and causes substantial economic damage (PIMENTEL et al. 2001, PIMENTEL et al. 2005). Hence, invasive alien species (IAS) are a global concern and explicitly treated in the Aichi Target 9 of the Convention on Biological Diversity (CBD 2011). Specific aims of the Aichi target 9 are the control and management as well as the prevention of introduction and establishment of priority invasive species (CBD 2011).

Introduced in the 18^{th} century from its native North American habitats, the giant Goldenrod (*Solidago gigantea*) was first distributed among Botanical Gardens in Europe and from there escaped a century after its introduction to natural mesic habitats especially endangering species-rich wetlands (VOSER-HUBER 1983, WEBER & JAKOBS 2005, BOTTA-DUKÁT & DANCZA 2008). Based on herbarium specimens and literature data, the spread of this species was estimated to reach 910 km^2 per year (WEBER 1998).

There are ca. 500-600 neophytes in Switzerland and of these 58 are considered invasive or potentially invasive (Neophyten (infoflora.ch)). The Giant Goldenrod is one of the most common invasive neophytes in Switzerland and since 2008 nationwide legally listed as forbidden to plant. The success of invasive goldenrods in Europe can be attributed to their high competitive strength and adaptability (ECKERT et al. 2020). A single plant can produce up to 10,000 wind dispersed seeds per year and its rhizome (up to 300 sprouts/m^2) allows the plant, once established, to propagate a colonised site very efficiently. In contrast to their original area of distribution in America, the plants in Europe are hardly damaged by insects (JAKOBS et al. 2004).

In Switzerland, especially in fens, the original vegetation is under pressure from the invasive *Solidago gigantea*. Therefore, monitoring of *S. gigantea* is crucial to protect the vulnerable local species. Combatting and monitoring the *S. gigantea* in Europe is, however, expensive and mostly ineffective. Remote sensing with Unmanned Aerial Vehicles (UAVs) offers expanded cost-effective opportunities to detect and monitor invasive species on a high spatial resolution up to a centimetre scale. The aim of this study was to identify Giant Goldenrod stands by creating high resolution multispectral maps acquired via drone images, monitoring remnant nature conservation areas of once extensive pre-Alpine wetlands.

1.1 Study Area

The areal coverage of wetlands in Switzerland dramatically decreased from 1850-2010, between 92 to 94% (STUBER & BÜRGI 2018). The study area – Entensee Pond – belongs to one of those wetland ecosystems that were at the brink of loss at the beginning of the 20^{th} century. ProNatura Switzerland bought the area in 1938 and saved it from drainage. Today, in winter and spring, parts of the wet meadows are flooded by ditches fed by a nearby creek.

The Entensee Pond is located in the Northeastern part of Switzerland in the Canton of St. Gallen at 407 m a.s.l. (Figure 1a). It is part of the Kaltbrunner Riet, which is listed in the Swiss Federal Inventory of water and migratory bird reserves of international and national importance (Ramsar site). It is one of the last remainders of once an extensive wetland, breeding and resting ground for birds, spawning areas for amphibians, and ecologically significant for rare plants such as rice cut grass (*Leersia oryzoides)* and yellow flat sedge (*Cyperus flavescens*) (Naturschutzgebiet Kaltbrunner Riet (SG) | Pro Natura). However, especially in species-rich purple moor-grass fen meadows (Molinion) with local and vulnerable species and often dominated by Reed (*Phragmites australis* (Cav.) Steud), a heavy giant goldenrod cover is observed (Figure 1e).

Combatting of the giant goldenrod in the area is continuing since 2013, but without major success. Although only in 2016, 1.4 tons of goldenrod have been removed from the nearby Kaltbrunner Riet, *Solidago gigantea* expansion is still a major threat to local species in the fragile ecosystem (PRONATURA 2016).

2 Materials & Methods

2.1 Data Acquisition & Materials

Due to the protected area status of the Entensee Pond, a limited time frame in August 2020, peak flowering time of the Giant Goldenrod and least disturbing time for birds, was granted to conduct field research and data acquisition. Data acquisition was planned in three different stages. In the first stage, field observations were conducted to document the dominant vegetation types in the area. Planning and simulating flights were the next stage of acquiring drone data, requiring careful preparation to achieve targeted coverage of different areas. Two flights were performed on August 17, 2020 by using an eBee SenseFly X drone together with eMotion3 ground station flight management software, which is used for planning, simulating, and monitoring the flights. Red Green and Blue (RGB) images were acquired with a S.O.D.A 3D camera and multispectral images were acquired using a MicaSense RedEdge-MX Sensor (Wavelengths: Blue= 475 nm, Green= 560 nm, Red= 668 nm, Red Edge= 717 nm, and Near InfraRed= 840 nm). To perform the drone flights, a day with full cloud cover was chosen to reduce the effects of shading from trees on the ground. Full cloud cover also reduced the correction needs for different bands, especially for the blue band, compared to sunny conditions (AKANDIL 2020). In the third stage, ground truth points were acquired with a GPS device (Leica iCON 70, Leica Geosystems, Heerbrugg, Switzerland) on August 30, 2020.

2.2 Methods

The data collected in the field research were first pre-processed to create the necessary orthomosaics, then classified, and finally validated by using the ground truth points (Table 1).

Before each flight, weather conditions were documented and a MicaSense Calibrated Reflectance Panel was utilized to capture the information about position of the sun and the sensor, and the irradiance data from the panel, indicating the light conditions of the flight and working as a control to adjust the rest of the pixels (MicaSense). Through radiometric calibration, digital numbers of the pixels in multispectral data were converted first to sensor reflectance and then to surface reflectance. Without robust calibration, the data acquired cannot be used for comparisons of images from different dates. Therefore, correct calibration is one of the crucial steps before the analysis, especially for future monitoring purposes.

Each photo taken by the drone during the flight was assigned to its correct geographic coordinates by a process called geotagging, which is another critical step for the accuracy of the maps and the Digital Surface Model (DSM). These geotagged photos are utilized to create orthomosaics for RGB and multispectral images in the Pix4D software. Very high resolution orthomosaics, 3.5 cm for RGB & DSM and 6.5 cm for multi spectral data, were generated (Figure 1c, Figure 1d). RGB and DSM were further resized to 6.5 cm resolution by using nearest neighbour method in ENVI 5.4.1 image analysis software. False colour composites (FCC) were also created by using multispectral images (Figure 1b). Compared to medium resolution data in meters scale, very high resolution drone data at a centimetre scale extends the analysis opportunities profoundly.

Table 1: Summary of the workflow performed in this research

Preprocessing	→	Classification	→	Validation
– Calibration		– Defining the Classes		– Cohen's Kappa
– Geotagging		– Classifying Surface Water		– Confusion Matrix
– Orthomosaics (RGB & Multispectral)		– Classifying Trees		– Producer & User Accuracies
– Digital Surface Model (DSM)		– Performing Jeffries Matusita & Transformed Divergence Test		
		– Creating Control and Training ROIs		
		– Maximum Likelihood Classification		

Spectral indices are produced by using two or more spectral bands to create new information related to biophysical parameters of interest (Jones & Vaughan 2010). To identify and mask the water surface area, the Blue Chromatic Coordinate (BCC) index was utilized, which is the ratio of Blue band to an aggregate of the Red, Green and Blue bands (Moore et al. 2017). Illumination conditions play a significant role for the digital numbers of the blue band, which are sometimes inflated up to 50% under sunny conditions (Akandil 2020). To avoid this problem, the drone flights were performed under full cloud cover, therefore no atmospheric correction were needed to be able to separate surface water reliably via BCC. To isolate water bodies, the index value was set as above or equal to 0.334, indicating the blue band is dominant in that pixel (Figure 1f).

The DSM model was utilized to isolate the tree cover around the Entensee Pond. Along with the field research, the trees and observation tower nearby were classified and masked by setting the threshold in DSM model at 410 m a.s.l. and classified everything above as trees (Figure 1g).

Richards (1986) defines five stages in a supervised classification: 1) defining the ground cover types to classify, 2) choosing the training data representative of each class, 3) using this training data to calculate the band statistics going to be used in the classification algorithm, 4) assigning each pixel to the possible classes based on the statistics, 5) producing the classification maps.

Based on the field observations and orthomosaics, five different ground cover types to classify the area were defined: Giant Goldenrod (*Solidago gigantea*), Reed (*Phragmites australis*) – a plant species that is morphologically similar to Giant Goldenrod, Surface Water, Trees, and Mown & Other Vegetation. As the clonal goldenrods have two different phenotypic stages, the class was further divided to vegetative and flowering goldenrod before the analysis. After the classification, they were combined under the class "Giant Goldenrod". A similar approach was taken for reed because the spectral footprint of reed plants growing in water or on land, was different.

Training samples through region of interests (ROIs) were chosen for different classes according to field observations with GPS data. CONGALTON (1991) recommends using at least 50 samples for each class. Therefore, 198 pixels for each class were determined in the analysis. Jeffries-Matusita and Transformed Divergence (RICHARDS 1999) tests were implemented in ENVI to assess the separability of the different classes in RGB and FCC for different band combinations (Table 2). We achieved the best result in FCC by combining Near Infrared (NIR), Red Edge (RE), and Green bands. Jeffries-Matusita and Transformed Divergence test result in values between 0 and 2. Any value above 1.9 indicates the classes are separable and any value between 1.7 – 1.9 is considered fairly good (JENSEN 1996).

Table 2: ROIs Separability test based on Jeffries-Matusita and Transformed Divergence. Bold numbers indicate in which band combination higher separability results were achieved.

Pairs to Separate	In RGB Bands	In False Colour Composites Based on NIR/RE/Green bands
Reed on Water vs. Mown & Other Vegetation	**1.46040**	1.31715
Flowering Goldenrod vs. Mown & Other Vegetation	**1.60247**	0.25575
Vegetative Goldenrod vs. Mown & Other Vegetation	1.71213	**1.96521**
Vegetative Goldenrod vs. Reed on Land	1.77214	**1.78316**
Reed on Water vs. Reed on Land	**1.77287**	1.51057
Reed on Land vs. Mown & Other Vegetation	**1.83301**	1.83144
Vegetative Goldenrod vs. Reed on Water	**1.99823**	1.99355
Vegetative Goldenrod vs. Flowering Goldenrod	**1.99884**	1.97353
Flowering Goldenrod vs. Reed on Water	**1.99890**	1.04508
Flowering Goldenrod vs. Reed on Land	**1.99999**	1.64385

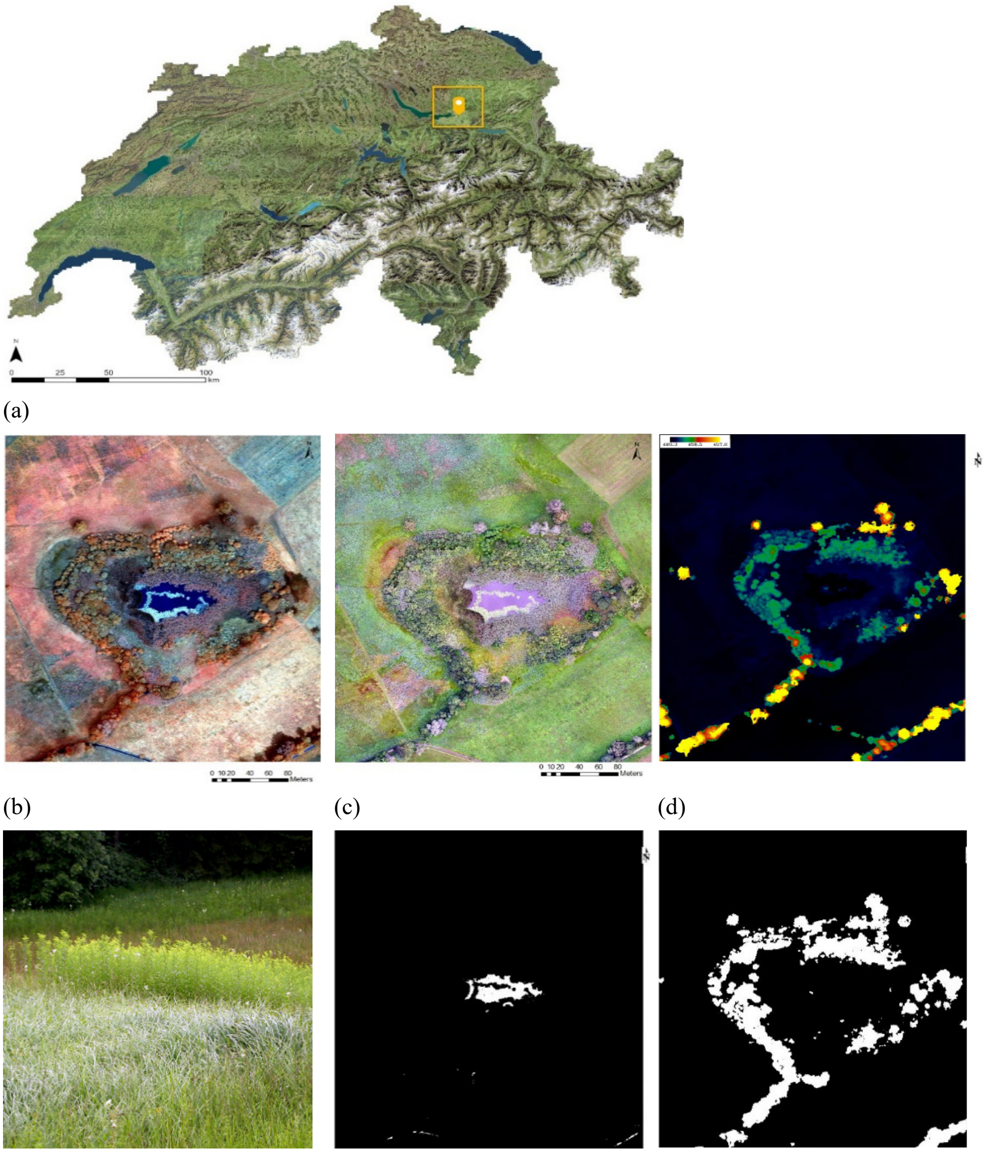

Fig. 1: (a) swissimage Level 3 (Geodata © swisstopo) with reference point on the Entensee Pond, (b) False Color Composite (FCC) of the Entensee Pond with 6.5 cm resolution acquired by a drone on August 17, 2020, (c) Red Green Blue (RGB) image of the Entensee Pond with 6.5 cm resolution acquired by a drone on August 17, 2020, (d) Digital Surface Model (DSM) of the Entensee Pond (colour ramp is meter above sea level), (e) Heavy goldenrod coverage in a wet meadow, (f) Mask created by using BCC index for isolating surface water, (g) Mask created by using DSM for isolating trees.

Before the classification, the ROIs were randomly separated into two groups as training and control. Training ROIs are used to classify the image and control ROIs are used to calculate the accuracy tables.

Classification of the Entensee Pond was performed based on a maximum likelihood algorithm, which runs a statistical analysis based on the covariances and means of the training data to assign probabilities to each pixel falling into a different class category (JONES & VAUGHAN 2010).

The ROIs separability test showed that Flowering Goldenrod and Reed on Water classes were better separable on the RGB bands; therefore, those classes were first classified (Table 2). Subsequently, the rest of the classes were classified in FCC as they were better or almost as well separable as RGB in the combination of NIR, RE, and Green bands. Therefore, RGB bands were used to classify the Flowering Goldenrod and Reed on Water, and FCC bands to classify Reed on Land, Vegetative Goldenrod, and Mown & Other Vegetation classes.

To validate the results of the classification, the Kappa coefficient, producer accuracies, and user accuracies were calculated and a confusion matrix was created by using the control ROIs.

3 Results

The dimensions of the area analysed were 331.7 x 398.4 m corresponding to 132,149 m^2. The areal coverage of Giant Goldenrod was determined to be 13,677 m^2 corresponding to 10.35% of the total area analysed according to classification run by a maximum likelihood algorithm (Table 3). Goldenrod cover was concentrated around the pond as well as the northern, and western portion of the area, which was similar to ground observations made by ProNatura (Figure 2).

Table 3: Areal coverage of different classes in the Entensee Pond

Class	**Percentage (%)**	**Total Area (m^2)**
Goldenrod	10.35%	13,677
Reed	20.31%	26,839
Surface Water	1.12%	1,480
Trees	11.57%	15,289
Mown & Other Vegetation	56.64%	74,849
Unclassified	0.05%	66

Producer's accuracy was calculated by dividing accurately classified pixels in a class to the total number of pixels of reference, indicating how well the area is classified including error of omissions. User's accuracy, on the other hand, shows how reliable the map is by dividing accurately classified pixels to the total number of pixels in that class, including error of commission (BANKO 1998). For every class analysed, above 80% producer's and user's accuracy were achieved in the classification of the Entensee Pond (Table 4).

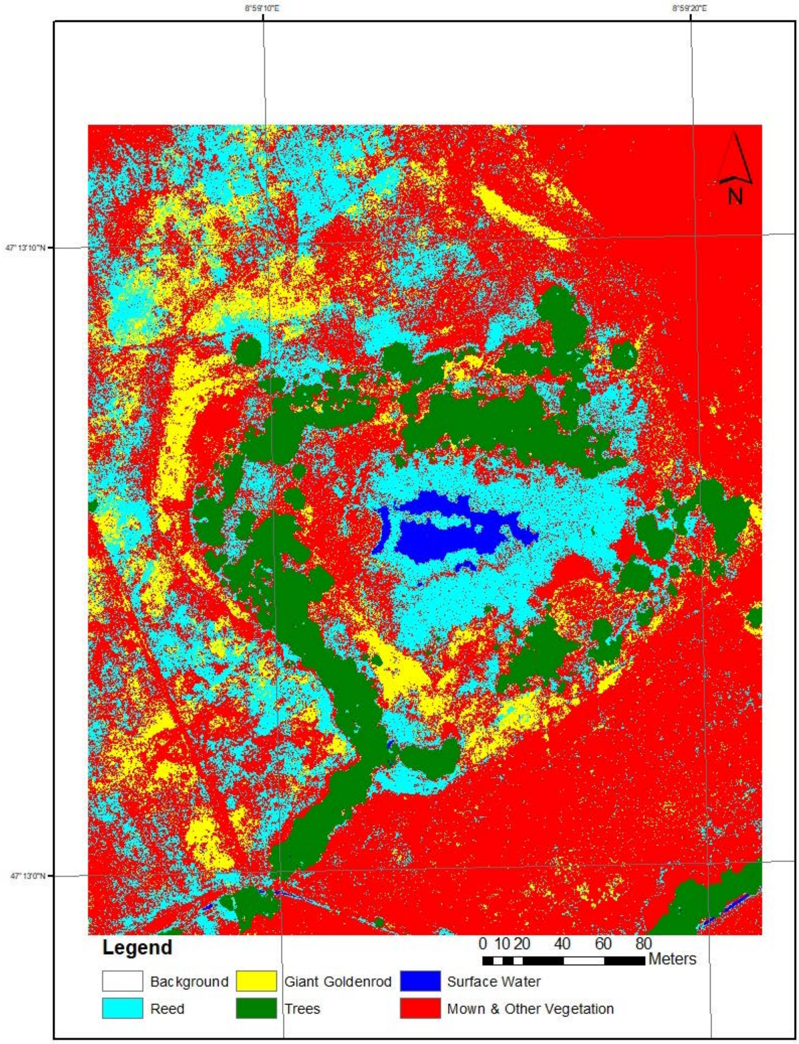

Fig. 2: Final classification of Entensee Pond based on RGB and multispectral data

The Kappa coefficient developed by COHEN (1960) shows how much of the error is reduced by the classification algorithm if the classification was performed randomly (JENSEN 1996). We achieved a Kappa coefficient of 0.902 indicating the classification process avoids 90% of the errors that a random classification generates. Overall accuracy of the classification was 92.12% (Table 4).

Table 4: Accuracy table of the classification of the Entensee Pond, including producer, user, overall accuracies, and Kappa coefficient

		Control Data						**User Accuracies**
Classified Data	**Class**	**Vegetative Goldenrod**	**Flowering Goldenrod**	**Mown & Other Veg.**	**Reed on Water**	**Reed on Land**	**Total**	
	Vegetative Goldenrod	94	0	0	0	2	96	94/96 97.92%
	Flowering Goldenrod	0	95	0	0	0	95	95/95 100%
	Mown & Other Veg.	0	4	91	8	8	111	91/111 81.98%
	Reed on Water	0	0	8	89	2	99	89/99 89.90%
	Reed on Land	5	0	0	2	87	94	87/94 92.55%
	Total	99	99	99	99	99	495	
Producer Accuracies		94/99 94.95%	95/99 95.96%	91/99 91.92%	89/99 89.90%	87/99 87.88%		
Overall Accuracy: (456/495) 92.12%								
Kappa Coefficient: 0.902								

4 Discussion

Our results demonstrate that remote sensing techniques with UAV are a powerful tool for monitoring and combatting invasive alien plant species by rapidly providing high accuracy maps with high resolution. Multispectral sensors beyond the 700 nm spectrum offer alternatives to differentiate structures with similar spectral characteristics in the RGB bands. In this study, Red Edge and Near Infrared bands were exploited to classify vegetative goldenrod (*Solidago altissima*) from reed (*Phragmites australis*) on land and mown & other vegetation classes which had similar spectral characteristics in the RGB bands.

Phenological phase and plant-community composition are important factors to differentiate the Giant Goldenrod from the other plant species in the community. Therefore, the peak flowering period of Giant Goldenrod was chosen to acquire the images. The methodology developed in this study might have been different, if the drone images were acquired at a different time of the year than peak flowering season of our target species. The absence of other bright yellow flowering plants in the plant community might have increased the accuracy of this study.

The Maximum Likelihood algorithm led to very high classification results in this study; however, the use of other machine learning algorithms such as random forest and minimum distance or convolutional neural networks are alternatives that might result in even higher classification results. It has been demonstrated that convolutional neural networks are extremely efficient to identify invasive species in the wild with very high accuracy (LEE et al. 2016, KATTENBORN et al. 2019, QIAN et al. 2020, QIAO et al. 2020). Convolutional neural networks might also be utilized to develop a methodology for upscaling the identification results to larger spatial extents.

Mapping Giant Goldenrod was the first step of a long-term monitoring study, which will extend to multi-year analysis with the aim of creating change-detection maps to quantify how the Giant Goldenrod stand responds to current available control techniques. Change detection maps will be critical to assess opportunistic growth patterns of the Giant Goldenrod to develop novel techniques to control its expansion.

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Geodesign Approaches, Technologies, and Case Studies

The Site Visit: Towards a Digital in Situ Design Tool

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Abstract: Can a historical, analog site mapping tool be translated into a digital tool to change the way landscape is currently designed? This paper illustrates the path to the development of an on-site design tool and discusses its implications for landscape architecture. The presented field survey exemplarily illustrates an in situ design process from capturing georeferenced points, lines, and polygons in the field with a GNSS receiver and a tablet PC using the ESRI Collector app. By exchanging data with ArcGIS Online and translating the captured design parameters into three-dimensional outputs (in this case, trees) in ArcGIS Pro, visual feedback of the captured design points was generated while still in the field. The goal of this study is to strengthen the connection of landscape architectural design process to the site through the use of the in situ design tool. In the long term, the plan is to integrate the tool directly into CAD programs and to expand it to include applications in virtual and augmented reality.

Keywords: Geodesign, GIS, mapping, on-site design, remote sensing

1 Introduction

Modern technologies offer an increasingly rich trove of information as a foundation for landscape design. Most notably, technologies that give us a better understanding of the design site promise massive gains in knowledge. GIS and site surveys, however, often offer only abstract methods for analyzing the site, and are not inherently linked to it. Most digital tools lack a direct connection to the design site and the integration of the "human touch". The "human touch" refers to specific elements or inputs that can only be given by the designer and not by parametric inputs. In this paper, the first step of an approach will be presented to link the site indispensably with design tools, as well as to enable an interaction of the designer on site with the design result.

The location of a design is arguably the most central and complex component for landscape architecture: The genius loci determines the success or failure of a design. For landscape architects, the physical site visit has since become the method for experiencing the place and starting the design process. However, this proven method has not been developed further for decades and, apart from a few documentation tools (i. e. photography, video), has hardly benefited from digitalization. With regard to the elaborate documentation and drawing tools that landscape architects used a hundred years ago, it can be said that the site visit loses its importance. This paper will introduce a new digital tool to demonstrate how the site visit can be given meaning again and possibly even become the core of landscape architectural design. Specifically, it is about enriching parametric design methods with subjective information and precise design anchors that can be set directly on site.

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2 Rediscovering a Design Workflow

The idea of turning the site visit into something richer is by no means new. Many contemporary as well as historic landscape architects have dealt with site-specific survey methods such as walking (BURCKHARDT & RITTER 2006; Fig. 1) or participatory workshops with local residents (SCHELLENBERGER et al. 2014). In recent years, Christophe Girot coined the term "Topology" for the holistic link between site, landscape design and designer (GIROT 2011). While this term is related but not identical with the mathematical and geometrical meaning of topology, it describes the interlinking of the morphologic, cultural and aesthetic dimensions of a landscape. His chair has therefore developed various techniques to map and document the site using point clouds, video and audio recordings, and other means.

Fig. 1:
Daniel Nikolaus Chodowiecki, Natürliche und affektierte Handlngendes Lebens. Der Spatzier Gang – La promenade, copper engraving, 1778

However, when the information gathered on site is translated into form, the greatest weakness of these methods becomes apparent: In most cases, the design information is only mapped in the mind of the person conducting the site visit and cannot be translated directly into a spatial reference or shape. About 200 years ago, Friedrich Ludwig von Sckell introduced a tool to establish this spatial reference and possibly even make the translation into a plan obsolete in his work "Contributions to the fine art of gardening" (VON SCKELL 1825).

2.1 The Vision of Friedrich Ludwig von Sckell

In his book, von Sckell describes both a method and a corresponding tool for designing landscape directly on site. The designer (called draftsman by him) holds a stick with an iron tip to mark the ground (Fig. 2). The designer now moves with this stick through the landscape and marks and draws the course of paths, the outlines of flowerbeds, the points where trees are to be planted and all other elements relevant to the design. He is guided by his "imagination", which he has trained through intensive study. Through the markings, the construction workers directly receive the information necessary for the physical implementation of the design. The design is thus carried out directly in the landscape, without a detour via any graphic abstraction. This simple, but highly precise design method, can hardly be surpassed in terms of site specificity. However, this method of designing seems to have fallen into oblivion to a large extent. Currently there seems to be no digital translation of this method for designers. The following paragraphs describe how the technical requirements for this have existed for years and are just waiting to be embedded in the landscape architectural design process.

Fig. 2:
Friedrich Ludwig von Sckell and his "Zeichenstab" – drawing stick, 1825

2.2 Drawing Digitally in the Landscape

The rapid developments in surveying and GNSS (Global Navigation Satellite System) technology have turned the surveying industry upside down over the last decades. The architecture industry has only marginally noticed this and has rather focused on other digital developments. Through the appropriation of surveying technologies by landscape architects, it would be possible to translate von Sckell's old design method into the 21st century. The necessary technologies have existed for years and are in daily use by surveyors in the field and in the office; however, they have not yet made the leap into design practice. A GNSS receiver in combination with a recording device for various inputs such as points, lines and areas with direct feedback about the recorded elements would most closely resemble a modern version of von Sckell's design tool. Such a digital drawing tool for design within the landscape can rely on a variety of base data: All the data, which is available to us in the office for traditional design processes at the screen or using sketch paper, could be likewise consulted in the field and support the in situ design. Modern tablets and larger smartphones, in combination with the widely available 3G, 4G and 5G mobile data standards and with market-proven applications, can provide this feedback and additional data in real time in the field. In the following paragraphs describes one exemplary case study for the setup, configuration and integration of such digital design tool.

3 Development of an in situ Design Tool

The simplest example of an in situ design process is already in use by a variety of designers. Points of interest, photos, videos etc. taken in the field are used in the later design process to incorporate site-specific conditions. The next step towards in situ design inputs is the recording of locations in the field with GNSS receivers and thus locating them geographically. While some practitioners are already working with georeferenced data, design and visualization are still largely conducted ex situ. A feedback system on the points recorded in the field and the associated design implications could shorten the post-processing in the office and possibly even enable a design process that takes place entirely on site. The exemplary development of this feedback of an initial design using geographically located inputs in the field was the focus of the following survey.

3.1 From GNSS to GIS

The first challenge for the prototypical setup was to achieve a higher geographic precision for data recorded in the field than with the conventionally installed GNSS sensors of tablets or smartphones. An R8-3 GNSS receiver from Trimble was used for this purpose. This model was able to provide sub-meter accuracy in the context of this experiment. The position correction SBAS (Satellite Based Augmentation System) and the data format GGA (Global Positioning System Fix Data) were used to setup the receiver.

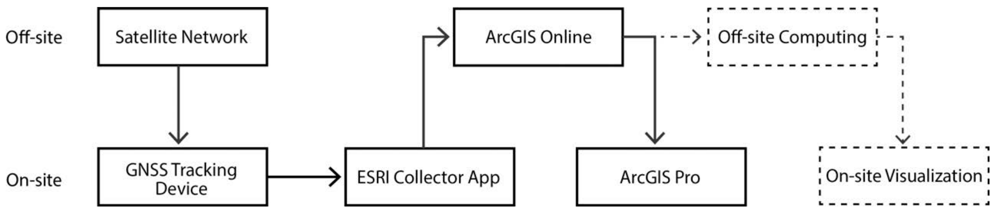

Fig. 3: Workflow diagram; divided into off-site and on-site elements. Dashed elements were not included in this study but are planned to be included in future studies.

The Trimble's Bluetooth interface connected it to a Microsoft Surface 7 Pro Tablet. While the GNSS receiver installed on a tripod about 1.4 meters high sent position data to the tablet, the tablet was to forward this data via ESRI Collector App and its G4 internet connection to the ArcGIS Online database.

For the digital elements to be referenced, the choice fell on points, polygons and lines. The three elements correspond to the most common two-dimensional inputs used by architectural design programs. Thus, it should be possible to map all desired design inputs based on these three features. In the further course, they were to be used in ArcGIS Pro as the basis for parametric design inputs. For this purpose, the ArcGIS Online database was linked back to ArcGIS Pro installed on the tablet.

Up to the data input in ArcGIS Pro, the presented workflow is only a method for recording geo-coordinates. By linking it to very simple parametric design inputs in ArcGIS Pro, the potential of the workflow for landscape architectural design shall be exemplified.

3.2 Parametric Design Inputs

In parallel to the preparation of the GNSS receiver and tablet, the digital design framework was prepared in the ESRI program ArcGIS Pro Desktop. The ArcGIS base maps "World

Topographic Map" and "World Hillshade" as well as 3D building data in LOD2 provided by the municipality served as base layers for orientation and context. The file was configured as a local 3D scene; the "WorldElevation3D/Terrain3D" dataset from the ArcGIS Living Atlas served as the base terrain enabling a three-dimensional display of the site. As mentioned above, three different data types were to be recorded in this survey. The following feature classes and its associated design implications for points, lines and polygons are only to be understood as exemplary features. The desired outputs are freely selectable within the framework of the design program used.

To give the inputs generated with the GNSS receiver an exemplary design meaning, the generated feature classes should inform various ways of tree placement in ArcGIS (Fig. 4 & 5). The placement of trees in the 3D viewport of the GIS program would be fully automated after a feature is entered via the GNSS workflow. The feature class for points exemplarily represents single trees. Several European deciduous trees were selected as 3D symbols for this feature class from the ArcGIS symbol library. In addition to the basic feature class data, attribute columns were created for the tree species and tree height. Using these inputs, the designer could control which preset trees with which height should be visualized in the design preview on the tablet without having to select them manually.

The line inputs are automatically translated into tree rows. The density of the symbols distributed on the line was defined in advance, but could have been parametrized as well. In addition to the representation of a row of trees use of the line input for the virtual creation of a wall in the landscape was also tested.

Finally, the polygon data was used as input for an area randomly planted with trees. The random parameter could have been replaced by a meaningful parametric input, but seemed sufficient for the exemplary nature of this paper.

Prior to the survey, the site in close proximity to the Campus Hönggerberg at ETH Zurich was limited to a perimeter of about four square kilometers for performance purposes. Finally, all three feature classes were published to ArcGIS Online via the "Publish to Web Layer" function and combined into one map making the them ready for use by the ESRI Collector App.

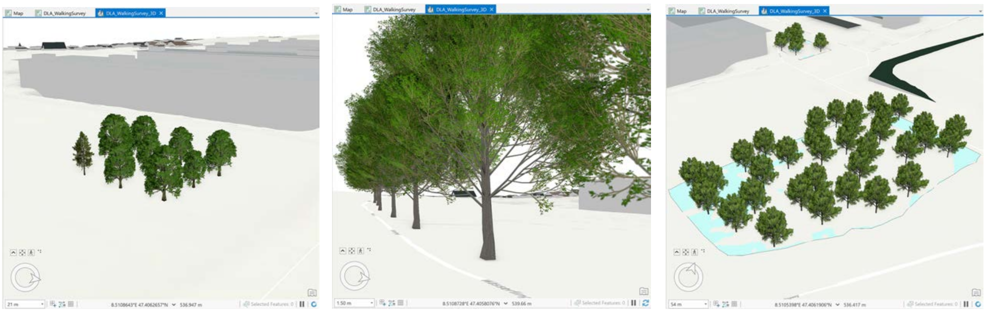

Fig. 4: Features of single points with 3D tree models as representations, as well as a line with a corresponding line of trees and two polygon features filled with trees. All three feature classes relate their Z-coordinate to the underlying 3D terrain model (in this case the ESRI World Elevation 3D terrain) and were informed by the on-site mapping with the GNSS Receiver.

3.3 The Site Survey

The goal of the survey was to collect the inputs for points, lines or polygons using only the Collector App. Consequently, no manual corrections were made within the GIS during the entire survey except for changes to the viewport.

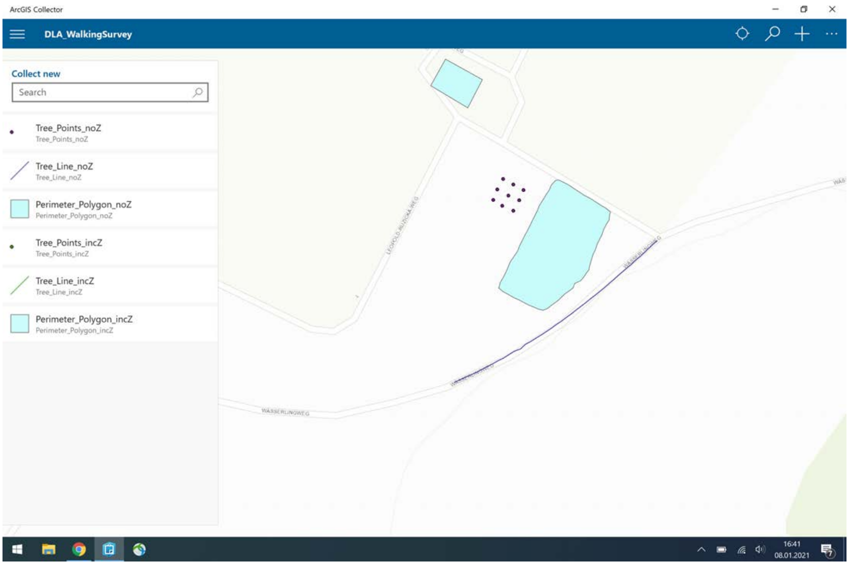

Fig. 5: Final input data in the Collector App showing one line object, nine point features and two polygons. The points constructing the features have been mapped by geo-locating them in the field.

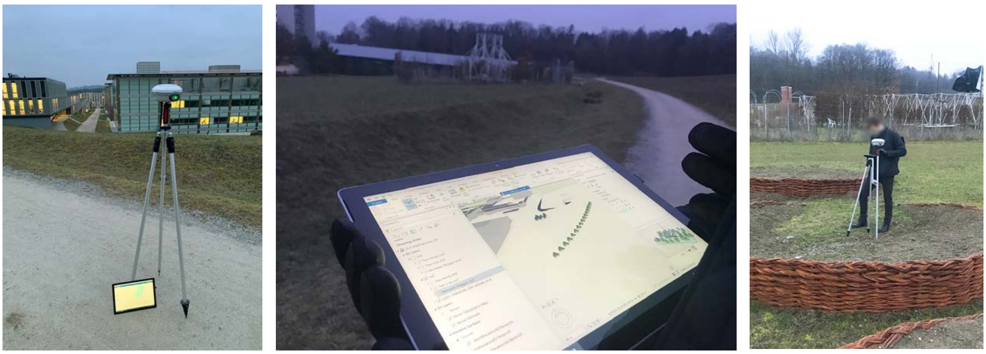

Fig. 6: Survey equipment with GNSS receiver and tablet; Visual design feedback in ArcGIS Pro on the handheld tablet; Process of georeferencing point data in the field

The ESRI Collector App provided access to the previously uploaded maps and contained feature classes in ArcGIS Online. New features were added by connection to a GNSS source at the geographic coordinates thus determined. Using the streaming function of the Collector App, data points for lines and the edges of polygons were continuously recorded at a varying frequencies (i. e. every second, every 10 seconds, every 30 seconds) to test the mapping accuracy. This made it possible to document the movement live with the GNSS receiver in the field and visualize it with only a short delay. Similar to von Sckell's movement through the landscape with his drawing stick.

While the ESRI Collector App also allows a limited two-dimensional viewing and modification of the collected geo-data, this preview was not sufficient for a meaningful design evaluation in the field. Therefore, the visualization and review of the collected data was performed in ArcGIS Pro. To establish a live feedback, the data collected with the Collector App was continuously synchronized with ArcGIS Online; while ArcGIS Pro running on the tablet was also linked to the corresponding ArcGIS Online map to visualize the collected data.

4 Results

The data collected during the exemplary survey described in this paper includes point data from existing tree rings to test the placement of trees in these sites, several polygons of landscape architectonic features not recorded in the basic data, and a line along a farm (Fig. 5). The data was collected both point by point (i. e. points and first polygon) and by walking along the shape to be recorded (i. e. line and second polygon). The feasibility of making live adjustments in the field was also tested (i. e. change of tree heights and tree species, correction of individual points within the Collector App).

A satisfactory workflow for all three feature classes from setting points in the Collector App using the GNSS receiver to ArcGIS Online to a visualization of the inputs in ArcGIS Pro in 3D could be established during the survey.

Although the conduction of this survey overall demonstrated the general feasibility of the method discussed at the beginning of this paper, there remain some challenges and redundancies to overcome before this tool can be efficiently deployed in the field.

Firstly, the precision of the GNSS receiver used was not fully satisfactory. Modern devices can achieve accuracies in the centimeter range (LI et al. 2015). In particular, the elevation data measured in the survey was unusable due to the inaccuracy and had to be replaced by an abstract predefined terrain model. In addition, the weight of the currently used receiver is not suitable for a lengthier survey. In the long term, a lighter and more precise model would be ideal. During the survey, it also became apparent that precision decreases rapidly in partially covered areas (e. g. forest) or narrow areas (e. g. between buildings). Since landscape architecture design does not only take place on the open field, but also in more complex environments, the device should also be able to deliver satisfactory results in urban or covered areas in the future with the help of further localization mechanisms (e. g. indoor WiFi localization; SALAMAH et al. 2015).

The field survey also showed that both the usability and processing power of the tablet used are not ideal, especially for desktop applications such as ArcGIS Pro. On the one hand, desktop applications require at least two different cursor inputs for full functionality and possibly even further inputs from the keyboard. Visualizations on a landscape scale quickly exceed the capacities of the tablet PC. One conceivable solution would be the use of off-site computing: While the tablet marks and uploads data points with GNSS as demonstrated in the survey, the inputs are visualized on an off-site computer or server and only the visual output is sent back to the tablet. With the 5G mobile communications standard currently under development, such real-time transmission could become possible. Also, the redundancy of upload and download to the same device be solved this way.

In addition, ArcGIS Pro is not a design software in the true sense and can only be used as such in an impractical way. Scale, response time and handling do not correspond to CAD programs used for landscape architecture. Nevertheless, ArcGIS was helpful as the first program for testing the in situ design tool due to its direct relation to geo-coordinates. In particular, the workflow to connect GNSS, tablet, ArcGIS Online and the visual feedback in the desktop program was seamless. ESRI has perfected the embedding of online data in desktop applications; a problem that not many CAD programs can yet solve satisfactorily.

Finally, the price of the whole setup tested in this site survey is not feasible for use by landscape architecture practices. Both the costs for GNSS receivers and for possible licenses for the data-recording program have to be significantly reduced in the further course of development.

5 Discussion

5.1 Towards Real-Rime in situ Design with CAD

In the future, it is planned to improve the presented tool functionally with the comments presented in the previous section and to embed it into a more meaningful design process. The aim is to reduce the use of proprietary software to the minimum. In order to minimize the cost factor of GNSS receivers, the possibility of using RTK (Real-Time-Kinematic) receivers will be examined. In this context, the use of multiple receivers for collaborative design will be tested, where multiple receivers in the field can access the same database.

In order to enable the integration of CAD programs into the in situ design process the current workflow has to be redefined once more. Already now, the feature classes in ArcGIS allown an export as e. g. dwg-file for the use by CAD programs. ArcGIS Pro as well as the Collector App will have to be replaced by a slimmer data workflow to load the mapping data directly from the receiver into a CAD. Some programs (e. g. Rhinoceros 3D), would be especially suitable for the setup of parametric design processes based on in situ inputs.

In the long term, the in situ design tool has to be integrated into a real-life design process. It would be particularly interesting to embed it in a fully automated fabrication process for landscape, as is currently being developed by the Robotic Systems Lab for an autonomously operating excavator (JUD et al. 2017).

As handheld devices like the tablet used in this study are limited in their ability to perform a detailed design review on site, it might in the future be feasible to combine augmented reality applications with the in situ design tool in order to verify and adjust a design on. In a further step, even an uncoupling of the physical site and the site visit could be considered, in which the site is made accessible with the help of virtual reality. In this way, even inaccessible or dangerous sites could be designed with the same sensitivity and site specificity.

5.2 Vision

The vision of this research is to rediscover the site visit as a treasure trove of design inputs and make it available to landscape architects. Especially with regard to new fabrication methods, such as described above, the design with in situ design tools might be the possibility to design landscape completely in the field instead of in the office. Just as von Sckell gave his markings carved into the ground directly as instructions to his workers, the tool described in this paper can serve as a direct input for robotic landscape fabrication. Without a detour via an execution plan. If the entire design process would be digital and the abstraction to the two-dimensional plan could become unnecessary, current problems such as the meaningful translation of point clouds to CAD plans may also become obsolete, as they could be smoothly embedded into the design environment without having been simplified or trans-formed beforehand (URECH et al. 2020). In the sense of Christophe Girot's "Topology", the inseparable link between site and design via the in situ tool would make a holistic and highly site specific approach to the design of landscape architecture inevitable.

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The Effects of Tree Cover Density on the Urban Heat Islands in the City of Adana

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Abstract: The detailed analysis and modelling of microclimate in the urban space has gained importance with the emergence of the urban heat island effect in recent years. ENVI-met is one of the commonly used microclimatic models to the microclimate variables of an urban fabric. Urban green spaces positively affect the urban climate. However, characteristics of these spaces within an urban fabric (the area size, location in the city, tree cover density, etc.) are important to change urban microclimate. Therefore, the aim of this study is to investigate the statistical relationship between the area size and the effect of the tree cover density in Adana City, Turkey. Three scenarios were primarily determined in order to explain the effect of the tree cover density on the urban heat island. Secondly, PET values were calculated for each urban green space by ENVI-met. Lastly, the mean PET values of each area size class for different tree cover were statistically analysed by ANOVA-Tukey HSD. Consequently, this paper aims to determine the suitable tree cover density for urban green areas and develop suggestions for planning and design strategies.

Keywords: ENVI-met, PET, tree cover density, urban green spaces, urban micro-climate

1 Introduction

Studies in urban physics aim to better understand the variance in micro-climatic conditions caused by factors such as building density, anthropogenic heat generation, traffic density, green areas, and water bodies. In recent years, the general awareness of urban microclimate has been continuously increasing. However, when population growth in cities around the world is considered, further research and planning are needed to better understand the impact of variance and development of the urban microclimate. An urban microclimate is critical for residents' health and well-being (thermal comfort, temperature stress, mortality rates) as well as for energy and environmental issues. Given the complexity of the urban fabric, it is widely accepted that heat storage in urban areas will be higher than in rural areas. The urban heat island (UHI), which defines the urban-rural surface and air temperature differences, is the most significant and studied urban climate phenomenon studied worldwide. Recent studies show that UHI is proportional to the urban area and population and varies according to the seasons and day and night (VOOGT & OKE 2003). The material properties of urban surfaces can cause higher urban temperatures. In general, undesirable thermal conditions in the urban environment are partly due to the characteristics of the materials used in constructing buildings, pavements and roads, and the reasons for urban settlement and structure, including topography, morphology, density and open space configuration. These factors can affect how solar radiation is absorbed by urban surfaces and air masses' flow through urban tissue. The urban microclimate not only increases the thermal comfort of people in cities but also increases the inconvenience caused by the overheating of indoor areas.

Most recent studies have analyzed the relationships between the physiological equivalent temperature (PET), mean radiant temperature (MRT) and vegetation density, vegetation spe-

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cies, water surfaces, shading elements, and albedo in highly urbanized hot cities with microclimate models such as ENVI-met and Rayman, in order to mitigate the urban heat island phenomenon. Studies evaluating the hottest period of the year to improve thermal comfort have examined areas with heavy pedestrian use, such as the squares (PERERA 2015, CHATZIDIMITRIOU &YANNAS 2016, MAKROPOULOU & GOSPODINI 2016, KÁNTOR et al. 2018,), urban green spaces (CHEN & WONG 2006, DUARTE et al. 2015, NASIR et al. 2015, LU et al. 2017, LEE & MAYER 2018), pedestrian zones (KETTERER & MATZARAKIS 2014, ELNABAWI et al. 2015, TALEGHANI et al. 2016, UNAL et al. 2018), urban canyons (ANDREOU 2013, PAOLINI et al 2014, BALLOUT et al 2015, LOBACCARO & ACERO 2015, ALCHAPAR & CORREA 2016, CHATZIDIMITRIOU & YANNAS 2017, SHARMIN et al 2017, DE & MUKHERJEE 2018), and campus areas (SALATA et al. 2017, TALEGHANI & BERARDI 2018).

The Physiological Equivalent Temperature (PET) is one of the most popular outdoor human comfort indices that can be used to evaluate both hot and cold conditions (HÖPPE 1999). Besides, it is widely used in different studies worldwide to analyze the thermal environment of cities in both local and microscale and investigate the effect of urban shading via ENVI-met.

ENVI-met is a widely validated and respected model for urban microclimate assessment and is the only model with the features and capabilities required for microclimatic studies (SHARMIN et al. 2017). ENVI-met has been widely used to evaluate outdoor thermal environments, tested, and approved for the assessment of different urban areas. ENVI-met processes and calculates the following variables:

- Short and longwave radiation flows related to shading, reflection, and re-radiation from building systems and vegetation;
- Surface temperatures in horizontal and vertical surfaces, such as floors and walls;
- The temperature in the soil and water, and heat change due to water bodies;
- Sensible heat flow as a result of interactions between plants and air, in which all the physiological processes of vegetation (photosynthesis, transpiration, evaporation, etc.) are included.

The three-dimensional presentation of vegetation including dynamic water balance modeling of plant species (EMMANUEL & FERNANDO 2007, ALCHAPAR & CORREA 2016) is also utilised to reveal the UHI.

The main purposes of this study were (1) to determine how tree cover density in urban parks affect the urban heat island in Adana, Turkey for August as the hottest summer month; (2) to identify the statistical relationship between PET according to the tree cover density and area size.

2 Materials and Methods

2.1 Study Area

In this context, in August, the hottest period in Adana, urban development and change of urban heat islands have been examined for the last thirty years (1990-2020). The Adana province in Turkey, an urban context that is characterized by a high density of urban settlements, is the most highly developed and fifth crowded area in the country (Figure 1). Adana has a typical Mediterranean Csa climate according to the Köppen-Geiger climate classification, with cool wet winters and hot dry summers. The mean daily maximum air temperature is approximately 31 °C in July and August (the hottest period), and approximately 15-16 °C in January and February (the coldest period). The weather in August is dry with no rainfall. However, during the year, the daily mean relative humidity remains high (above 80%). The dominating wind direction in Adana is northeast in winter and southwest in summer. Agriculture and agricultural industries have developed intensely because Adana covers the most productive agricultural land in the country. This development created a significant employment level, resulting in intense internal migration from rural to urban areas. The population was 500,000 at the beginning of the 1980s, rising to about 2,220,125 in 2018. Adana's development and improvements plan for 1985-2015 have been prioritized to meet housing needs due to the increasing population in the city center. The subsequent immense construction activities of this plan caused the rapid and unplanned urbanization of especially the Çukurova district located in the northern part of the city (Fig. 1) with a high number of urban green areas and dense high-rise settlement population.

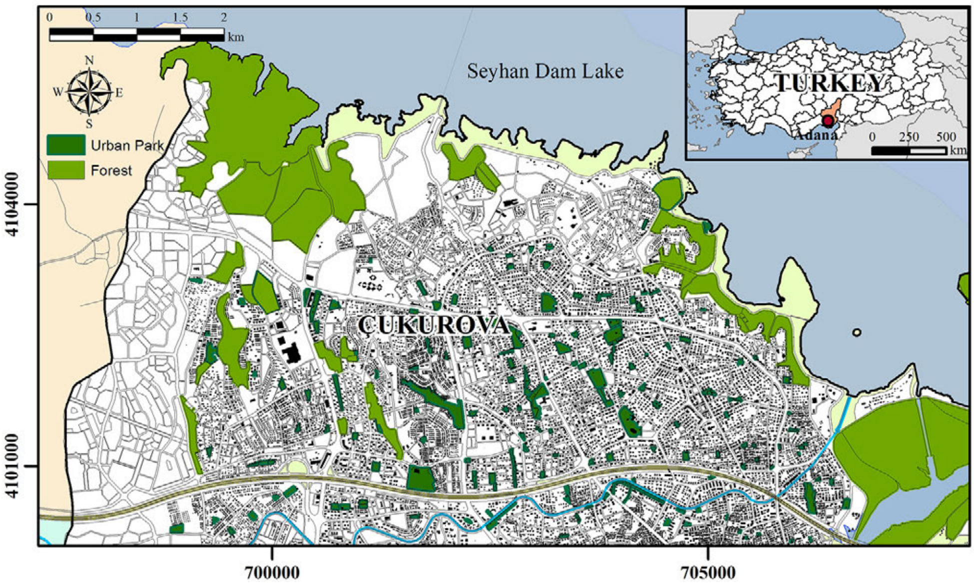


Fig. 1: Study area (Adana, Turkey)

2.2 Methodology

The study methodology consists of four main stages.

Firstly, three scenarios, including 100% grass cover, 50% tree cover, and 100% tree cover, were determined to obtain how vegetation cover density in urban parks affect the urban heat island.

Secondly, the thermal condition of Çukurova district was modelled with an ENVI-met microclimate model which simulates urban microclimate by taking into account many climatic parameters simultaneously. This model includes spatial, simulation and climate data. Moreover, it includes personal human parameters to calculate PET (Table 1). Therefore, GIS data used for digitizing study area and meteorological data and personal human parameters used to calculate PET were obtained before ENVI-met analysed. However, when it comes to mathematical computing, making a multidimensional spatial calculation of the urban space's microclimatic dynamics is very complex. The end time of simulation gets longer and it is difficult to perform for computers, as the study area size, spatial resolution, and simulation period increases. Therefore, the simulation period was determined as three hours including the hottest hour of the day in this study.

Table 1: Parameters used for ENVI-met simulations

Spatial data	with Spaces and Monde	Building height	Variety			
		Outdoor surface Materials	Roads and parking lots		ST-Asphalt	
			Urban Green Spaces		Scenario 1: 100% grass cover; Medium-density grass XX-50 cm tall	
					Scenario 2: 50% tree, 50% grass	
					Scenario 3:100% tree	
			Other surfaces		LO-Loamy soil	
			Water surface		WW-Water	
			Forest area		BS-20 m tree density, mixed crown	
			Coast		SD- Sandy soil	
Simulation data	with ENVI-guide	Date	8 August		Hottest day	
		Start Finish	12:00:00-15:00:00			
		Simulation period	3 hours			
		Grid size (m)	x =20; y=20; z=3			
Climate data		Simulation day	8 August (1990-2019 climate data)			
		Simulation hours	12:00	13:00	14:00	15:00
		Air temperature (°C)	33.80 °C	34.45 °C	34.47 °C	33.92 °C
		Relative humidity (%)	47.50 %	44.22 %	44.00 %	49.10 %
		Wind speed (m/h)	2.4 (min)		2.9 (max)	
		Prevailing wind direction	45° (NE)		225° (SW)	
		Specific humidity (g/kg)	2.2 (min)		8.0 (max)	
Personal Human Parameters	with Biomet	Age	35			
		Size	1.75 m (ISO 7730)			
		Weight	75 kg			
		BMI	18.5-24.9 kg/m^2 (*healthy weight*)			
		Metabolic rate	1.4 (5 km/h walking speed)			
		Clothes	0.60 clo in the summer (trousers or skirts and shirts made of fine fabric)			

There are many differences in spatial data from the albedo varieties of roads, buildings, green areas, and water surfaces. To simplify these varieties, each land-use type was assigned a single type of material. Since the buildings' color differences affect thermal comfort, all building surfaces are considered the same color. Existing plants located in the street network, refuges, building parcels were ignored. Thus, it is aimed to determine the effect of green spaces on the building area.

Thirdly, PET was used to examine how human outdoor thermal comfort changed according to the cover density and area size of urban green areas. PET was calculated by Biomet and visualized by using Leonardo in ENVI-met for all scenarios before statistically comparing with one-way ANOVA. In addition to climatic and spatial data, personal human parameters were also used to calculate PET. PET values for each urban green spaces were categorised in terms of thermal stress (Table 2).

Table 2: PET categorised in terms of thermal stress (MATZARAKIS & MAYER 1996)

PET (°C)	Thermal perception	Grade of physiological stress
<4	Very cold	Extreme cold stress
4.1 – 8.0	Cold	Strong cold stress
8.1 – 13.0	Cool	Moderate cold stress
13.1 – 18.0	Slightly cool	Slight cold stress
18.1 – 23.0	**Comfortable**	**No thermal stress**
23.1 – 29.0	Slightly warm	Slight heat stress
29.1 – 35.0	Warm	Moderate heat stress
35.1 – 41.0	Hot	Strong heat stress
>41.0	Very hot	Extreme heat stress

Finally, the statistical relationship between six area size classes of urban green spaces and their mean PET values were determined by using ANOVA-Tukey Honestly Significant Difference (HSD) test for each scenario. However, ANOVA requires assumptions for variance analysis, such as normality and homogeneity (JACKSON & FERGUSON 1972). Therefore, normality tests with Kolmogorov-Smirnov tests, Q-Q plots, and histogram comparisons and a test of homogeneity of variances (Levene's test) were carried out to evaluate the assumptions of normality before the application of ANOVA (GELETIČ et al. 2016, 2019). ANOVA was generally used to examine the significance of the difference between groups and tried to determine whether there were any differences between groups, while it could not investigate which group or groups caused the differences. In this study, the Tukey HSD test was used to determine which pairs of tree cover density were significantly differentiated in terms of their mean PET according to the area size classes.

3 Results

In this study, three steps were followed to obtain the results. These steps comprised three scenarios where the **first** was concerned with the determination of the urban green spaces, namely as; (i) 100% grass cover, (ii) 50% tree cover, and (iii)100% tree cover. The PET values were calculated for each green space by ENVI-met according to these scenarios. Secondly, 205 urban green spaces with generally rectangular or square shaped were classified into six classes according to their area sizes in which the average PET values of the green areas differ statistically in 100%grass cover scenario. The mean PET values of six area sizes were determined for each scenario (Figure 2).

Figure 2 shows that the 100% grass cover scenario has the highest PET (42°C), while the 100% tree cover scenario has the lowest PET (29°C). PET values generally increase as the area size increases in the first scenario. Small parks (S1) and large parks (S6) have the highest value with approximately 42 °C, while medium parks (S3) have the lowest PET with nearly 39°C. On the other hand, the PET value linearly decreases as the area size increases in the second (50% tree cover) and third scenarios (100% tree cover). However, the peak values in the same green space class especially in S4 are due to the building height and building density in the parcels adjacent to the green spaces.

			Mean PET (°C)		
		The number of urban green spaces	100% Grass cover	50% tree cover	100% tree cover
Area size (m^2)	S1: 400-1200	43	42,76	39,12	36,27
	S2: 1201-3000	59	40,84	36,33	33,21
	S3: 3001-5000	47	39,32	34,73	31,67
	S4: 5000-20000	42	40,79	34,04	30,77
	S5: 20001-40000	9	41,49	33,22	29,71
	S6: 40000-90000	5	42,20	33,11	29,39
	Thermal Perception	Slightly warm	Warm	Hot	Very hot

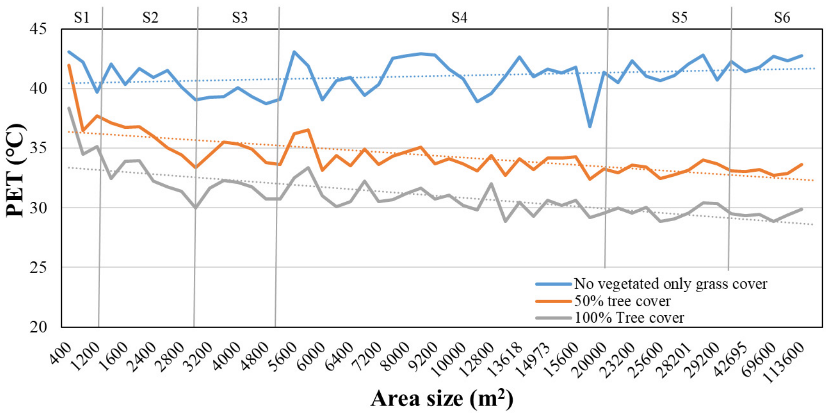


Fig. 2: Distribution of PET values by green space area according to scenarios

Thirdly, the ANOVA-Tukey HSD test was applied to determine statistically significant relationships between PET and area size according to three scenarios. Results were summarised in Figure 3. Figure 3 shows that all groups of 100% grass cover vegetated simulations are statistically differentiated from simulations with 50% (except S1) and 100% tree cover. While the 50% tree cover simulation PET results were approximately 3-9°C cooler than the 100% grass cover simulation, the 100% tree cover simulation PET results were roughly 6-13°C cooler than the 100% grass cover simulation (Figure 4). When we compare 50% and 100% tree cover simulations, all groups of scenarios are not statistically significant ($p>0,05$).

Because S5 and S6 area size classes in the 50% tree cover simulation and S1 and S2 in the 100% tree cover simulation have similar PET values. Moreover, the S1 class in the 100% tree cover is warmer than the S3-S6 classes in the 50% tree cover simulation and the statistically significant difference from the S4 class in 50% tree cover. It can be concluded that in order to obtain a park having thermal comfort, it can be designed and planned either as a very small area size with 100% tree cover density or a very large area size of 50% tree cover density.

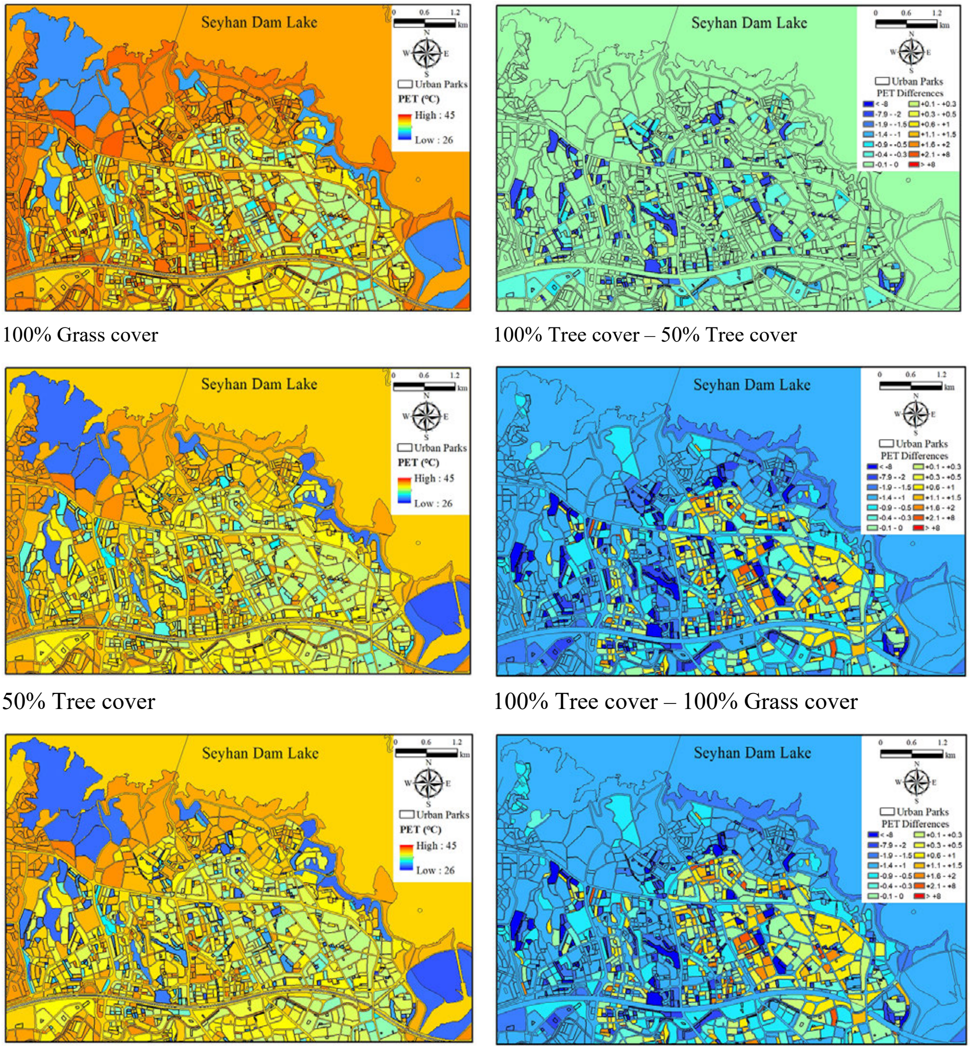
	100% grass cover						50% tree cover						100% tree cover						
	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	S5	S6	
100% grass cover		1,9	3,4	2,0	1,3	0,6	3,6	6,4	8,0	8,7	9,5	9,7	6,5	9,6	11,1	12,0	13,1	13,4	S1
			1,5	0,1	-0,7	-1,4	1,7	4,5	6,1	6,8	7,6	7,7	4,6	7,6	9,2	10,1	11,1	11,5	S2
				-1,5	-2,2	-2,9	0,2	3,0	4,6	5,3	6,1	6,2	3,0	6,1	7,6	8,5	9,6	9,9	S3
					-0,7	-1,4	1,7	4,5	6,1	6,7	7,6	7,7	4,5	7,6	9,1	10,0	11,1	11,4	S4
						-0,7	2,4	5,2	6,8	7,5	8,3	8,4	5,2	8,3	9,8	10,7	11,8	12,1	S5
							3,1	5,9	7,5	8,2	9,0	9,1	5,9	9,0	10,5	11,4	12,5	12,8	S6
50% tree cover								2,8	4,4	5,1	5,9	6,0	2,9	5,9	7,5	8,3	9,4	9,7	S1
									1,6	2,3	3,1	3,2	0,1	3,1	4,7	5,6	6,6	6,9	S2
										0,7	1,5	1,6	-1,5	1,5	3,1	4,0	5,0	5,3	S3
											0,8	0,9	-2,2	0,8	2,4	3,3	4,3	4,7	S4
												0,1	-3,1	0,0	1,6	2,5	3,5	3,8	S5
													-3,2	-0,1	1,4	2,3	3,4	3,7	S6
100% tree cover														3,1	4,6	5,5	6,6	6,9	S1
															1,5	2,4	3,5	3,8	S2
																0,9	2,0	2,3	S3
																	1,1	1,4	S4
																		0,3	S5
																			S6

Fig. 3: Tukey-HSD comparison matrix for all scenarios, where the blue and red grids show the significantly different ($p < 0.05$) mean pets.

The results of the scenarios are interpreted according to the grade of the physiological stress (Table 1). While the S1 and S6 classes had a grade of '*extreme heat stress*', S2 to S5 had *'strong heat stress' grades* in the 100% grass cover simulation. However, S1, S2, S3, and S4 classes had *'strong heat stress' grades* in the 100% tree cover density and they rose to grade one physiological stress. S5 and S6 classes rose to grade two, i. e., the *'moderate heat stress'*. This shows that the area size is an important factor as the tree cover density to determine the suitable PET value for thermal comfort.

Mean PET values obtained ENVI-met based on settlements parcel for three scenarios

Mean PET differences of tree cover densities on urban spaces



100% Grass cover

100% Tree cover – 50% Tree cover

50% Tree cover

100% Tree cover – 100% Grass cover

100% Tree cover

50% Tree cover – 100% Grass cover

Fig. 4: ENVI-met modelling results: Mean-PET for Çukurova district

4 Conclusion

The expansion of urban area causes a decrease in green spaces, an increase in impermeable surfaces, and an increase in temperature from rural areas to urban areas. Thus, the urban heat island effect increases in an urban area where the outdoor thermal comfort has adversely been affected from UHI. Previous studies highlighted that the best way to improve thermal comfort is to increase the shade ratio. Plant existence is one of the main factors positively affecting the PET value and outdoor thermal comfort. According to this information, our study aims to statistically compare PET changes in urban green areas based on the area size of green spaces and three tree cover density scenarios. The general results and suggestions of the study can be listed as follows,

Design strategies: Green spaces with large area size and high tree cover density have lower PET values and are the most suitable areas in terms of thermal comfort due to their high shade ratio. However, it is impossible for all urban green spaces with 100% tree cover in a city. Although this situation provides a high shading area, it decreases wind speed, high specific humidity, and high PET value. Consequently, the suitable tree cover density can be determined according to the characteristics of each urban green space including area size with more detailed resolution. Before implementing the decisions on the development of green spaces in a city, the optimum tree cover density and tree species for outdoor thermal comfort of different seasons should be determined in the study areas.

Planning strategies: The climate of green spaces is directly affected by the settlement located nearby. We determined that, especially, small green spaces located at the east side of a high-rise building have lower PET values in any scenario because of the shading effects of these structures. On the other hand, inevitably, large green spaces with 100% grass cover adjacent to on the east side of high-rise settlements have higher PET values.

The microclimatic analysis of urban areas is difficult due to a large number of variables. In this study, the area size is as important as the tree cover density. However, the expanding area size is the most difficult characteristic of urban green spaces in the planned city. Therefore, it should be preferred to high tree cover density for green spaces with unsuitable thermal stress. Green areas contributing to the urban microclimate should also be located in the right place with the proper plan decisions. Consequently, the study results can be useful for city planners and decision-makers in developing appropriate spatial planning strategies in terms of urban climate design.

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How Sprawl Shapes Public Parks in an Urban System: Spatial Analysis of Historical Urban Growth in Orlando Metropolitan Region, Florida, USA

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Abstract: Public parks are defined by historical changes in land use and land cover (LULC). Influences of broader urban processes, like sprawl, are visible consequences of these processes, sometimes including the dysfunction of amenities and facilities in parks, and the decrease of multi-functional open space on a regional scale. When planners and designers are preparing solutions for public parks in specific sites and areas, the lack of credible regional understanding has become a research gap that can be potentially bridged by applying the geodesign framework. Our goal is to comprehensively explore the historical development of urban systems and the impacts of this development on public parks in the Orlando Metropolitan Region, Florida, USA today. A prior study recorded some initial results based on the land use changes from 1970 to 2011 demonstrating how significant sprawl patterns emerged in this system. We now study how this influenced the form and distribution of public parks within the urban system. We standardized land-cover data between 2001 and 2016 and used public parks as an interpretive indicator through which to enhance the geospatial understanding of sprawl. Our findings include the following: We observed significant decreases in the natural area and found that the majority of non-urban lands have been converted to urban growth within our study boundary. Such results indicate the needs of urban growth have been centered on residential lands. In addition, we superimposed sprawl buffers and examined the ratio of urban land area to public parks per count and per unit area. We concluded that the inconsistent and unbalanced distribution of public parks is correlated with sprawl. Specifically, in the range of 6 to 12 miles, sprawl has greatly influenced park form and distribution. Finally, we discussed the implications of this study for future geodesign, landscape, and planning applications.

Keywords: Sprawl, public parks, land cover changes, Orlando Metropolitan Region

1 Introduction

This is a descriptive paper and includes some initial findings for landscape resources in the process of the dynamic and complex urban systems. Specifically, we focus on studying how sprawl shapes parks in the urbanization process. Due to the length of this paper, we have emphasized the regional scale in documenting the territorial and vegetation changes between 2001 and 2016 and overlaying the distribution of public parks within the study boundary. Instead of detailing the findings associated with specific settlement patterns, we focus on the distribution of sprawl in rings around the metropolitan region that influence the numbers and sizes of public parks in the study location. Through spatial analysis in GIS, we aim to identify the necessity of a regional understanding in order to guide future geodesign applications.

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1.1 Stage of Knowledge

Urban sprawl, a phenomenon of urbanization, has brought much attention to urban issues in the fields of urban and landscape planning. To accommodate a booming population, metropolitan growth has amplified urban sprawl through increased urban development in areas with lower population density and increased low-density LULC (SETO & REENBERG 2014). Beyond the urban fringe, the establishment of human-dominated environments by sprawl has altered the continuity of the land cover, eliminating the possibility of preserving large open spaces where a large number of people can spread out at a lower density (EWING 2008). Some observations have been conducted on a community scale, revealing repetitive sprawl patterns at the street level, and with private home sites encroaching on a variety of open space areas and limiting the space available for parks (SCHNEIDER 1970). Under the conditions of decreased natural resources in exchange for urban growth, the study of public parks associated with sprawl is becoming more significant. Simply put, the form and distribution of public parks have been influenced by historical patterns of urban growth. Parks, which are influenced by the outcomes of urban sprawl, can be referred to as positive or negative responses to environmental conditions and historical LULC change processes (FORTIN & DALE 2005).

Previous studies attempting to increase our geospatial understanding of public parks have focused on the specific sites and functions of parks (KACZYNSKI et al. 2008). However, a few have examined public parks as an interpretive indicator, using them to understand the urbanized context in terms of development trends in parks. Historical settlement patterns shape regional landscapes by opening up some opportunities to accompany housing but constraining others in the review of park design and planning. This is a classic case of studying human adaptation within the living environment, reflecting the dynamic relationship between land-use decisions and settlement patterns. Actions from local residents and people surrounded by amplify humans' modification of natural resources in their living environments (OLDING-SMEE et al. 2013, MURTHA 2015). Thus, it is necessary to emphasize long-term spatial and temporal perspectives to reveal human-nature interaction (DEARING et al. 2010). The measurement of kinds, distributions, and patterns of LULC from the past serves as a platform for studying the interacting social, physical, and ecological systems of parks (TURNER et al. 2007). Thus, in this study, we want to learn how public parks are influenced by urban growth and in particular sprawl. Such an evaluation of parks also offers information to think about the geodesign framework and how recreation systems can be integrated within broader geodesign themes.

1.2 Study Design and Findings

We conducted a case study in central Florida to describe the spatial and temporal dynamics of urban development in land-cover changes, urban sprawl, and landscapes during critical periods of the urban system. In our pilot study, the necessity of understanding public parks was established by sprawl patterns resulting from historical changes in LULC analysis from the 1970s to the 2010s (MURTHA et al. 2019). This paper supplements and reinforces the pilot study's results with further investigation of settlement and vegetation changes in the past decade to explicitly examine the recent effects of land-cover changes on public parks between 2011 and 2016.

The objectives and major findings of this study include the following. First, we explored the types of land morphology that characterize parks. We documented the forms and distribution of land-cover changes in the Orlando Metropolitan Region from 2001 to 2016. We found that with relatively stable changes, urban lands still increased significantly over those 15 years, demonstrating that urban growth is continuing. Second, we sought to determine what major changes had occurred and under what conditions they occurred. We found that most forested or natural lands had declined, thereby increasing the proportion of urban lands. More importantly, our investigation of urban land conversion revealed evidence of rising rates of residential land alongside declines in open-space urban lands. Third, we worked to understand how sprawl affects the regional conditions of surrounding public parks. We found that the ratio of developed lands to public parks, both per count and per unit area, was distributed inconsistently, but not randomly. Some of the findings showed that the public parks located at distances of 6–12 miles from the city center and on the periphery had a clear influence over the number and size of accessible parks. Given this interpretation, some of the results from these crossed temporal-dynamic comparisons illustrate that current park opportunities are insufficient, which offers potential room for future decisions about planning and design for public parks.

2 Materials and Methods

We standardized several data sources, including land-cover data that was obtained from the Multi-Resolution Land Characteristics (MRLC) Consortium [1] and public park and county boundaries data from the Florida Geography Data Library (FGDL) [2]. Within the Orlando Metropolitan Region, land-cover data were processed first for each of the following years: 2001, 2006, 2011, and 2016, in ArcMap. Major land-cover types included: shrub, cultivated crops, herbaceous, evergreen forest, deciduous forest, hay/pasture, open water, woody wetlands, mixed forest, developed land (including open space, and of low, medium, and high intensity), barren land, and perennial snow. In addition, we quantified land-cover conversions via the combine tool in ArcMap for the periods 2001-2006, 2006-2011, and 2011-2016. Third, guided by our pilot study on sprawl, we investigated the relationship between public parks and the sprawl buffers in each year, focusing specifically on the distance from the city center; our sprawl buffers ranged from two to eighteen miles. Finally, we used ratio analysis to compare urban land areas by years to the public parks at the alignment of the sprawl buffers.

3 Results

The results of our analysis can be summarized under three key headings: (1) land-cover distribution analysis, (2) land-cover conversion, and (3) sprawl and public parks. Our results reveal how major land cover was distributed, what land conversion happened between non-urban and urban lands, and how sprawl shaped public parks from 2001 to 2016.

3.1 Land Cover Distribution Analysis

We observe land-cover changes in the Orlando metropolitan region between 2001 and 2016 (Table 1). We observe a declining trend in the land-cover types of deciduous forest, evergreen forest, mixed forest, and hay pasture. Hay pasture decreased the most, with 2% of lands in which areas of 8,087 hectares changed. Evergreen forests were converted or lost, around

4,091 hectares of land, which amounted to a 1% change. However, despite the stable changes of land cover over 15 years, we still found a significant rise in developed (urban) lands. In total, the developed lands from open space, including low intensity, medium intensity, and high intensity developments, increased from 34% in 2001 to 38% in 2016. When we analyzed them separately, the types of developed land that increased the most were medium intensity by 1.84%, while high intensity developed land had the smallest increase rate of 0.65% from 2001 to 2016. The remaining developed land from open space, including low intensity, accounted for increased rates of 1.43% and 0.85% from 2001 to 2016. For the other types of lands, unstable changes happened. In particular, barren lands, cultivated crops, woody wetlands, and emergent herbaceous wetlands eventually dropped below their 2001 numbers. Not surprisingly, in the Orlando Metropolitan Area, there has been a significant and steady decline in natural or forested areas associated with population growth.

Table 1: Land cover analysis in years of 2001, 2006, 2011, and 2016 in Orlando Metropolitan Region

Code	Land cover	2001%	2006%	2011%	2016%
11	Open Water	9.32	10.00	9.69	9.72
21	Developed, Open Space	14.81	15.11	15.31	15.66
22	Developed, Low Intensity	11.59	12.07	12.65	13.02
23	Developed, Medium Intensity	5.40	6.11	6.87	7.24
24	Developed, High Intensity	1.71	1.95	2.24	2.36
31	Barren Land	0.42	0.35	0.36	0.39
41	Deciduous Forest	0.05	0.06	0.05	0.04
42	Evergreen Forest	7.35	6.74	6.24	6.18
43	Mixed Forest	1.00	0.86	0.83	0.80
52	Shrub/Scrub	2.16	1.75	1.91	1.57
71	Herbaceous	0.75	1.17	0.91	0.98
81	Hay/Pasture	11.98	10.96	10.25	9.66
82	Cultivated Crops	0.77	0.80	0.71	0.61
90	Woody Wetlands	26.87	26.05	25.97	26.09
95	Emergent Herbaceous Wetlands	5.80	6.03	6.02	5.68
	Total	1	1	1	1

3.2 Land Cover Conversion

While we observed significant decreases in natural areas, what those lands become is potentially more important than simply the decline in natural areas. To investigate these changes, we analyzed patterns of nonurban lands that were converted to urban lands between 2001 and 2016 (Fig. 1), and measured conversion of specifically non-urban land types to developed (urban) lands. We then calculated the total area of land conversion that occurred from 2001 to 2016 (Table 2). We observed that the most converted non-urban land was hay/pasture, which contributed 6,452 hectares to urban land growth. The second largest land conversion was evergreen forest and woody wetlands which both dropped by more than 2000 hectares. Deciduous forest and emergent herbaceous wetlands had the smallest increase, around 50 hectares. To sum up, a total area of 16,612 hectares of non-urban lands were converted to urban lands.

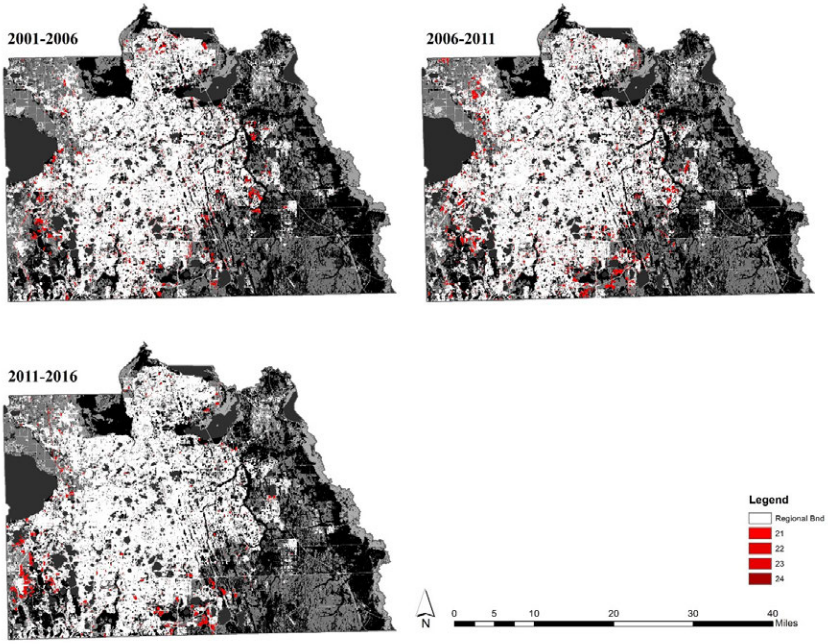

Fig. 1: Land cover conversions from 2001 to 2006, 2006 to 2011, and 2011 to 2016 in Orlando Metropolitan Region. Note: Numbers in legend refer to land cover code on table 1, represents the consequences of non-urban lands converted urban lands.

Table 2: Land conversion summary: non-urban lands to urban lands between 2001 and 2016 in Orlando Metropolitan Region

Non-urban lands	**To urban lands: 2001-2006 (ha)**	**To urban lands: 2006-2011 (ha)**	**To urban lands: 2011-2016 (ha)**	**Sum: 2001-2016 (in ha)**
Open Water	100.53	130.1661	21.42	252.12
Barren Land	174.6	96.93	112.68	384.21
Deciduous Forest	26.19	16.83	1.8	44.82
Evergreen Forest	1691.19	804.78	494.01	2989.98
Mixed Forest	363.6	140.4	89.19	593.19
Shrub/Scrub	439.47	318.6	218.07	976.14
Herbaceous	245.16	979.47	136.08	1360.71
Hay/Pasture	1965.51	2299.32	2186.91	6451.74
Cultivated Crops	113.04	247.23	314.1	674.37
Woody Wetlands	753.21	1142.37	438.93	2334.51
Emergent Herbaceous Wetlands	139.86	205.2	204.93	54.99
Total	6,012.36	6,381.296	4,218.12	1,6611.78

In addition, our analysis reveals that land conversion occurred in four types of developed lands: open space, low intensity, medium intensity, and high intensity. Because we found that the open space of developed lands was not equal to or covered up by public parks, it is necessary to study how functional lands such as open space have been affected by urban land conversions, and how residential areas were interchanged with each other. From 2001 to 2016, no open space was gained overall, but more areas were converted to other residential patterns. For example, the open space lands converted the most from 2006 to 2011 amounted to 1559.97 hectares and contributed to a medium-intensity increase of 961.56 hectares. When we measured housing settlement patterns, we found evidence of low intensity areas converted to higher density patterns, but none of the areas converted back. For example, from 2001 to 2011 low and medium housing patterns were converted to medium and high patterns, whereas the existing high intensity patterns did not change. Moreover, from 2011 to 2016, none of the housing patterns changed; we observe only that open space continually changed for residential needs.

3.3 Sprawl and Public Parks

This historical study has quantified land conversion, illuminating assumed patterns for regions experiencing rapid urbanization. Orlando has witnessed increasing residential areas in urban growth and a decline in nonurban lands. Specifically, the most significant declines have been in natural and forested lands. Because of these historical trends, we wanted to document and understand how these patterns might have shaped public parks. For example, were these patterns of urbanization coupled to shifts in the form and distribution of public parks?

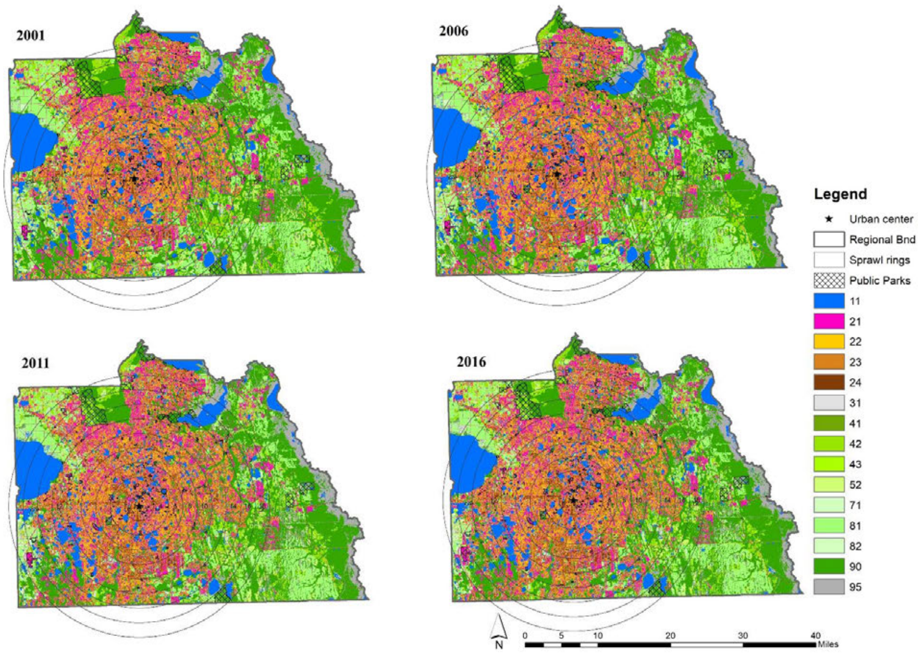

Fig. 2: Land cover distribution and sprawl buffers between 2001 and 2016 in Orlando Metropolitan Region. Note: numbers in legend refer to the land cover code in Table 1.

Or were public parks limited in their size and distribution? Guided by our pilot study of sprawl in the Orlando Metropolitan Region, we overlaid available data about public parks over a series of concentric sprawl buffers that document patterns or intensity sprawl (low density residential) development from the urban center to the periphery. Our analysis first quantified the distribution of key land-cover categories in each ring from 2001 to 2016 (Fig. 2). We designed the buffers to range from two to eighteen miles from the urban center. We observed key distribution and proportions of all land-cover types across the buffers. In detail, we observed that woody wetlands occupied a greater proportion of land in the buffer rings of 12 – 18 miles. Developed open space, developed low, and developed medium accounted for most of the area between 6 and 12 miles. Open water, hay pasture, evergreen forest, and evergreen herbaceous wetlands occupied large areas between 14 and 18 miles.

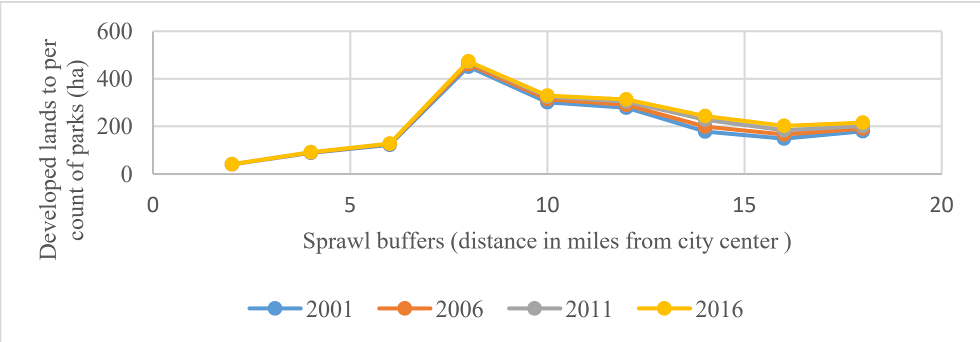

Fig 3: Ratio analysis: developed lands to per count of parks

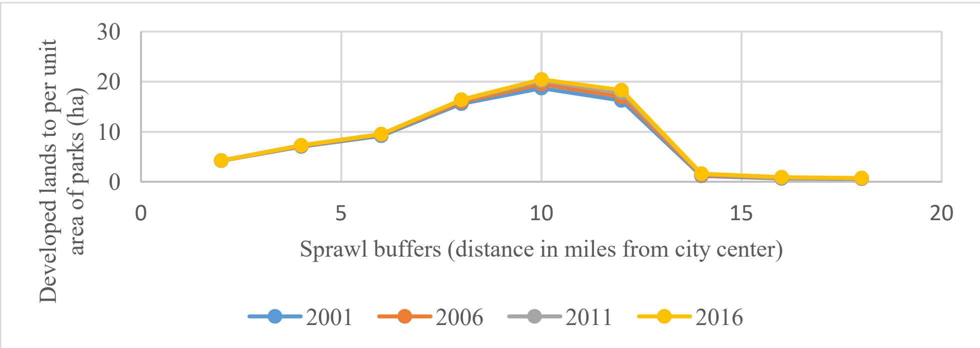

Fig 4: Ratio analysis: developed lands to per unit area of parks

Because we identified an upward trend in urban areas, we are curious about how urban development has shaped the formation of public parks. We performed a ratio analysis of each buffers' urban area to the count and the area of parks. Specifically, we combined four categories of developed land into one because we wanted to know the overall relationship between developed lands and public parks. Our analysis of the ratio of developed lands to parks identified the 8-mile sprawl buffer as the turning point that is between two opposite trends: the climbing trend within the 8-mile buffer, and a declining trend beyond it (Fig. 3). We also examined the ratio of developed land to unit area of parks. In Figure 4, we show that the of 10-12 miles contains the highest proportion of urban land. At the periphery of the Orlando metropolitan region, the lowest proportion of urban lands was found per unit area of parks.

4 Discussion and Outlook

This study delineates several major consequences of urban growth in relation to land cover, sprawl, and public parks in the Orlando Metropolitan Region. First, urban lands have maintained rapid growth, growing faster than other land-cover and vegetation categories. Second, we gathered evidence of the fact that not only the majority of non-urban lands have been converted to urban lands, but that urban lands of open space and lower density residential areas have been correspondingly converted to medium- and high-density housing patterns. Most importantly, at a regional scale, the ratio of urban lands to parks and park area in regions outside the urban core is inconsistent and unbalanced.

Notably, public parks in a rapidly urbanizing context have been at the center of guiding the spatial organization of Central Florida. As reflected in our findings, buffers of more than 6 miles show that urban growth and sprawl patterns have played important roles in the change. For example, we found the greatest area of urban land lies between the 6- and 12-mile buffers, indicating population pressure and the need for public facilities such as parks. These needs are also reflected in the number and area of parks from 6- to 12 miles, with each individual park facing human-dominated activities due to urban growth. In addition, at the periphery, our study reveals the consequences of urban sprawl on landscape resources. Because the lowest number of public parks appears between the 14- and 18-mile buffers, each park has been confronted with increasing residential lands, but still less than in the inner regions. This seems logical because people in the inner regions live in single houses with backyards, reducing the demand for public parks.

However, some limitations have restricted our understanding of landscape resources in urban systems. For a comprehensive urban systems analysis, we plan to investigate the exact land-use and land-cover changes between the critical distances of 6 and 12 miles. We will adapt the methods of historical image analysis and statistical summary for our future work.

Our study of how sprawl shapes public parks uses an explanatory research design, showing potentially valuable aspects of landscape planning and design for future urban growth. It suggests that we rethink urban issues from a long-term perspective and in a landscape dimension in order to prioritize parks in the land system. Our study offers several lessons for alternatives in future geodesign. For instance, in the case of smaller parks that serve larger urban areas, we suggest several solutions: (1) expanding areas by land-use decisions, (2) enhancing the functionalities of parks, and (3) designing the parks to be part of the green infrastructure, such as corridors to connect the public park system. As a result, the planning and design of parks will better serve the local region and fit the intertwined natural and human contexts.

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Which Locations in a Solar Energy Project Contribute the Greatest Visual Impact?

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Abstract: Current visual impact assessment for permit approval is (has?) to include a viewshed that shows the number of sampled project points seen from locations in a study area. These analyses typically do not weight the impact of points closer to the viewer higher than points further away. Perhaps more important, the analysis does not represent the portions of a project that have the greatest visual prominence. This paper develops a method to conduct these analyses and applies it to a photovoltaic solar energy project in Maryland, USA.

Keywords: GIS, visibility analysis, distance zones

1 Introduction

GIS visibility analysis is one of the standard methods used for visual impact assessment (VIA) (FELLEMAN 1979). Typically, the VIA prepared as part of a permit application includes a cumulative viewshed map that displays the number of turbines, or other project elements that are visible from locations within the study area. This analysis answers the question: Where in the landscape is the project visible?

ERVIN & STEINITZ (2003) pointed out that visibility is a two-way phenomenon. The analysis can also be adapted to answer the question: Which locations within a project are most visible to the surrounding landscape? This second application of visibility analysis would seem to be of particular interest to permitting agencies, since it has obvious uses for identifying areas that require mitigation or removal from the project. PALMER (in review) reviewed the viewshed maps in wind energy VIAs prepared by 25 different firms and did not find any examples that analyzed which turbines had the greatest visual impact.

It is known that visual impact decreases as the distance between the project and viewer increases. Often VIAs discuss distance zones that are used to characterize this shift in perceived visual prominence (LITTON 1968, USFS 1995) and include buffer-lines at the zones' threshold distances surrounding the project elements. PALMER (in review) review of wind energy VIAs found that none of the VIAs systematically incorporated distance to evaluate the extent of visual impact. All of the cumulative viewshed maps sum all visible turbines into a single count without reference to distance.

PALMER (in review) demonstrates a method that evaluates visual prominence by incorporating distance zone weights into the visibility analysis. This approach provides more useful information about how individual locations in the study area that are impacted. It can also be applied to answering the question about which project features have the greatest impact on the surrounding area. The answer to this question is critical for identifying optimal wind project configuration when developers seek approval for more turbine sites than the project's permitted energy production requires – an increasingly common situation.

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Wind turbines are discrete visual targets, highly suited to demonstrating the method of evaluating which parts of a project that are most visible. It is less obvious how to adapt the method to a project that occupies a large area but is not very tall, such as a photovoltaic solar project. This paper demonstrates how to do that.

2 Methods

2.1 Photovoltaic Solar Energy Project Case Study

The energy company Constellation partnered with Mount Saint Mary's University, the second oldest Catholic college in America to develop Mount Solar, a 16.1 megawatt (MW) photovoltaic solar energy project in Emmitsburg, Maryland, USA. Mount Solar was the largest solar energy project in the state when it became operational in 2012. The project is arranged into three discrete sections: Papa is the largest occupying 208,631 sq m and accounts for approximately 10.5 MW, the Mama is 102,058 sq m for 5.2 MW, and the Baby is 8,168.75 sq m for 0.4 MW. The Mama and Baby sections are enclosed by a single security fence; Papa is enclosed by a separate security fence. Figure 1 shows the study area with a 4 mi (6,437 m) radius from the solar panels.

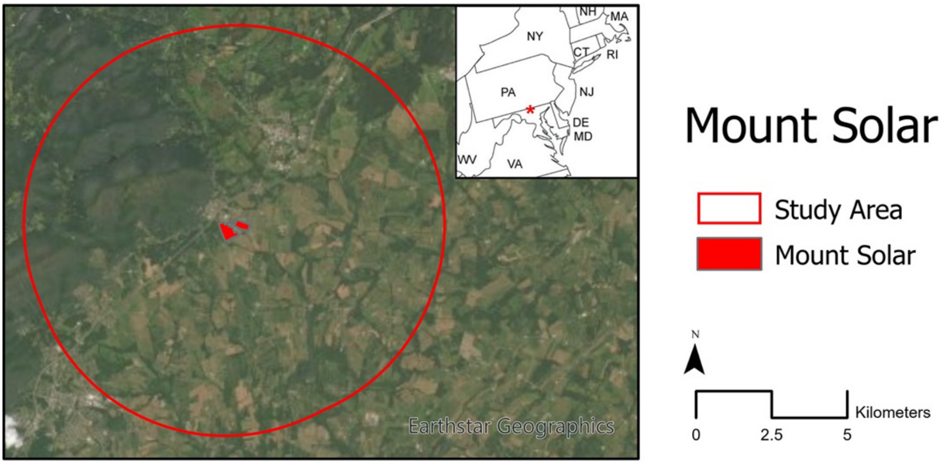

Fig. 1: Mount Solar study area

2.2 GIS Data

Plans for the project were not available, so the three sections occupied by the solar panels were digitized by hand. A 40 m grid was located over the project area, and the intersections of the grid lines within the area of solar panels was saved as a point shapefile. In addition, a point was located every 40 m around the perimeter of the three solar panel areas. LiDAR-derived digital terrain model (DTM) and digital surface model (DSM) with 1 m resolution were used to calculate visibility from each of the project-points.

2.3 GIS Analysis

The approach used here assigns visual prominence weights to distance zone. It is possible to calculate the decay of visual dominance as a function of distance and avoid the use of distance zones. For instance, TARA et al. (2021) recently calculated the decay in visual dominance for buildings using visual magnitude and distance measures. In a review of the literature, he found general agreement that the decay generally follows a negative power function, though the specific parameters vary among studies. However, this approach is purely geometric and does not account for perceptual meaning and interpretation. PALMER (in review) reviews the literature relating distance to visual prominence of wind turbines observed in the field and the results also generally follow a negative power function. However, a similar literature does not exist for solar projects. A pragmatic reason not to use distance decay is the computation time it takes to calculate the distance of 203,285,569 cells from each project-point, of which there are 303, and then apply a non-linear function to the results in a second step. In the end, it is unclear whether using calculated distances would provide significantly more useful results than prominence weights for distance zones.

Five distance zones were proposed based on TJBA's experience conducting VIAs for solar energy projects of this size (e. g., PALMER 2019), and the distance zone thresholds the US FOREST SERVICE (1995) used to evaluate forest harvest openings, which are often the same area as the Mount Solar case study. The distance zones are described in Table 1 along with their visibility weights.

Table 1: Solar Project Visual Prominence Weights by Distance Zone

Distance Zone	Description	Weight
Immediate Foreground 0 to 80.5 m	Close proximity, such that a short walk of a minute or two would allow you to touch project structures, limited space for intervening objects, clear recognition of materials, textures and shapes. Awareness of sounds at 40 dB.	8
Foreground 80.5 to 805 m	Walking to foreground object may take several minutes. Textures and materials are apparent but become less detailed. Shapes of small and large project elements are clearly visible.	4
Near-midground 805 to 3219m	Walking to near-midground objects may take tens of minutes. Textures and materials and smaller shapes are not clearly visible, but larger shapes are still easily distinguished.	2
Far-midground 3219 to 6437 m	The walk to far-midground objects may be more than an hour. The pattern of solar panels rows may still be apparent, but no other details.	1
Background Beyond 6437 m	The large shape of uniform color and texture may be visible from elevated positions without it being apparent that it is a project with rows of PV solar panels.	NoData

The process of analysis is conducted in three steps, as described below. For those interested in the workflow, the Appendix describes it in more detail.

Step 1 Preparation. This involves obtaining: (1) project files (solar panel area and secured fenced area), (2) digital terrain and surface elevation models (DTM and DSM). The DSM is adjusted by assigning a height of 3.66 m (12 ft) above the DTM elevation for cells within the solar panel area. The project-point sample is located on a grid space 40 m apart within the solar panel area, and every 40 m along the perimeter of the solar panel area.

Step 2 Individual Weighted Viewsheds. A viewshed is determined separately for each project-point using the normal method, which causes some confusion since it is calculated by looking from the project to the viewer in the landscape.[1] In this case study, the viewer in the landscape is given an eye-level of 1.5 m, and visibility is calculated over the DSM to a radius of 6,437 m (4 mi). The results of this calculation show locations where the uppermost part of the land cover is visible; values are 1 for locations where the project-point is visible and 0 for locations where it is not visible. Since viewers cannot see the project if they are standing in an area where the land cover is over their head (i. e., DSM – DTM > 1.5 m), those areas are change to no visibility. In addition, since viewers are not permitted within the project's security fence, it is unreasonable to assign impact weights to this area and it is assigned a value of 0 (i. e., no visibility).

Distance zones are represented as concentric bands around the project-point and assigned the corresponding visual prominence weight. This is multiplied by the viewshed producing a weighted viewshed for each project-point. The mean value for the weighted viewshed is saved to the cumulative viewshed table along with the point ID and X Y coordinates.

Step 3 Impact from Project Locations. The mean visual prominence at a project-point location is an index that can be compared to other locations to determine which parts of a project create a relatively greater or lesser visual impact. Nonetheless, they are just a selection of points that do not represent an equal probability sample, which would allow the calculation of statistics for comparing different projects. The solution is to interpolate the mean prominence rating for all the raster cells within the solar panel area, not just the project-points. Inverse distance weighted (IDW) interpolation is selected because it is most appropriate for a well distributed dense sample of points. The IDW parameters were a 50 m radius search and a power of 2; the interpolation is confined to the solar panel area.

Once all cells have a mean visual prominence value it is possible to calculate the mean value for the project or sections of the project. A cost-benefit index of the project's utility can be calculated from the mean visual prominence for the project or section, multiplying it by the area of the project (sq m), and dividing it by the nominal power (MW) to create a standardized index describing the degree of visual impact per unit of potential energy production.

3 Results

The map in Figure 2 displays the interpolated results on a linear scale between the highest and lowest values. Mama – the midsized section – has high visual prominence on its east side. Papa also has a higher visual prominence in its southeast corner. Overall, Mama displays warmer colors, indicating its visual prominence is higher than Papa. This generalization is borne out by Table 2, which gives the summary statistics for the Mount Solar project and the three project sections. The Cost-Benefit Index, (i. e., the ratio of the visual prominence sum to the nominal power production) for Mount Solar is 162. These results support the observation in Figure 2, Papa's Cost-Benefit Index is approximately 80 percent of the project's value and Mama is at approximately 140 percent. Said another way, Papa's impact per MW is approximately 60 percent of Mama's.

[1] The ArcGIS term for the project-point is termed OBSERVER and the viewer is the TARGET.

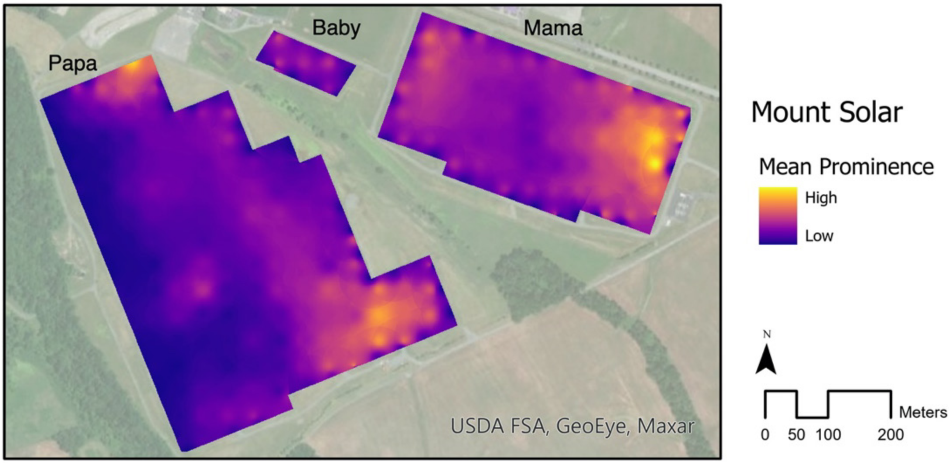

Fig. 2: Interpolated visual prominence of locations in the Mount Solar field

Table 2: Descriptive Statistics for the Solar Project and its Sections

Project Section	Area (sq m)	Sum Visual Prominence	Mean Prominence	Nominal Power (MW)	Cost-Benefit Index
Papa	208,621	1377	0.0066	10.5	131
Mama	101,998	1178	0.0116	5.2	229
Baby	8,170	61	0.0074	0.4	148
Overall	318,858	2616	0.0082	16.1	162

4 Discussion

It is becoming more common for VIAs to be included as part of the environmental analysis accompanying an energy project's permit application. Often the VIA relies solely on a descriptive narrative based on professional judgement, for instance describing how distance moderates the visual effects of the project. Sometimes they are accompanied by visualizations of how the project will appear from a viewpoint selected by the developer. The limitation of a viewpoint analysis is that it considers a very limited selection of possible views. Less often, a VIA includes a cumulative viewshed map showing how many of the project features or sample points are visible from locations in the surrounding landscape. Even so, these maps are of limited value in determining impact because they do not consider how the visual prominence of a project decreases with distance. While academics demonstrated how to incorporate a distance decay function in a visibility analysis over three decades ago (e. g., HULL & BISHOP 1988), it has not become accepted by the professionals conducting VIAs. Instead, they have preferred the more intuitive (and less mathematical) concept of distance zones. This paper demonstrates how to associate visual prominence weights with distance zones and incorporate them in a visibility analysis. While not demonstrated here, simply merging individual weighted viewsheds provides an improved description of a project's visual impact on the surrounding landscape.

This paper concerns an important visibility question that is not addressed, but should be addressed in VIAs: Which project locations or features have the greatest impact on the surrounding area? A method is described to answer this question using standard ArcGIS Pro tools without relying on coding custom scripts to complete the analysis. It demonstrates how to map the results and proposes a Cost-Benefit Index that is a ratio of a project area's visual prominence to its nominal power capacity. This index can be used to compare separate sections of a project, as demonstrated here, or to compare different projects. With wide acceptance of this approach, it would be possible to evaluate how a proposed project compares with other projects.

5 Conclusion and Outlook

A method is demonstrated to map and measure the visual prominence different project locations have on the surrounding landscape. This is a concern of obvious importance to environmental permitting agencies who must determine whether portions of a project must be relocated or receive mitigation treatment. The case study presented here is a photovoltaic solar project, but the same approach could be applied to planning a land fill, permitting a mine expansion, or evaluating a proposed Amazon distribution center.

The analysis requires specification of distance zone thresholds and visual prominence weights appropriate to the project under consideration. These should be grounded in observations of similar projects in the field and not photographs (e. g., SULLIVAN et al. 2014, PALMER 2020). With increased knowledge based on these observations, it may be possible to propose calibrated mathematical functions of the relationship between perceived visual prominence and distance for different project types and conditions.

This method has the potential for wide application in VIAs. Though it is somewhat more complicated than the current implementation of cumulative viewsheds, it answers a question of particular relevance to a permitting decision. If it comes into common usage it may warrant inclusion as a standard part of the GIS visibility analysis toolset.

Acknowledgements

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Appendix: Project Workflow

This appendix describes a simplified schematic workflow to conduct the analysis in ArcGIS Pro. The two figures primarily refer to the tools used, and only reference the primary input and output files. Tools are orange rectangles, and the iterator is an orange hexagon. Shapefiles are ovals and tables are rectangles with rounded corners; blue represents an input file and green an output file. This information will supplement rather than repeat the description of the process in the methods section.

Step 1 is Preparation. In addition to gathering data, it is necessary to prepare an empty cumulative viewshed table to write the viewshed values and counts. It is also necessary to use the *Geometry Calculator* to write the X and Y coordinates to the project-Points shapefile.

The workflow for Step 2 Individual Weighted Viewsheds is represented in Figure 3. This step uses an iterator to process each project-point, one at a time. The visibility tool identifies the areas that are visible (value of 1) or not visible (value of 0) from the project-point. Two masks with a value of 0 are multiplied by the project-point's viewshed, one for areas with view-obstructing land cover (i. e., above eye-level) and the other for areas within the project's security fence.

The multi-ring buffer tool creates concentric distance zones around the project-point. The associated prominence weights are written to the buffer shapefile using the add field and calculate field tools. The multi-ring buffer is converted to a raster that is registered to the viewshed where the value of each cell is its prominence weight. This is multiplied by the project-point's viewshed, resulting in a new raster where all the cells with visibility have the value of a prominence weight. The table for this raster (i. e., the weight value and the cell count) and the project-point are written to the cumulative viewshed table.

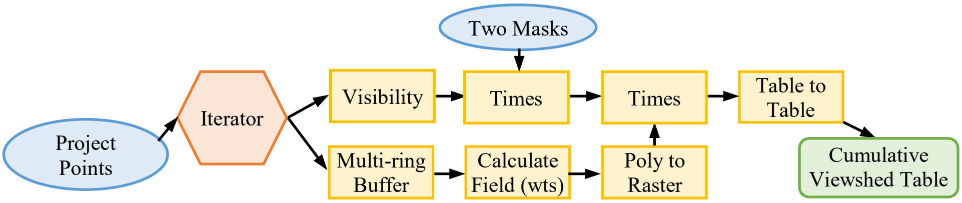

Fig. 3: Schematic workflow of iterative visibility analysis for a sample of project -points. Visibility is weighted by distance zone. The viewshed table for each point is written to the Cumulative Viewshed Table.

The workflow for Step 3 Impact from Project Locations is represented in Figure 4. The X Y coordinates from the project-point shape file are added with a join to the cumulative viewshed table. Use calculate field to multiply value (i. e., prominence weight) by count (i. e., the number of cells with that value) to obtain a weighted cell count. Using the project-point ID and X Y coordinates as the case identifiers to calculate summary statistics: mean of the weighted cell count, and the sums for value and count. Use XY table to point tool to convert the summary statistics table output to a point shapefile. Inverse distance weighting (IDW) interpolation uses these points to assign a mean prominence value to each cell within the solar panel area. The statistics for the project and any sections are calculated using zonal statistics to table.

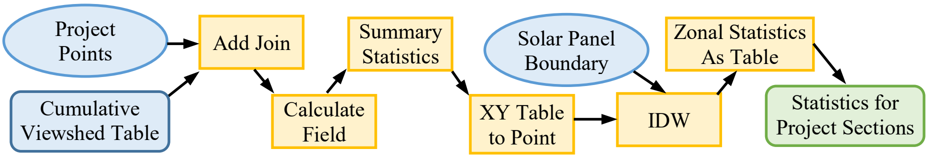

Fig. 4: Schematic workflow to determine mean prominence of sampled project-points and then interpolate mean prominence for solar panel area using inverse weighted distance. The statistics for the projects identified sections are written to a table.

GIS-Landscape Quality Assessment Using Social Media Data

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Abstract: This paper aims to demonstrate and discuss how social media data may serve to elucidate and determine landscape scenic values for planning purposes. Analysing landscape perception by employing social media data has the potential to be an efficient and effective way of integrating information on public landscape perception into planning practice. The paper presents a GIS-based approach to landscape quality assessment that includes data harvested from social media. The approach was developed to be used for planning purposes at a variety of different scales

Keywords: Landscape, assessment, social-media, social-media-harvesting, landscape scenic value

1 Introduction

In landscape design and planning, landscape quality assessment is widely discussed both nationally and internationally (e. g. ROTH & BRUNS 2016, SCOTTISH NATURAL HERITAGE 2017, SWANWICK 2002, SWANWICK et al. 2018, VAN LAMMEREN et al. 2011). These discussions are linked to developments of public participation in landscape quality assessment (JONES 2007, STEINITZ 2012, STENSEKE 2009). Socio-constructivist landscape theory holds that public landscape perception and valuation vary according to people's socialization, experience and age (BURCKHARDT 2008, IPSEN 2006, KÜHNE 2008, KÜHNE 2009). In consequence, a plurality of landscape ideas exists within any given society and it is important for planners to consider as many different landscape ideas into planning as possible. Attempts made to link public participation with landscape quality assessment have led to promising results. However, while today there is no question that public participation can improve planning significantly (COAFFEE & HEALEY 2003), a number of challenges remain. One challenge to be addressed is when people make reference to landscape, they often introduce a variety of arguments into planning processes that are originally not landscape but personal value arguments (STEMMER & KAUßEN 2018). In addition, arguments may be biased, reflecting not only information but also the assumptions people make regarding the landscape changes they expect projects and plans might cause. Rather than actively addressing said challenges, planners sometimes cease to trust in public participation, especially when citizen initiatives are involved (REUSSWIG et al. 2016, SCHMIDT et al. 2019).

Giving up on participation altogether is not a viable or even permissible solution. What follows are suggestions to search for approaches to involving the public on "neutral" ground. One way to conduct landscape assessment and avoid confrontational situations is to employ social media. Social media users voluntarily generate large amounts of data, originally not intended but possibly very useful for public participation (VAN LAMMEREN et al. 2017). Users post data without linking them to specific plans or projects and the assumption is, therefore, that they lack the bias typical of planning processes. The main advantages of employing social media, compared to standard participatory approaches (survey, information event, etc.),

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are the large amounts of data existing in user profiles, and the abundance of evaluation possibilities. Different approaches to landscape quality assessment using data from social media have recently been developed and tested (e. g. DUNKEL 2016, FRIAS-MARTINEZ et al. 2012, MONTAÑO 2018). Building on these approaches, an innovative model and method to conducting landscape quality assessments for large areas is presented below.

2 Approach

At the OWL University of Applied Sciences and Arts, we developed an Anticipative-Iterative-Geographic-Indicator-Model for Landscape Preferences (AIGILAP) that supports planning practitioners in social-media-harvesting. Using this model, we are able to conduct landscape quality assessments for large areas (RIEDL et al. 2021).

Social-Media-Harvesting

Every day, social media users voluntarily generate large amounts of photographs, geographic information and text elements, such as descriptions and comments. For planers, these data offer enormous potentials. Photographs including metadata, geographical information and written comments are particularly interesting for planners as they meet most of the needs of landscape quality assessment. Within the approach presented in this paper, the social media network FlickR was used (YAHOO! 2017). FlickR offers the possibility to sort photographs by categories or tags and to find images on particular topics (KAUßEN 2018). As illustrated in Figure 1, different users feed different data, metadata, personal references and photographs into the database of the social network that may be harvested using the application programming interface (API) of Flickr. To make use of the API, a software tool has been developed that is able, by using a set of keywords, to automatically harvest all imagery in a particular geographical space.

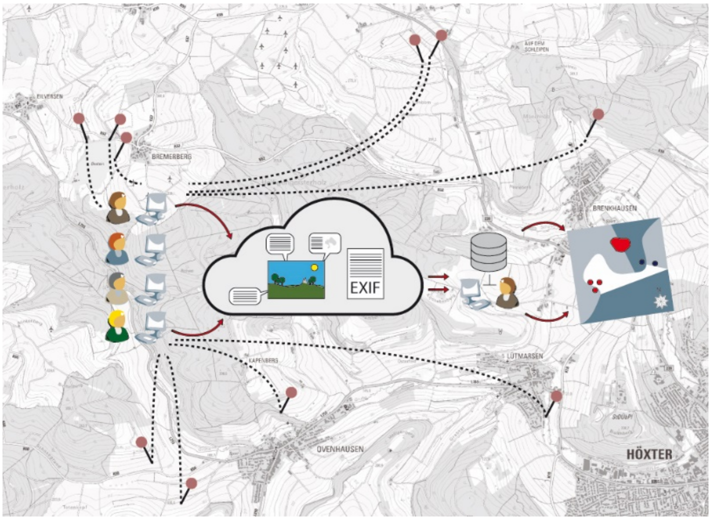

Fig. 1: Workflow social-media-harvesting (KAUßEN 2018)

The keyword (tags) "landscape" was used in our examples to filter imagery available in Flickr. When a search query is given, the software saves the filtered data in different ways.

On the one hand, all photographs including the selected tag are downloaded, and on the other hand, an Excel-sheet with metadata of the respective photographs is created. Metadata include the title of the photograph, anonymized information about the person who uploaded the photograph, comments from other users, the coordinates (geotag with longitude and latitude) of the place where the photograph was taken, as well as information about the camera and settings, if available.

After data harvesting, it is possible, within five steps of analysis to gain new insights into the perception of landscape through the photographs taken in a certain area. These insights include the following:

- By spatial analysis we learn how photographs are geographically distributed within the given area and this distribution might point to places that social media users find meaningful in certain ways (DUNKEL 2016, MONTAÑO 2018).
- By conducting an image analysis (structure, elements, etc.) of photographs it is possible to find out which landscape elements are depicted in the photographs.
- By analysing the content, the social media community discusses (impact) and combining this content with metadata and written (verbal) contributions (HOKEMA 2013, KOOK 2009, KÜHNE 2006, KÜHNE 2018, LINKE 2018, LINKE 2019, MICHEEL 2012), we might gain insights into people's reasoning or evaluation.
- A text analysis via tokenization (HEROLD 2003) shows which elements are textually highlighted by comments and descriptions, what content is being communicated, how the images are being described, and so forth.
- A network analysis shows which users upload individual images, and who is communicating with whom. Finally, yet importantly, we can gain more knowledge about motives, backgrounds and opinions of the respective users by the network analysis including the user profiles and evaluate how they act in this social network.

Employing results from this data analysis, a characterization of the respective landscapes becomes possible, highlighting valuable elements that correspond with the perceptions of the public. This knowledge is used in the following to evaluate landscape beauty.

Anticipative-Iterative Geographic-Indicator-model for Landscape Preferences (AIGILaP)

Originally, the AIGILaP-Approach was developed for nationwide analysis of general landscape quality and sensitivity against wind turbines in Germany (RIEDL et al. 2021). However, in its original version the tool did not include any analysis of social media data. It was rather based upon existing landscape expert knowledge about landscape-quality that was transformed into a GIS-approach. This approach mostly employs existing land-use data as well as other environmental information to calculate landscape quality and sensitivity.

Taking the limited options for landscape assessment on the nationwide level into account, first, methods for landscape quality assessment, especially those common on other scale levels, were analysed in order to determine which criteria are common in landscape planning and architecture (RIEDL et al. 2021, STEMMER et al. 2019). Then, to select the criteria used for the AIGILaP-Approach, the following conditions were defined:

- The criteria are frequently used in the evaluation methods examined and in practice.
- The criteria are transferable to a nationwide level.
- The criteria can be recorded in a geographic information system (GIS).

To conform with provisions made by the German Federal Nature Conservation Act – BnatSchG the analysis has to consider aspects of landscape diversity, specificity, beauty, naturalness and recreational value (BRUNS & STEMMER 2018). In particular, the attribute 'beauty' is difficult to operationalize and it is not included in many common evaluation methods. One additional challenge was identified during the process of the development of the AIGILaP-Approach; it became apparent that for nationwide assessments of landscape beauty in particular, there is near to no useable information available.

In a follow-up research project[1] a refinement of the approach became possible. Social media data were included to assess landscape-beauty. An overview of attributes, criteria and indicators is presented in Table 1. Indicators characteristic of a particular landscape are processed employing GIS. Several indicators represent individual criteria. The criteria-value as well as the overall landscape quality is calculated by an algorithm by using a grid (Fig. 2). Thus, the model guarantees a transparent and reproducible assessment (Table 1).

The basis for the calculation of "beauty" are the indicators "beauty in protected areas", "perceived dominance of water", and "perceived beauty of landscape" (Table 1). "Perceived beauty of landscape" consists of a number, an area, and their share of valuable landscapes elements that are gained through the analysis of social-media-harvesting imagery.

Table 1: Overview of attribute, criteria and indicators of the AIGILaP

Attribute	Criteria	Indicator
Diversity	Diversity of land use	Number of different types of land use per defined area unit
	Diversity of relief	Terrain Ruggedness Index (TRI)
Specificity	Character of the distribution of land use	Deviation of the usage distribution of a defined area unit from the usage distribution of the associated cultural landscape type
	Landscape change	Landscape change since 1996
Beauty	Beauty in protected areas	Presence of protected areas
	Perceived dominance of water	Proportion of water area per defined unit of area
	Perceived beauty of landscape	**Area share of valuable landscape elements**[2] **Number of valuable landscape elements**
Recreational value	Potential recreational suitability for local recreation	Diversity, specificity, beauty and naturalness
	Potential recreational demand for local recreation	Distance to sparsely populated and densely populated settlement areas
	Potential recreational value for long-distance recreation	Presence of protected areas
Naturalness	Naturalness Land use	Naturalness of the types of land use
	Close to nature in protected areas	Presence of protected areas
	Presence of disturbances	Presence of acoustic and visual impairments

[1] Project funded by the Lippe district as part of the Lippe 2025 future concept.

[2] Only within the Lippe-District-Project.

For this purpose, land use data are converted into a grid of 12.5m × 12.5m cells that describe valuable landscape elements. Each grid cell is assigned a value as soon as a valuable landscape element is present within the cell. The 12.5m × 12.5m grid is then aggregated to 500m × 500m, with the number of 12.5m × 12.5m cells that receive valuable landscape elements being counted for each 500m × 500m cell. This means that the percentage of valuable landscape elements within the cell can be determined for each grid cell (500m × 500m, Fig. 3-4).

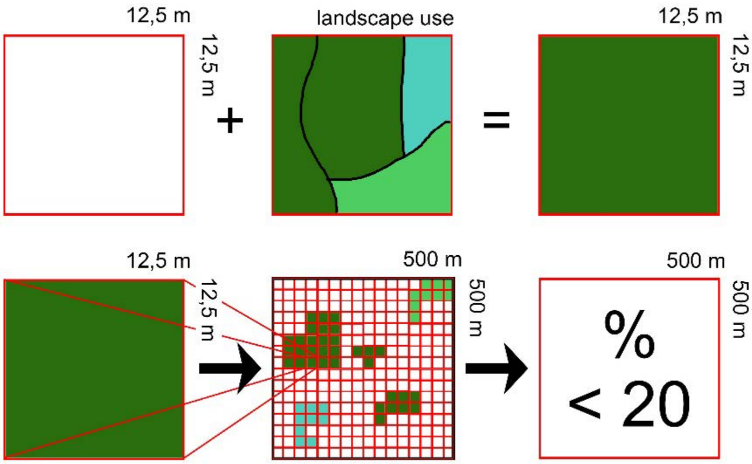

Fig. 2: Calculation of area share of valuable landscape elements (KAUßEN 2021)

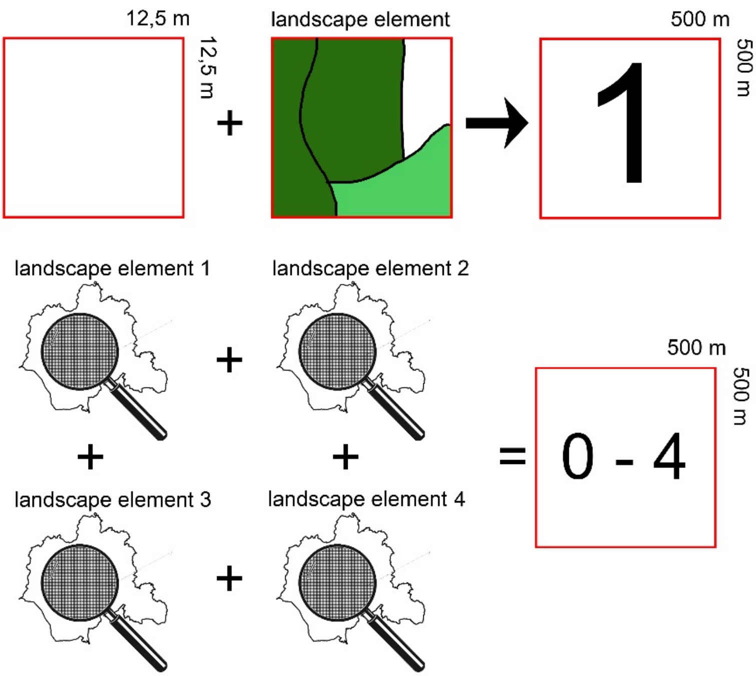

Fig. 3: Calculation of number of valuable landscape elements (KAUßEN 2021)

3 Output

We conducted landscape analysis using variations of the approach in different research projects, different planning assignments and at different scales. At the district level we were able to carry out the analysis in North Rhine-Westphalia within the Lippe-District. At the federal level we applied the approach in a way modified for that scale.

The approach was used for different project-aims. In the Lippe-District the aim was to contribute to the general assessment of landscape values as a contribution to the mandatory landscape plan (Fig. 5) (STEMMER et al. 2020).

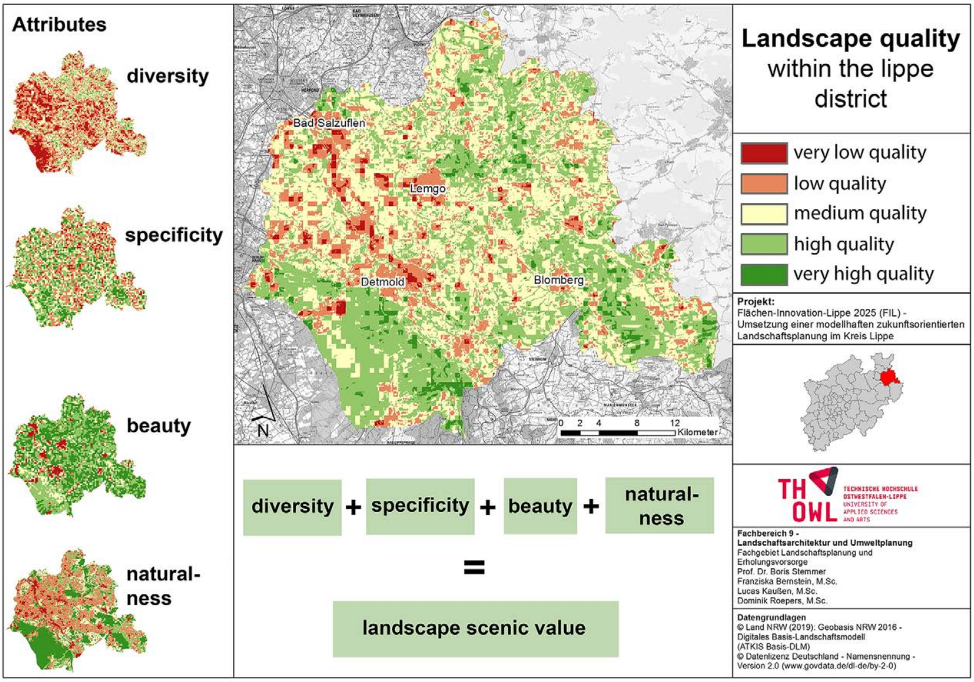

Fig. 4: Landscape quality within the Lippe-District (From green to red: very high to very low quality) (STEMMER et al. 2020)

At the nationwide level, an assessment of landscape sensitivity to wind turbine planning was evaluated[3] (Fig. 5). The approach was slightly modified for this project. With respect to the fact that landscapes across Germany differ al lot, we decided to analyse valuable landscape elements within landscapes of the same type (SCHMIDT et al. 2014). In consequence, we could no longer use the indicator "Area share of valuable landscape elements" (Table 1). Valuable elements within landscapes differ much in typical extent. Therefore, a nationwide evaluation

[3] Research and Development project funded by BfN (Federal Agency for Nature Conservation) with funds from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)).

standard could not be defined. Other changes in indicators were made but are not listed in detail here. Mostly data availability and homogeneity lead to minor changes within the AIGI-LaP.

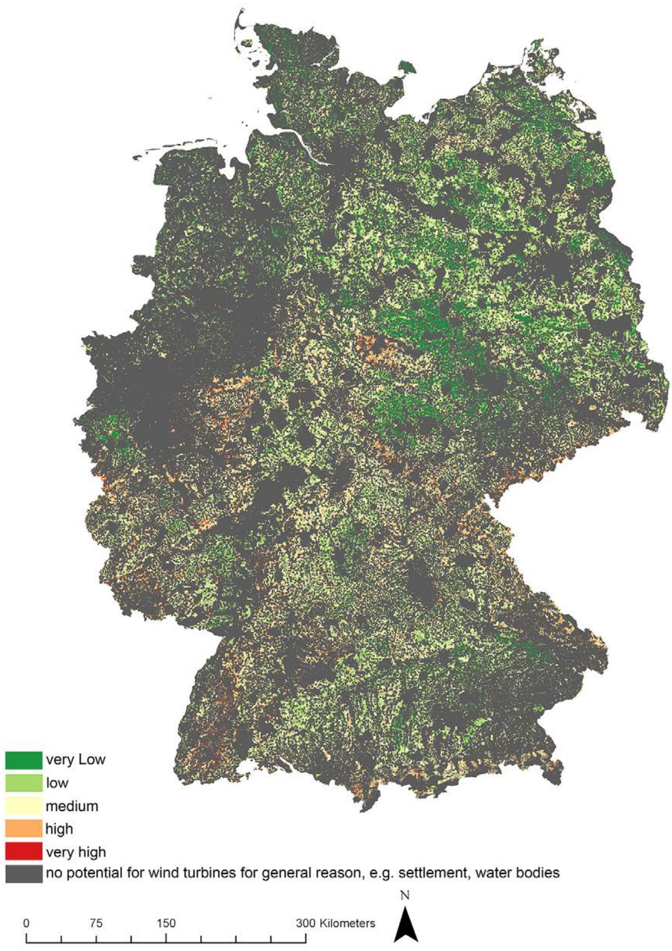

Fig. 5: Landscape sensitivity to wind turbines within Germany

To date, evaluations of the analysis output was conducted in expert discussions, both on nationwide level as well on the district level at different occasions (regional to local). Two outcomes are that, first, experts considered analysis output to be highly plausible, even and particularly at the regional scale. Consequently, planners showed high interest in using the outcome for upcoming planning tasks for example within regional planning. Second, within the Lippe-project, experts were able to compare outcomes of early versions of our model to the latest versions that then included the new social media harvesting approach. The expert-group clearly stated how remarkable the improvements in output were, that the model made possible in its most recent versions.

4 Outcome

It has to be clear that the approach presented here still is in an exploratory state. Nevertheless, our approach combines expert GIS based methods on landscape quality assessment with data analysis method for social media. In doing so, it offers a couple of advantages compared to other methods of landscape quality assessment. The most important ones are these: The new model does not rely on public participation in landscape assessment with all its shortcomings without neglecting the importance of public landscape perception for landscape quality assessment. Then, even if it were possible to elaborate landscape assessment empowering public participation, as planning areas increase in size, the effort for reasonable participation would constantly grow as well. In contrast, the AIGILaP Approach is usable for a wide range of planning scales from regional to federal planning level. One of the strengths of the model is its ability to help practitioners to evaluate large areas with ever-lower effort. Moreover, the AIGILaP-Approach turned out to be suitable for different project-aims with only few modifications. In this way, it was possible to avoid some challenges of public participatory approaches in landscape quality assessment (STEMMER & KAUßEN 2018).

This approach takes on the challenge to assess all attributes of landscape assessment regulations within the German act of nature conservation: recreational value, diversity, specificity and the most controversial attribute of beauty as well. Especially for beauty the integration of social media data shows that it is possible to find a way of evaluating landscape beauty with respect to public landscape perception.

The output of model application is an area wide evaluation of landscape quality that is based upon transparent criteria. Moreover, it is reproducible at nearly any planning scale. Thus, it meets the demands of planners working on the local, regional and nationwide scale.

However, the approach is not intended to replace lively public participation within the planning process (e. g. mandatory landscape plan). It simply describes a way to integrate public perception of landscape presented in social media into the stage of assessment of landscape beauty. It also delivers a reproducible and transparent assessment of other criteria relevant at least in landscape planning in Germany employing a standardized GIS-process. Therefore, it is important to point out that at other stages of the planning process it is still highly necessary to involve the public directly, depending on the aim and topic of the plan or project (SCHMIDT et al. 2019).

5 Further Research

As mentioned above, until now, an evaluation of the output of the new approach and model was made only with experts. The positive expert opinion is very encouraging to start further systematic evaluation.

With respect to social media harvesting and the analysis of the imagery, there are different starting points for evaluation and further research.

- First, we need more data on how imagery from social media represents public perception within a certain area e. g. Lippe-District. Members of the public might be invited to take part in a survey and asked to evaluate imagery harvested from social media. In addition, a photo-competition within the region might result in sets of imagery that differ from harvested ones and that might be used for analysis and comparison.

- Second, our approach to imagery analysis needs further refinement for practitioners to reliably identify important landscape characteristics. Besides that, within a survey public should be asked which of the landscape elements that are common in a region they believe are typical for certain landscapes. Finally, it has to be asked if available land use data is appropriate to be used in any analysis of what is considered "valuable" landscape elements (are the relevant elements prevalent in datasets?). In this context, it is also necessary to learn if taking into account combinations of elements would improve analysis outcome.
- Third, it is relevant to conduct longitudinal studies to gain knowledge about the fluidity of outcomes over time. For that purpose, a new dataset (2 years) has been harvested and is currently analysed. Moreover, we plan to take random photos within the district to compare output of the analysis for valuable landscape elements to the harvested datasets.
- Fourth, we have to determine for which scale the outcomes are valid. We have already demonstrated the use of landscape types for this purpose on the nationwide level. Comparable approaches for regional and local level have to be developed and tested.

Until now, the influence of social media analysis within the whole approach is limited to only two indicators as described above. Thus, after answering the further research questions we would rather tend to introduce more and more indicators for not only beauty but also other attributes. That would mean to switch the baseline from a classic expert approach to a new social-media approach.

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Landscape Suitability Analysis for Developing a Framework of Green Infrastructure Protection in Bandung Basin Area, Indonesia

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Abstract: GIS-based landscape suitability analysis is a useful approach in the practices of urban design, planning, and management, especially for developing future land use, which includes the identification of land suitable for green infrastructure protection. We explored applying a multi-criteria decision analysis through GIS-based suitability tools to create a combined criteria map for developing a green infrastructure protection plan in Bandung Basin Region, Indonesia. We used two overlay techniques, the Weighted Sum Overlay and the Fuzzy Overlay. Both approaches aided the land suitability identification process for developing a green infrastructure plan in the region based on proposed objectives. Results showed that both cities of the region were predominantly built areas while the other three regencies were mostly vegetated open space, which suggested that the outer urban areas offered more opportunities to develop a green infrastructure protection plan. We also identified the key issues for future improvement of the overlay techniques application to help inform the planning and design process.

Keywords: Landscape suitability, geodesign, green infrastructure, urban greenspace protection, bandung basin

1 Introduction

Urbanization, followed by loss of greenspace and other natural or semi-natural areas, has altered the urban environment's quality through an extensive land cover conversion. A predominantly impervious surface, as well as poorly connected urban natural or semi-natural patches, significantly degraded the quality and services provision of urban ecosystems. This was especially true regarding the water cycle and urban micro-climate regulation, pollution and flooding control, urban wildlife habitat provision, and cultural services such as recreation, education, and social functions of greenspace. These changes challenged the urban environment's resilience and brought up questions about how landscape planning and design could help mitigate such effects through green infrastructure planning (BENEDICT and MC MAHON 2006, MELL 2014). Green infrastructure is defined as a network of connected greenspaces to serve both ecological and social functions (BENEDICT and MC MAHON 2006). This concept had often been identified as an approach to integrating conservation and development in landscape planning. It can be applied at various spatial scales, from urban to regional landscapes (BENEDICT & MC MAHON 2006).

In this paper, we aim to explore and report on the application of landscape suitability analysis and interpretation as part of the foundation for developing future green infrastructure planning scenarios for the study region. It is part of a research project focusing on integrating green infrastructure protection in land-use plans at the scale of urban regions. Green infrastructure protection, which consists of conservation of existing greenspace and, whenever possible, provision of new greenspace, is a critical approach to conservation and development balance (BENEDICT & MC MAHON 2006, GORDON et al. 2009) to enhance the resilience of

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urban landscape. However, this approach's integration in the urban plans needs further exploration, especially for application in rapidly changing and high-density urban regions. It becomes necessary to assess future green infrastructure protection opportunities beyond administrative boundaries to develop an integrated green infrastructure planning framework that ensures future conservation of the urban regions.

The concept of urban regions (FORMAN 2008) is adopted to identify potential greenspace patches, corridors, and matrices within the study region and assess them as the base elements for developing future green infrastructure protection scenarios. The evolving geodesign framework (STEINITZ 2012) and GIS technology (MALCZEWSKI 2004) allow us to explore the application of multi-criteria decision analysis (ROMANO et al. 2015). We utilized the GIS-based suitability functions using two overlay techniques (MALCZEWSKI 2004): Weighted Sum Overlay and Fuzzy Overlay. We then interpreted what the results might inform the green infrastructure planning and design process.

2 Methods, Analysis, and Results

2.1 Study Region and Materials

The study region of this research is Bandung Basin Area, or also known as Bandung Metropolitan Region, in Indonesia. The region (Fig. 1) consists of two cities: Bandung City and Cimahi City as the central urban areas. The region also includes three regencies: Bandung Regency, West Bandung Regency, and parts of Sumedang Regency as the outer urban (suburban and rural) areas. All data used in this study were retrieved from the Indonesia Geospatial Portal website (https://tanahair.indonesia.go.id, accessed June 6, 2019) in the form of a GIS-based shapefile format. Each administrative area has its own large sets of raw data, therefore a series of data cleaning and grouping was required. The process included projection, merging each data from all five regions into one dataset of the overall study region, data conversion to raster-based format, and data features recategorization. While the datasets were digitized based on the mapping process in 1998, they were visually verified using the region's latest aerial maps provided by ArcGIS. A general field survey of Bandung City in 2019 was used as a reference for other areas outside the city.

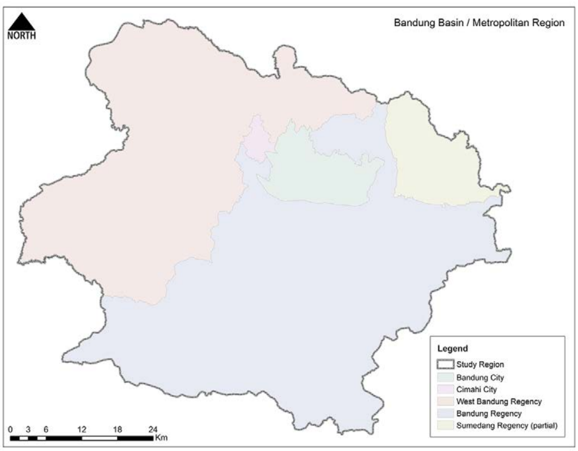

Fig. 1: Study Region

Five maps were used as base data for analysis, including elevation map and slope map (generated from DEM of the region), land cover map and surface water body map (generated from geomorphology map of the region), and roads and railways maps. These maps were included since representing the region's main physical, ecological, and urban characteristics: a basin surrounded by mountains and formed by multiple watersheds and a rapidly urbanized metropolitan. Using these basic maps to create multi-criteria suitability surfaces, we expected to identify potential areas to develop future green infrastructure and protect existing ones.

2.2 Suitability Maps for Green Infrastructure Protection Objectives

The first step of analysis was to create individual suitability maps based on selected green infrastructure protection objectives. The first objective was to conserve areas with an elevation of 750 meters and higher per regional rule. The second objective was to protect areas with a slope of 30% or higher. The third objective was to protect existing greenspace such as forests, parks, and other vegetated areas, also to seek potential areas to develop new green infrastructure. The fourth objective was to protect and conserve buffer areas or floodplains of water bodies, including dams and lakes, rivers, and creeks. The fifth objective was to protect buffer areas of main roads and railways as potential street trees and open space corridors. The datasets were analyzed using ArcGIS functions, including slope, distance, and reclassification, to assess their suitability value in terms of the objectives. The results were then reclassified into a range of values between 1 (one) to 9 (nine), with nine being the most suitable and one being the least suitable for the objectives (Table 1).

Table 1: Suitability scale of each dataset for the green infrastructure protection objectives

No	Objectives	Approach	Scale
1.	To protect areas with an elevation of 750 meters and higher	Reclassification	9: > 1,500 meters (m); 7: 750-1,500 m; 5: 625-750 m; 3: 500-625 m; 1: < 500 m
2.	To protect areas with a 30% slope or higher	Slope	9: > 30%; 7: 15-30%; 5: 8-15%; 3: 2-8%; 1: 0-2%
3.	To protect existing green-space and seek potential areas for new green infra-structure	Reclassification	9: Forest Area; 7: Non-forest Vegetated Area; 5: Agriculture Area; 3: Water Surface; 1: Built Area / Sand Surface
4.	To protect surface water buffer or floodplain	Distance Reclassification	Dams and big rivers: 9: 100 m; 8: 200 m; 7: 300 m; 1: >300 m Small rivers: 9: 50 m; 8: 100 m; 7: 150 m; 1: >150 m Creeks: 9: 30 m; 8: 60 m; 7: 90 m; 1: >90 m
5.	To protect main roads and railways buffer areas	Distance Reclassification	Railway buffer: 9: < 50 m; 1: > 50 m Roads buffer: 9: < 25 m; 1: > 25 m

The next step was to combine the individual suitability maps into one map. We explored two approaches in creating the combined suitability surfaces for the overall suitability value to develop a green infrastructure plan: (1) the Weighted Sum Overlay approach and (2) the Fuzzy Overlay approach. Both techniques were performed in ArcGIS.

2.3 Combined Suitability Map with Weighted Sum Overlay Analysis

Weighted Sum Overlay analysis allows us to combine multiple rasters (or objectives) with specifically assigned weights for each to create an overall suitability surface. This analysis applied five alternatives to weight values assignment with the total value of all objectives equal to 1 (Table 2). The first alternative was an equal weight of 0.20 across all five objectives (Figure 2). The second alternative was weighted more towards protecting surface water buffer or floodplain with weight 0.40. The third alternative was weighted more towards the protection of existing greenspace. The fourth alternative was weighted more towards the topography-based (elevation and slope) area conservation with a total weight of 0.55. The fifth alternative was weighted more towards the protection of roads and railways buffer areas.

Table 2: Weighted value assignment for the Weighted Sum Overlay alternatives

No	Objectives	Alt.1	Alt.2	Alt.3	Alt.4	Alt.5
1.	Protection of areas with elevation of 750 meters and higher	0.20	0.15	0.15	0.275	0.15
2.	Protection of areas with 30% slope or higher	0.20	0.15	0.15	0.275	0.15
3.	Protection of existing greenspace and potential provision of new green infrastructure	0.20	0.15	0.40	0.15	0.15
4.	Protection of surface water bodies buffer or floodplain	0.20	0.40	0.15	0.15	0.15
5.	Protection of main roads and railways buffer areas	0.20	0.15	0.15	0.15	0.40

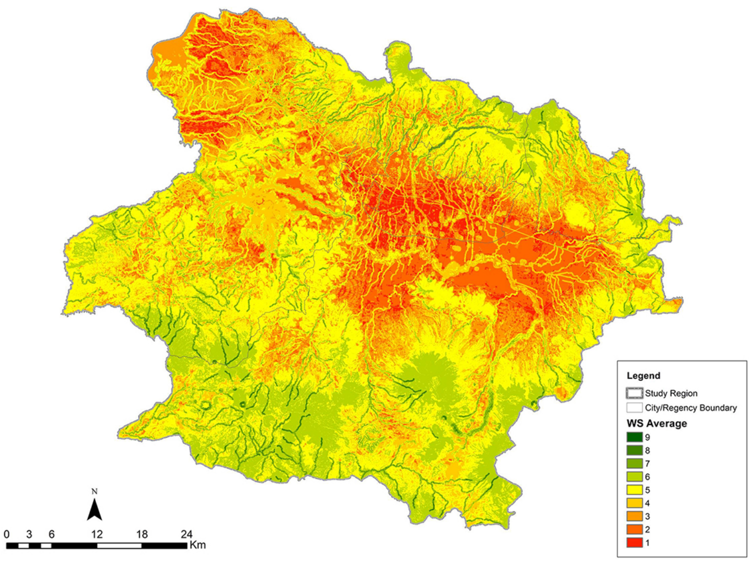

Fig. 2: Combined suitability map using Weighted Sum Overlay approach with an equal weight of 0.20 for each of five objectives (Alt. 1)

The combined suitability surface with equal weights (Figure 2) showed that the higher priority (value range 7-9) was located on some segments of the surface water buffer areas. A more moderate priority (value range 5-6) was located on existing mountainous areas and agricultural lands. A large portion of the study region can be considered less or not suitable (value range 1-4) for developing a green infrastructure plan. As a comparison, the map on the left in Figure 3 illustrates the Weighted Sum Overlay result for the second alternative weighting. A higher priority was given to all buffer areas of the surface water bodies. The map on the right in Figure 3 illustrates the third alternative weighting result in which a higher priority was more equally distributed to existing forests, other vegetated areas, partial agricultural lands, and surface water buffers.

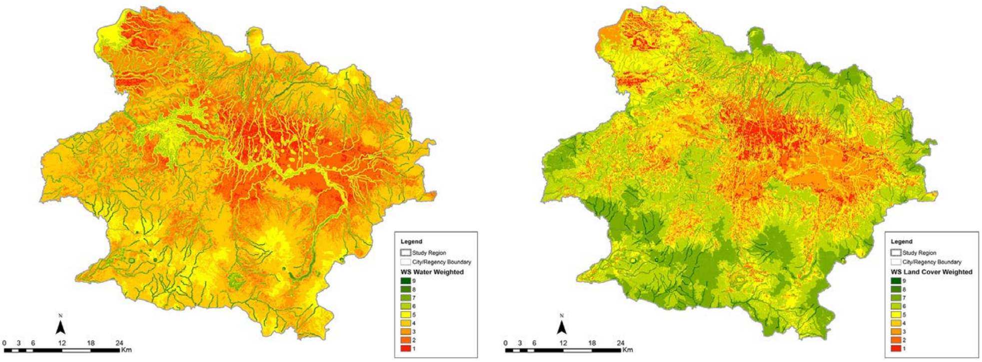

Fig. 3: Comparison of combined suitability map using Weighted Sum Overlay approach with weighted towards Objective 4 (Alt. 2 – left); and weighted towards Objective 3 (Alt. 3 – right)

2.4 Combined Suitability Map with Fuzzy Overlay Analysis

Besides applying the Weighted Sum Overlay analysis, we also explored the possibility of using Fuzzy Overlay analysis to generate a better-combined suitability map of multiple objectives. The traditional suitability approach assigned the weights of objectives in a numerical form, which often disregarded the level of importance of the objectives themselves (MALCZEWSKI 2004). The fuzzy logic approach offered a way to address this issue and gave place for imprecision in the land-use suitability analysis (MALCZEWSKI 2004). In this paper, the Fuzzy Gamma method was used to combine all objectives in five alternatives with Gamma values of 0.10, 0.25, 0.50, 0.75, and 0.90 assigned for each. Before applying the Fuzzy Overlay function, we first transformed each objective-based suitability model with the Fuzzy Membership function to rescale the value of 1-9 into 0-1. However, the Fuzzy binary value range works opposite to the objective-based suitability value range. In the objective-based suitability models, the value of 9 indicates the most suitable, while 1 indicates the least suitable instead of the other way around. Therefore, in the Fuzzy Membership models, the value of 1 implies the least suitable instead of being the most suitable.

After having all objective-based suitability models transformed into Fuzzy Membership models, we performed the Fuzzy Overlay analysis to combine all of the outputs using the Gamma method. We generated seven models by applying Gamma values of 0.00, 0.10, 0.25, 0.50, 0.75, 0.90, and 1.00. In this case, the model with a Gamma value of 0.00 showed the 'total' suitability values of all combined criteria, while the model with a Gamma value of 1.00 showed the 'multiplied' values of all combined criteria, therefore less than any of the input criteria. The model with a Gamma value of 0.50 represented equal importance of relationship among all combined criteria. This model (Figure 4) showed the higher priority (smaller values) to be distributed on some segments of surface water buffer areas, followed by the buffer area of roads and railways, and lastly the green areas on mountains. As a comparison, Figure 5 showed the models with Gamma values 0.10 (left) and 0.90 (right). The model with Gamma value 0.10 showed a higher priority to be more expansively distributed, including on the area of surface water bodies and their surroundings. Conversely, the model with Gamma value 0.09 showed a higher priority to be less distributed throughout the region, while areas with lower priority or less suitability were more expanded.

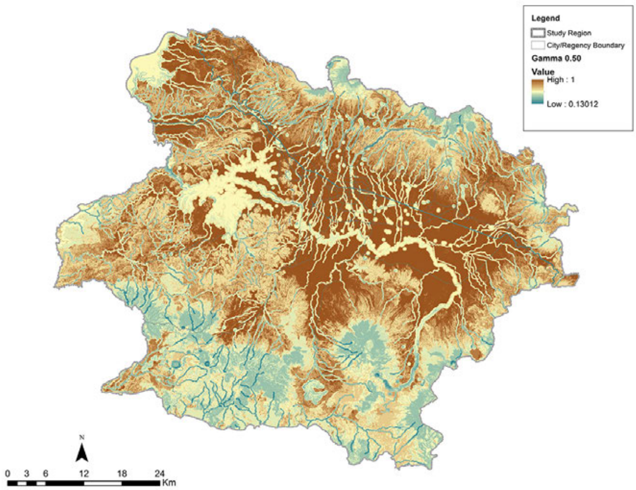

Fig. 4: Combined suitability map using Fuzzy Overlay approach with a Gamma value of 0.50, representing equal importance across all objectives

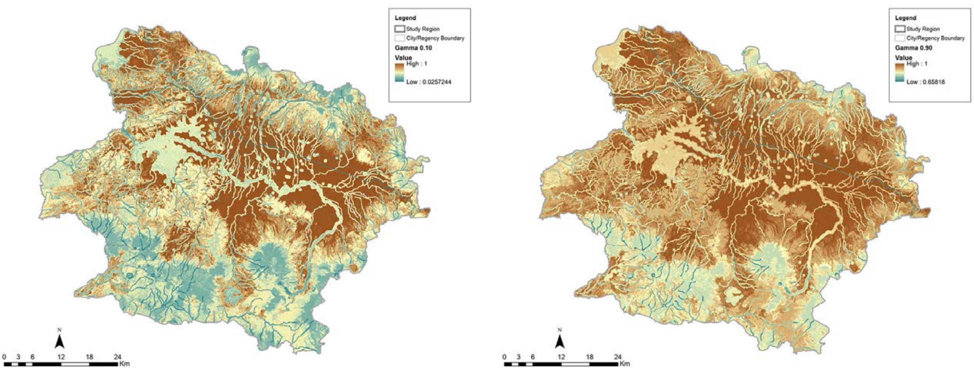

Fig. 5: Comparison of combined suitability maps using Fuzzy Overlay approach with Gamma values of 0.10 (left) and 0.90 (right)

3 Discussion

The purpose of having the GIS-based suitability analysis performed using the overlay functions reported in this paper was to explore its application in creating a combined criteria map for developing a green infrastructure plan, particularly in the Bandung Basin Region. A multi-criteria analysis approach was considered useful for this goal as it could provide relatively objective reasoning to determine priority for future green infrastructure planning. Two key issues for discussion were identified through performing the overlay approaches:

1) In the Weighted Sum Overlay analysis, each criterion's weighting factors must be carefully determined while creating the combined output. There was no universal consensus on assigning a set of weighting factors towards the criteria included in the suitability analysis (MALCZEWSKI 2004). It was most likely to depend on our specific goals and objectives of planning and the number of criteria to be counted. One basic approach to use is by assigning an equal weighting factor for each criterion. Another approach is assigning more weighting factors toward a criterion we consider as more important, with a clear reasoning, and then giving an equal factor for the rest. In addition, there is also an expert opinion approach or a stakeholder approach, where we survey related experts or stakeholders to get their opinion on the weighting factors, which then can be averaged or determined by a discussion and consensus approach (MALCZEWSKI 2004). We will explore these options in a follow-up research.
2) The Fuzzy Overlay analysis offers a different way of creating a combined criteria map through its five methods, including the Gamma method applied in this study. The Gamma value suggests the probability of a region meeting all the criteria instead of weighting each criterion's influence towards the combined model. However, there is one critical issue from the technical aspect in this process, as reported in the Method Section 2.4. We need to reverse the individual objective-based suitability model's values before processing with the Fuzzy Membership function to generate the suitability models for the Fuzzy Overlay analysis. They need to be changed from 9 (nine) being the most suitable and 1 (one) being the least suitable to 1 (one) being the most suitable and 9 (nine) being the least suitable. The individual suitability models used in the Weighted Sum Overlay analysis cannot be directly used in the Fuzzy Membership operation as it will reflect an opposite suitability value. While the results can be read in reverse, it contradicts the concept of what the binary value of Fuzzy Overlay output represents.

The outputs from both approaches increased awareness of the region's landscape characteristics regarding its suitability for developing a green infrastructure plan. All results showed that both cities of the region (Bandung and Cimahi) were predominantly built areas. The other three regencies were mostly open space with vegetation ranging from wildwood/forest, parks/gardens, fields, and rice fields. These interpretations suggested a challenge in proposing a green infrastructure protection plan in the central urban area, but more opportunities were identified in the outer urban (suburban-rural) areas. There is a possibility to have green infrastructure networks of different scale or structure in the rural areas versus urban areas. The green infrastructure network in the urban areas may be limited to pocket parks, stormwater parks, urban gardens including food producing or wildflower gardens, green streets, green roofs, bioswales, and rain gardens. The surface water greenway was identified as a prominent feature to connect large greenspace patches in the surrounding regencies and small greenspace patches in the central urban area. The riparian greenway was also considered extremely important for protecting water quality and wildlife habitat/corridors. A separate analysis is needed to assess the value of connectivity and its integration in the suitability models.

4 Conclusion and Recommendation

GIS-based landscape suitability analysis is a useful approach in urban design, planning, and management practices, especially for developing future land-use visioning and plans (MALCZEWSKI 2004). This approach includes identifying land suitable for green infrastructure planning, which was explored in this study using Weighted Sum and Fuzzy Overlay techniques. Both techniques were considered helpful in aiding the identification process as part of developing a framework to propose future green infrastructure planning scenarios. The suitability modeling can be applied at multiple scales, providing opportunities to identify areas with potential suitability regardless of the administrative boundaries.

The landscape suitability models need to be more actively incorporated in planning and design and spatial planning-related policy development processes to better inform decision making (GORDON et al. 2009). The scale of suitability criteria should be carefully determined in alignment with the resolution of the spatial analysis. One key area of improvement is to develop a more appropriate approach in determining the weighting factors or Gamma value associated with a more adaptive future green infrastructure planning (AHERN et al. 2014).

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Landscape and Building Information Modeling (LIM + BIM)

Digital Futures in Landscape Design: A UK Perspective

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Abstract: The world is facing unprecedented environmental challenges, of which the construction industry is a significant contributor. Building Information Modelling (BIM) is supporting the digital transformation of the industry as we seek new and more efficient ways of working. The implementation of lean construction and just-in-time processes will mean we are making better use of existing materials, reducing waste, and extracting less of our finite natural resources. BIM is not the complete answer, but it introduces better decision-making processes that will help reduce the impact construction has at a global level.

Keywords: Digital futures, digital transformation, digital twin, building information modelling, BIM

1 Introduction

According to the United Nations (UN), if unchecked, the world's population is projected to increase to 9.7 billion by 2050, mainly because better health care means more people are surviving to reproductive age and living longer. This means we will see an approximate 30% increase in the global population in only 30 years.

This explosion in population numbers parallels an increasing migration to cities. The UN World Urbanization Prospects estimate that by 2050 68% of the world population will live in urban areas, many of which have not been built yet or are not meeting the needs of today's populations. This increases pressure to improve existing cities and provide new places to live.

These trends will have a significant impact on the construction sector, of which landscape is a contributor. The UK Green Building Council have estimated that the construction sector uses more than 400 million tons of material a year, and many of these materials have an adverse impact on the environment. The "Supporting material for the Low Carbon Construction IGT Report" (2010) stated that: "The amount of CO_2 emissions that construction can influence is significant, accounting for almost 47% of total CO_2 emissions of the UK."

Whilst this estimate is over ten years old, there is little to suggest that this is changing. According to new research by construction blog Bimhow, "the construction sector contributes to 23% of air pollution, 50% of the climatic change, 40% of drinking water pollution, and 50% of landfill waste". In separate research by the U.S. Green Building Council (USGBC), it is suggested that "the construction industry accounts for 40% of worldwide energy usage, with estimations that by 2030 emissions from commercial buildings will grow by 1.8%".

It is assessed that the UK's biggest consumer of natural resources and generator of waste is the construction industry. The Department for Environment, Food & Rural Affairs (DEFRA), in their February 2018 edition of UK Statistics on Waste, report that in 2014 the UK generated 202.8 million tonnes of waste. And construction, demolition, and excavation (CDE) was responsible for 59% of that number.

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The Brookings Institution (2017) reports that the world's middle class is growing fast. It indicated that today 140 million people are annually entering the status of the middle class and this number could rise up to 170 million in the next 5 years. This suggests that the world's middle class is expected to increase to about 5.2 billion in 2030, representing 65% of the planet's population. With approximate 400,000 people joining the global middle class each and every day there will not only be pressure to provide housing, health care, areas to recreate but with more wealth comes a growing demand for consumer goods, such as cars, washing machines, refrigerators, mobile devices, digital connectivity, etc. It is estimated that powering these lifestyles will require double the amount of world energy currently produced, requiring us to find new, cleaner sources of energy.

At the 21st Conference of the Parties in Paris in 2015, UNFCCC reached a landmark agreement to combat climate change and to accelerate towards a sustainable low carbon future. As part of the 10th annual World Green Building Week, the World Green Building Council (WorldGBC), issued a vision for how buildings and infrastructure can reach 40% less embodied carbon emissions by 2030, and achieve 100% net zero emissions from buildings by 2050.

In June 2019, the Landscape Institute (LI) Board (UK) declared a climate and biological diversity emergency. In May 2020, it published the "Climate and biodiversity action plan" that describes its overall mission, and strategic areas for direct action to address these issues.

If we are to meet these global challenges, we need to accelerate the shift in both what we make and how we make it. To achieve this, we need to work: better, by making more efficient use of time and resources; smarter, though informed decision-making that is supported by accurate modelling, sensory feedback and connectivity via the Internet of Things (IoT); and, use less, both resources and energy from non-renewable sources and, as an outcome, our production of waste.

This is where Building Information Modelling (BIM) can help. BIM provides a framework for project delivery, construction and operations management that supports the entire life cycle of the project. In essence. it seeks to apply the proven prototyping and Just-in-Time management processes of manufacturing to deliver lean construction. This seeks to introduce efficiencies and reduce waste at all stages of a project. The Landscape Institute (UK) publication, "BIM for Landscape" (2016) discusses how BIM can benefit landscape projects and how this relates to design, construction, and maintenance of landscapes, ensuring a better use of resources.

2 BIM in Landscape Design

In my previous article for the Journal of Digital Landscape Architecture (SHILTON 2018), I stated that, as landscape professionals, we aspire to: "create better performing landscapes, specify products that are fit for purpose, deliver projects on time and to budget and require cost effective maintenance, all within the context of improved sustainability and a reduced carbon footprint". This objective remains, and I set out how this could be achieved through prototyping, defining processes and the adoption of standards. I referenced how the UK BIM Task Group felt this could be achieved through the "Levels of BIM", and this was supported by the "Pillars of BIM" and the BS/PAS 1192 standards suite.

Whilst this provided a great foundation, there were many reasons that prevented widespread adoption of BIM. This includes:

a) Too many confusing and often contradictory definitions of BIM
b) Difficulty defining the levels of BIM, in particular BIM Level 2 that was the primary target of the UK BIM initiative
c) The term “Building”, inferring it was only relevant to building projects. Despite many commentators suggesting we should consider this as the verb, “to build”, rather than the noun, “the building”, this was widely overlooked. Too many architectural-based exemplar projects did little to change this view
d) Too many professions trying to stake their own claim, resulting in the proliferation of new definitions around information modelling (IM), such as Landscape (LIM), Site (SIM), Water (WIM) and others
e) Miss-information suggesting BIM is only 3D and, therefore, only for the few
f) Clever marketing by software vendors suggesting BIM required you to use their, often expensive, software and which required high end hardware and specialist training
g) BIM only being relevant to the bigger companies working on larger projects.

The consequence of these and other factors meant that many companies either avoided making the jump to BIM or, where they did, it was through trial and error, reinforcing the notion that BIM was complicated and expensive to implement.

To provide clarity, and support the industry with its implementation of BIM, the UK BIM Alliance was formed. Its remit is to help the built environment sector take the first fundamental steps on their journey towards “digital transformation” and “to bring together all interested parties to respond to the challenges set by BIM Level 2 and to continue the work of the BIM Task Group”. One of its first tasks was to remove the levels of BIM and develop the conversation around digital transformation, governed by new standards and supported by BS EN ISO 19650, which superseded BS1192. This culminated in the publication of the UK BIM Framework and an associated resources website (https://www.ukbimframework.org) that seeks to provide: “The Overarching Approach To Implementing BIM In The UK”.

The UK BIM Framework is a collaboration between BIM Alliance, British Standards Institute (BSi) and the Centre for Digital Built Britain (CDBB). A key aspect of the CDBB is the concept of providing a digital twin that represents the real-world asset. When considered at the site level, the digital twin helps define BIM in a form that resonates with most landscape professionals. This is because many already work digitally and are familiar with producing data-rich, contract documentation to inform project delivery.

The concept of a digital twin and how this is governed by BIM processes is outlined in Figure 1. In principle, it takes a 360º approach to the design, construction, and management of an asset. All too often BIM is focused on delivering efficiencies and improvements during the design and construction phase of a project and we lose sight of where the most significant savings can be realised, the lifetime management and ongoing maintenance of the asset. When the “asset” is an ever-changing landscape, comprising of planting that will live for decades or centuries, these benefits could be considerable.

The digital twin concept not only uses the virtual model to build the real-world but, through sensory feedback, becomes a real-time dashboard of how the asset is performing. This has potential benefits for landscape because it would allow site managers to target maintenance where and when it is needed, rather than rigidly following prescribed schedules of work, which have to be fulfilled whether the feature requires attention or not. The virtual model has the potential to assess the implications of change, whether environmental or maintenance, by modelling the cause and effect in the virtual world before it is considered in the real world.

When defining BIM, we seek to identify the key exchange points and standards necessary to allow information to flow seamlessly through the 360° system. For this to work, we need each transaction to receive, process and pass on the right amount of information, at the right time, to make the right decisions. This information may comprise of geometry and data. Geometry is typically very heavy to pass around, especially if it is a complex, 3D model. This can be very useful at the design and construction phase, where the model will provide an understanding of the asset before it is built, hold technical specifications, and include cost information about each component. As the elements are brought together, the model can also be assessed for potential clashes, avoiding costly mistakes and delays during construction. For landscape, this can include the interaction of roots with underground services and foundations, or canopies with buildings and overhead structures.

During the operations phase of the asset, data is more relevant because it is lightweight and easier to access. This can describe what maintenance is required, how it should be undertaken and comprise specifications if it needs to be replaced. During this phase, it is more useful to locate and access the information quickly, rather than negotiate a complex 3D model, so a grid reference, GPS coordinate or an address may suffice. Where geometry is provided, it need only be a simple place holder for the data and not a cumbersome model, in all its glory.

BIM is often considered to be complex and difficult to implement. This is typically because the questions we are trying answer are not known or defined at the outset. Consequently, the model is either hijacked by the few, to support their own processes, or becomes unwieldly, as it seeks to fulfil too many different and competing purposes. As a result, such a model does not get used beyond handover because it fails to provide any value to the client.

An important document is the UK Cabinet Office “Government Soft Landings” (2013). This seeks to define the purpose of the information gathering, the exchange processes and how the data will be used within the operations phase of the project. This requirement ensures the design and construction phases contribute to the overall purpose and delivery of the relevant information and enable the effective maintenance of the asset in the future. This is referred to as the ‘golden thread’, and without it the project is doomed to only deliver an expensive model that has no life beyond project handover A key contributor to define the golden thread(s) is the operations representative, who needs to know what information is required to maintain the asset and how this is to be used. Also, early involvement of the operations management team provides the opportunity to be aware of new maintenance requirements and to plan investments in new equipment and staff training so the handover process is seamless.

The application of the golden thread is still in its infancy but has many opportunities for landscape design and site maintenance. The realisation and success of our design replies largely on the correct implementation of accompanying maintenance plans. Embedding this data within the BIM object could help with scheduling of works, locating the feature and recording that an action has been completed. For example, if the object requires a maintenance visit on a specific day, this would be identified and included within the scheduled works. When this work is complete, this could be recorded via a barcode or sensor located on site and the virtual object updated with the details. In this way, the virtual model provides a historical log of the object throughout its life.

The nursey industry is already using plant passports as a means of tracking the movement of plants from seed to site. This includes information about the plant, such as its botanical name, registration number, traceability code and country code of origin. It would not be beyond the possibility to extend this asset identifier to include recommended maintenance, record that work has been undertaken and, finally, when, and why the plant was removed. This could provide a whole life picture of the plant and contribute to a better understanding of how plants grow and the implications of maintenance in different scenarios, allowing us to compare a tree in a park with a similar tree planted in a constrained streetscape setting. If we are able to include sensory feedback relating to the moisture content in the soil or chlorophyll levels in the leaves, this could alert us of the early onset of drought or disease. Rather than religiously following a prescribed schedule of works, this would allow for more targeted maintenance, better use of limited resources, and avoid unnecessary site visits.

The value of an accurate, data-rich BIM model in landscape has yet to be fully realised but it has been tested and used when undertaking ground modelling. We are increasingly seeing the use of autonomous earth moving machines on site, where the BIM model and GPS devices are used to control vehicles and achieve the desired grading. This not only means that design changes made to the model can be implemented within minutes, but the machines can run 24-hours a day, seven days a week, with only minimal lighting and supervision.

The use of the BIM model is starting to deliver innovations in construction that make better use of scarce resources. Technologies like 3D printing and offsite construction can make better use of local materials and produce far less waste, compared to building on inclement and hazardous construction sites. The fully 3D printed, 12 metre stainless steel bridge, developed by MX3D, is a great example where advanced digital modelling and robotic engineering have combined to produce a structure that will be installed across one of Amsterdam's oldest canals. A key aspect of the design process allowed multiple iterations to be generated very quickly and determine the most cost-effective solution, without comprising on form, function, or strength. When installed, hopefully later this year, sensors within the bridge structure will provide feedback to the virtual model that shows how it is performing, allowing for any safety issues or concerns to be quickly identified and addressed.

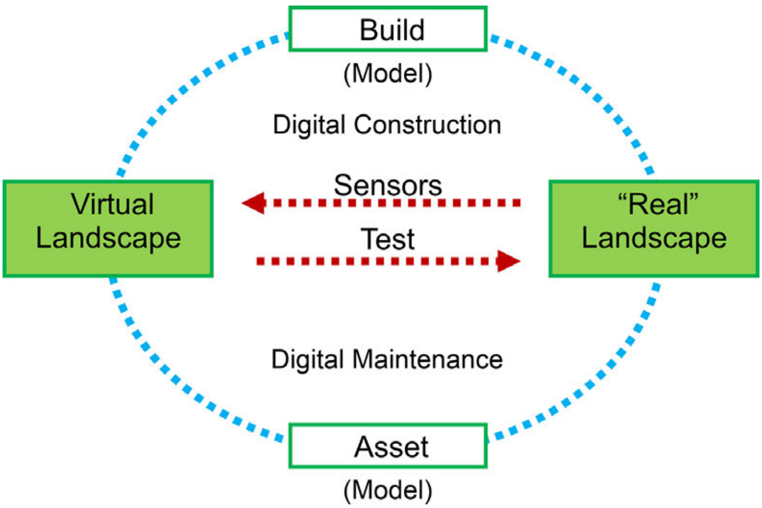
The use of local materials to support construction is not new. Many cities provide good examples of architecture that is determined by access to local stone and materials. Extending this into 3D printing provides an opportunity to use materials in unique ways. Rather than traditional methods where materials, such as stone, are extracted and carved into shape, 3D printing allows complex structures to be created by building up layers of material with internal spaces. The result of this additive approach is a lightweight, structurally sound product that uses less material and that can be easily replaced by simply printing the part again. A recent example is the new Elizabeth line on the London underground. Here, the contractor was able to 3D print 1,400 unique wax moulds that were used to cast 36,000 different shaped concrete panels to clad the interior of the stations.

This approach has huge potential for landscape design, most notably within the design of street furniture. Very often we must select from a limited range of standard options or pay a premium for something different from the norm. If manufacturers are able to 3D print multiple forms of the same object with no additional setup required, designers could become more creative and produce bespoke solutions at no, or minimal, extra cost.

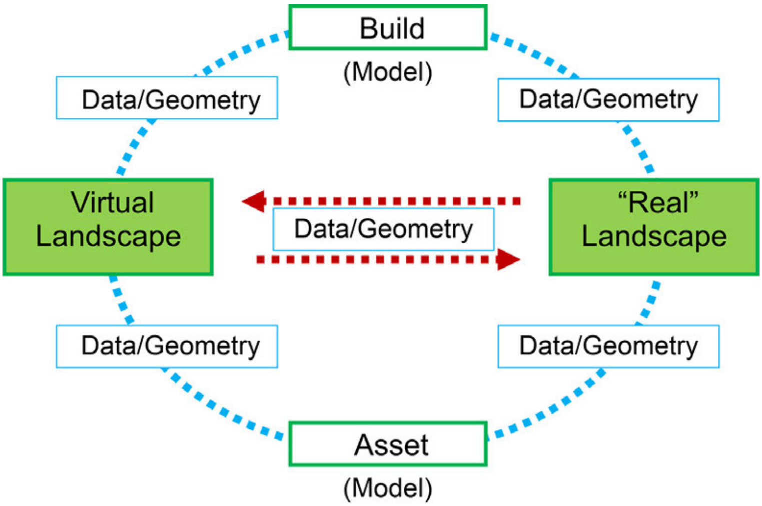
These approaches support initiatives like the “EU Circular Economy Action Plan” by making better use of local resources. The BIM requirements plan should not only stipulate sourcing from sustainable supplies but consider the end of life decommissioning of the asset, ensuring that materials are recycled, lessening the need to extract further. Taking this concept one step further, NASA sees the successful colonisation of other planets, such as the Moon and Mars, being driven by digital models, robotics, and 3D printing, and where local materials are used to create habitable structures in advance of humans arriving to occupy them.

Another increasing use of the digital model is to inform off-site fabrication. The ability to produce components in a safe, clean, and controlled environment means that suppliers can introduce manufacturing efficiencies to the construction process and achieve a higher level of consistency. Whilst more widely used for house building, initiatives like the durable, plastic bike path, installed in the Dutch city of Zwelle in 2017, provide a good example where prefabricated modular units, made from recycled plastic waste, were installed to create new cycle routes. Furthermore, the structure includes sensors that monitor durability, temperature change and the number of bike trips. Whilst the digital twin in this instance may not be a 3D model, it provides a feedback mechanism that can be used to make better informed decisions regarding maintenance and future installations.

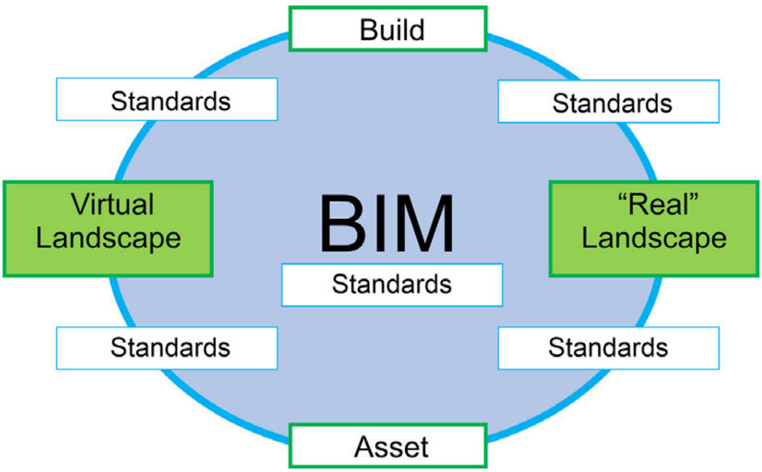
Effective use a well-formed, fully adopted BIM execution plan that takes into consideration some of the aspects outlined above will not solve all aspects of the climate crisis we face, but it will ensure that the construction industry, including landscape, significantly reduces its global footprint by introducing more efficient systems, using more renewable resources and producing less waste.



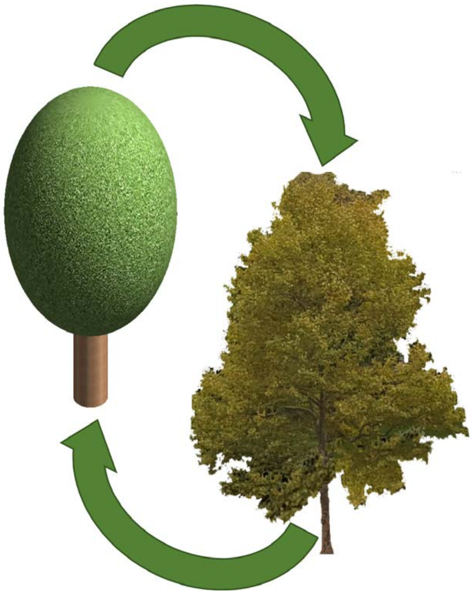
a) The 360º approach considers the virtual model to be the mirror of the real-world asset. The virtual model will inform design and construction and sensory feedback loops from the “real” landscape provide updates on performance and condition. The virtual model can be used to test “what if” scenarios and the real world show the implications over time.



b) For the system to work, data needs to flow through the system. The data can be in the form of geometry, to visually represent the feature, or data that describes it, such as the supplier, technical specification, expected maintenance.



c) The exchange points only work if you know, what is required, when it is needed and how this is to be transferred. This is defined in the project requirements and the implementation of agreed protocols and standards. This is BIM.



d) The virtual model and real-world asset are intrinsically linked

Fig. 1: The Digital Twin and BIM

3 Conclusion

The digital twin provides an opportunity to better understand what is built, how it is used and how it should be maintained. In increased use of sensory feedback systems provide early warning systems that allow us to be more responsive to performance and environmental changes. The implementation of BIM is providing the processes for the digital transformation of the construction industry. Providing information and just-in-time management allows us to make quicker, informed decisions, this will result in better performing landscapes that meet the client's expectations and fit for purpose.

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Applied Integration of GIS and BIM in Landscape Planning

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Abstract: For the future of BIM collaboration, a close exchange of information between constructional and environmental issues is needed. The way there is via integration of the respective BIM construction models along with the respective data sets into the GIS model of the given environment. There are two technical approaches for this data integration. We present some examples from our real-life projects, showing how BIM-GIS integration and subsequent environmental assessments were carried out. Considerable non-automatic work is still needed. However, we clearly state added value for interdisciplinary cooperation as well as for a more adequate representation of environmental facts and hence for professional advances in landscape and urban planning.

Keywords: Geodesign, GIS, BIM, semantic 3D-model, landscape planning

1 Introduction

Today, most construction projects are designed and executed by architects and engineers using CAD (Computer Aided Design) software. Landscape planners however are mainly operating GIS (Geographical Information Systems) to assess the environmental impacts of those construction projects. Against the background of ongoing digitalization represented by applications such as virtual reality, robotics or drone mapping, and the focus on BIM (Building Information Modeling) in the field of construction, the urgent need for a seamless coupling of those two ecosystems becomes clearer every day.

The central concept of BIM lies in the intensified and systematized digital cooperation of all stakeholders involved, including planning, construction, project lead, customer, authorities and, increasingly importantly, the public. At its core, BIM is represented by a collaboration model built of multiple sub- or specialist models. A CDE (Common Data Environment) serves as the central tool for communication, logging and file exchange and is generally coupled with the collaboration model. This architecture allows for a consistent data flow and prompt collision control between different technical expert groups over the whole building lifecycle. Another term often used for the BIM concept is "digital twin".

The concept of BIM is not new. The term was first used in the early 1990s (VAN NEDERVEEN & TOLMAN 1992) and has evolved in different places around the globe. During the past couple of years, BIM developed from a mainly experimental approach and new business opportunity to a widely used tool which can also be called a megatrend in construction in Germany, and also – and for an even longer period – in a variety of other countries. This is due to the high efforts of the government and economy. For example, multiple infrastructure projects were used as pilots to gain deep practical knowledge about the BIM method. The Deutsche Bahn for instance has made the application of BIM a mandatory requirement for all of their construction projects (DB 2021).

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Regardless of those efforts, integrated and systematized BIM processes with workflows in all project phases of all environmental planning instruments (e. g. EIA) do not existent so far. That applies to the used software systems and their interactions, the common Industry Foundation Classes (IFC) interface as well as paperless, 3D-applications at the building site. Due to a partly still competing development of international and national BIM standards (e. g. ISO, CEN, DIN), as well as worldwide efforts for unified data exchange standards (buildingSMART International), it is supposed that a complete transformation to digital BIM processes will be reached only in a few years from now. The trend, however, points in the direction of a rapid change to the application of the BIM method as part of an extensive digitalization movement in the construction sector.

As BIM not only includes engineering and architecture, but all stakeholders involved in a construction project, it also has effects on the work of landscape and environmental planners. Until now however, there is still rather weak activity in this field. This is due not least to the misinterpretation of BIM solely as a 3D visualization software which may seem unnecessary for landscape planning from a conservative viewpoint. That however misses the core of BIM not only being one of many software tools, but a complete method placing its focus on the sharing of data and information as well as optimizing the communication during the whole building lifecycle (DVW & RUNDER TISCH GIS 2019), or the management of a settlement quarter or of a city.

The objective of this article is to evaluate the practical application of integrated GIS and BIM planning, especially in the early planning phases. Therefore, two projects performed by Prof. Schaller UmweltConsult (PSU) will be presented where current software technology was used for realizing this interconnection of both worlds. The examples will be examined for findings helpful to environmental planning as well as to interdisciplinary work. Our work aims to represent a solid and practical groundwork for a further integration of BIM and GIS in order to get the most out of the available data.

2 State-of-the-Art Methods

In the GIS context, the goal of coupling the design process – and here you could e. g. also understand BIM as a method for integrated collaboration models – with geospatial data and analyses and is named geodesign (FLAXMAN 2010, MILLER 2012, STEINITZ 2012). It is a GIS-based method for digitalizing planning workflows of engineers, architects and designers in one process and through optimizing it by using 2D and 3D geodatabases. It is based on proven GIS applications from a variety of fields (e. g. landscape planning, landscape architecture, geography, environmental sciences) and offers an interdisciplinary synergetic approach for solving critical planning problems in the built environment. The methods discussed in this paper can therefore be seen as parts of that bigger picture called geodesign.

Withing GIS there are different ways of implementing this integration. The main focus hereby usually lies on the conversion of data between the different GIS and BIM data formats without losing or changing relevant information. The most common approaches can be categorized as follows:

1) Proprietary interfaces provided by the used software.
   Meanwhile, it is common that both GIS and BIM software provide import and/or export functionality of different data formats that can be applied by both used platforms. In

current Esri products, for example, a direct import of .rvt files produced by the BIM Software Autodesk Revit is offered.

2) Data format conversion using ETL Tools (Extract Transfer Load).
Tools like FME (Feature Manipulation Engine, by Safe Software Inc.) can be used to transform a variety of (geo-)data formats and include all common GIS formats as well as a variety of CAD and BIM formats. The approach offers more control and flexibility in the translation process and can therefore lead to more correct results than the mostly black box imports of approach 1). In the case of FME it also offers import logging for further control over the process. A visual comparison of the results of both approaches is shown in Figure 1.

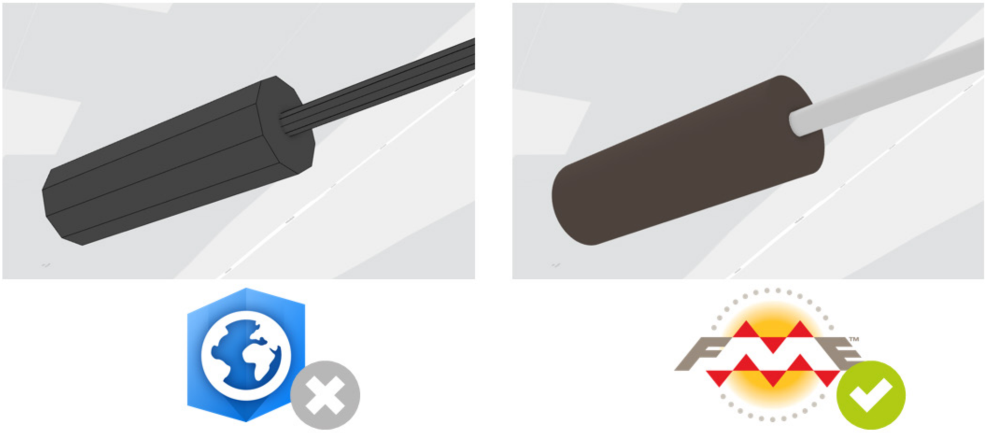

Fig. 1: Results of a data conversion from a .rvt file using ArcGIS Pro (left) and FME (right)

Based on those insights, the second approach was used in the following two project examples.

3 Selected Projects

The practical application of a deepened BIM and GIS integration has numerous positive effects on the planning process. This can be shown using two examples by PSU, one being the A99 expansion project, the other in the context of the Second S-Bahn Main Line in Munich. From these two projects, we illustrate just a few extracts of the entire GIS-based environmental assessments and the comprehensive BIM infrastructure project.

3.1 The A99 Expansion Project

For testing different workflows and data exchange procedures for the implementation of the German Road Map for Digital Design and Construction, the German Federal Ministry of Transport and Digital Infrastructure (BMVI) has launched a number of pilot projects (BMVI 2015). One of those is the eight-lane expansion of the Motorway A99 in the Munich Metropolitan Region, commissioned by the Motorway Authority of South Bavaria and projected by the SSF Engineering Group. The focus of this project lies on defining future requirements for a frictionless information sharing between environmental planners and civil engineers in order to incorporate all concerns into the engineering process from the start of planning, to project implementation, to completion and monitoring of environmental measures.

For achieving those targets, an integrated data exchange concept (Fig. 2) was elaborated. Its key concept is the integration of the BIM planning process into a geodatabase structure. This way the corresponding information can be exchanged and processed very quickly. For this purpose, 2D and 3D CAD and BIM data were integrated into the GIS data model. By assessing the GIS model, the parties were enabled to determine the potential impact of construction projects on the environment as well as technical or infrastructural constraints.

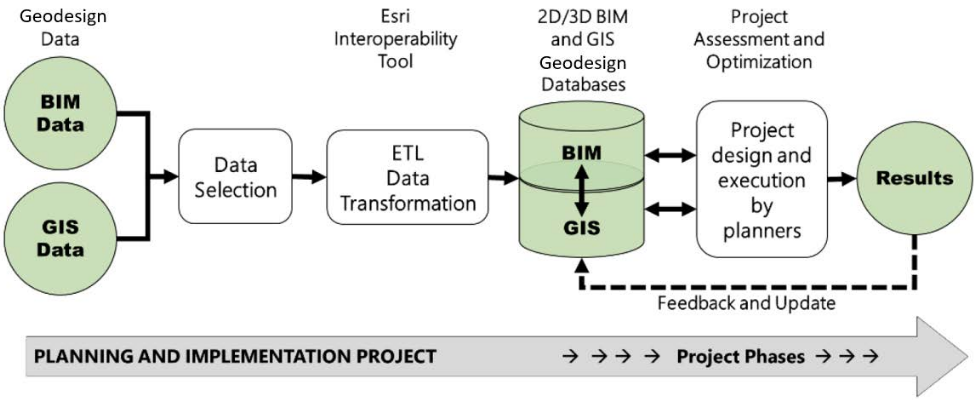

Fig. 2: The integrated data exchange concept (PSU)

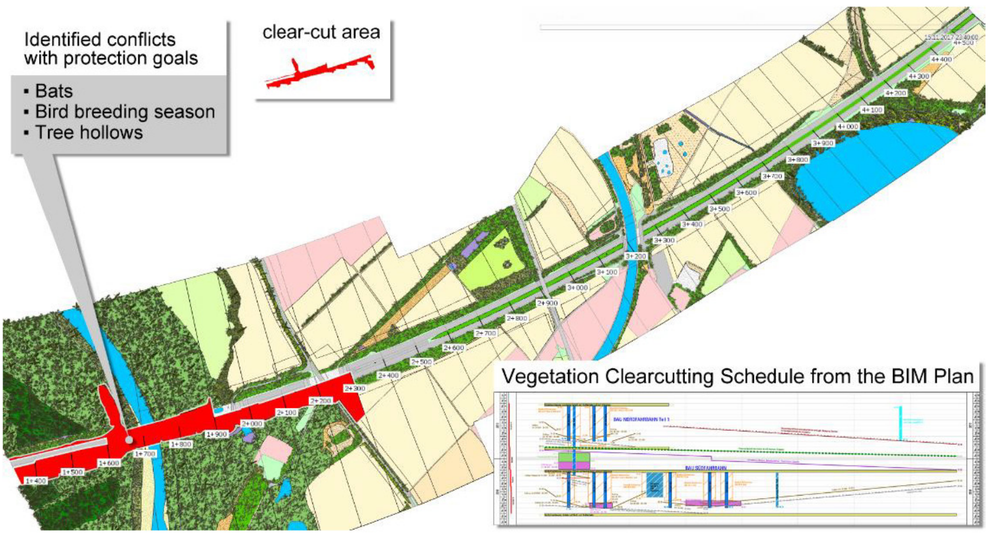

Fig. 3: Identification of potential conflicts between the BIM schedule for vegetation clearcutting and protected flora and fauna (PSU)

By applying this concept in practice, potential conflicts between construction planning and ecological aspects can be identified (Fig. 3 for an example). The combination of the BIM schedule for vegetation clear-cutting and protected flora and fauna allows the identification and illustration of conflicts in spatial as well as in temporal dimension. This goes along with the German Nature Conservation Act (BNatSchG) and German Building Act (BauGB) and ecological requirements which state that every phase of the engineering planning process has to be accompanied by specific environmental assessment, planning and monitoring procedures.

As a key insight of this project we conclude, that – although there are still difficulties, like implementing CAD geometries into the GIS dataset, e. g. with substantial amount of manual editing required – the multitude of advantages of a close technical collaboration justifies any effort.

3.2 Second S-Bahn Main Line (2nd SBSS)

The aim of the ongoing project 2nd SBSS is to create a GIS database that centrally bundles all spatial data (inventory, current planning statuses and real-time data) and to make it available to all parties involved. For this purpose, various geographic and tabular data, reports and surveys with spatial reference as well as BIM models for the entire route are converted, homogenized and linked using GIS and the ETL tool FME. An example of this integration is illustrated in Figure 4.

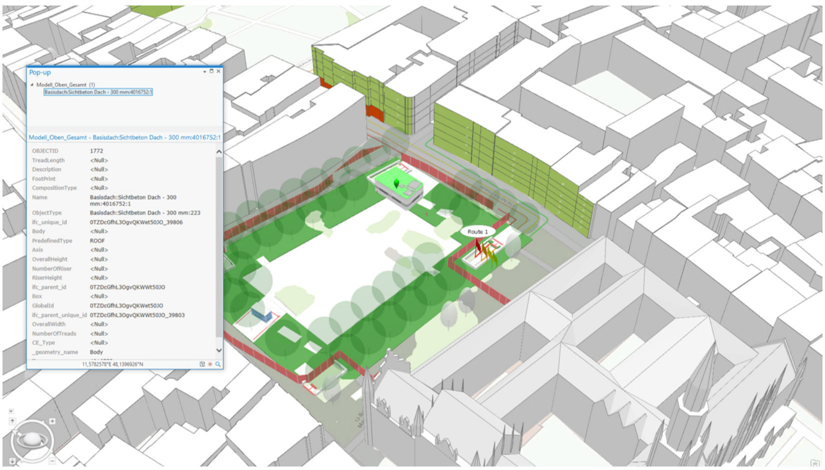

Fig. 4: Integration of BIM Models in GIS at Marienhof (PSU)

This digital twin allows for advanced geospatial analyses including the up-to-date construction planning. At Marienhof, for instance, the integrated GIS model was used to simulate the predicted noise generated by trucks with excavated material. Relevant noise data were acquired from a professional noise survey and projected to the surrounding building facades which were segmented by each storey. This led to a clear visualization of the impacts caused by the construction activities and therefore enables decision makers to act accordingly. The outcome also provided useful material for communicating relevant information to the public.

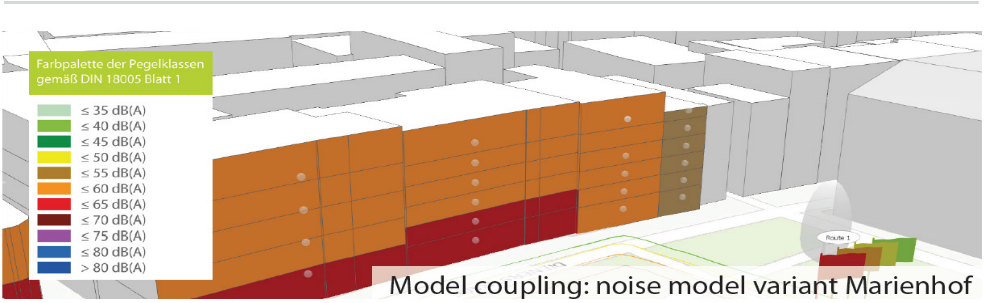

Fig. 5: Noise Model at Marienhof (PSU, Moehler + Partner)

Another application from this project is the modelling of 3D trees including breeding cavities for determining potential conflicts with infrastructure elements as shown in Figure 6. The location and dimension of the trees are based on current field data collection and the BIM construction models are always kept up to date within the GIS model. This allows for a rapid collision detection and therefore for a fast feedback loop between the planners involved.

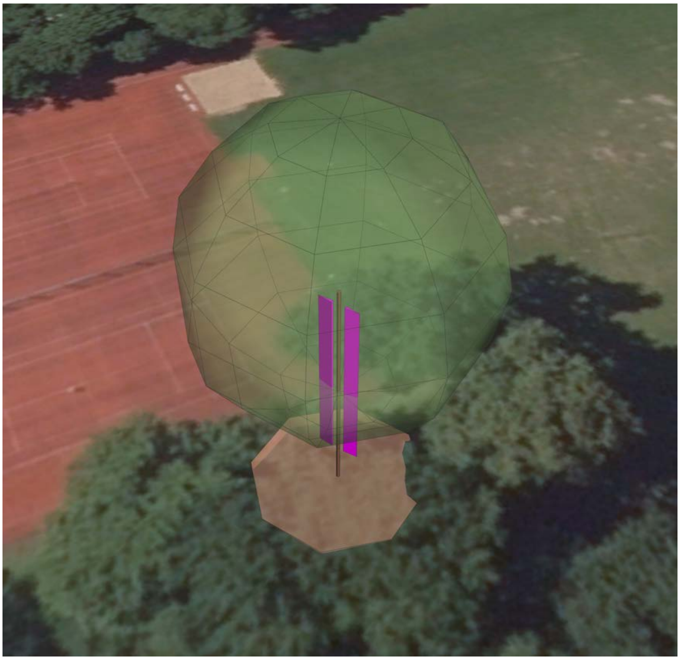

Fig. 6:
Tree with breeding cavities modelled in GIS for collision control (PSU)

4 Discussion

The examples clearly show that the integration of BIM and GIS data is possible with state-of-the-art data transformation tools. Even though there are still some difficulties to overcome (like a substantial amount of manual work for transforming GIS geometries to BIM and vice versa), the benefits of shared data already outweigh those problems.

The example of the 2nd SBSS provides some possibilities of using 3D data generated in both GIS and BIM software. With the exact representation of planned construction objects in the GIS model, the results of environmental analyses, like noise effects or species endangerment, directly refer to the predicted impact. By means of the 3D visualization, the existing situation, as well as the effects of the construction project on the environment, become directly perceivable. This results in a more intensive data exploitation as well as in a more convincing information transfer. The benefit of visualizing planning related information stored in BIM in a GIS not only in 3D but also in 4D gets obvious in the A99 example. The implementation of the clear-cutting schedule into the 3D model enables planners from other disciplines to directly understand potential effects caused by time collisions.

For a seamless integration however, there are still some barriers that need to be overcome. Most of the tools only allow for an integration of BIM data in GIS software. In current projects however it is required to also make the GIS data available in the BIM collaboration model. Due to the complex structure of BIM formats like IFC and unclear or missing definitions for GIS objects, the transformation from GIS to BIM still requires a lot of manual work and individual workarounds. This especially applies to the missing of standardized class catalogues for GIS objects like e. g. habitat types. This makes a productive and timely exchange of data still nearly impossible and therefore is one of the main reasons for the still existing delay of (seamless) model coupling.

It also needs to be mentioned that the discussed methods as shown in the two case studies are mainly based on Esri and the connected BIM products. As of today, there are other BIM solutions that allow for a variety of workflows for integration of both methodologies. Those developments show how many opportunities this fast-changing technology offers but also outlines the need for standardized procedures and their integration into major software solutions to ease the overall collaboration between both worlds.

5 Conclusion and Outlook

Several examples for coupling of data sets and models from different sources and planning contributions exist. There is evidence for the technical integration of 3D geometries and attributes from different professional sources, allowing to perform the required landscape and environmental analyses within a semantic 3D GIS data model. Within the BIM cycle, workflows, data and information exchange have to be systematically developed for the planning phases of all environmental instruments and finally as standard procedures for planning practice.

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Integration of BIM and Environmental Planning: The CityGML EnvPlan ADE

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Abstract: While disciplines such as architecture, structural design or technical building equipment have already integrated their processes, data structures and tools well into Building Information Modeling (BIM), this has not yet been sufficiently achieved in environmental planning and landscape architecture. Problems that make integration difficult arise from differences in the scope and scale of the models needed for building construction on the one hand and environmental planning on the other: while building construction models focus mainly on the structure itself, environmental planning also considers natural objects such as habitats and protected areas within a larger radius of the structure. Data about such objects are typically maintained in GIS, so the integration of BIM and environmental planning is a matter of BIM-GIS integration. Based on a requirements analysis and an evaluation of existing standardized information models, this paper presents CityGML EnvPlan ADE, a new 3D information model for integrating BIM and environmental planning. As a proof of concept, the information model is tested in a real railroad construction project.

Keywords: Environmental planning, BIM, LIM, 3D GIS, CityGML, spatial-temporal modeling

1 Introduction

Building Information Modelling (BIM) has become mandatory in construction processes in many countries. BIM pursues the goal of integrating all disciplines working in a construction process in an overall integrated data environment. While disciplines such as architecture, structural design or technical building services have already integrated their processes, data structures and tools well into the BIM process, this is not yet sufficiently achieved in environmental planning and landscape architecture (FRITSCH et al. 2019, JUPP 2017, PETERS & THON 2019). This paper presents a novel approach to integrate BIM and environmental planning on the level of information models.

In the context of this paper, the term environmental planning serves as a collective term for the development and implementation of spatially related objectives of environmental policies. Based on geospatial data, such as protected sites and the mapping of species and biotopes, conflicts with planned technical constructions like buildings or infrastructure works are identified and environmental measures are derived. The results of this process are documented and visualized on plans, that describe all conflicts and measures related to a specific construction project.

Consequently, integrating environmental planning into the BIM process means to integrate digital representations of planned buildings or infrastructure work and the digital representation of their environmental context. Whereas the construction data originates from BIM authoring tools, the environmental context including environmental conflicts and planned environmental measures is maintained using Geographic Information Systems (GIS). A major characteristic of the BIM method is that planning is carried out at least in 3D with time and cost as two additional dimensions. For environmental planning this leads to a shift from 2D-

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planning to a multidimensional planning approach, which has to be reflected by an appropriate information model. In general, the construction process requires data at different levels of detail. Environmental data in GIS is mainly represented at the macro level whereas the building data in BIM is at the micro level. Therefore, information models from these two domains have been developed independently and the respective standards differ strongly in their structure as BIM and GIS are treated as two separate scopes (ZADEH et al. 2019, KOLBE & PLÜMER 2004). Topographic 3D GIS data can be represented using the City Geography Markup Language (CityGML), a standardized information model for semantic 3D City and Landscape models. BIM models can be standardized via the Industry Foundation Classes (IFC). Since the two standards were developed for different purposes, they have different structures. IFC comprehensively maps the building structure, CityGML focuses on the 3D and semantic representation of topography and thus includes thematic domains such as terrain, buildings, streets, vegetation or water bodies (KOLBE & DONAUBAUER 2021, OPEN GEOSPATIAL CONSORTIUM & BUILDINGSMART INTERNATIONAL 2020, STOUFFS et al. 2018).

Taking into account the information requirements of environmental planning, our investigations show that neither CityGML nor IFC is capable to represent all the information required and produced in the environmental planning process.

However, as many tools, data sets and digital methods in environmental planning are based on GIS, the aim of the integration concept presented in this paper is to use a model from the geospatial domain as integration platform. Furthermore, there is a wide range of software for BIM and GIS. So the second aim of the integration concept is to enable a solution, which is defined independently of a specific software platform. By the standardization of the information model, interfaces can be created, which facilitate and simplify the subsequent management and processing of the data in their respective authoring systems. Consequently, the integration approach is designed on the level of a standardized, comprehensive information model.

2 Related Work

2.1 General BIM GIS Integration Research

There are different ways to integrate BIM and GIS. WANG et al. (2019) distinguishes three typical types: (1) BIM leads and GIS supports, (2) GIS leads and BIM supports, (3) BIM and GIS are equivalent. HIJAZI and DONAUBAUER (2017) identify four main approaches for integrating BIM/GIS at the standardization level: converting IFC to CityGML, CityGML/GIS to IFC, a unified model, or linking BIM and Urban Information Model (UIM). BECK et al. (2020) call for a differentiation between integration efforts in the field of "BIM-GIS Integration", as this term serves as an umbrella term. The authors introduce three main categories, "information characteristic", "solution characteristics" and "purpose", the integration approaches can be differentiated according to their challenge and purpose. A CityGML application domain extension (ADE) – i. e. an extension of the standardized CityGML information model – for example, is located under the "solution characteristics" with sub category "integration method" and "extension".

Several studies show that data exchange between GIS and BIM can be useful for both sides (e. g. CHOGNARD et al. 2018). In the field of automatic conversion from CityGML to IFC a workflow for the conversion of the different properties for representing real world entities of both standards (semantics, geometry, topology, encoding, georeferencing) has been developed (SALHEB et al. 2020). Integration of BIM and GIS can also be achieved with generic triple graph grammar: TAUSCHER (2020) introduces workflows for the generation of IFC and CityGML metamodels specified as ECore. The workflow for the creation of integration rules allows its application to future schema extensions, too. LIM et al. (2020) developed a Web-based viewer, which is able to visualize CityGML ADE-enabled files, as several ADEs for the BIM to CityGML conversion have been developed.

2.2 BIM GIS Integration in the Environmental Planning Domain

Several integration concepts in the discipline of landscape architecture and landscape planning are based on the further development of IFC (BRÜCKNER et al. 2019, PETERS & THON 2019, SHILTON 2018, WIK et al. 2018). The Norwegian BIM for Landscape Initiative has developed a set of definitions, parameters and code lists to represent 44 landscape objects. The goal is to thereby obtain a uniform standard for landscape objects (WIK et al. 2018). The UK is developing a BIM for Landscape at the Landscape Institute with Product Data Templates (PDT) to provide uniform product information. The BIM in Landscape Architecture Section of the German Chapter of buildingSMART is currently discussing an Information Delivery Manual for plants and paved surfaces. For example, the PDT will integrate plant metadata, planting instructions, service life, and process engineering and maintenance (PETERS & THON 2019, SHILTON 2018). In addition, an Activity Proposal IFC for Site, Landscape, and Urban Planning by Jeffrey Ouellette proposes the extension of the IFC schema for Site, Landscape, and Urban Planning (BRÜCKNER et al. 2019).

The literature emphasizes the importance of 4D-BIM for environmental planning. JUPP (2017) highlights two interlocking processes for a 4D platform to improve environmental planning and management. On the one hand, the cooperation of all disciplines of environmental planning and environmental management must be ensured and on the other hand it must be possible to monitor the environmental impact on site. In order to meet both requirements, a 4D model must guarantee five prerequisites: “scheduling and simulation, environmental equipment modeling, construction site layout modeling, environmental impact significance modeling and visualization, rule-checking capability”. SHEINA et al. (2019) also proposes a 4D BIM for engineering and environmental planning. The technical model should be integrated into a map displayed using a GIS software. SCHALLER et al. (2016) extended the phases in the life cycle of a building with environmental planning as BIM-GIS-Cycle. They emphasize the required data transfer and data exchange at certain points in time during the lifecycle of a building. For a holistic model, the interfaces between BIM and GIS are seen as a requirement. EGGER (2020) sees semantic 3D City and Landscape Models based on CityGML as basis for an integrated planning model. All relevant geodata are mapped onto the CityGML data model. The BIM planning is carried out in the imported GIS environment and then integrated in the CityGML overall model. The work presented in this paper extends this approach focusing on the specific requirements of environmental planning, which are not fully covered by the related work described above.

3 Requirements and Existing Information Models

3.1 Requirements for the Integration of BIM and Environmental Planning

The first step in developing a comprehensive information model based on existing standards was to analyze the general requirements for integrating BIM and environmental planning. Both literature research and discussion with environmental planning experts from the major German railway company “Deutsche Bahn" led to the following main requirements:

1. Fundamental geospatial data such as protected sites, project specific data, such as surveys of vegetation and species, environmental conflicts and measures as well as planned objects from BIM with their attributes/properties need to be represented.

2. The following use cases in environmental planning should be supported:

- environmental impact assessment of the planned building and the construction works,
- clash detection and visualization of conflicts between construction and environment,
- compensation calculation taking into account the BIM data,
- monitoring the construction process from an ecological planning perspective,
- monitoring the environmental impact during the operation and maintenance phase of the building or construction.

3. Special attention must be paid to adequately represent temporal aspects. Four different temporal domains in environmental planning should be represented in the model: (1) time spans with fixed absolute start and end time (e. g. important during construction for a fixed date), (2) recurring regulation time period (e. g. legal time period for clearing woods and scrubs), (3) date/time period with dependencies on actual/planned construction time (e. g. continuous ecological functionality (CEF)-measures have to be implemented before construction start), (4) task depending on predecessor task (e. g. construction of a substitute habitat before the relocation of specific species).

3.2 Assessment of Existing Information Models

In a second step, various standards were examined for their ability to meet the requirements of integrating BIM and environmental planning as described in section 3.1. Six standards were identified to be suitable for modelling environmental planning as they fulfil parts of the listed requirements: CityGML, INSPIRE (Infrastructure for Spatial Information in Europe) and LandInfra (Land and Infrastructure) as international standards, XPlanung and OKSTRA (Objektkatalog für das Straßen- und Verkehrswesen) as German national standards. Furthermore, IFC as BIM standard and approaches to extending IFC by landscape objects were evaluated. The result of the comparison is found in table 1: “++” means that the standard fully fulfills the requirements, “+” means some requirements are fulfilled and “-“ means none of the listed requirements were fulfilled. For the specific requirements of environmental planning, CityGML offers a good foundation with the support of vegetation, water and different land use (GRÖGER et al. 2012). IFC as construction standard could map technical components used in environmental planning such as protection fences. Landscape objects could be represented using generic object types like *IFC_Proxy* or (mis-)using other classes like *IFC_Wall*, but the semantics would not be explicitly clear. IFC does not include the mapping of objects, which are important for the definition of project specific environmental data, e. g. protection sites or environmental measures. OKSTRA allows the mapping of landscape planning objects (landscape, conflict, measure) (HEINS & PIETSCH 2010), but the representation of dynamics is not possible. In XPlanung the core "Landscape planning" (BRENNER 2019) is focused on representing legal landscape plans as part of the zoning of a municipality and is therefore not detailed enough for representing environmental planning of an individual construction project. The INSPIRE data specifications are not specifically adapted to environmental planning, apart from representing protected sites (INSPIRE THEMATIC WORKING GROUP PROTECTED SITES 2010), and, apart from buildings and DTM, 3D objects are not supported. LandInfra covers a few aspects of environmental planning, e. g. vegetation, but not sufficiently, for example regarding the representation of temporal aspects. In relation to the temporal representation, CityGML supports both the static time component (GRÖGER et al. 2012) and dynamics, with the Dynamizer ADE (CHATURVEDI & KOLBE 2016). The comprehensive time representation of IFC (BUILDINGSMART 2020) is inconvenient for environmental planning due to the separate handling of the work calendar (*IfcWorkCalender*), as temporal information should be directly added to the specific object. INSPIRE, LandInfra and XPlanung only support basic static representations of time, which are not sufficient enough for environmental planning. For example the INSPIRE data specification "species distribution" (INSPIRE THEMATIC WORKING GROUP SPECIES DISTRIBUTION 2013) defines no activity period for a species. OKSTRA defines temporal properties for environmental measures (BUNDESANSTALT FÜR STRAßENWESEN 2019), but the specification of time periods is missing.

Table 1: Comparison of different standards according to their integration of requirements regarding BIM and environmental planning

	CityGML 2.0	**IFC 4**	**INSPIRE**	**LandInfra**	**XPlanung**	**OKSTRA**
construction data	+	++	–	–	+	+
fundamental geospatial data	+	+	+	+	+	+
project specific environmental data	+	–	+	+	+	+
environmental conflict	–	–	–	–	–	++
environmental measure	–	–	–	–	+	++
impact assesment	++	+	–	–	–	–
ecological construction supervision	–	–	–	–	–	–
monitoring environmental impact	+	+	+	-	–	–
time: static	+	++	+	+	+	++
time: dynamic	++*	+	–	–	–	–
3D	++	++	+	++	–	++
extensibility	++	+	+	+	++	+

*Dynamizer ADE, a CityGML extension to support time dynamic property values
++ comprehensive*, + basic*, – not included*; *according to personal assessment

The comparison in table 1 reveals that none of the selected information models is fully matching the requirements. However, CityGML was chosen as the basis for developing a comprehensive information model for the integration of BIM and environmental planning for the following reasons: First, the semantic model of CityGML is able to represent many required objects (these are already represented in 3D, as required by the BIM process). Second, CityGML provides the Application Domain Extension (ADE) mechanism, which allows for extending the information model according to the requirements of an application domain. This is a unique property of CityGML compared to the other standards mentioned above, besides XPlanung, which also uses the ADE mechanism, but only supports 2D. For example, IFC can easily be extended by application specific attributes (property sets), however, it is not possible to add new classes to the IFC information model without running through a formal buildingSMART process that involves user consensus and validation. We applied the CityGML ADE mechanism for developing the Environmental Planning ADE (EnvPlan ADE), a comprehensive information model for integrating environmental planning and BIM.

4 The CityGML EnvPlan Application Domain Extension

Figure 1 gives an overview of the CityGML EnvPlan ADE, which was developed based on the requirements described in section 3.1. The extended classes of the CityGML core module are marked yellow. Existing CityGML classes that are extended by attributes are marked in orange. The newly created classes of the EnvPlan ADE are highlighted in green. Concepts of existing CityGML modules as well as from the other standards described in section 3 have been reused wherever possible in order to facilitate data integration from existing data sources.

New attributes are assigned to the classes *AbstractCityObject*, *AbstractBuilding* and *SolitaryVegetationObject*, for example in order to represent the cost of environmental measures as well as the construction cost for the new buildings or infrastructure works. New classes are derived from *AbstractSite*, *AbstractBuilding*, *CityFurniture* and *AbstractWaterObject*. *AbstractEnvironmentalSite* and *Species* are specializations of *AbstractCityObject*. *AbstractEnvironmentalSite* is a container of common properties of sites where environmental measures are planned for (*MeasureSite*), mapped habitats and biotopes (*HabitatAndBiotope),* sites under environmental protection *(ProtectedSite,* reused from *INSPIRE)* and construction site facilities, that are removed after construction is completed (*TemporaryConstructionSite*).

Information without geometric representation is modelled as specializations of the CityGML class *AbstractSite*: these are measures (*EnvironmentalMeasure,* aligned with OKSTRA), their maintenance (*EnvironmentalMaintenance,* aligned with OKSTRA) and *Conflicts* (aligned with OKSTRA*)*. These objects get a spatial representation when they are actually implemented, which is expressed by relating them to measure areas (*MeasureSite*) or measure objects (*AbstractMeasureObject*). *AbstractMeasureObject* is derived from the CityGML class *CityFurniture*, as measure objects like protection fences or nest boxes are immovable objects and can be geometrically represented by prototypes (e. g. 3D geometries from an object library).

The class *Compensation* has an association with the class *AbstractCityObject*, which allows to assign environmental compensation values (see use case in section 5.2) to each object causing an environmental impact.

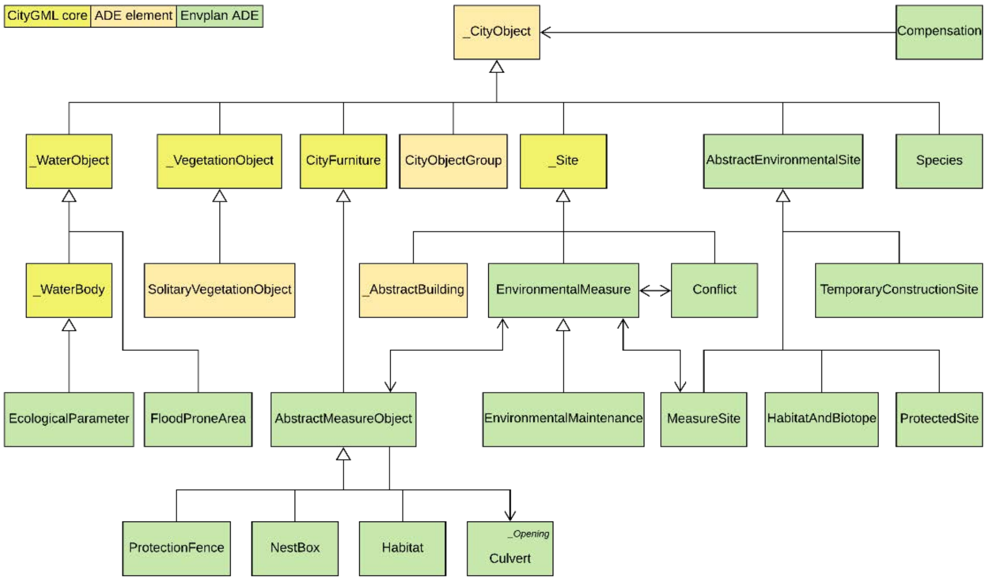

Fig. 1: Structure of the Environmental Planning Application Domain Extension (EnvPlan ADE) for CityGML as a UML class diagram

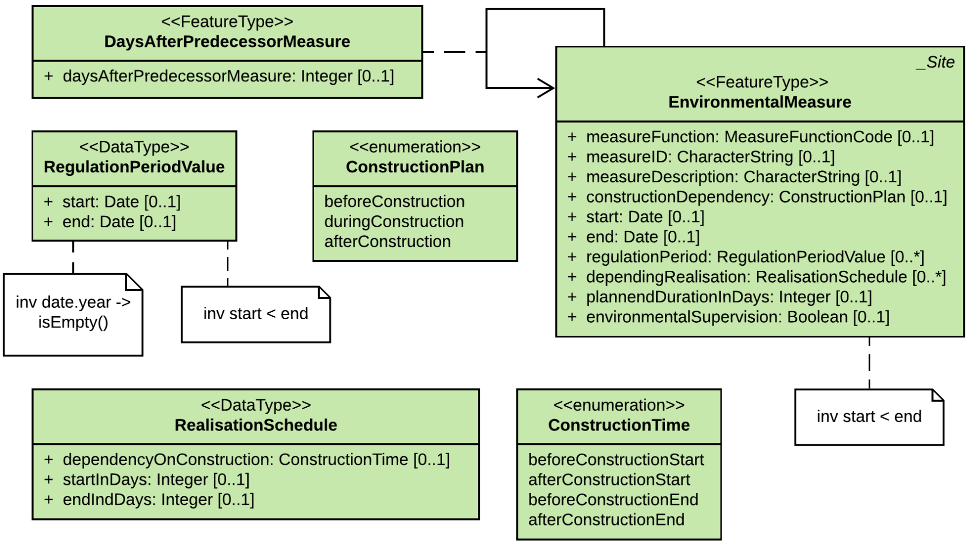

Fig. 2: Implementation of the four different temporal domains in the EnvPlan ADE

The requirements related to the four different temporal domains used in environmental planning were taken into account, for example, by adding a temporal reference to the class *EnvironmentalMeasure* (see Fig. 2). The specific temporal attributes are implemented according to the mentioned prerequisites. Besides the data type "date" for specific start and end times (case 1 of the temporal requirements defined in section 3.1), the depending time periods are represented. Recurring periods (case 2) are implemented as *RegulationPeriodValue*. Since the duration of the construction project can last several years, the object constraint language (OCL) rules shown in the UML diagram ensure that no year is specified for the periods and that the start time is before the end time. The dependence on the construction time (case 3) is modelled as *RealisationSchedule*. Regarding the actual construction time, the number of days before, during or after construction start/end has to be added. The case of a predecessor measure (case 4) is solved by using a reflexive association and the number of days between both measures.

The UML model EnvPlan ADE is converted into an XML Schema using the software ShapeChange[1]. The UML model, as well as the XML Schema files, are provided on GitHub[2].

5 Proof of Concept

The EnvPlan ADE was tested using BIM and GIS data from a railway project – the refurbishment of a train station and the extension of a train platform, located in Bavaria, Germany.

5.1 Implementation of the EnvPlan ADE as a Spatially Extended Relational Database Schema

The conceptual model as described in section 4 was implemented as a spatially extended relational database schema using the tools provided by the open source project 3DCityDB (YAO et al. 2018). This allows to automatically derive the database schema for any CityGML ADE from the UML model. 3DCityDB is based on the database management systems PostgreSQL with PostGIS extension or ORACLE. In our implementation, PostgreSQL was used. The queries and analyses described in section 5.3 can then be defined using SQL statements.

5.2 Data Integration Workflow

The construction model was exported from the BIM authoring tool Autodesk Revit to the IFC format. For the environmental planning data, different sources were used: fundamental geospatial data from a public Web Feature Service, project related data (format: Shapefiles) and information from the conflict and measure plan (formats: Shapefiles, DWG). The GIS data of the environmental planning and BIM data of the construction planning were transformed into the CityGML EnvPlan ADE using the tool FME (Feature Manipulation Engine, Safe Software). The transformation included a process to lift the 2D environmental planning data to 3D and the data import into the PostgreSQL database with 3DCityDB schema. In this process, fundamental geospatial data, such as protected sites were transformed to planar polygons or line strings floating at a specific height level (the reference height of the construction project). Project specific environmental data, such as measure sites and objects, were draped over the digital terrain model, which results in high resolution triangulated geometries for these objects. All project relevant data from construction and environmental planning was visualized as an overall model (see Fig. 3). The test proved that all relevant planning data can

[1] https://shapechange.net
[2] https://github.com/tum-gis/CityGML-EnvPlan-ADE

be successfully transformed to CityGML EnvPlan ADE and thus an integrated data environment for BIM and environmental planning can be realized.

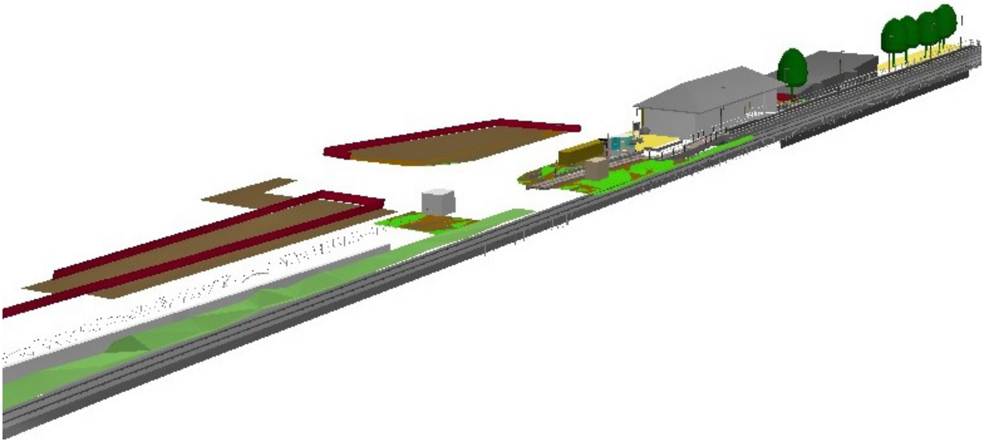

Fig. 3: Overall model showing objects from construction and environmental planning; the construction objects are visualized in grey; the colored features are environmental measure sites and objects

5.3 Queries and Analyses Based on the Information Model

In the following, two use cases based on the information model are described as examples.

The first use case shows clash detection and visualization of conflicts between construction and environment. To find space for temporary construction areas, spatial-temporal queries can be performed. These queries check whether this is possible on the start day of the construction period (in the railway project: construction period from 2021-02-01 until 2021-08-31). The query shows which environmental measure affects the areas and whether there are time restrictions related to the start day of construction (2021-02-01). The result of this spatio temporal clash detection is shown in table 2. The temporary construction areas are spatially intersected with the environmental measure areas. The column "possible" shows that the construction site cannot be set up on the 1st of February as environmental measure specifies a time regulation for tree cutting from 1st October until 28th of February.

Table 2: Clash detection of the date for the setting up of temporary construction site

measureid	measuredescription	startday	startmonth	endday	endmonth	possible
002_VA	clearing woods	1	10	28	2	FALSE

The second use case is about an automatic compensation analysis. By law[3], any intervention in the environment must be compensated. This calculation is an important part of environ-

[3] The used railway project takes place in a city in Bavaria, Germany, so the regulation of the state of Bavaria was applied: https://www.lfu.bayern.de/natur/kompensationsverordnung/index.htm.

mental planning and is represented in the EnvPlan ADE by the class *compensation*. The compensation calculation is integrated into the data integration workflow as described in section 5.2 above and therefore carried out using FME, but it could also be implemented using any GIS software, that is able to connect to a PostGIS database or directly in PostGIS using as a set of database queries.

In our railway project, the newly built and thus sealed areas, the temporary construction areas and the cut trees have to be compensated. For calculating the compensation value, a formula specified by law[3] is used. Using this formula, the compensation value is calculated as impacted area times value of the underlying biotope times a factor depending on the type of impact (sealing, planting, construction, operation). To determine the impacted area, the areas affected by the construction (objects of classes *Building* and *TemporaryConstructionSite*) are spatially intersected with the mapped biotopes (objects of class *HabitatAndBiotope* and *SolitaryVegetationObject*). The values of the underlying biotopes are derived from attributes of the class *HabitatAndBiotope,* the type of impact is derived from the type of the object causing the impact (*Building* → sealing, *TemporaryConstructionSite* → construction). The result of this calculation is represented as an object of the class *Compensation*.

The use cases and their implementation are described in greater detail in the master thesis by WILHELM (2020).

6 Conclusions and Outlook

The EnvPlan ADE supports the integration of environmental planning with BIM regarding the following aspects:

- Common standards-based information model and data format including relevant data from different disciplines involved in the BIM process: This enables standardization of interfaces and still being able to use different software tools from the respective domains. In our approach CityGML is used as a comprehensive model combining construction data and environmental data on one platform.
- Combining the requirements of environmental planning for BIM-integration in a comprehensive information model: BIM projects are still lacking environmental context information and the EnvPlan ADE can be used to standardize the required environmental data.
- Spatio-temporal representation: The EnvPlan ADE allows a 4D-BIM for environmental planning. This supports e. g. the generation of construction time tables and spatio-temporal clash detection between construction and environmental planning.

The EnvPlan-ADE extends CityGML and defines a specialized model for environmental planning. Future work will focus on the one hand on testing the ADE with further real world projects and use cases. On the other hand, the round trip BIM authoring tool → CityGML EnvPlan ADE → BIM authoring tool will be investigated.

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BIM Model Landscape_Open Spaces: An Approach for Landscape and Environmental Planning in Infrastructure Projects

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Abstract: Using the example of the landscape planning aspects of the BIM Autobahn Pilot Project A10/A24, the increased value of engineering projects using BIM to integrate landscape and environmental planning is demonstrated. The basis is the development of the Landscape_Open Space model. This leads to improved communication for all participants especially in regards to planning meetings and appointments. On this basis, the concerns of landscape and environmental conservation can be better considered during the building phase.

Keywords: Building Information Modeling, landscape design, BIM workflow, BIM elements

1 Introduction

The German federal government aims to use Building Information Modeling (BIM) for all future public infrastructure projects costing over 5 million euros. Project participants should supply obligatory performance results in digital form, and be able to participate with other project partners digitally. The long-term goal is to use BIM in construction projects over the entire process: from planning, building, and operation, all the way to dismantling (BMVI 2015). Until now landscape and environmental planning have often played only a marginal role. However, they are of increasing importance as can be seen in such projects as the second main S-Bahn line in Munich (DB Netz AG) (OTTO 2019), the autobahn intersection at the Funkturm in Berlin (DEGES) (BERGER 2020), and others.

The advantages of the cooperative planning method of BIM are seen above all in the possibility of optimizing the collaborative effort of the different trades by increasing the quality, lowering the costs, and keeping to the projected period of construction. In linked planning processes, traffic and landscape planners work together for the best possible solution for the realization and operation of traffic routes. An optimized flow of information between actors of the various areas of expertise is a necessary requirement for having high quality, interdisciplinary planning results. The integration of landscape and environmental planning in the BIM processes of infrastructure building seems therefore advisable.

Until now the use of BIM in landscape architecture has been concentrated in the area of object planning, and the first workflows have been developed (BRÜCKNER et al. 2018). In contrast, BIM has rarely been used in landscape and environmental planning. This issue was addressed in the research semester of the Master of Landscape Architecture program at the University of Osnabruck. The goal was to develop a method of integrating landscape conservation into the BIM process of road construction (REMY 2020). This was carried out using the BIM pilot project "PPP-A10/A24 (Public Privat Partnership) in cooperation with the working group ARGE A10/A24 Havelland Autobahn. ARGE is a part of the contractors' consortium and is responsible for the area of planning and construction.

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There is an especially close interlinking with the BIM processes in infrastructure construction with the environmental impact assessment (LBP) as well as the landscape management detailed design phase (LAP). The basis for the BIM method is the sectoral planning, which is brought together in a 3D coordination model and tested for consistency. This follows on the basis of the international, non-proprietary interface Industry Foundation Classes (IFC) of digital descriptions of the construction models which are based on 3D models of components, volumes, etc. The IFC interface assures the open BIM process. This means that all planners can work using their own specific software. In the ideal case, the current state of planning is available for all parties involved, as rule in the cloud-based Common Data Environment CDE. The digital building models can be used as an information databank and as reliable sources for decision making during the entire life cycle of the structure.

The coordination model for the BIM Pilot Project A10/A24 at this time makes use of a 3D model for the ground surface, subsoil level, road segment, petrol and rest areas, as well as civil engineer constructions (see Fig. 1). Landscape plans are provided by the responsible landscape and environmental planners as 2D CAD plans, and therefore cannot be integrated in the overall coordination model. Weaknesses in the communication of landscape and environmental planners with other project participants as a result of differing planning methods seem foreseeable.

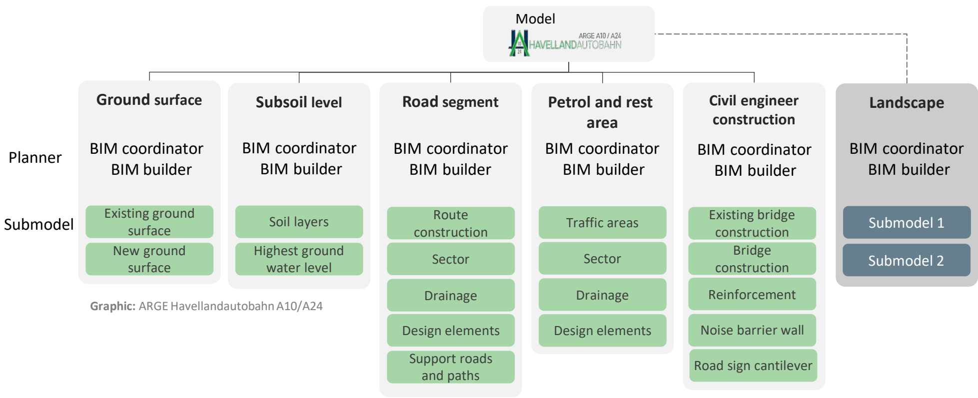

Fig. 1: Extension of the existing model through the Landscape_Open Space Model (ARGE Havellandautobahn A10/A24)

2 Standardizing BIM

For the successful implementation of projects using BIM, a strong structuring and standardization of the processes is necessary, especially in regards to data exchange (who delivers what, when, to whom and to which degree….). At present, necessary standards are still being developed. This holds true for the extension of the data exchange format IFC for infrastructure building objects (IFC Road, IFC Rail, etc.) which are also, to some degree, relevant for landscape architecture. At the moment, the most current IFC version (4.3 RC2), in the "candidate stage", has few elements to describe bridges and infrastructure elements on the basis of lines (IfcBridge, IfcAlignment, see BUILDINGSMART 2021). First, with IFC 5.0 will there be comprehensive consideration: international working groups from buildingSMART will be working from here on. When compared to structural engineering, the BIM method is less developed in regards to data standards and software tools, on the national as well as on the international levels. (Overview in KÖNIG et al. 2016, BORMANN & HEUNECKE 2020). A first attempt in Norway to standardize objects in land design has not yet been integrated in international standardization processes (WIK et al 2018).

For the use of BIM in Germany, a three-step plan (BMVI 2015) was formulated by the Federal Ministry for Transport and Digital Infrastructure already in 2015. The goal was the implementation of BIM as standard on a broader basis by the year 2020. To reach this goal, a series of BIM pilot projects were carried out and supported. To support project sponsors, as well as all other project participants putting BIM to practice, the results and findings were summarized in ten guides which are readily available, and which also offer landscape architects a first orientation for the structuring of BIM projects, BIM applications, the content and development of information requests by principals (AIA), and BIM as well as winding up plans (BAP) (BIM4INFRA2020 2019). The goals of the phased plan have not yet been able to be fully realized. The work is to be further developed for both building construction and infrastructure in the newly established Center for Digitalization in Construction, "BIM Deutschland" (BIM DEUTSCHLAND 2021)

The lack of standards for required information on the national level continues to lead to the parallel development of isolated solutions.

A contribution to the (pre)standardization on the national level is the recently published catalog "BIM Classes of Traffic Routes" put together by the working group BIM Traffic Routes of buildingSMART Germany. This was supplemented by the team of specialists BIM in landscape architecture who supplied classifications of landscape and open spaces so that in the future, environmental requirements can also be represented in BIM models. There continues to be further development of features of this first version (BUILDINGSMART-FACHGRUPPE BIM-VERKEHRSWEGE 2020).

3 Integration of Landscape and Environmental Planning in the BIM Process

3.1 BIM Autobahn Pilot Project A10/A24

The autobahn project PPP-A10/A24 used a 5.5 kilometer road section to tender and be granted as the BIM pilot project. A diverse number of BIM case applications from BIM coordination on basis of the model were tried out, first as prototypes, and then finally put into practice. These ranged from visualizations to the use of BIM models in operations and in maintenance (TSCHICKARDT & KRAUSE 2019). The Deutsche Einheit Fernstraßenplanungs- und -bau GmbH (DEGES), which realizes largescale infrastructure projects in Germany, is responsible for the project. The planning and implementation of the project were carried out by ARGE A10/A24 Havellandautobahn GmbH.

The segment of autobahn used in the project is 64.2 kilometers long and belongs to one of the most heavily driven sections in the Berlin area. Within the next 5 years, it is to be upgraded and repaired while still being used. The contractor of the PPP project is to plan, build, maintain and partially finance the different construction measures over a period of 30 years.

ARGE A10/A24 Havellandautobahn GmbH has developed an overview structure for all models used in cooperation by the project participants in the BIM Coordination Model. The models can therefore be accordingly subdivided into further component models, structural element groups and model elements. The information of a model can be passed along hierarchically. The chosen project structure offers the project participants user friendly navigation in the coordination model and assures access to required information.

3.2 BIM Model Landscape_Open Space

The Landscape_Open Space Model is furthermore being developed to integrate landscape and environmental planning issues into the BIM Model of the PPP-A10/A24 project. (Fig. 1) The landscape conservation implementation plan, in accordance with the predefined structure, is then organized in the Landscape_Open Space Model. The technical terminology that is used comes for the most part from the pre-standardized work "BIM Transportation Route Classifications" (BUILDINGSMART-FACHGRUPPE BIM-VERKEHRSWEGE 2020). Illustration 2. Shows the structure of the Landscape_Open Space Model. It is divided into two parts. This division is based on the State of Hessen's concept for landscape conservation implementation planning (LAP). The goal of this concept is to make the often complex landscape conservation plans more accessible in construction preparation.

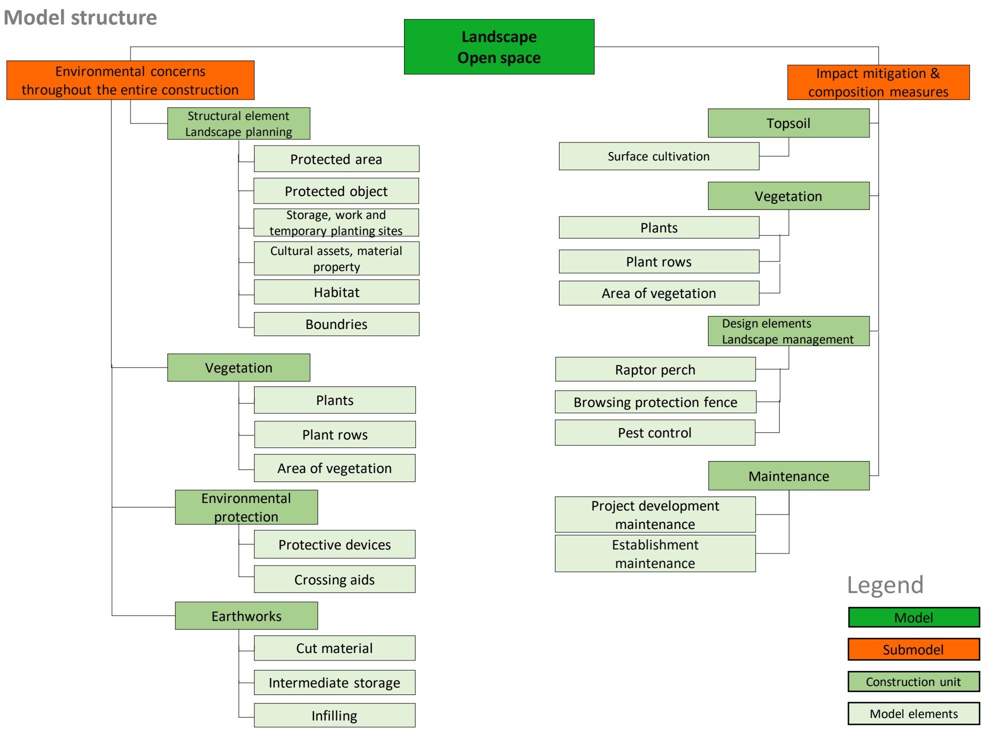

Fig. 2: Structure of the Landscape_Open Space Model

Using the submodel, "Umweltbelange während der gesamten Bauphase" (UwbB), i. e. Environmental Concerns throughout the Entire Construction, particularly landscape and environmental mitigation measures are modeled throughout the entire building phase. Model elements include protected areas; protected objects; storage, work and temporary planting sites; protected plants, or trees to be felled. This submodel is available to all project participants and is meant to serve the environmental monitoring of construction.

The contents of the submodel "Ausgleichs- und gestaltungsmaßnahmen" (AuG), i. e. Impact Mitigation and Composition Measures are primarily oriented to carrying out environmental measures. Examples are compensation planting, as well as protective objects such as raptor perches or browsing protection fences. Development, maintenance and finalization measures can also be linked to the submodel.

In general, it makes sense to divide the mitigation, compensation and design measures into two submodels in that for example the measures of the UwbB submodel are carried out much earlier than submodel AuG. It can also help make understanding details easier.

The UwbB submodel was modeled on a 2 km segment of the entire 5.5 kilometer contract section, and was integrated into the BIM coordination model of the project. All required information for the project was taken from the existing LBP and LAP. Because there were no pre-defined landscape classifications, these had to be generated generically and semantically described by means of user-specific features.

3.3 3D Models in CAD-BIM Software

Autodesk Civil 3D, often used as the modeling software in BIM infrastructure projects, was chosen for use in this case. It is complemented by an engineering application module. The current dominance of CAD solutions in BIM infrastructure projects can be attributed to the cooperation of Autodesk with ESRI in the development of interfaces for optimizing data exchange between BIM CAD and GIS in BIM processes. Road planners in the A10/A24 Project therefore used Autodesk Civil 3D to enable a seamless data exchange. Autodesk Civil 3D having the required IFC interfaces builds upon the functions pallet of Autodesk AutoCAD offering 3D tools for engineering and infrastructure planning as well as site modeling and processing. The last was essential in creating the submodel UwbB because the digital site model which encloses the route using BIM coordination model, needed to be allocated to different zoning areas.

Accordingly, areas of the DTM near the construction site were declared protected areas, or storage and work sites. For this, specific areas were cut out of the DTM and using the same coordinates exported as new DTM: The exported DTM could then be seamlessly connected in new data. Within the Civil 3D Autodesk software, such generated areas were assigned the function "define characteristics" of different zonings and features. Additionally, for defined work sites, the DTM was converted into solids so that soil that was to be removed could be automatically calculated already in the BIM model. Point objects in the UwbB submodel such as single plants, or linear objects such as fences or topsoil pits, were extracted as 3D solids and linked to specific features. The landscape classification Plants is used as an example in Figure 3. Because a realistic visualization is not required here, an abstract 3D tree model is sufficient.

This required a lot of individual work. Libraries having landscape objects and tools available that support modeling are necessary to enable efficient work in the future.

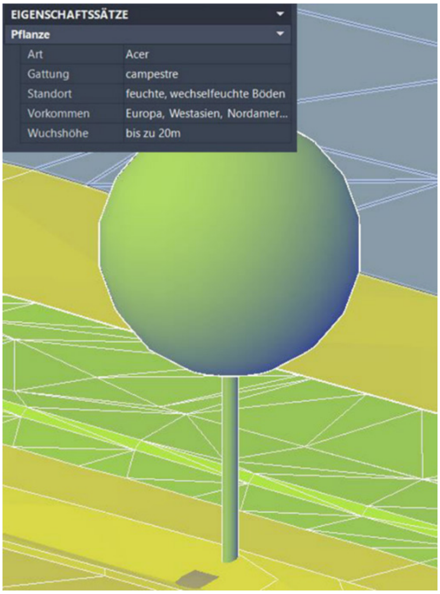

Fig. 3:
Landscape Classification – Plants

3.4 BIM Coordination Model in the BIM Management Software

To bring the individual models together in the coordination model a BIM Management software is required. Desite BIM md pro was used and the data exchange was based on IFC.

The submodel UwbB was subsequently transferred into IFC and could successfully be imported into the BIM coordination model for the PPP A10/A24 project. This means that all geometrics were available in data already entered.

With help of the BIM management software, a hierarchical data structure of the entire model and component models is realized (see Fig. 1 and 2). The installation of extensive technical data (characteristics and values) is even more user friendly than in CAD BIM software itself. An important task is checking the quality of submodels' individual disciplines, as well as the consistency of the entire model. An additional function is quantity determination. A 3D viewer is used for observation and movement in the overall 3D model. BIM management software was used primarily for data structuring and scheduling

The classification of areas in the BIM model is visible in Fig. 4 where all protected areas are presented in light green, work sites along the stretch are light brown, and storage sites for top soil are olive green. Using the example of the protected area marked in yellow, it becomes clear that landscape classifications in the BIM model are linked with information. With the building component code (BTC) for example, the existing model structure for the respective class can be comprehended. This assures the coordination of different component models and close cooperation of the planners in the BIM coordination model. Specific characteristics that were already entered in Autodesk Civil 3D are visible in the landscape planning (LAP) rubric.

On the basis of the integrated UwbB submodel, the environmental issues considered during the construction phase can be easily conveyed to other project participants in the BIM coordination model. This offers the chance to improve protection of the surrounding landscape during construction work.

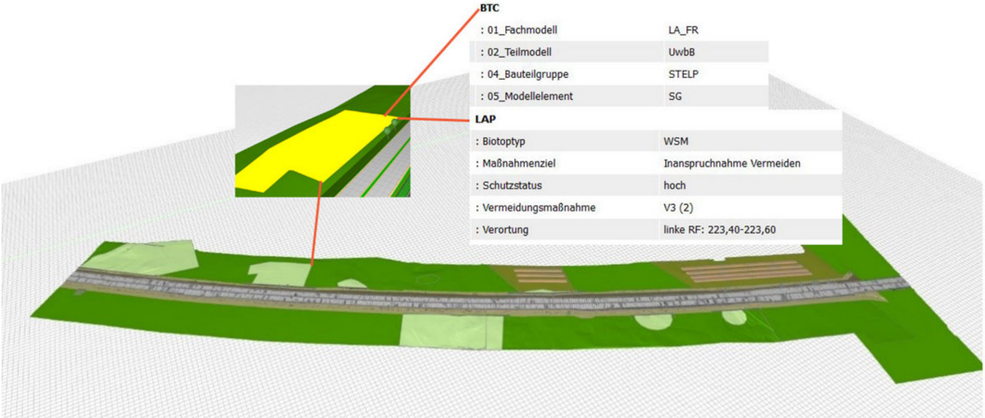

Fig. 4: Submodel UwbB in BIM coordination model

3.5 4D Scheduling

Another advantage of using BIM is seen in the so-called 4D planning. Here, various landscape classifications of the sub-model UwbB are linked with scheduling. On this basis, a 4D construction workflow visualization can be produced. For example, areas bordering the construction site can be presented with their according protection status over time. The same is true for protective fences that need to be erected and then taken down again, for the setup of work and storage areas, and for clearing the building site. The depiction is presented as a table as well as diagram, and is clearly illustrated through the visualization as animation of the changes in the 3D model.

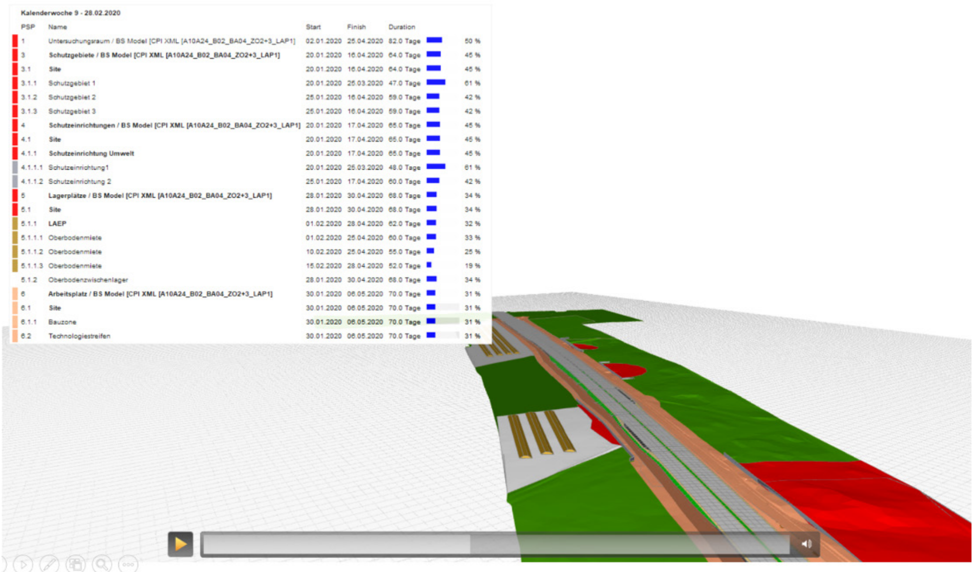

Fig. 5: Submodel UwbB – 4D Visualization

On the basis of this 4D visualization, potential conflicts of time between the building plan and specific environmental requirements can easily be recognized in the BIM model and therefore avoided. This also aids others involved in the project, such as route planners and civil engineers, carry out the various stages according to landscape and environmental conservation.

A further step would be to realize the second submodel, Impact Mitigation and Composition Measures (AuG), according to the methods presented. It is to be expected that the coordination of different construction phases using 4D visualization would be beneficiary here as well. Information required during the operation phase would be essential for the successful development of the AuG submodel.

4 Discussion and Outlook

The necessity of integrating demands of landscape and environmental planning in BIM processes has already been recognized and formulated. SHILTON (2018) discusses how the British approach to digital twin and the three levels of BIM can be carried out in landscape design and emphasizes the necessity of an IFC standard for landscape elements. WIK et al. (2018) present a Norwegian standardization project with a hierarchy of objects for infrastructure and land design with the goal of integrating this into international standards, allowing developers to create the necessary support for landscape objects in their software. Another approach is to convert CAD and BIM data to GIS formats and combine it with GIS datasets so that the necessary environmental analyses can be performed. An appropriate workflow is presented by SCHALLER et al. (2017) using the example of the Autobahn A99 expansion in Munich. CARSTENS (2019) reports on the improvement of interfaces between BIM and GIS.

In the future, the phase of operations and maintenance should come increasingly into focus because exactly here lies the greatest potential for an increase in value in the “green” sector. The increased integration of BIM and GIS could make an important contribution. The goal of green space management would be to increase the quality of maintenance and with this the quality of the appearance of the roadside vegetation. A special challenge for further research would be to find a workable approach of taking into account the development of vegetation over time.

The transition to the 3D planning presented here means considerably more effort in terms of landscape and environmental planning, especially in the initial phase. The participation in BIM cannot just be self-serving, rather is only justifiable through significant improvement in the course of the project. This requires an explicit definition of the desired BIM goals. Using the example of the BIM pilot project A10/A24 and the defined applications of UwbB and AuG within the framework of the landscape management implementation plan, the advantages for integrating landscape and environmental planning into existing BIM processes is clear. By means of the central storage in the Landscape_Open Space Model, communication with other project participants is faster, more direct, and more understandable. With this, the chance arises that landscape increases in value using the BIM method in the construction program, and that landscape and environmental protection can be improved during the building phase.

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BIM in Landscape Architecture: A Report

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Abstract: This paper summarizes the current status of BIM application in a number of large-scale landscape architecture design projects of a German-based landscape architecture firm during the years 2016 and 2021. In light of the increasing amount of infrastructure projects where Building Information Modelling (BIM) is applied, the knowledge spreads that only with BIM can competitiveness be ensured and new assignments obtained. An approach to projects based on BIM offers many significant advantages. These could be less need for reworking, fewer mistakes, better collaboration generally, and layout data which can be used in retrospect to support operation, maintenance, and property management. Clients that request infrastructural buildings, including public authorities, do not want to forego these advantages and increasingly demand the use of BIM in their projects. The current BIM experience is shown by several projects explored in this paper.

Keywords: BIM, BIM coordinator, landscape architecture and BIM

1 Everything in a Model?

The BIM planning method is gaining more popularity in its mass application in the construction sector. Since 2018, "elements of digital support in all phases of a project", are already considered for the construction of Federal buildings.

Although expectation and reality are not always in agreement, the development of work processes with the BIM method in the building planning sector is quite clear and well laid out.

This means that there is an increasing demand for landscape architects at least in large-scale interdisciplinary projects. They not only have to deal with BIM as a topic in itself, but also have to provide detailed information on the type and scope of landscape architecture projects and how they can operate on the terms of the planning methods of BIM.

For landscape architects, it is vital to define the goals of applying BIM for oneself while considering one's own contractual (official), technical and personal capabilities in order to know how to execute BIM in an economically successful manner. It is important to have clarity on the question of "BIM – What for?" right at the beginning of a project. The question of how much use of BIM is needed in landscape architecture is specific to each individual project. However, the BIM coordinator cannot answer this question all by himself. He needs to partner with a competent landscape architect who can bring expectation and reality into balance and into harmony with the economic, temporal and technical possibilities in landscape architecture.

Not everything which is technically possible makes sense to actually apply. The phrase "less is more" holds true for BIM application. The risks and challenges within the project process in terms of time and finances when working with BIM should be kept to a minimum. This is only possible through experience, exchange of information and sometimes even with trial and error. Not every possible BIM feature is useful for every project. Providing basic service according to the contract, simplifying planning tasks, and avoiding additional costs should

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all be examined and taken into account. These solutions can be reached by individually assessing all tasks and possibilities of the involved firms whose data and results can vary depending on their abilities and equipment.

The model-based planning process as a data-based exchange of planning content is fundamentally different from the drawing-based layering of data which is common for paper-based work processes. The parallel processing based on a shared digital planning space is vital in this case. Its application within the field of landscape architecture, however, is not. The term "BIM" always makes reference to a certain building, which is not always needed with landscape architecture. Likewise, the application of the interconnectedness of several buildings relates to infrastructure such as supply networks or streets.

One definition of BIM is as follows: "The term Building Information Modelling describes a working method of interconnected planning, implementation, the management of buildings and other structures by means of software. In doing so, all relevant structural data are being modelled, combined and collected. The construction is also geometrically visualized as a virtual model (computer model). The application of Building Information Modelling is adaptable to the building sector for construction planning and construction work (architecture, engineering, building services, civil engineering, city planning, railway construction, road construction, hydraulic engineering, geotechnical engineering) as well as facility management."[1]

Data from the landscape in between buildings or infrastructure are often only visualized for presentation purposes and in earlier project phases. They are often not continued in the model in the planning- and implementation process as well as the future operation of the Buildings.

The continuation of data relating to outdoor facilities can be useful, for instance with the development of integrated solutions for multi-coded land use. Multi-coding allocates different functions to surfaces which are, while overlapping, simultaneously filled. Ornamental waters with functions as retention areas and retention basins or green roofs that combine retention functions and filter applications with the creation of biodiverse habitats, photovoltaics and residence functions can be given as examples here. Rainwater harvesting, environmental remediation as well as geothermics, may possibly share areas which are to be categorized with building foundation.

Different surfaces are mutually dependent within multi-coded planning, so that surfaces above and beneath buildings and in the terrain must be considered jointly. The purpose for this is that planning approaches for all surfaces are synchronized and optimized with each other. The contributions of other planning partners should be taken into consideration as well.

At the beginning of the project realization there should be an agreement on which project-specific areas outside of the building planning itself are reasonable to process within the data model.

All areas which are worked on collectively by all the planners in question, are essentially suitable. If these data are developed in collaboration, significant synergies can be achieved for all participants. If for example, besides the building sectors for line corridors, foundations and borehole heat exchangers, the space requirements due to vegetation are also to be shown in the model; the opportunities for the segmentation of this installation space can take place

[1] „Building Information Modelling", Wikipedia – German Wikipedia website. https://de.wikipedia.org/wiki/Building_Information_Modeling (28.02.2021).

very early on when considering the creative demand of the landscape architect. For this purpose, the landscape architect – at best working shoulder-to-shoulder with the structural architect – has to coordinate the area surrounding buildings responsibly. Only if this superordinate activity is carried out by the landscape architect, it can be guaranteed that the result of the planning process does not only depict technical requirements.

2 Project Data Becomes More Volatile (Unstable, Erratic)

The speed of a project process has been steadily decreasing and clients who request flexibility have been increasing. This is often justified by a lack of time and a tight budget. In addition to this, key changes keep taking place when the planning teams collaborate. In many projects, with technical services and equipment, there is a growing number of planners who are involved and therefore data exchange in structural engineering needs to be more efficient. Then, there is also structural engineering, based on the architect's model data. Therefore, during the early stages of planning, detailed and coordinated reports are made which can lead to a faster flow of work.

Unfortunately, fundamental changes to the project keep taking place even later. Although they can be more easily implemented because of the model-based process, they are also used by the client to control costs and change appointments during the course of the project and to integrate further goals to the project which are not considered from the start. Such demands are not always economically feasible. Unfortunately, as a countermeasure, architects follow well-trodden paths for their part in the project. Solutions which have already been developed and design solutions from previous projects are used, even if they do not entirely solve the problems of the current task. Although this manner of working has the advantage of creating fewer mistakes and optimizes how construction evolves, it also holds the risk of repetition and lack of innovation.

When projects are driven by deadlines, reaching into the "digital cabinet" is often the only way which enables integrating all of the client's requirements and achieving the project goals as quickly as possible. This method of working promotes standardized, industrial, and patterned procedures in architecture. The results are often criticised as being so-called "investors architecture" which is partly true but also contributes in changing the work process.

This methodology is only partially applicable in landscape architecture because we always deal with real locations. Although well proven approaches for equipment or sub-areas can be adopted, this type of digital recycling is more limited in landscape architecture compared to other planning areas of expertise. This need not be a disadvantage, but it rather confronts the landscape architect with the usual challenge of designing and identifying all tasks in almost every project using the location itself without having to dig up his data storage beforehand.

During the course of making extensive adjustments in projects, the subsequent construction or enlargement of an already planned building will reduce the space for working for the landscape architect. This goes hand in hand with lost or wasted planning and new or re-planning within a work phase. The extra effort in planning is not always adequately paid even if such fundamental changes are introduced during the conceptual, approval and execution planning phases of the project. This leads to a repetition of entire planning phases instead of approaching with a preliminary basic evaluation. As a consequence, a cordial and peaceful agreement with the client is not always easily achievable.

BIM promotes less developed and not full-fledged working phases without a clear ending for each individual work phase. This bears the high risk of the client requesting a change in further planning phases without additional compensation. It is likened to what is referred to as “infinite preliminary planning“ on the part of the client. This requires self-organization of every planner and planning teams to ensure fair work flow options for their own benefit. This also applies to other professional partners who make changes during the planning process which can lead to a loss of already finished planning in a given work area of landscape architecture. In that respect, communication within the planning team is crucial. This is to recognize the work process of areas which have to be left out due to required alterations, or rather to receive approval to continue working on the areas for which all specifications exist. This is the only way to mutually negotiate additional costs for these services when changes are made.

In open areas where rainwater pipes, sewage lines and cable routes are running in the open and in areas with green or paved roofs, a set of guidelines and specifications should be approved in coordination with building services and the architecture. This enables an economic workability in the area concerning landscape architecture.

3 Which Data is Modelled in Building Construction? (BIM is not Equal to BIM)

In the coordination model, all the planning data from all planners involved in the project is brought together, coordinated and optimized to avoid any clashes. In projects with a high infrastructure proportion, public transport projects, complex site-developments for industrial or commercial use, the coordination requirements are not exclusively reduced to areas of building construction. There is also data from traffic areas, underground networks, public supply assets, site regulations of unbuilt areas, which must be coordinated with one another.

Therefore, it is crucial to check if the conditions for model-based work exist outside the building construction sector and if working with BIM leads to a favourable work-flow that compensates for a higher working effort. Otherwise, the application of BIM itself within the corresponding project is without use. When the additional planning effort is rewarded, this point is achieved more easily. This way the client also has the opportunity of promoting as well as requesting BIM. The cost effectiveness of BIM as a planning method has to be ensued for everybody. If the client wants to promote data usage for the operation of the installation of BIM, the current expenditures for the model development within the planning process are to be rewarded (at present partially as an addition). The developments concerning the area of BIM seem to be evolving with similar dynamics as the introduction of drawing with the CAD program once had.

It is to be expected, that through ever more efficient planning tools and the increasing distribution of BIM as a planning method over the course of the next years, that the additional efforts and expenditures for model-based planning will decrease in the field of landscape architecture as well. The advantages, for example with the matching and error correction of planning data during the course of the planning are to come to therefore increasingly.

The basic commodity for the handling of projects with the planning method BIM are data. Thus far, in the projects known to us, the data from the public supply network were mostly not available in digital form and had to be procured very elaborately from paper format into digital data. Even for industrial projects in various expansion levels, the only data available on supply lines are those which were prepared digitally during recently preceding projects. The information thereby often comes from measurements made when the lines (or pipes) were being laid. Even this data cannot be converted into information models without an extensive post work-process, which would then become the starting point for expansions, modifications, and additions. The effort it takes for such data processing cannot be covered with normal fees.

Most landscape architects are not involved in planning larger pipeline systems. However, when working on a BIM project, it may be necessary to get connected with these networks in order to be integrated in the entire project. It is necessary to work with pipeline cadastral plans also for the planting of trees to establish a coordination of supply assets and urban planning. In these projects contract rules have to be established and regulations should be made to enable working with BIM. Often, after naming the effort it would take, the BIM planning method is not integrated into the work process. This however is all the more preferable than not having the work properly rewarded.

Terrain data make particularly high demands on integration into a coordination model. For instance, when creating digital terrain models, considerable amount of data is quickly generated, which can overload even high-performance systems if the data required for further processing is not filtered out for its integration into the coordination model.

Data from vegetation which is recorded in a registry should be integrated into BIM projects, especially if the data is to be used permanently for property management. If the results of tree inspections are integrated, specifications concerning maintenance and renewal measures can be derived from this data. These measures can be documented and kept up-to-date by entering information from regular controls. Information concerning aspects of protection of species, e.g., endangered species dwelling in trees discovered during the course of maintenance or from maps and documents can also be integrated into the BIM model. Because of this, the database of the BIM model will become more and more valuable over the years, as a need for action as well as developments can be derived and effectively planned by recognizing long-term observations. Thereby, an economic planning of measures can be carried out for inventory development instead of merely reacting to sudden events. Thus far, such questions have been dealt with more often in a GIS environment. For an effective management of a number of complex buildings and open spaces, the database can be merged more comprehensively in a BIM environment. This is possible because all aspects of management can be taken into account and not only those related to vegetation.

4 Data Management, Interfaces, Programs (4d, 5d)

The success of the work process with BIM depends on the handling and exchange of data with the BIM coordinator in the coordination model with the direct cooperation of other participating planners. On the one hand, missing data can lead to planning errors, clashes and a load of unnecessary work while planning, and on the other hand, an excess of data or unfiltered transfer generated during its development can make the coordination model slow thereby frustrating the partners.

It makes no sense to integrate all data which are generated in the course of the work process into a coordination model because not all of them are relevant for further planning. The triangular prisms data of digital terrain models are usually quite bulky but are not further processed. Interestingly, the information on newly created surfaces of a terrain regulation can be used by other co-planners as a reference for construction measures. During the collaboration, the amount of run-off soil can be reduced by optimizing the process by improving soil management. This is achieved by buildings being optimally classified according to their heights, achieving a balance of masses in the construction site. For the planning of construction pits, foundations, infiltration systems, interpolated courses of transitions of different homogenous areas from drilling profile can be relevant for architects, structural engineers, and landscape architects. The selection of who needs which data and which data needs to be integrated into the coordination model to enable joint coordination has to be aligned on a project-specific-basis. This helps in developing an optimal workflow of the project. The landscape architect should have the competence to coordinate with the BIM coordinator to secure this data which is profitable for the field of landscape architecture.

5 Does Everything have to be in a Coordination Model?

Just like how data on furnishings and cable routes is hardly relevant for outdoor facility planning, the data from tree registry or other outdoor elements are hardly going to be of interest to a structural planner. So, in case of large and complex construction projects, does it make sense to break down BIM processing into individual models, such as construction phases, buildings, etc.? A disadvantage for this aspect is that between these individual models, errors and clashes could be created. But on the positive side, since different teams work on each model separately, it enables them to interact and work together, since these teams need to be in close communication at any rate.

These models can be merged through coordinated transfer areas between them. For example, an "outdoor space model", which consists of all supply's connections in a distribution room, yet without including the entire building. The distribution room with the corresponding supply transfer points is then included in the building model and is linked to the building's supply-lines data as well as other building data. This is also how we as a landscape architect company amongst others worked on a major automotive infrastructure project. In this case, the distribution room worked like an insertion cube, which is used to insert application interfaces into the building model and it can be kept in every other application model. By incorporating standardized versions of these transition areas or insertion objects, the coordination between each individual model can be simplified.

Generating and organizing data during all work phases and its consequent management with BIM makes perfect sense. But this asks for technical and organizational modifications, also when there are modifications to the work process itself to ensure economic processing (see illustration under point 2).

It also makes sense if only some parts of the work process are based on the BIM model. In such a case, the tasks concerning general problem solving and coordination between the partners can be carried out using BIM until the end of the conceptual design phase. In landscape architecture this is reasonable, because the cost of outdoor facilities is only a fraction of the total budget including the technology currently available, and the complete workflow in all phases with BIM does not seem economically depictable. Outdoor facilities are seldom designed in grid structures with repetitive elements. In most buildings, small and large modules like rooms, doors, windows, etc. are used in greater numbers. These structures along with network and supply lines can be standardized and therefore are far better suited for a model-based process than outdoor systems with elements that typically do not repeat themselves.

In many outdoor area designs, the characteristic elements are customized to the specific building site. Often times, elements such as characteristic vegetation, patches, walls, surrounds or edging and square spaces result more from design principles with individual shaping than the mere copying of such elements. This method influences the *genius loci*, often constituting the essential quality of a good plan.

Since landscape architecture always focuses on implementing something new into an environment, the interfaces require many individual adaptations. These adaptations are likely to require a lot of detailed work when integrating into the planning model yet are only applicable in one individual place. Model based work should only happen in transition areas, if for example it is indicated with the connection of infrastructure facilities, and thus being of benefit to the operation of the facilities. Low-data areas such as lawn areas are less relevant in this case.

In landscape architecture it is important to visualise the sequence of spaces to know how the end result looks like. Therefore, BIM is likely to become the standard of work process, especially when landscape architects are in pursuit of the right planning approach in coordination with the essential requirements and visualization of the given space. Videos and perspectives are helpful for the layman who is often overwhelmed with plans and sections. Quite often, data is used to create digital representations to bring together landscape and the building in order to virtually comprehend the planning.

After the conceptual planning is approved by the client, the work that follows is no longer model-based in many of our projects. The individual models within the implementation planning phase can get so complex during the course of the project, that a solely model-based process would exceed the possibilities to achieve our goals by the process time given by the fee amount. This includes the model-based execution of planning as well as its adjustment with all parties involved via a coordination model. As of yet, the Companies in the “gardening and landscaping” sector in Germany is hardly equipped for project processing with BIM, so that in this regard a collaboration with executing companies is currently technically not feasible.

This results in processing with mixed technologies (model-based in project phases 1-4, then without BIM). This enables us to make decisions with all partners during the early phases of the project. It is often required when continuing the planning according to previous processing methods with the implementation planning, call for proposals and with the implementation into the actual facility together with the gardening and landscaping companies, to work with 2D-plans without connecting to planning data. Detail plans, planting plans and many others, we are yet able to produce more economically the conventional way directly as a paperplan.

Data exchange with building companies concerning stacking-out, accounting and for documentation, or for information purposes and for the operation of a facility are not the standard at present but more the exception. What is more, still a lot has to change with the project processing inside the office until BIM will become the standard.

For this purpose, the processing effort of freely shaped, curved and twisted objects has to become so simplified that it is as quickly manageable as horizontal projections. Then BIM will become usable in all project phases within landscape architecture. Another aspect would be an easy made connection of objects for the quantity determination to date bases, so that newcomers can also proficiently use the data without having years of previous experience with various software. Maybe the deduction of the planning methods from the planning areas with more standardized content is the reason for this kind of work method not being more economically feasible within landscape architecture.

6 An Outlook

According to the BMVI, BIM will become general standard for building projects of the federal government in Germany. Can individual processing methods be preserved by this for long-term? Do landscape architects have to adapt to working as the "smaller" partner only or do they have more liberty and opportunities in undertaking projects than large-scale technical trades have? Through continuing and advanced further training of differently skilled employees, landscape architecture can influence the design and specifications of the work process with BIM also as a small trade. This could work if we build professional competence for model-based planning thereby having a voice in the shaping of BIM in our project. Such a competent contribution to projects will make a difference in the way we apply and involve ourselves.

Generally speaking, Germany also seems to be lacking a leadership role in this area of digitalisation as well: "Press release. More efficiency through digitalisation within the building sector. The national centre for the digitalisation of the building sector starts its work (January 29th, 2020). The national centre for the digitalisation of the building sector "BIM Germany" aims at a uniform and coordinated approach in infrastructure construction and building construction. State secretary Dr. Tamara Zieschang (Federal Ministry of Transport and Digital Infrastructure) and state secretary Anne Kathrin Bohle (Federal Ministry of the Interior, Building and Home Affairs) opened the centre's office today. It is jointly operated by both Federal Ministries. By using the digital planning method BIM – Building Information Modelling – it is expected that there is a solid data basis available over the whole life cycle of the building. Already at the establishment of the building, this leads to more cost efficiency, high quality and timeliness."[2]

Also, on the part of software companies, it still appears as if the planning method BIM still has to be promoted. The transformative effect of BIM on its processes and project approaches.

Summary and Overview

"In light of the increasing amount of infrastructure projects where Building Information Modelling (BIM) is applied, the knowledge spreads that only with BIM the competitiveness can be ensured and new assignments obtained. An approach to projects based on BIM offers many significant advantages. These could be less need for reworking, fewer mistakes, better collaboration generally as well as layout data which can be used in retrospect to support the

[2] Source: BIM Deutschland – Zentrum für die Digitalisierung des Bauwesens. Geneststraße 5, Aufgang A, 10829 Berlin. Tel.: +49 30 95 99 89 560. E-Mail: info@bimdeutschland.de. https://bimdeutschland.de (Accessed 25/03/2021).

operation, maintenance, and property management. Clients that request infrastructural buildings, including public authorities, do not want to forego the advantages and increasingly demand the use of BIM in their projects.”[3]

7 Exemplary Projects with Images and Graphics

Graduation Tower

The graduation tower in Bad Schmiedeberg was developed via a 3D-model. The entire coordination process including the client, approval authorities and structure planning was carried out based on the model data. The optimisation of the structure, the integration of the technical base and the quantity calculation for the tendering was also done model-based. After surrendering the model to the executing company, the corresponding plans are currently developed from the data. The construction is planned for midyear. The soil replacement, underground pipes and the shell construction of the brine tub were already done in 2020.

Fig. 1: Graduation tower tarpaulin

[3] https://www.autodesk.de/solutions/bim/hub/bim-for-infrastructure-implementation-guide (28.02.2021).

Fig. 2: Piping layout and interior construction, project phase no. 5

Fig. 3: Coordination basic pipework, concrete construction, wooden construction

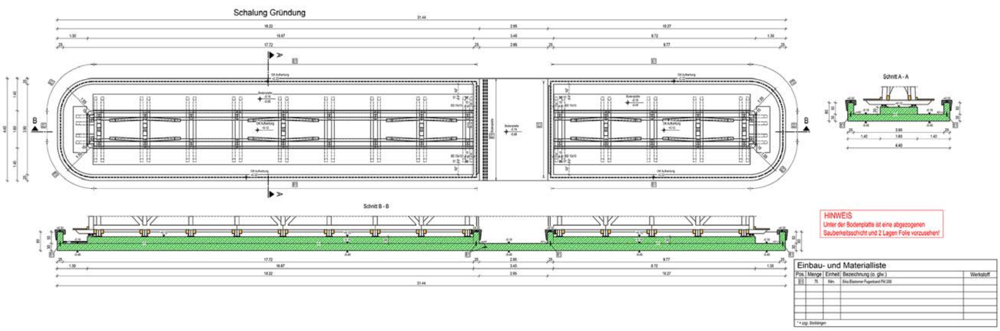


Fig. 4: Concrete construction

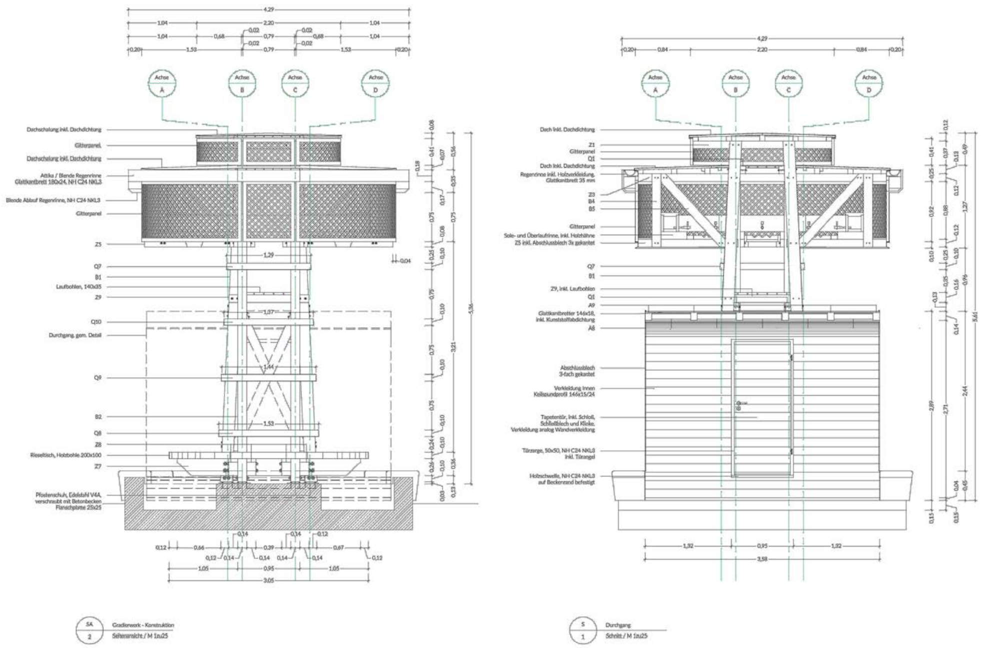


Fig. 5: Cross-section wooden component

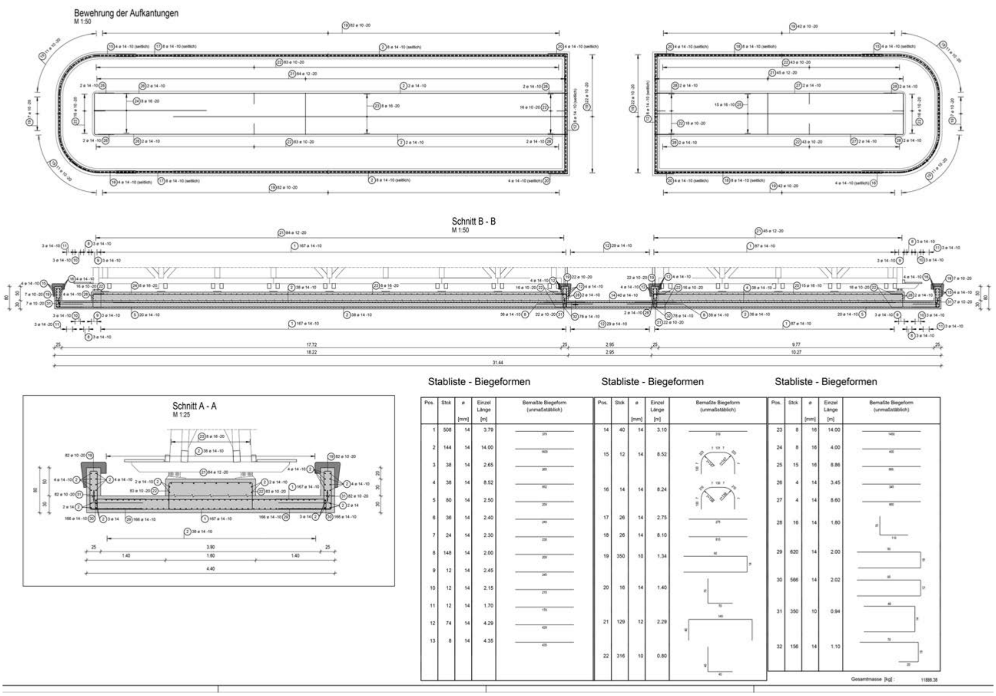
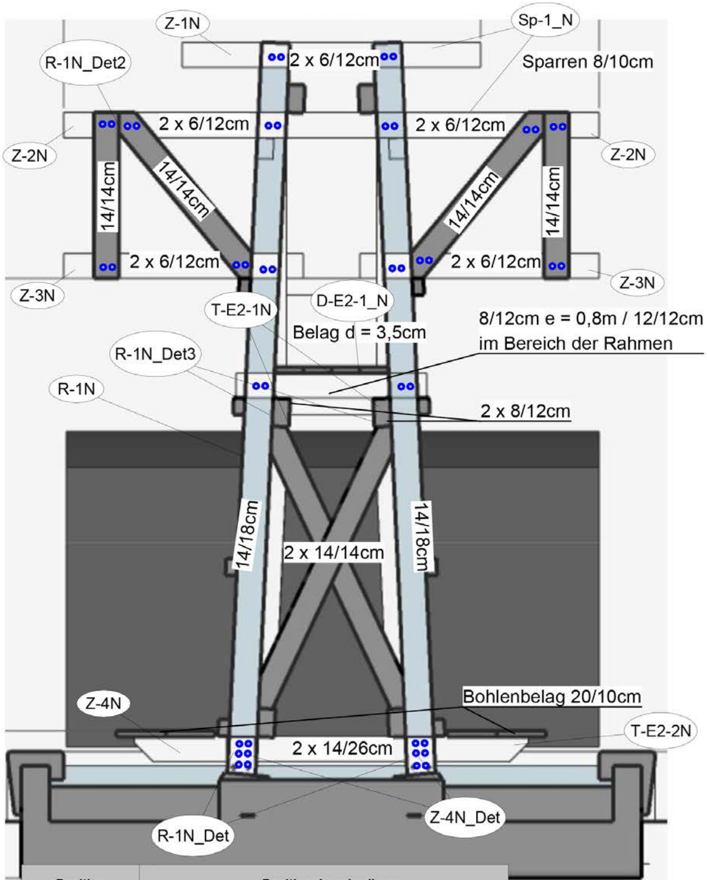


Fig. 6: Shuttering- and reinforcement plan

NR	BEZ (Plan)	BEZ (3D Modell)	L	B	H	Stückzahl	BESCHREIBUNG
1	B1	B-1N	14	18	522	28	Hauptbauwerk, Stütze
2	B2	B-1N_Kopf	14	18	522	4	Hauptbauwerk, Stütze Kopf
3	B3	B-1N_Durchgang	14	18	260	2	Hauptbauwerk, Stütze Durchgang
4	B4	B-2N	14	14	112	34	Hauptbauwerk, Stütze Auskragung
5	B5	B-3N	14	14	150	30	Quer/Diagonalverbindung, Auskragung
6	B6	B-3N_Kopf	14	14	138	4	Quer/Diagonalverbindung, Auskragung Kopf
7	B7	B-4N	14	14	237	16	Quer/Diagonalverbindung, Kreuz
8	B8	B-5N	8	12	284	24	Quer/Diagonalverbindung, Aussteifung unten
9	B9	B-6N	8	12	205	28	Quer/Diagonalverbindung, Aussteifung oben
10	B10	B-6	14	14	90	6	Quer/Diagonalverbindung, Unterzug
11	Q1	Q-1	8	12	199	64	Quer/Diagonalverbindung, Querriegel
12	Q2	Q-1_Kopf	8	12	212	12	Quer/Diagonalverbindung, Querriegel Kopf
13	Q3	Q-1_Durchgang	8	12	220	4	Quer/Diagonalverbindung, Querriegel Durchgang
14	S1	Sp-3N	12	12	122	11	Quer/Diagonalverbindung, Unterzug Wartungsgang
15	Z1	Z-1N	6	12	212	30	Zange, Dach
16	Z2	Z-1N_Kopf	6	12	52	8	Zange, Dach Kopf
17	Z3	Z-2N	6	12	380	30	Zange, Auskragung oben
18	Z4	Z-2N_Kopf	6	12	134	8	Zange, Auskragung oben Kopf
19	Z5	Z-3N	6	12	153	60	Zange, Auskragung unten
20	Z6	Z-3N_Kopf	6	12	133	8	Zange, Auskragung unten Kopf
21	Z7	Z-4N	14	26	280	28	Zange, Tisch
22	Z8	Z-4N_Kopf	14	26	75	8	Zange, Tisch Kopf
23	Z9	Z-5N	6	12	122	30	Zange, Wartungsgang
24	S2	Sp-1	8	10	199	48	Dach, Sparre
25	S3	Sp-1_Kopfanschluss	8	10	212	4	Dach, Sparre Anschluss Kopf
26	S4	Sp-2	8	10	199	48	Dach, Sparre
27	S5	Sp-2_Kopfanschluss	8	10	212	4	Dach, Sparre Anschluss Kopf
28	S6	Sp-2_Kopfanschluss-Dach	8	10	213	4	Dach, Sparre Anschluss Kopf Dach
29	S7	Sp-3	8	10	199	36	Dach, Sparre
30	S8	Sp-3_Kopfanschluss	8	10	212	4	Dach, Sparre Anschluss Kopf
31	S9	Sp-3_Kopfanschluss-Dach	8	10	205	2	Dach, Sparre, Anschluss Kopf Dach
32	S10	Sp-4	8	10	107	4	Dach, Sparre Kopf
33	S11	Sp-5	8	10	107	2	Dach, Sparre Kopf
34	S12	Sp-6	8	10	107	2	Dach, Sparre Kopf
35	S13	Sp-7	8	10	193	4	Dach, Sparre Kopf diagonal
36	S14	Sp-8	8	10	121	4	Dach, Sparre Kopf diagonal
37	S15	Sp-9	8	10	74	4	Dach, Sparre Kopf diagonal
38	S16	Sp-10	8	10	110	2	Dach, Sparre, Kopf
39	S17	Sp-11	8	10	48	4	Dach, Sparre Kopf diagonal
40	S18	Sp-12	4	6	115	4	Dach, Sparre Kopf Unterzug
41	Q4	Q2	6	10	199	72	Querriegel Bedornung
42	Q5	Q2_Durchgang	6	10	220	12	Querriegel neben Durchgang
43	Q6	Q2_Ende	6	10	234	16	Querriegel am Kopfende
44	Q7	Q2_Kopf	6	10	153	2	Querriegel Kopf
45	Q8	Q2_Kopf1	6	10	145	2	Querriegel Kopf
46	Q9	Q2_Kopf2	6	10	137	2	Querriegel Kopf
47	Q10	Q2_Kopf3	6	10	129	2	Querriegel Kopf
48	A1	A_Attika_Befestigung	4	6	82	96	Hilfskonstruktion Attika
49	A2	A-Attika_Befestigung Ecke	4	6	104	4	Hilfskonstruktion Attika
50	A3	A_Lager_Sole	6	12	53	68	Lager Sammelrinne
51	A4	A_Durchgang_Pfosten	10	10	204	8	Pfosten
52	A5	A_Durchgang_Balken1	10	10	380	2	Kopfbalken
53	A6	A_Durchgang_Balken2	10	10	123	4	Balken
54	A7	A_Durchgang_Diagonale	10	10	210	8	Verstrebung
55	A8	A_Durchgang_Sparren	6	8	57	12	Sparren
56	A9	A_Durchgang_Leimbinder	10	12	320	6	Bogenbinder

Maßangaben in cm

Fig. 7: Component lists



Position	Positionsbeschreibung
D-E2-1_N	Belag Lauffläche b/h = 14/3.5 cm NH C24
R-1N	Rahmen gesamt b/h = 12/12...26/28 cm NH C24
R-1N_Det	Holz-Anschluss Fuß 6*Stabdübel 20 S235
R-1N_Det2	Holz-Anschluss Streben oben 2*Stabdübel 12 S235
R-1N_Det3	Holz-Anschluss Längsträger an Stützen 2*Stabdübel 12 S235
Sp-1_N	Sparren b/h = 8/10 cm NH C24
T-E2-1N	Balkenträger Lauffläche b/h = 8/12 cm NH C24
T-E2-2N	Bohlenträger Schwarzdorn b/h = 100/10 cm NH C24
Z-1N	Zangen Dach b/h = 12/12 cm NH C24
Z-2N	Zangen Dach b/h = 12/12 cm NH C24
Z-3N	Zangen Solerinne b/h = 12/12 cm NH C24
Z-4N	Zangen unter T-E2-2_N b/h = 28/26 cm NH C24
Z-4N_Det	Holz-Anschluss 4*Stabdübel 20 S235

SGHG PLANUNGS- & PRÜFGESELLSCHAFT BAUTECHNIK mbH

Position P-X-1N Positionsplan Sicht Plan — Maßstab 1:100
Bauvorhaben Statik GW_2019
Neubau Gradierwerk Bad Schmiedeberg — Datum 05.06.2020
SGHG Planungs- & Prüfgesellschaft Bautechnik mbH — Seite 126

mbBauStatik S030 2018.051

Fig. 8: Statics deduced from a model

Goldbeck

The presentations of the outdoor installation planning was presented to the client in a video format. The building data where hereby made available to the landscape architect to obtain a realistic overall impression of the planned facility. After the approval of the conceptual design the project was continued without data modelling as a 2D CAD project.

Fig. 9: Bird's eye view of rendering based on building data and landscape architecture

Fig. 10: Forecourt and pond system perspective

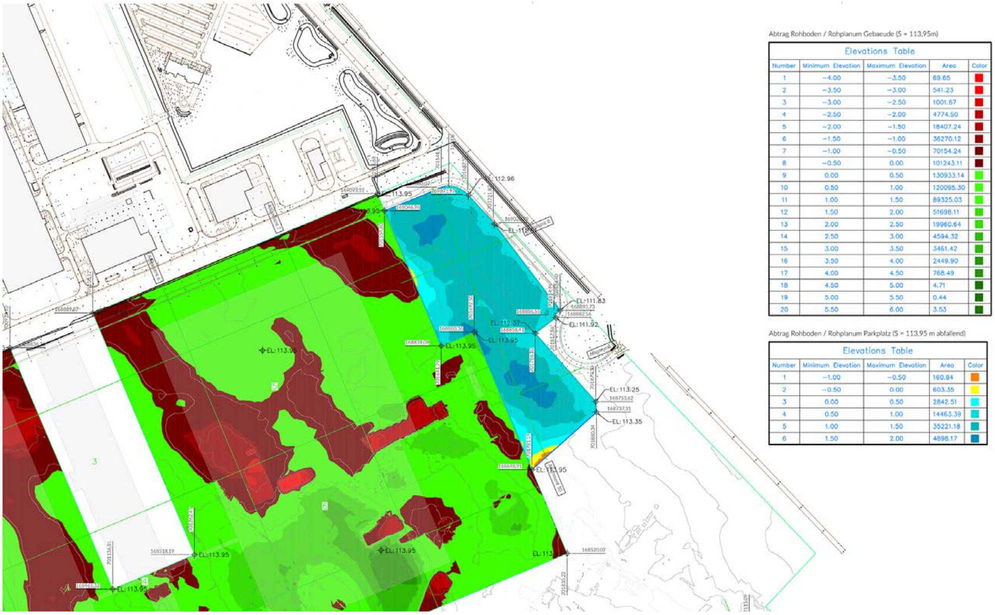


Fig. 11: Cut- & Fill plan

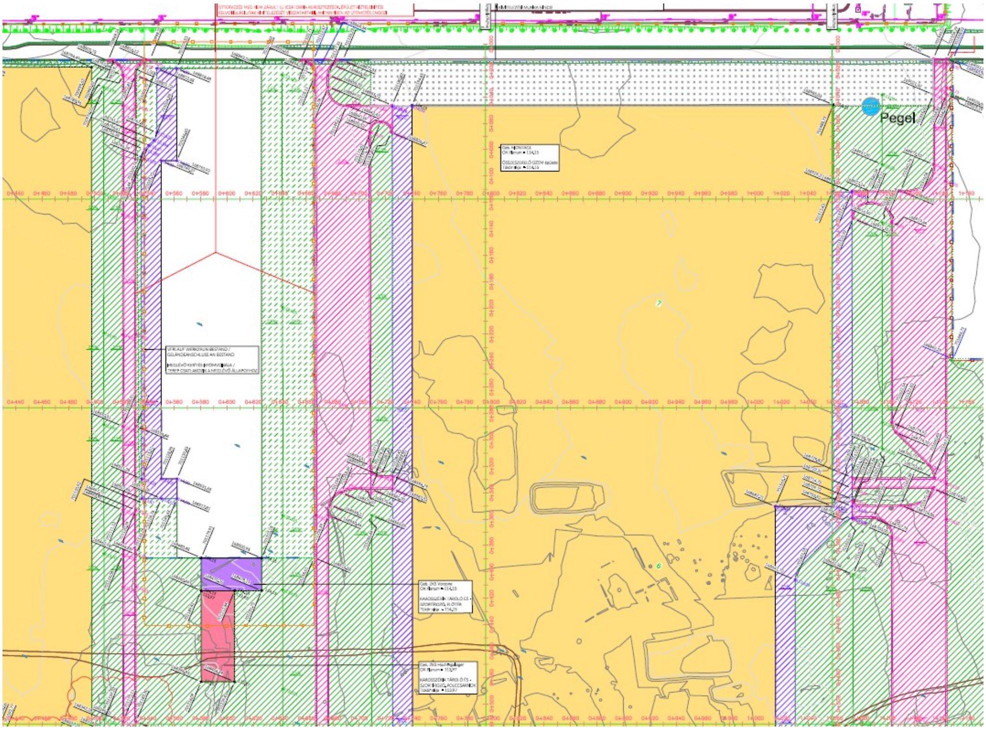


Fig. 12: Rough subgrade height plan

Kecskemét

The location development of the 2nd Mercedes Benz plant in Hungary was based on survey data and created as a digital model. Data from the building planning, traffic management and from infrastructural planning of the media were synchronised within the model and formed a basis for the implementation of land levelling. About 1.5 million cubic metres of soil was moved to make the area of the facility arable. The overall planning of the plant was realized with BIM.

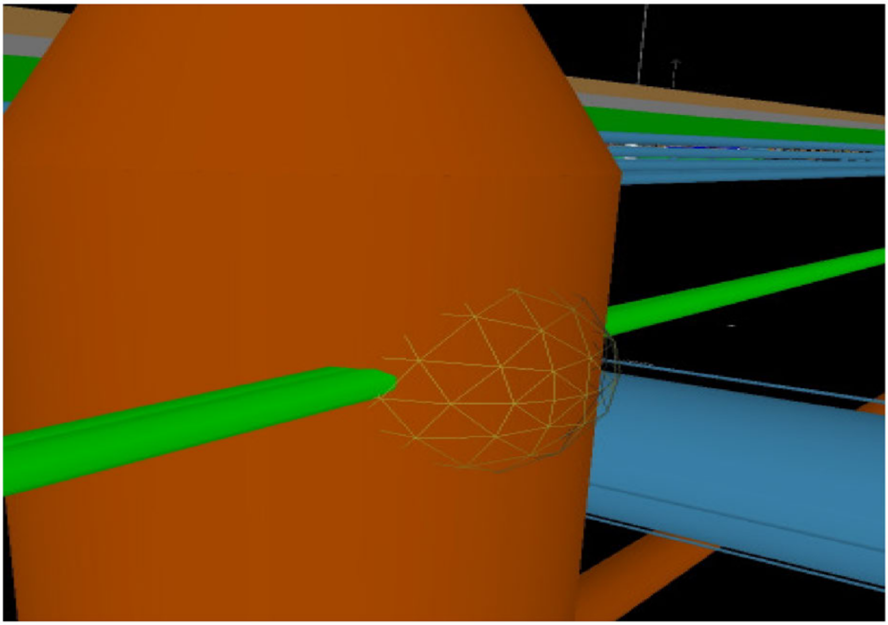


Fig. 13: Agreements concerning route coordination

Elstermühlgraben

The inner-city former mill race in Leipzig, which over the course of the 20th century were tubed because of the water contamination, are again brought to light during the implementation of a flood protection concept to make them visible in the cityscape. These projects serve besides hydraulic engineering aims also urban developmental aims, where road independent footpaths and cycle paths are integrated into the urban districts. The moats are designed in a way that they become appealing spaces with a high quality concerning their design and a stay in this place.

Over the course of the preliminary planning and conceptual design phase and on the basis of the planning data of the hydro-engineering project part, the planned adjoining public areas were developed via 3D model presentation. The coordination between the infrastructural planning (pipelines- streets and bridges) and licencing authorities (building regulations, historic preservation, environmental- and water protection) were realized without BIM, which lead to a very high processing time within the complex variant analysis.

Fig. 14: Perspective 1 video, project phase no. 3

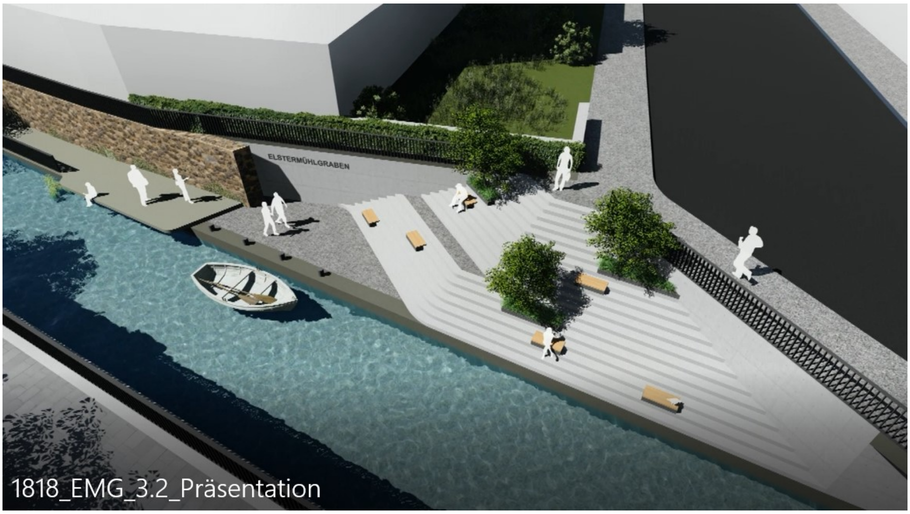


Fig. 15: Perspective 2 video, project phase no. 3

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[3] https://www.autodesk.de/solutions/bim/hub/bim-for-infrastructure-implementation-guide (28/02/2021).

PlantingSMART: The Parametric Approach for Trees in BIM with Full Lifecycle Application

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Abstract: The purpose of the study is to test the methods of and to evaluate the effects of a proposed parametric modelling approach to developing the individual tree model in BIM software for the full lifecycle application.

Current tree models can't utilize many benefits of BIM, such as clash detection, scheduling, and quantity-take-off. We experiment with a parametric approach towards estimating the shape and growth of trees in a BIM environment with different levels of LoD (Level of Detail).

The selected envelope model allows for a description of a wide range of crown forms, including asymmetric forms for existing trees and symmetric forms for planned trees. It also includes the growth function with specific parameters for overall height, height of clear stem, largest crown diameter, height of largest crown diameter, length, and depth of root, and helps calculate the shapes and volumes in time (age), while describing the morphological traits of a tree specific to its inherent species characteristics.

Apart from the geometry of the model, we define the information required in each design stage and lifecycle phase as a consistent parameter set based on our proposed modelling approach, attempt to standardize for landscape BIM elements.

The proposed envelope model, function, and parameter sets are shown to be effective. We implemented a set of Revit families, including generic models, and a list of species used for teaching in higher education in Switzerland. We successfully performed clash detection, connected to assets for real time visualization, and validated the proposed parameter set by demonstrating the use of the model during the construction phase and handover of the Digital Twin to GIS.

The parametric tree object is an important element in the development of BIM for landscape architects and contractors. It ensures that designers, contractors, suppliers, and clients can use the same object across the entire life cycle for the project. Parametric trees will create a better link between the BIM model and the building environment, and give us the possibility to create intelligent facility management models, also known as digital twin.

Keywords: BIM, parametric tree model, Extract-Load-Translate (ELT), machine operator

1 Introduction

Through a developing experiment, we present a parametric approach towards a full lifecycle application to trees in a BIM environment. We propose a tree with complete and archiving BIM standards and capabilities, which includes crown and roots as solids/mesh for clash detection, parameters for performance analysis, and LoD. It is consistent in classification, and the parameter sets allow for automatic scheduling, age representation, and shapes and sizes specific to species. Its data exchange is on a parameter level rather than a geometry level. Its parameters are concise and correctly describe the shape and growth for existing, generic, and species-specific trees based on parameters and allometric relationships.

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The proposed BIM trees are developed for a full life cycle application. It functions well with design optimization, instant rendering, and guidance of machine operators on construction site through developed applications. The attributes of the trees allow for seamless integration between BIM to GIS, and help to make workflow more efficient from design to construction, management, and the Digital twin models.

2 Experimenting with the Parametric Approach

2.1 Method: Parametric Approach to the Tree in BIM

The methods for development of the parametric is as follows:

1) Select an envelope that allows for description of asymmetric forms of existing trees, as well as envelopes for a wide range of different species of planned trees, using easy to understand parameters and common allometric relationships.
2) Select and define the number of growth functions for calculating shapes and volumes by time (age), and for describing the morphological traits of a tree specific to the characteristics each species.
3) Develop a consistent parameter set for trees over their complete life cycle to realize cloud-based BIM synchronization between the files and management using digital twin. We propose parameter sets for proper classification and information collection from the construction site, linking them to models with a unique asset identification ID such as an attached QR/bar code label. We facilitate bidirectional workflows between BIM data and GIS by API-based Extract-Translate-Load (ETL) and snapshot software.
4) Test the proposed modelling approach in the Dynamo visual programming environment and Revit family program, develop an app to guide the machine operator at the construction site, and realize a more efficient workflow for the management of smart landscape and smart city architecture.

2.2 Selecting the Algorithm Model for Envelopes of Crowns and Roots

Crown envelopes are the basis for creating crown volumes, and for correct visualization of crown-volume-based performance analysis. They are commonly used in forest measurements and stocktaking (WEISKITTEL 2011). We use the asymmetric hull model originally proposed by HORN (1971) and KOOP (1989), and then extended by CESCATTI (1997), which is defined by using six control points in six directions and two shape factors that control convexity.

For symmetrical tree shape, the parameter set can be aligned with parameters used in forestry and tree nurseries. These include total height of the tree (HT = P1.Z), clear stem height or height to the base of the live crown (HLBC = P2.Z), spread or largest crown radius (LCR/2 = P3.X, P4.Y, -P5.X, -P6.Y), and the height of largest spread or crown radius (HLCR = P3-6.Z).

The shape parameters can be considered as constant over the life of a tree and inherent to the species. Thus, the shape of the crown at a specific age can be calculated as a rotational object by the lower and upper heights, and the largest crown radius and the height of the largest crown radius can be spread as a function over time using species related parameters. The model can be extended to root systems as well, based on information of typical root forms and allometric parameters describing the relationship between crown and root (KOOP 1989).

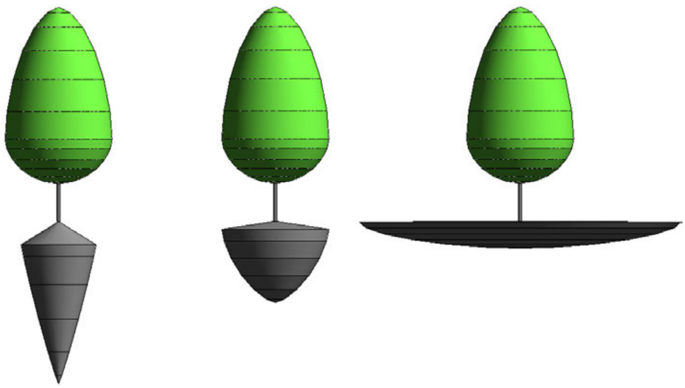

Fig. 1:
Typical root forms based on parameters for ultimate depth, ratio crown radius to root radius and one single form parameter

2.3 Selecting Algorithms and Parameters for Describing Tree Growth

The change in the size of an individual over time can generally be described using growth functions (BURKHART & TOMÉ 2012). They are often based on Von Bertalanffy's hypothesis, which expresses the rate of growth of an organism as the difference between anabolic rate (constructive metabolism) and catabolic rate (destructive metabolism). Most of them express an S-shaped curve between the initial and final size (the lower and upper asymptotes), a lag phase, an accelerated growth rate until their time of maximum growth (inflection point), and finally a slowed growth rate upon approaching the final size. We selected the Chapman-Richards growth function, one of the most popular models for describing the growth of various trees and forest stand growth variables, such as tree and stand height, diameter at breast height, basal area, and volume. Using a site index to describe the quality and availability of resources, we can estimate the final height of a tree based on its given location (i.e., expressing differences between optimal conditions in a park, limited open surfaces in urban settings, or soil depth over underground car parks).

In the Chapman-Richards function, the curve starts with germination and has only three parameters. This function can be further re-parametrized for direct interpretation of important characteristics of observed growth patterns. Here is the function:

h(t) = hmax * (1-exp(-K/t/(d^(d/(d-1)))^(1/(1-d)

with inflection point t_i = ln(1/(1-d))/K*d^(d/(1-d)); h(t_i) = hmax * d^(1/(1-d))

Table 1: Explanation of variables in the function

Parameter	Function (meaning)	Interpretation
$\mathbf{h_{max}}$	Upper asymptote	Adult value
K	Slope at inflection	Maximum relative growth rate
t	Time at inflection	Age at maximum growth
d^/(1-d)	Proportion of upper asymptote at inflection	Relative value at maximum growth

As growth estimation has long been established through yield tables in the forestry industry, we have a reliable base for the estimation of tree growth in an urban environment. The curve can be fitted using an iterative nonlinear regression obtained from known values. As we often have empirical knowledge about the parameter h_{max}, K, and t_i, we can determine the shape parameter directly.

2.4 Developing Consistent Parameter Sets for the Whole Life Cycle of Trees

Extending the dataset to consider information exchange throughout the whole lifecycle is a key benefit to using BIM in a collaborative environment. Efficient information exchange requires certain information in certain formats to be delivered to the client and project partners at key points during the project lifecycle as data becomes available.

We propose a parameter set based on the UK Product Data Template for COBie, with additional parameters to aid in proper classification. Due to the lack of IFC standards in landscape architecture, we also include national classification systems (eBKP for Switzerland, Uniclasses, or OMNIClasses).

We also propose additional parameters for information collection during the construction process, including parameters for the contractors, procurement, installation, quality checks, and commission information. With a standardized parameter set, this data can be digitally collected. Construction data are usually recorded in a relational database, and the link between the models and the database is established through a unique asset identification ID.

The reliable asset tracking system with unique identifiers is the key to successfully implement a cloud-based BIM synchronization system and for facilitating smooth handovers to facility management. The asset tag can be an attached QR/bar code label or an RFID tag used for scanning and tracking.

2.5 BIM Data Integration for GIS-based Landscape Facility Management Using Digital Twin

After construction is completed, the tree in BIM is to be setup for its maintenance using the digital twin modelling system. Because landscape facility management using digital twin is mostly based on a GIS system, seamless integration between BIM to GIS is critical. The display of GIS information within BIM is already well established. However, the integration of BIM information within GIS still requires a three-step process. First, the required content gets extracted from the BIM system and stored outside the source in an intermediate format like IFC, CSV file, or Excel. Second, these data are translated into a schema readable by GIS. This task often involves removing missing or outlying data, converting variable formats, and even more important translation between coordinate systems. Finally, the data are ‘loaded’ into the GIS software.

More seamless integration can be achieved using the Extract-Load-Translate (ELT) process. Standard API allows for reading of content from a snapshot of the BIM system data, and waits for translate data for use as native content. As the creation of the snapshot can trigger an automatic refresh/update on the GIS, ELT preserves the connection back to the BIM system and can facilitate bidirectional workflows.

3 The Implementation in Dynamo and Revit Families

The implementation step applies the parametric approach by experimenting with it in Dynamo and Civil 3D. We focused on Revit and created two all-purpose generic families, one for existing trees with asymmetric crowns and one for new trees with symmetric crowns. With a growing number of parameter sets, we organized such information in a database and established a connection with an existing plant database.

3.1 Testing Algorithm and Parameters in Dynamo

Dynamo is a visual programming environment from Autodesk for Revit and Civil 3D. We developed a set of Dynamo scripts for testing the asymmetric hull model and the Chapman-Richards growth function. The Dynamo environment allows immediate visual control of the results, allowing experimentation with different parameters and algorithms.

It showed that the asymmetric hull and Chapman-Richards growth function can be implemented into the design software from Autodesk with reasonable effort.

We found that we need different parameters of the growth functions for height, height of clear stem, largest crown diameter, height of largest crown diameter, and root depth, as they vary more widely in their characteristics. Roots reach closer to the maximum depth much faster than the crown reaches its maximum height. For many species, the spread relative growth rate lags behind the height relative growth rate in younger trees, but in mature trees, the height growth rate is relatively small as the spread continues. The spread of the roots can be related more closely to the spread of the crown than the root depth.

3.2 Developing Revit Families

In accordance with the requirements for defining the LoD in BIM standards we developed three families.

1) Family for existing trees using asymmetric hull

This model is based on 6 geometric controlling points for the crown and 2 shape parameters: the height of clear stem and diameter at breast height (DBH). The six points and two shape parameters can be interactively adjusted, and a Dynamo script creates and updates the complex form of the crown envelope and stores it as a solid/mesh inside the Revit family. The critical root zone (CRZ) is derived from the DBH and crown drip line (CRZ = DBH *12 or the crown drip line, whichever is bigger).

Attached is the information from the arborists (number (id), common and Latin name, protection class, health, remove/remain/credited) for preparing tree protection plans and tree survey tables with mitigation measures.

2) Generic tree with basic forms (symmetric) and basic growth characteristics.

This family looks at symmetric crowns based on height, diameter, clear stem height, root depth, and allometric coefficients (relative position of largest diameter, Height/DBH, Root/Crown, two shape parameters for the crown, one shape parameter for root). This family comes with common types for planning (i.e. slow growing, medium heigh, narrowly conical evergreen broadleaf tree) with associated parameter sets. The appearance of foliage for summer and autumn, and clear stem height can be adjusted in each instance. The referenced size is that of a 25-year-old tree.

3) Species type tree

The species-specific information is defined using its common and Latin names, the characteristic size and growth (25 years reference size, ultimate size, growth rate, shape factors, allometric coefficients) links to plant databases, available nursery stock sizes, construction requirements, and yield.

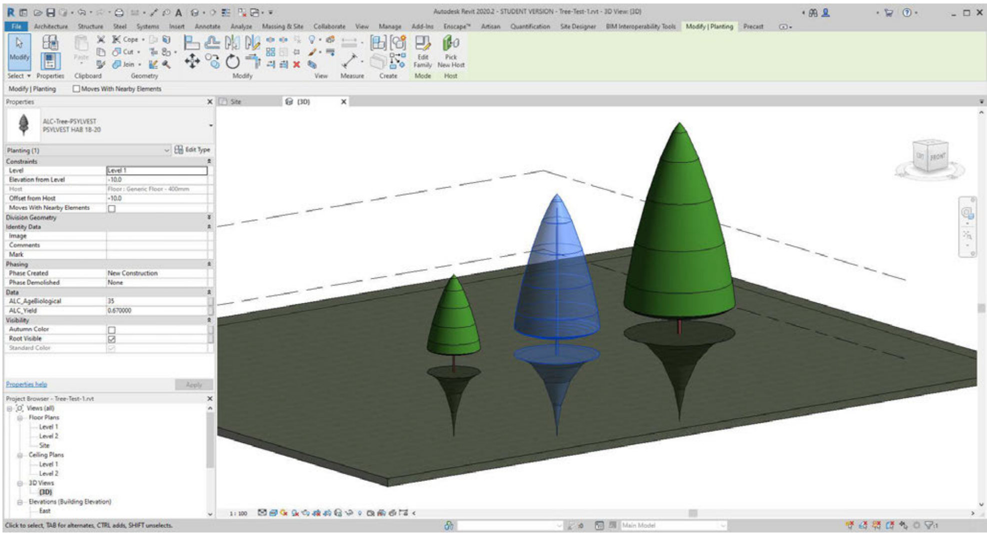

Fig. 2: Revit species type tree with parameters in different ages

3.3 Developing an App for the Guidance of Machine Operators on the Construction Site

The application was developed with Autodesk's cloud platform Forge, using services and APIs for accessing drawings uploaded to BIM360. The viewer is embedded in a standard web browser, and design automation API was used for updating the BIM model with the information collected from the construction site. All data exchange between different mobile devices are handled with nodejs and javascript, and the viewer extensions handling the overlay of the BIM model, label decoding, and real-time positioning information are coded in javascript.

3.4 Workflow for the Management of Smart Landscape Architecture and Smart City

As this is the prototype, we demonstrate a manual ELT approach extracting tree data from Revit with Dynamo and exporting it to a CSV file. The file is loaded and translated using GIS (QGIS) software, and there it is overlayed with other spatial information (a point cloud). Then, by using an API-based ETL, the snapshot is created by uploading or syncing a Revit drawing on the BIM360 server. With the Forge 'model derivate' API we can directly query the Revit file and access all information related to the trees and push them as JSON into the QGIS API.

4 Results

Through experimentation, it has been verified that the proposed parametric approach with a consistent property set can create tree models that work throughout the complete life cycle of a tree. We have built more than fifty tree species using this parametric approach. These smart tree models have BIM functions that include real-time visualization, clash detection, and automatic mechanical applications. The tree species include: Acer campestre, Alnus glutinosa, Alnus incana 'Aurea', Acer platanoides, Acer pseudoplatanus, Betula pendula, Carpinus betulus, Fraxinus excelsior, Fagus sylvatica, Juglans regia Sämlinge, Laburnum anagyroides, Liquidambar styraciflua, Liriodendron tulipifera, Magnolia soulangeana (x), Prunus avium, Platanus hispanica (x), Populus nigra, Populus tremula, Prunus yedoensis (x), Quercus robur, Robinia pseudoacacia, Salix alba, Sorbus aria, Sorbus aucuparia, Salix caprea, Tilia cordata, Tilia europaea (x) 'Euchlora', Tilia platyphyllos, Abies alba, Juniperus communis, Larix decidua, Picea abies, Pinus mugo, Pinus nigra subsp. Nigra, Pinus sylvestris, Sequoiadendron giganteum, Taxus baccata.

We selected Tilia cordata, a tree with a medium growth rate, as an example to illustrate the results. The shape parameters can be easily estimated from the silhouette picture (Figure 3). The two super-elliptic arcs can be approximated by two splines each with 3 CV (control vertices). The weight of the middle CV is directly related to the shape factor of the super-ellipse.

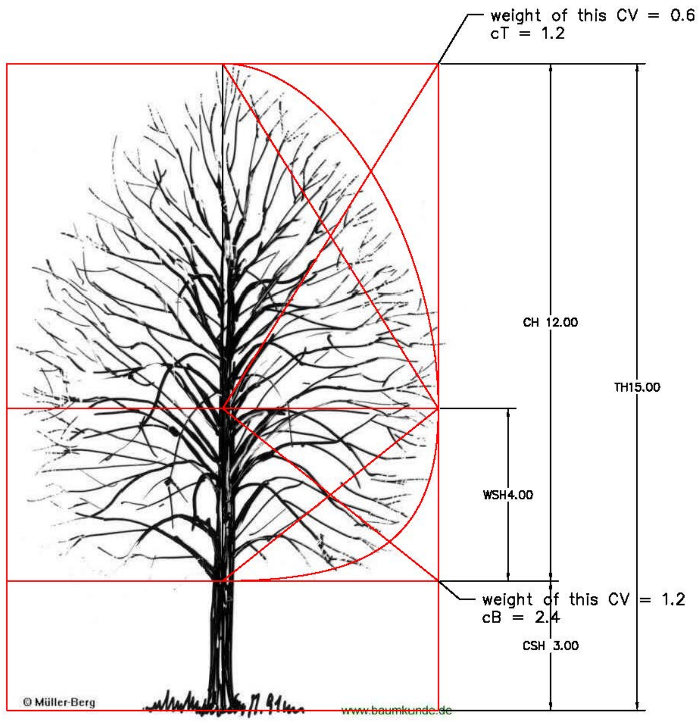

Fig. 3: AutCAD Drawing of the silhouette of Tilia cordata Mill

The main sources for obtaining data to estimate the growth function's parameters are forest inventories, nursery production data, and plant databases. The reference data we are using for the curves were developed from a 2012 Bavaria forest inventory, in addition to standard size data found in literature and plant databases (Jardin Suisse i.e.). The maximum growth rate and the time of maximum growth (K = 0.6 m) is well-known from tree nursery production data, as well as the ultimate height (40 m) reduced by the yield factor (0.625) to 25 m. We visually fitted the curve on varying shape parameters (d = 1.02) using spreadsheets and line charts. From K_{max} and d we calculated k and p.

We estimated the growth curve for spread and roots based on the relative height growth curve. For the root depth, we know that the maximum root depth is reached very early. For the spread, we adjusted the growth rate and changed the shape to a later inflection point. We visually assessed the resulted shapes with pictures and allometric relationships in charts.

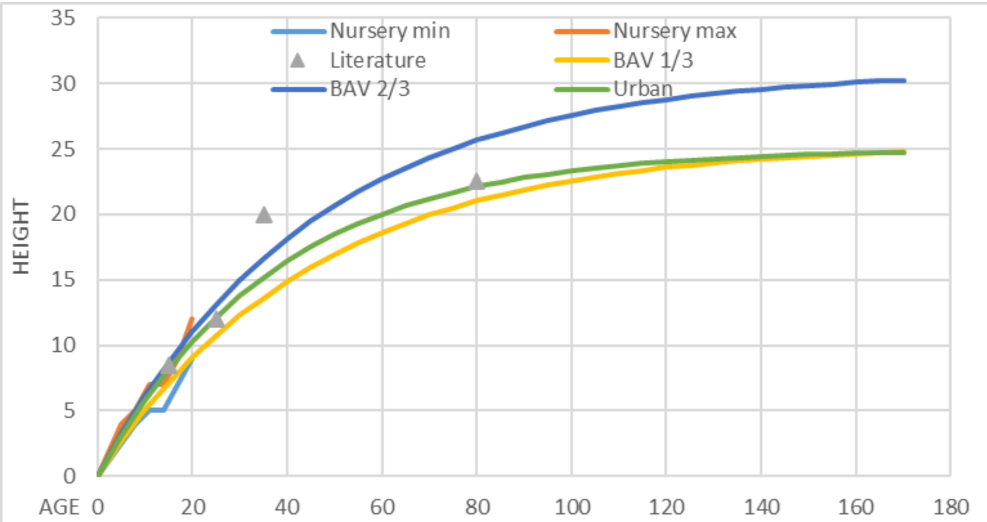

Fig. 4: Growth curve of *Tilia cordata Mill*

Table 2: Parameter for relative growth of *Tilia*

	max	p	k
Height	25.00	1.022	0.027
Spread	10.00	2.000	0.020
Depth	2.00	1.111	0.065

An additional parameter (asset id) estimated the height from the information for asset management in the visualization/rendering pipeline. By linking the asset parameter to the Revit family we can automatically override/replace the BIM trees with high resolution rendering trees inside the rendering environment, without bloating the BIM model (Figure 4).

Fig. 5: Family in Revit and rendered in Enscape with the linked assets

The proof-of-concept implementation of an app suite shows that with a consistent parameter set and a unique identifier, it is possible to request and track assets, and give on-site guidance for machine operators. With the main augmented reality app running on a tablet mounted on a machine (i.e. a construction forklift), and connected to a positioning sensor and label reader, the operator can identify an asset by its EAN number, find possible positions for planting, and monitor the machine/asset position. After positioning the tree correctly, the BIM data gets updated by marking the position, and adding values such as planting time. It is also possible use the app to select a specific plant on the plan and send a request to find and identify that plant on another mobile device, and obtain a response from this mobile app.

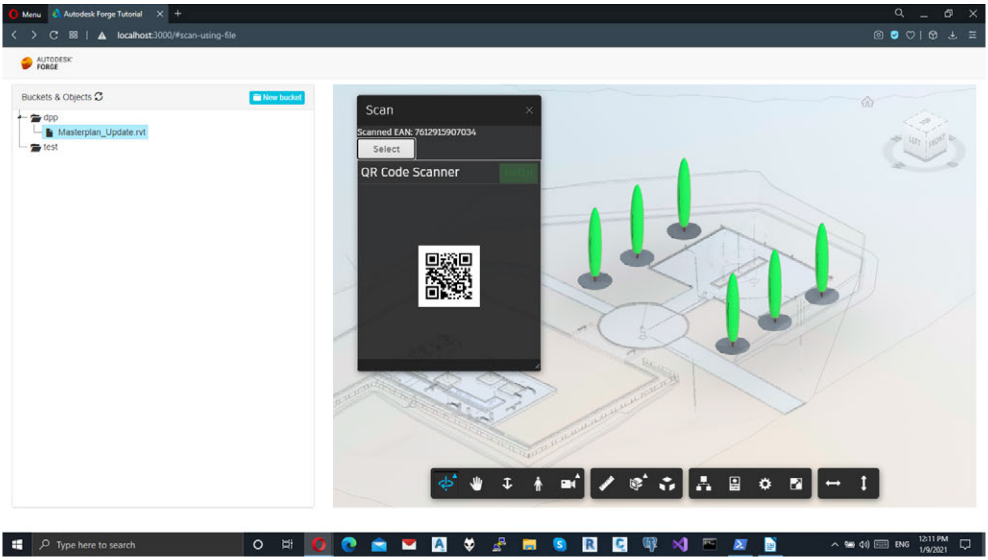

Fig. 6: Forge Application highlighting potential planting positions after scanning and decoding a QR code on the label

The proof-of-concept suggests that it is possible to transfer data from the BIM model into GIS and display it as augmented reality. We show how to extract the necessary information with a manual ELT, and translate it into the correct geographic coordinate system. Inside the GIS software the data are translated into a transparent yet selectable and simple geometry, associated with points from a Lidar based point cloud, and using the data transferred from the BIM system. Thus, data sets include information relevant for maintenance, the metadata of the BIM model, and unique identifiers that allow assets to be found in the BIM model.

We successfully automated this process by creating a cloud service that uses an Autodesk Forge API to query the Revit file and send JSON to the GIS software updating the system. We are also able to use the parametric model to represent existing trees with asymmetric crowns, and simulate their future growth inside the GIS software.

5 Conclusion and Outlook

The parametric tree object is an important element in the development of BIM for landscape architects (or LIM) and contractors. This will ensure that designers, contractors, suppliers, and clients can use the same object across the entire life cycle of the project. Better tree models will make professionals more effective and increase the value of collaboration between architects and engineers. Parametric trees will create a better link between BIM models and the built environment, and give us the possibility to create intelligent facility management models (digital twin).

With the parametric tree model, landscape architects can benefit from BIM capabilities, such as:

- Clash detection with infrastructure and buildings for root and crown space
- Analysing their model by extending the model with performance parameters
- Improving collaboration with other disciplines, throughout the whole life cycle (on-site, FM)
- Reducing duplication of models for different tasks
- Using BIM tools for sequencing and on-site management

The parametric tree can be integrated in the workflow of landscape architecture by connecting the parameter sets to established plant databases, and by using their selection tools as well as connecting the BIM trees with assets for rendering/visualisation.

Acknowledgement

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Flux.Land: A Data-driven Toolkit for Urban Flood Adaptation

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Abstract: Climate-change-induced hazards are causing large scale displacements of communities, destruction of property, and disruption of critical infrastructure. These increasingly unpredictable climate events result in complex and cascading impacts, emphasizing the need for comprehensive, data-driven, multidisciplinary design and planning toolkits. To effectively adapt to such unpredictability, these toolkits must consider a complex network of interdependencies – a range of interconnected factors, datasets, and stakeholders – that influence the planning process. With the emergence of powerful and accessible web-based computational capabilities, there is an opportunity to enhance risk management tools and allow for data-driven planning and design scenarios to support adaptive infrastructure provisions and retrofits. This paper shares the development of Flux.Land, an accessible and collaborative spatial decision support system (SDSS), allows community and planning agencies to visualize climate impacts and take collective action. In the context of flood-prone Broward County, Florida, this paper showcases how a large corpus of data-driven design and planning scenarios can be generated through the systematic definition of quantifiable design goals, evaluation metrics, and curation of computationally derived design recommendations. Through Flux.Land, we illustrate how data-driven, collaborative, web-based toolkits can be harnessed for data-driven planning and decision making across geographical, social, and environmental scales.

Keywords: Climate change, urban flooding, risk management toolkits

1 Introduction

Many cities around the world are experiencing more frequent rainfall events, storm surge, saltwater intrusion, and an increased risk of urban flooding due to climate change (HETTIARACHCHI et al. 2018). The intensification of unpredictable weather events results in significant impacts at the environmental, geographical, and social levels (DOOCY et al. 2013). As cities attempt to prevent and reduce the negative impacts of climate change, critical urban issues related to these impacts are often treated independently (BETTENCOURT & GEOFFREY 2010). This lack of cross-sectoral collaboration can result in ineffective policy-making and urban planning, sometimes leading to unfortunate and "disastrous unintended consequences" (JABAREEN 2013). For instance, design of hard and mechanical infrastructures such as levees or seawalls that are not sensitive to future cascading impacts can prove to be inadequate to future climatic conditions, either because of their limited assumed variability (MILLY et al. 2008), or inaccurate climate projections (JOHN & WICKEL 2009). Some of these consequences result in increasing socio-economic vulnerability of many low-lying coastal cities by precipitating adverse impacts of disasters such as flooding. Some projections depict that the cost of future flood losses in South Florida could be over US$ 50 billion (€ 41.4 billion) by 2050 (HALLEGATTE et al. 2013); while others indicate a 1.8m sea-level rise by 2100 would displace over two million people (OPPENHEIMER et al. 2019). To avoid such consequences,

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planners and stakeholders should not only consider physical vulnerabilities, but also socio-economic and environmental aspects (TINGSANCHALI 2012).

With difficult-to-quantify social, environmental, and economic dimensions involved in climate change adaptation, one strategy devised to address the 'ill-structured' problem domain is the utility of spatial decision support systems (SDSS) and visualization tools for adaptation planning (LIESKE 2015). Referencing Goudine's Climate Visualizations for Adaptations Products (CVAP) framework, existing SDSS and visualization tools can be categorized into the spectrum of "Inform", "Consult", "Involve", and "Partner" themes (GOUDINE et al. 2020). As SDSS and visualization tools move from "Inform" to "Partner" engagement themes, they become increasingly interactive, realistic, and suitable for high-risk decision making.

Within the "Inform" engagement theme, SDSS and visualization tools are often used to support decisions associated with lower risk in terms of outcomes and impacts; most often used to present, rather than produce research findings (GOUDINE et al. 2020). Examples include SimilarityExplorer, a visual inter-comparison tool that allows for filtering and cross-comparison of climate level data but does not reflect a high accuracy of data related to vital public infrastructure or demographic data (POCO et al. 2014). On the other end of the spectrum, the "Partner" theme in the CVAP's framework describes realistic SDSS and visualization tools that allow for interactivity, communication and fostering 'partner-like' relationships between decision-makers and stakeholders, facilitating decision making processes with a high level of inherent risk. Examples of such tools include the Mobile Augmented Reality (MAR) app, where a user is allowed to track an unspecified location, populate it with geometry, and visualize an augmented reality flooding of that environment (HAYNES et al. 2018).

The research team from the University of Toronto's Centre for Landscape Research (CLR) and MIT's Urban Risk Lab (URL) has developed *Flux.Land* to address the increasingly complex problem domain in climate change adaptation. *Flux.Land* is a web-based SDSS that extends the functions described in CVAP's "Partner" engagement theme to facilitate discussions in situations where solutions to climate-driven urban planning problems are not apparent (GOUDINE et al. 2020), but involve a high level of inherent risk. *Flux.Land* aims to facilitate these discussions through the three following approaches:

1. Developing data visualization features on *Flux.Land* to visualize precise geospatial data sets
2. Implementing data clustering algorithms and tools on *Flux.Land* for rapid analysis of hidden relationships across social, environmental, and economic dimensions
3. Introduce an integrated, data-driven design and scenario planning methodology, allowing stored data points on *Flux.Land* to be used to generate data-driven recommendations, enabling use cases such as rapid prototyping of land use intents

By combining visualization and analytical capabilities with the latest data-driven design methodologies, *Flux.Land* is able to foster greater interactivity and understanding of the intertwining relationships that exist between climate change, environment, social and economic factors.

2 Methods: Integrating Data Visualization, Data Analytics, and Data-driven Design

Using Broward County's urban-flooding vulnerability as the subject of study, *Flux.Land* focuses on the environment, infrastructure, and demographic datasets of the region. This data was collected from Broward County's open-source data platforms (BROWARD COUNTY GOVERNMENT 2019), cross-referenced with land-parcel data, and further hosted on cloud-based database servers. The data was then processed for visualization through each of *Flux.Land*'s different modules. These modules include data visualization and querying, clustering presets, and data-driven design examples.

2.1 Data Visualization Capabilities

For *Flux.Land*'s data visualization capabilities, we developed two main interfaces: a 3D/ orthographic map view and a sectional tool that correlates elevational information of streets, water bodies, and future sea-level rise impacts on groundwater tables. *Flux.Land*'s 3D/orthographic map view allows for layered visualization and analysis of geospatial data (Figure 1). A user can use this view to identify relationships across a diverse set of factors such as income, elevation saltwater intrusion areas, and flood risk zones. *Flux.Land*'s sectional tool allows for the visualization of above and below ground data, highlighting the relationship between groundwater and surface elevation considering sea-level rise (Figure 2). Emphasis was placed on the platform's simple navigation and design aimed at stakeholders from varying degrees of expertise – from the general public to planners. These visualization approaches were adopted as they have shown to be effective in the exchange of views on spatial decision problems (ANDRIENKO et al. 2007). In addition, collaborators using a shared map interface often experienced a heightened awareness of different scopes relevant to other collaborators, allowing for more efficient inter-disciplinary discussions (ARCINIEGAS & JANSSEN 2012).

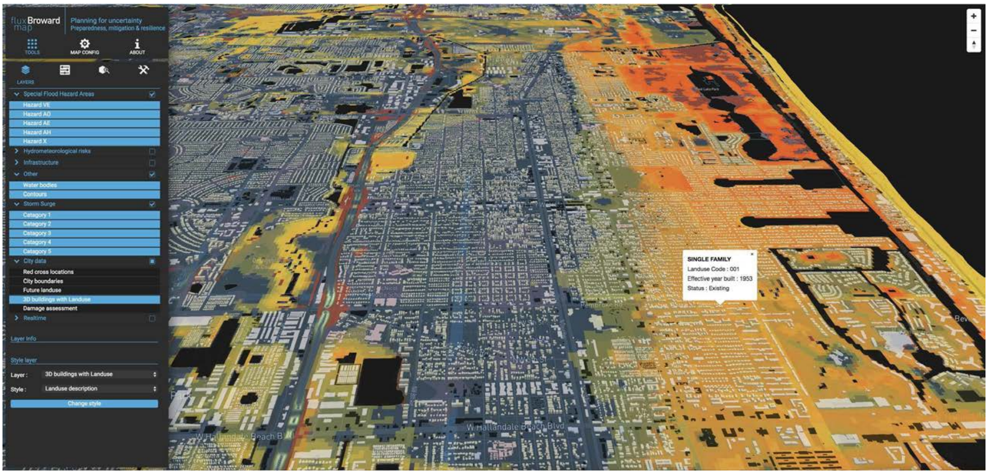

Fig. 1: Flux.Land's 3D orthographic map view

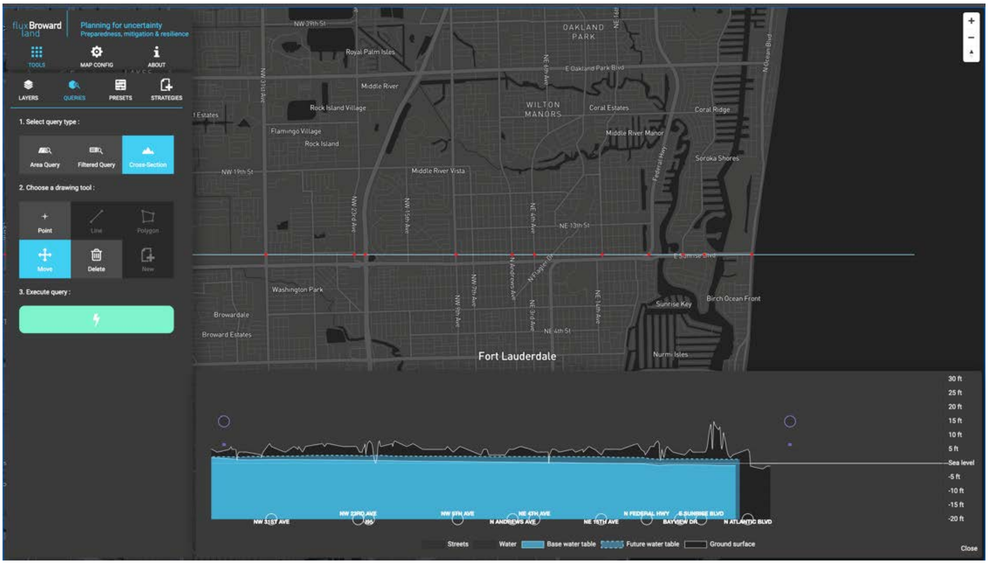

Fig. 2: Sectional tool depicting relationship between groundwater, surface elevation and water bodies

2.2 Hierarchical Clustering: Identifying Latent Relationships

While planning processes are often constrained within the administrative boundaries, the impacts of climate change and climate disasters are not (YOO et al. 2011). A hierarchical data clustering feature was developed in order to elicit these underlying similarities and differences within areas of interest beyond simple visualization of datasets across administrative boundaries. Contrary to conventional tapestry segmentation where a model of social classifications is created with segments of neighbourhood derived addresses (ESRI 2020), *Flux.Land*'s hierarchical clustering allows segments to form from a confluence of geospatial, social and environmental data that are often not bounded by administrative boundaries. By visualizing geographical clusters with similar properties, identified through a hierarchy-based relationship tree (algorithm 1), *Flux.Land* can highlight latent relationships across social, economic, and environmental factors and provide impetus to collaborate across administrative divisions to overcome these issues. Here, the clustering feature identifies different non-administratively bounded regions that have shared characteristics, enabling policymakers and stakeholders to effectively deploy different climate adaptation strategies based on different vulnerability patterns that transcend physical factors.

On *Flux.Land*, a set of parcel-level features for clustering were selected via working sessions with government officials from Broward County's Environmental Planning and Community Resilience Division. In order to represent three general areas of interrelated impacts – age and affordance of the built fabric, latent socio-economic factors, and future forecasts, clusters were generated based on selected features that include building age, land value, base flood elevation, median income, percentage of minorities, homeownership rate and residential building usage. Once the features for clustering were identified, the overall clustering approach can be broken into 3 main steps: (1) generation of clusters based on input geospatial, parcel-level data, (2) creation of a cost layer to present relationships between identified clusters and (3) visualization and analysis of resulting clusters (Figure 3).

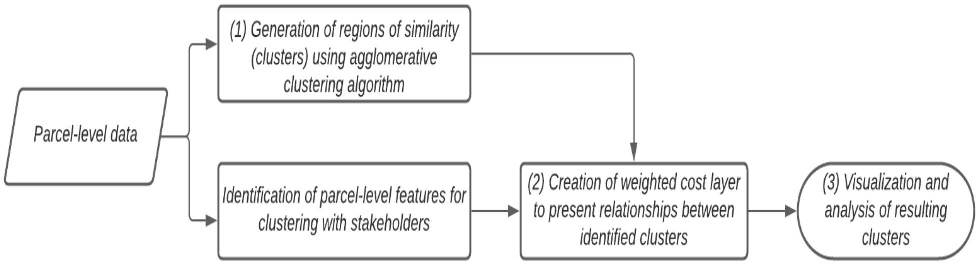

Fig. 3: Workflow to create clusters that have shared characteristics

Using parcel-level data, neighbourhoods and regions of similarity were generated using an agglomerative clustering algorithm (algorithm 1). We first identified the distribution of each parcel-level feature across Broward County. Then, we implemented a distance function to derive a relationship tree based on the variance between each feature in a group of parcels, relative to each parcel's feature's position in the overall distribution (DIAS & SILVER 2018).

Algorithm 1: Hierarchical Agglomerative Clustering (DIAS & SILVER 2018)

Input: Parcel data $\{X_N\}_{N=1}^{N}$, group-wise distance $Dist(G, G)$

$A \leftarrow \emptyset$ > There are 0 clusters in the *Active Set* at the start

for $n < 1 \dots N$ **do**

$A \leftarrow A \cup \{\{x_n\}\}$ > Each parcel is added as a cluster to the *Active Set*

$T \leftarrow A$ > Create a tree containing every cluster generated

while $|A| > 1$ **do** > Loop until all parcels are in a single cluster

$G_1^*, G_2^* \leftarrow minimum\ Dist(G_1, G_2)$ > group parcels with the smallest distance

$A \leftarrow (A \setminus \{G_1^*\}) \setminus \{G_2^*\}$ > remove individual cluster/parcels from Active Set

$A \leftarrow A \cup \{G_1^* \cup G_2^*\}$ > add resulting cluster into Active Set

$T \leftarrow T \cup \{G_1^* \cup G_2^*\}$ > add resulting cluster into tree

end while

The resulting clusters of similarity were then joined against a cost layer that was developed based on a heuristic equation derived from the normalized values of the factors of interest, highlighting the hierarchical relationships between each cluster. In the current implementation, the weights for each factor of interest are identified and refined via working sessions with stakeholders, where factors of greater importance to existing planning problems are given higher weights.

Cost Layer Equation

$$c_{region} = \alpha \frac{(F1 - F1_{min})}{(F1_{max} - F1_{min})} + \beta \frac{(F2 - F2_{min})}{(F2_{max} - F2_{min})} + \gamma \frac{(F3 - F3_{min})}{(F3_{max} - F3_{min})}$$

c_{region} = cost of region

F1, F2, F3 = values of factors

α, β, γ = pre-defined weights

The resulting clusters were then uploaded onto *Flux.Land,* enabling users to examine latent relationships across geographical areas and interdisciplinary factors.

2.3 Data-driven Design Methodology

Building on the data points and clusters embedded on *Flux.Land,* we further propose an integrated data-driven design and scenario planning methodology, where government officials, planners, or individuals are able to use the data points stored on the platform to generate a set of data-driven recommendations. Using contextual-specific data points and clusters generated on the platform, a practitioner can leverage the platform's information database to make better design decisions. The integrated data-driven design methodology can be summarized in three key steps: (1) defining design priorities and goals, (2) quantifying evaluation metrics and design parameters, (3) design discovery, optimization, and curation of design recommendations.

In the first step, two key design goals were established for this initial study in the context of South Florida by reducing flood risk for 2.5 million residents by generating interconnected open-space networks of floodable low-lying parcels, and increasing land values and the municipal tax-base by maximizing developable, infrastructurally connected parcels on high-ground.

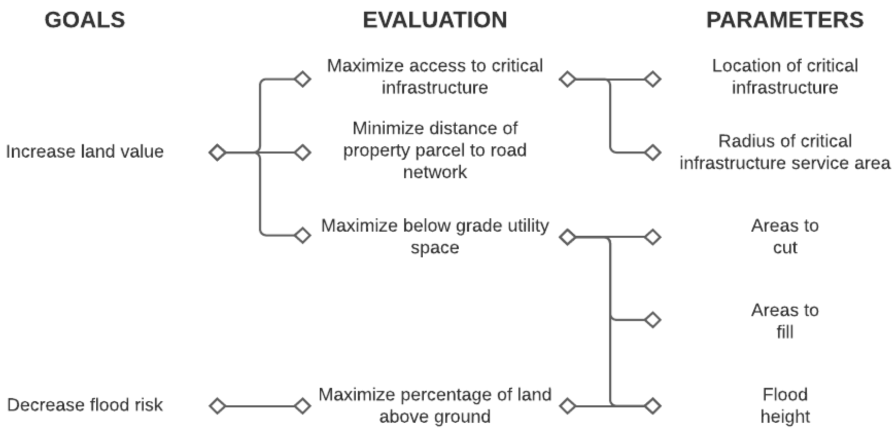

Fig. 4: Goals, evaluation metrics and design parameters designed to reduce flood risk and increase land value

The second step of the data-driven design methodology further distills each design goal into evaluation metrics and the urban morphology into constituent design parameters through an iterative design process. For *Flux.Land*'s initial proof-of-concept, land value was evaluated by a combination of coverage by critical infrastructure, the distance of property parcel to transportation networks, and below-grade utility space. To evaluate flood risk, the amount of percentage of land above ground was calculated. These evaluation metrics were then further broken down into design parameters, including the location of critical infrastructure, the radius of critical infrastructure coverage, areas for cut and fill process, and sea-level rise scenarios (Figure 4).

Finally, in the third step, these design parameters and evaluation metrics were processed with the Galapagos library (RUTTEN 2013), a suite of evolutionary algorithms via Rhino3D. The algorithm iterates through permutations of defined parameters, producing recommendations that are performed based on the defined evaluation metrics. These recommendations would then serve as a starting point for further in-depth design ideation, or land-use zoning reconsiderations.

For our study with Broward County, using the goals, evaluation metrics and defined parameters (Fig. 4), a series of conceptual urban landscape configurations were parametrically generated using simulated 'cut and fill' processes, in tandem with rising sea levels. By simplifying a digital elevation surface model of the existing urban landscape into a grid of 3D elevation points and evaluating the gradient between each point, the availability of land above water, and the area of a given radius around each point, we were able to identify which point on the surface was the most optimal for cut-and-fill processes at each increment in sea level rise. By simulating the sea level rise of 0.25, 0.5, and 0.75 metres, we were able to observe how sea-level rise affects the generated urban landscape configurations.

3 Results and Discussion

To test the implementation of *Flux.Land,* review sessions were held with Broward County's Environmental Planning and Community Resilience Division on the 10th of July 2019 and 18th February 2020. Feedback was provided for our implementations of data visualization, clustering, and data-driven design methodology on the *Flux.Land* platform.

On *Flux.Land*'s data visualization capabilities, reviewers found its 3D/orthographic map view (Fig. 1) to be intuitive, especially users who had prior experiences in GIS technologies. Reviewers also found the sectional tool (Fig. 2) to be very useful in capturing quick snapshots of the water table in geographically sensitive locations like airports for preliminary planning discussions. In time-sensitive situations, *Flux.Land* provides a more accessible method to quickly retrieve analytical data, as compared to requiring specialized GIS software and data science teams to access and analyze similar data. However, as the platform is not currently equipped with a self-serve data upload capability, reviewers voiced the need for SDSS platforms like *Flux.Land* to be equipped with data management features that allow for new geospatial datasets to be uploaded, removed, and managed easily. This would allow the platform to be updated based on the evolving needs of the users.

Using the parcel-level features and weights defined by stakeholders from Broward County, reviewers were also presented with the results of *Flux.Land*'s data clustering feature. For each combination of factors, the primary factor of interest was assigned a weight of 0.4, and secondary factors were assigned a weight of 0.3 each in the cost layer which was used to derive the relationships between each cluster. The reviewers' observations of the clusters presented are as follows:

Table 1: Observations of cluster results

No.	Factors	Cluster Description	Reviewer's Observations
1	Building age, land value, base flood elevation	The resultant clusters examine the relationship between land value, base flood elevation, and building age. A higher-valued cluster depicts an area with greater land value, lower base flood elevation and younger buildings.	Reviewers identified that areas with greater land value, lower base flood elevation and younger buildings were deeper inland, whereas regions close to the downtown core were most vulnerable to urban flooding and had older buildings (Figure 5).
2	Median income, land value, base flood elevation	The resultant clusters examine the relationship between median income, parcel size and base flood elevation. A higher-valued cluster depicts an area with lower median income, higher base flood elevation and higher land value.	Reviewers identified that the median income was lower in the downtown core, where communities were more susceptible to flood risk due to higher base flood elevation (Figure 6).
3	Median age, land value, base flood elevation	The resultant clusters examine the relationship between land value, base flood elevation and median income. A higher-valued cluster depicts an area with greater land value, higher base flood elevation and higher median age.	Reviewers identified that populations with higher median age and a higher risk of displacement due to flood vulnerability were more likely to be located along the coastal areas.
4	Percentage of minorities, land value, base flood elevation	The resultant clusters examine the relationship between land value, base flood elevation and percentage of minorities. A higher-valued cluster depicts an area with greater land value, higher base flood elevation and higher percentage of minorities.	Reviewers identified that the percentage of minorities was higher in the downtown core, where base flood elevation was higher, resulting in higher flood vulnerability.

Fig. 5: Cluster indicating the relationship between building age, land value, base flood elevation. Darker colored clusters depict areas with greater land value, lower base flood elevation, and younger buildings.

Fig. 6: Cluster indicating the relationship between median income, land value, base flood elevation. Darker colored clusters depict areas with lower median income, higher base flood elevation, and higher land value.

Using the resultant clusters, the team further tested the proposed data-driven design methodology and produced a series of landscape configurations based on the parameters defined (Fig. 4). The blue areas on the plotted areas in Figure 7 indicate water bodies, and the white lines indicate the topographical contour of the site of study. The two configurations depict how the contours of the area of study could change as more cut-and-fill operations are applied as sea level rises. The left diagram depicts conditions before cut and fill operations and sea-level rise, while the right diagram depicts conditions at 0.75m sea-level rise. These configurations were then consequently evaluated against the expanded evaluation metrics (Figure 8).

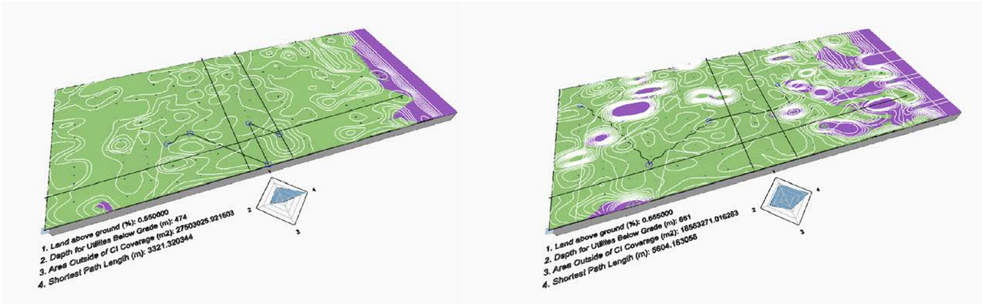

Fig. 7: Parametrically derived landscape studies

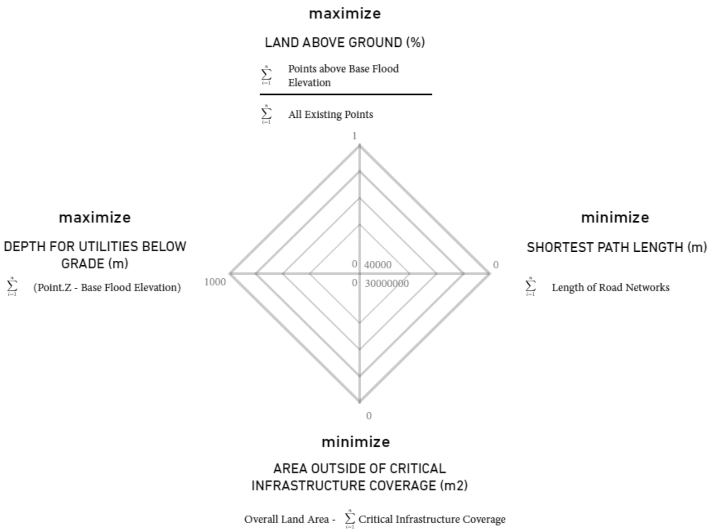

Fig. 8: Expanded evaluation metrics illustrated as a spider chart

The resulting configurations exemplify how our data-driven design methodology can be applied to data points on SDSS like *Flux.Land*, and be used to parametrically generate planning configurations, while allowing practitioners to measure the performance of the configurations using the defined evaluation metrics.

4 Next Steps

While the processes and features highlighted above have been contextualized for Broward County, this approach can easily be extended for other jurisdictions as well. The feedback retrieved from reviewers of the platform will continue to shape future iterations of *Flux.Land* and other similar types of SDSS. In future deployments of *Flux.Land*, an API first approach will be taken when integrating data sets onto the platform, so that organizations can continue to visualize updated data in a self-serve manner. We also plan to add more features to enhance the usability of the platform – for example providing customizable topographic representational options like colours and annotation tools for greater interactivity with geospatial datasets. We are also in the process of conducting a formal usability evaluation of the platform to understand how it has impacted users, ranging from urban planning practitioners to school students.

The current versions of the parametrically generated designs for Broward County have also demonstrated that the platform can facilitate smarter decision making within the defined constraints. With these results, we intend to further refine the robustness of the clustering algorithm and extend the application of the data-driven design methodology in more complex urban scenarios through continued collaboration with different agencies that can benefit from *Flux.Land*.

5 Conclusion

With increasing complexity in the problem space of climate resilience and adaptation, there is a pressing need for more interactive and collaborative tools so that cross-disciplinary collaboration can happen more effectively. Through *Flux.Land*'s visualization, analytics, data-driven design, and planning features, we illustrate how SDSS and visualization tools can be extended to become participatory design tools. As computing power continues to increase, analytical tools will become more sophisticated in describing the complex social, environmental, and economic factors that determine the form and function of urban landscapes. As such, tools like *Flux.Land* have the potential to become more assistive in the design and management of climate-informed adaptation planning. As seen in the context of Broward County, *Flux.Land* is a nascent example of how data-driven, collaborative, web-based toolkits can be harnessed for data-driven planning and decision-making across scales. Here, *Flux.Land* enabled human decision-makers to experiment and understand the nuanced relationship between geographical, social, and environmental context through customizable datasets; advancing the efficiency and robustness of design-based decisions in the face of highly complex planning scenarios. By enhancing access to the underlying data and presenting it in an easily digestible manner to a wider audience, tools like *Flux.Land* will also help make the resilience planning processes become more participatory and equitable. The development of Flux.Land was carried out with an understanding that vulnerability to disasters and climate change is underpinned by complex socio-political processes, and by providing a way to visualize some of these complexities, SDSS tools may help in mitigating the impacts of changing climate.

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Digital Landscape Architecture in Practice

Big Scale Landscape Project from Design to Fabrication: A Report on Digital Methods

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Abstract: Most landscape projects share a similar history: they start with an idea, continue with seemingly endless planning iterations of each profound planning phase and end in a more or less successful fabrication stage. As the size, budget, and timeframe of the project are often fluctuating during the process, digital methods can help us to cope with them. This paper reports about digital methods used to realize the project "Summer Island" at the Bundesgartenschau (BUGA) 2019 in Heilbronn, a big scale landscape project as a part of the Federal Horticultural Show in Germany.

Keywords: Digital design methods, digital fabrication, parametric model, digital landscape

1 Introduction

The Bundesgartenschau BUGA area in Heilbronn with its inner part called "Summer Island", is situated between the canalized Neckar river and one of the river's branches and was held from 17th April until 6th October 2019. This area used to house wet docks as well as industrial and railway facilities. The Summer Island itself lies between two former wet docks, which today are named Stadtsee and Karlsee. The BUGA laid down the infrastructural ground (ERHARDT 2013) for a huge housing development situated very central in Heilbronn. The Berlin landscape architects Sinai did the design for the master plan. LOMA architecture.landscape.urbanism was commissioned in 2016 to design the temporary development of the Summer Island.

At the beginning of the planning phase, in 2016, the summer island was covered with large soil piles. Excavators, large trucks and tipping lorries had piled up huge depots of the river Neckar's clayey alluvial soil here – a material more suited to creating a lunar landscape than a base for a horticultural show. The construction site (Fig. 1) had nothing in common with the predefined term of "Summer Island" but it was more like a "zero-place". The planning task was to develop a vision for this huge area that should also deal with all the stored material without removing it from the site and preparing it for building quickly and within a limited budget.

The paper will report about digital tools in the different phases of the project. These phases were not lined up one behind the other but were overlapping during the whole process. This means that during the development of the schematic design, there were already tests made on simple parameterized models to calculate the material masses. Moreover, parallel to the design development, experiments were made to extract construction drawings from the 3D-model.

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Fig. 1: Excavations at the Summer Island

2 Report on Digital Methods

2.1 Design

The Summer Island landscape design is based on creating the soil's natural wave formation, which forms ripples analog to a glacier-shaped, gently undulating moraine landscape. The visitors should be able to walk on and between the ripples. Early drawings of natural science from the 17th century were studied, in which cartographers had tried to trace the Upper Bavarian moraine landscape. Application of this analog technique to synthesize a new and unique landscape for the Summer Island failed. During the schematic design, the need to use digital methods to create the landscape was recognized early. The expertise in digital methods at LOMA was there through a previously realized project, the Ripple Park, that was accomplished with a fluid Add-on of Maya Software in 2008, a time when processual and parametric digital tools in modeling software were not widely known yet.

One of the project's important parameters was 16,000 m^3 of soil stored on the site that had to be built into the design. This earth amount was not a fixed number as there were ongoing excavations, and Summer Island was used as a storage area. So any design had to keep flexible with the volume. Another long undefined parameter was the number, location, and size of pavilions which were planned very late and significantly impacted the distribution of material on the site. The Summer Island's surrounding streets and infrastructure were already realized so that only several cable trenches had to be planned and incorporated into the design.

The new landscape was parametrically realized with the 3D modeling software Rhino 3D add-on Grasshopper. Nurbs-curves placed on the site formed the main input for the parametric model that created each formation element. The height of the element was parametrically coupled to the length so the inclinations were in between a predefined range. Furthermore, the endings of the elements were defined with some built-in irregularity. The goal was to have a simplified geometrical input (the nurbs-curves), as this would speed up any changing of the wave formations. As the Summer Island was supposed to be a complex wave system that contextualizes spacial or dramaturgical demands, three-wave patterns differed from each other with diverse individual properties (Fig. 2).

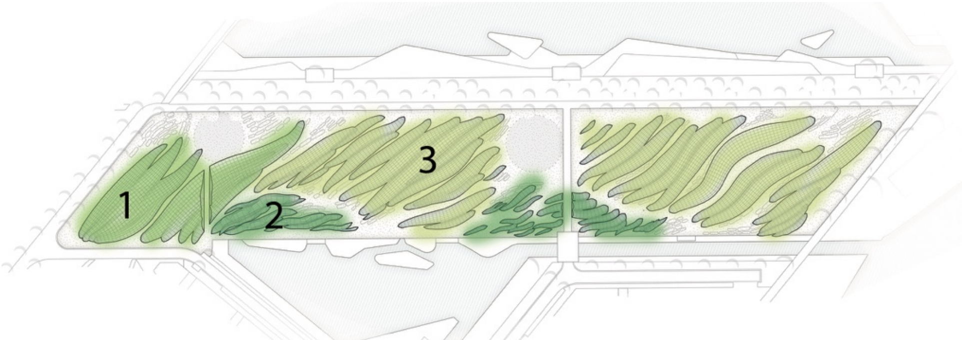

Fig. 2: Summer Island wave types. Type1: higher wave in ratio to the length, simple curved ridge; Type 2: small waves with alternating slopes; Type 3: lower wave in ration to the length, undulating ridge

Except for type 3, the wave's height would be defined by the underlying curve's length. All waves had, depending on the type, fixed slope angles that were defined in a specific range so people could still climb them, the robotic mover would be able to reach all points, and the grass would not slip. Even though the elements are formally rising out of the ground, they had to be technically modelled as attached objects so that they could be modified easier during the process. South-west of the Summer Island, an adjacent area called Rose Garden was also located, and its individual ripple pattern was formally not connected with the huge wave formation of the main area of Summer Island.

During the design process, the form of the waves changed, so the overall picture was determined by the density – depending on the earth volume -, the wave's thickness – thinner at an earlier stage – and the wave's shape – getting more expressive with much sharper or wider heads. These changes are the result of continuously adapted parameters (Fig. 3), like the volume of stored earth, changing client requests – they demanded a "tribune"-like wave toward an open stage, as well as infrastructural needs – some shafts on the site had to be accessible

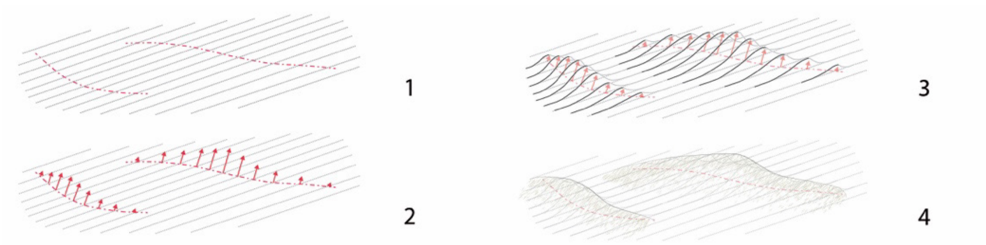

Fig. 3: Main parameters: 1 – Curve positioning; 2 – Height distribution from 1 – 9 meters; 3 – Slope definition; 4 – Topography

for vehicles. One of the last "settings" was the precise positioning of the two pavilions (SONNTAG 2019, BODEA 2020) and the definition of their installation space.

Starting from the scheme development towards production drawings, only one 3D model was used. This model was repeatedly refined through the process and broke only once. When a parametric model brakes, it means that all components' internal setup configuration cannot fulfill proceeding development and needs to be reconfigured from the ground up (DAVIS 2013). This happened during the setup of new wave types, and it was recognized that additional types have to be organized universally and extremely flexible. As Grasshopper is a graphical programming tool, there is no possibility to set objects and classes like in normal programming languages, but a similar approach was chosen.

2.2 Planning

One of the uncertainties of this project during the planning process was how the landscape would be actually built. The bidding process for the earth surface modulation has not determined the building technology. Two scenarios were possible: building by the construction drawings or by the 3D construction model. This means that preparations were made for both, but the main work was outlining a strategy for extracting construction plans out of the model. Also, the client was not clear what to collect for the documentation as that would mean he needed to handle hundreds of plans.

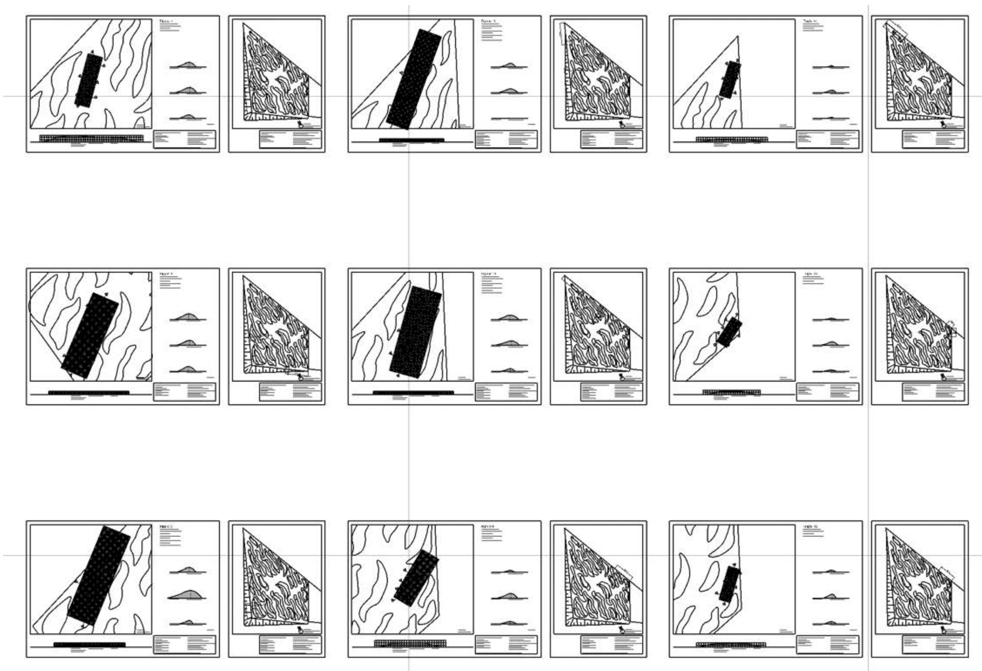

Fig. 4: Excerpt from a set of automatically delivered construction drawings for a part of the Summer Island called Rose Garden. Every ripple had its own detailed drawing and a DIN A4 page with its dimensioned position.

For the scenario of producing construction drawings, the solution came from the same parametric system as it allowed to automatize the setup of detailed drawings and sections together with automatic numeration, scaling, dimensioning, and labelling. The extracted floor plans and sections were parametrically scaled down (from 1:1 to the desired scale) and were populated with dimensions measuring the important points. This system was tested and found effective and reliable, although a final human control was necessary.

Shortly after finishing the design development, a more precise measurement of the terrain was incorporated into the model. The model was moved from its previous zero-near position to the actual coordinates, in this case, according to the Gauß-Krüger coordinate system. As the distance to the zero point was about $3 \quad 10^6$ in x, y, and z, it was recognized that the model is not practicable as the program had to calculate all drawing information with a huge increase of the number sizes. The rendering process was flawed and the whole model unstable. As all outgoing site plans had to fit and be referenced, a solution was found to leave the original model at the near-zero position and insert it into a block. This block has been referenced to another block with an exact position in space.

Getting the right coordinates was also important for establishing basic slopes for the surfaces between the waves and planning the drainage system. Drainage pipes were positioned in areas where rainwater could not drain away. Those channels were then also built into the model to detect eventual intersections with other infrastructural elements.

2.3 Fabrication

The prepared dual setup of the drawing output, classical drawing plans, and a 3D-model turned out to be a good decision as two companies with complete opposite building strategies won the tenders: one that wanted to handle terrain modelling with drawn construction plans at the area of the Rose Garden and the other that got the main area of Summer Island and wanted to utilize the 3D construction model. Both companies could be served immediately, and the deadline pressure forced a quick delivery of data.

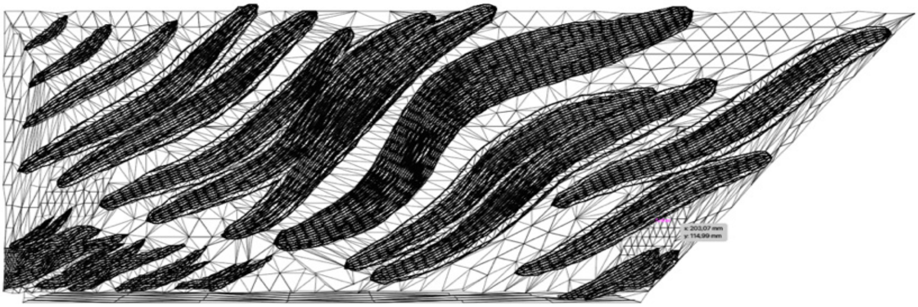

Fig. 5: Exported triangulated mesh of the northern part of Summer Island

The workflow of exporting the 3D model for fabrication contained several preparation steps. As the Rhino3D model is a Nurbs-model with all elements as separated entities, all objects had to be merged cleanly. This was only partly possible in the parametric model and, for the sake of precision, was done manually and inserted back to the parametric model. Here this model was transformed into a mesh model (Fig. 5) with adapted mesh resolution. A resolution gets higher where the model gets more complex. The triangulated model needed to be "waterproof", without any open edges or missing faces.

The excavators that modulated the terrain were equipped with GPS-sensors and an internal referencing system (Fig. 6). During the machining, the conductor's aid was established with visual and sound feedback and delivered a precision of 1 cm. After the main terrain modulation, minor onsite manual corrections were made to improve the waved landscape's effectiveness.

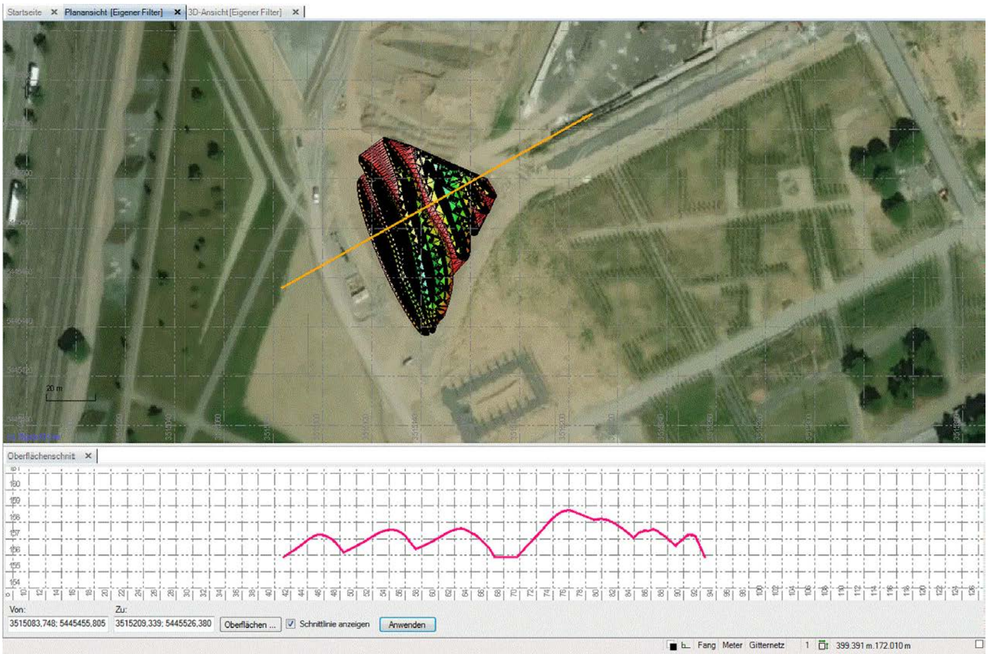

Fig. 6: Imported model in the software system of the construction company Wolf und Müller before transferring the data to the excavators

3 Conclusion

Temporary landscape projects like BUGA exhibitions (Fig. 7 and 8) that are suited very well for experiments cannot be directly compared with long-life landscape projects. These horticultural shows are not only sandboxes for form creation but also for upcoming planning and fabrication methods. Like most landscape projects this project also started with an idea, continued with planning iterations and ended in a successful fabrication stage. The difference to any usual process was the extremely limited planning and construction timeframe. The implemented parametric model fitted well with all the constraints and limited time. The formal simplicity paired with an uneven and complex output also helped the client pursue all the stakeholders involved.

Fig. 7: Areal view of the Summer Island at the BUGA 2019 in Heilbronn

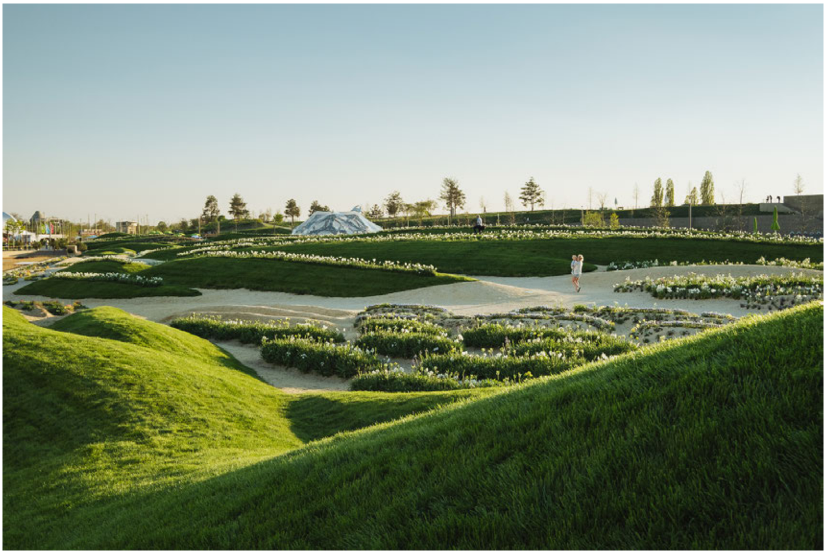

Fig. 8: Visitors view of the Summer Island

Having all data and numbers ready at all times helped in avoiding unpleasant surprises. This was one of the reasons the project had no cost increase. During such a development, planners are urged to build models that can quickly react to different situations. To be one step ahead is a valuable planning strategy. Building up and developing a parametric 3D model and maintaining it over the whole process of planning and during the construction time can be crucial for the project's success. As the planner is also a programmer, he or she has to organize the data and communication with the project leader, similar to how software engineers organize their software projects. The danger of the project running into a bottleneck at the parametric model is very serious. For this, at least two persons must share the same knowledge, the structure, and the detailed workflow of all elements in the 3D model. One essential part is the right documentation of all programmed parts and, if possible, a written and drawn explanation about the output. A comprehensible file storage system of directly related files: 3D model, parametric model, plan output, has to be made.

4 Outlook

The advances in parametric modelling helped this project through all steps from design to fabrication. It utilized the whole spectrum of available tools in the software package Rhino 3D and made the project highly adaptable through the planning process. Still, the next big landscape projects will probably be done with tools that are nearer to the natural growth of forms and with the help of digital generative methods, with the consequence of reduced formal control of the model. Furthermore, the result can be a cross of landscape architecture and landscape planning with social, climatic and ecological topics coped with a distinctive, surprising and unique appearance.

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Searching for New Ways to Design Landscape: Experience with Parametric Design in Interaction with Computer-Aided Manufacturing Methods in Landscape Architecture and their Effects on the Design Process

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Abstract: Computer-aided manufacturing processes enable the landscape architect to complete the digital workflow from the idea to the physical prototype or the finished project component, not only as a model, but also as a built project. A conceivable workflow progresses from a first idea for a design solution to a digital sketch, e. g. on a tablet, and then to a CAD drawing or a digital three-dimensional model. This design can then be physically produced using computer-aided manufacturing processes – such as additive or subtractive manufacturing – in order to create the desired model, prototype, or finished project component. The fact that these physical-digital technologies continue to expand and grow suggests that it is also time to take a closer look at the design process. On the basis of a case study, I will examine how the existence of physical-digital technologies can affect the processes followed by designers. This paper discusses both benefits and risks. It deals with a formal aspect of design and must therefore be seen in a broader context of design activity (reflection, perception, thinking, expression). On the basis of the practical case study, it is possible to illustrate the potential of computer-aided manufacturing methods in landscape-architectural design processes and make this potential available through the applied method of analysis.

Keywords: Model, physical-digital, method, tool, design process

1 Background

Landscape architecture is based on the development, communication, and realization of ideas for the designed exterior space. The landscape architect's central task – ideally derived from target-oriented ideas – is to create designs showing a solution for the respective design job.

This process, as the decisive and crucial component of finding a design solution, is influenced by a variety of factors, oscillating between the poles of subjectively personal and objectively pragmatic decisions, experiences, and perception. Inspired by Otl Aicher's insight "We have to move from thinking to doing and learning to think new" (AICHER 1991, 76), I endeavored not only to examine my own design process and the noticeable influence of tools on the results of my work in the field of landscape architecture, but also to look at the effects in a more general manner, providing guidance for designers from other design disciplines throughout their design process.

In this paper, the terms *design tools* and *tools of design* are understood in the sense of the definition given by Gänshirt: "'Design tools' are not tools in the same sense as a hammer or a screwdriver. The term is a metaphor, transferring the image of a hand tool to complex states of affairs" (GÄNSHIRT 2011, 94).

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With regard to the constantly growing range of tools for the design process, it is important that the effects on the designers and the findings resulting from them be examined under prescriptive consideration. The methods guiding the process (such as sketching and modeling) operate simultaneously as carriers of information and tools.

Taking the above-mentioned developments as a starting point, I focus on landscape-architectural design and its process and identify the growing number of computer-aided tools for the development of models and project components. From my point of view, these include above all computer-aided additive and subtractive production methods. This also involves methods for digitizing physical objects, allowing a change in the approach to the design work based on the model. These computer-aided manufacturing methods include

- 3D printing (additive),
- subtractive methods such as CNC milling and water-jet or plasma cutting, and
- the digitization of physical objects using 3D scanners and processing, along with the appropriate software.

The effects of these "design tools" on the landscape-architectural design process have never been empirically investigated. This fact justifies the need to devote attention to the subject in light of the saying "the hammer forges the blacksmith" – especially considering the constantly changing digital possibilities. A number of empirical and non-empirical studies have already been conducted on the theory and method of the landscape-architectural design process. These include, in addition to those cited in this paper, the book *Design-Based Research* (edited by Jürgen Weidinger). The impact of different computer-aided manufacturing and digitalization processes on the work of landscape architects and especially on their design work – such as finding solutions on a model – have yet to be sufficiently investigated. In this context, reference can be made to Barbara Wittmann's observations and contemplations on design tools.

> The portraits of design tools assembled here explore the exteriority of designing, forming, and thinking both thematically and methodically: on the one hand, in relation to the concept of the tool, which is undergoing a critical revision; on the other hand, in relation to the concept of designing as a practice that characterizes and justifies the artist, architect, engineer, and scientist, and in general the future-oriented subject of the modern age (WITTMANN 2018, 1).

In addition, Gänshirt examines general processes during the design process (design cycle). He describes and analyzes the significance of various tools, such as drawing, model, or video. The work of both authors laid the groundwork for the study presented in this paper. Although my approach is based on the understanding and knowledge these authors imparted, I will begin by focusing on (more) formal aspects of the design.

2 Question

In principle, this paper deals with the thesis of creating, or facilitating the creation of, new forms through a "changing approach" to the digital and analog model with the help of computer-aided design methods in landscape architecture. In this context, the following question arises:

What influence do computer-aided manufacturing methods, combined with digital practices, have on design?

This paper is part of a series of further studies concerning the influence of physical-digital practices on landscape-architectural design.

The term "changed approach" in reference to the model as a design method specifically describes the emerging or already existing orientation of model making in landscape architecture. The creation, or the utilization and processing for design purposes, turns away from its analog counterpart in the context of the design and decision-making process, moving instead towards the completion of the digital workflow (Fig. 1).

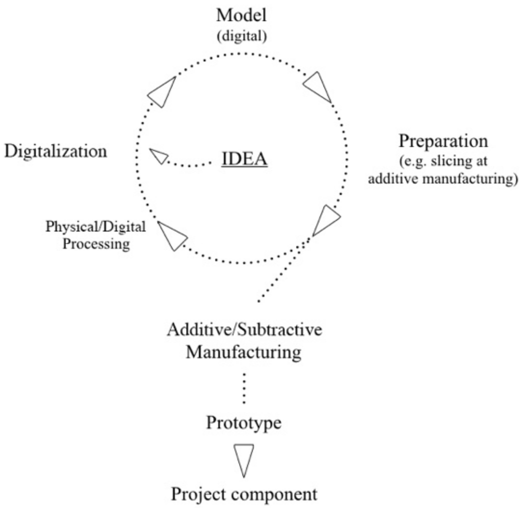

Fig. 1:
Possible digital workflow from analog to digital and from digital to analog (leveling) up to the model, prototype, or implemented project component (Source: own illustration)

Computer-aided manufacturing processes, such as additive and subtractive methods (Fig. 2), and the intertwining of software solutions differentiate the physical model from analog manufacturing techniques within the design and execution process (cf. THEIDEL 2020). This paper focuses on the influence and impact of these manufacturing techniques and the resulting relevance of the digital model for design in landscape architecture, illustrated using a practical example. Decisions are crucial within the design process and require separate consideration.

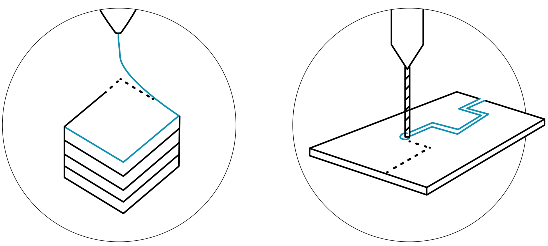

Fig. 2:
Additive (left) and subtractive (right) manufacturing processes as a schematic representation of their functionalities
(Source: own illustration)

Parametric software solutions are an example of this. Changeable models are generated based on numbers and ratios. However, the selection of parameters that shape the design and the task will always be the responsibility of the designers. Therefore, these (parameters) are determined by the design attitude and defined by the awareness of the personal design process (BIELEFELD & KHOULI 2007, 14 f.).

3 Goal

This paper aims to use a practical example (Bryum/Pocket Park – Basel)

- to illustrate the changed approach in the landscape-architectural design process through the model as a design method,
- to record the significant experiences of the designers with regard to the physical-digital practices being used, and
- to put them up for discussion.

Expert interviews were chosen as a method of visualizing decisions and influences. They provide conclusions regarding the use of specific digital tools as well as physical-digital practices in the examined design process. The ideas shared in this paper are introduced and supported by my publication "Model / More than visual communication method considering a changing approach" (in the anthology "Methods of visual communication in spatial planning" by the University of Kassel), which presents the thesis that the changing approach to the digital and analog model in the design process is facilitating the emergence of a new formal language.

The case study under consideration is representative of other projects that were also developed using specific practices and tools. In this way, the paper aims to both initiate a further, exploratory research approach and point out possible systematic studies in this character.

4 Case Study

The Pocket Park in Kaiseraugst, Switzerland, was chosen as the subject of this case study owing to its special type of development, its formulation in relation to the formal language of the ground covering (Fig. 4), and the great precision of its execution. It was clear, even when viewing the project from the outside, that the collaboration between the designers, the client, and the executing agency in the context of the created result would be relevant for the investigation and possibly innovative on different levels. Throughout the development of the project, various digital practices and production methods were used, which also proved to be useful for the practical implementation. These practices included parametric software, which was capable of reacting to changing influences such as tree locations, and additive manufacturing processes, such as 3D printing. Furthermore, the project had received the "European Award for Ecological Gardening 2019" as part of the master plan for the campus area of the pharmaceutical company Hoffmann-La Roche Ltd., located near Basle. The jury's positive rating was based on not only the innovative approach to the factors of man and nature within the master plan (Fig. 3), but also the parametric design of the Pocket Park located in the center of the campus area (Fig. 4). "The project is a groundbreaking implementation of parametric design in Landscape Architecture" (COMPETITIONLINE 2019). In the Pocket Park, unlike in the overall concept, the visitor is not considered a "silent" observer or a part of the ecosystem, who is mostly interpreted as a disruptive element, but instead is brought into the foreground due to their usage requirements (gastronomy etc.), whereas nature moves into the background.

The master plan aims to develop a system that implicates humans as a "disruptive element" and sees them as part of succession and development (WEINSBERG 2020).

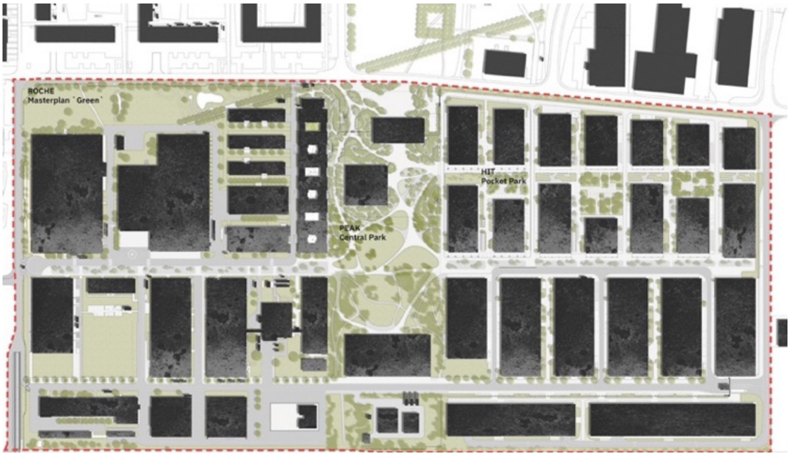

Fig. 3: Master plan for the campus area in Kaiseraugst (Source: WEINSBERG (2018, May 13), personal communication May 13, 2018, Image © BRYUM)

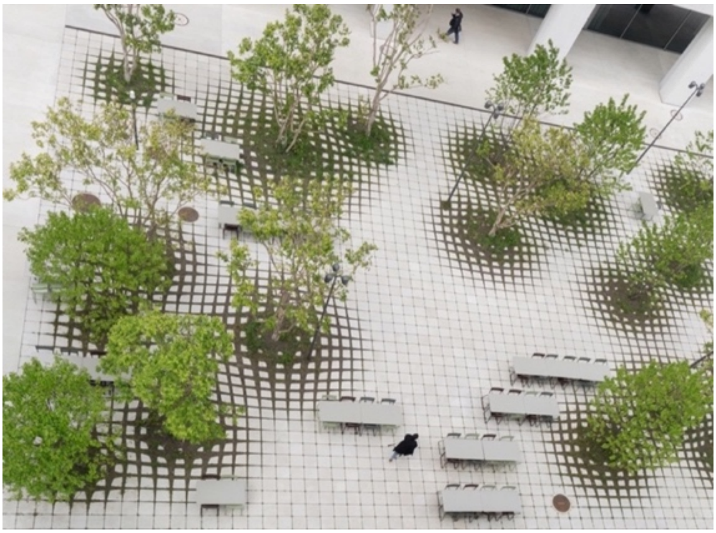

Fig. 4: Surface of the Pocket Park on the grounds of Hoffmann-La Roche AG in Kaiseraugst, Switzerland (Source: WEINSBERG (2018, May 13), personal communication May 13, 2018, Image © BRYUM)

5 Method

In order to investigate the link between the design process and the tool, guideline-based expert interviews were conducted with various people who were involved in the design process.

The qualitative content analysis method described by Mayring makes it possible to structure and analyze the collected statements using deductively formed categories (Mayring 2015, 20). The analysis provides information on how the work of the designers was influenced, not only by the model as a design method but also by digital practices and computer-aided manufacturing processes in particular. The deductive categorization via 1. the definition of the categories, 2. anchor examples and 3. the coding rules enabled me to structure the captured content and evaluate it as described below (MAYRING 2015, 97).

At a personal meeting, the questions were addressed to the people involved in the design by BRYUM, landscape architects from Basle, Switzerland. The answers from the recorded interview were transcribed and used for the content analysis in point 6. The following questions were relevant to this study:

1. How would you define the term *design tools*?
2. Which design tools did you use during the design phase of the project (Pocket Park)?
3. Are there any design tools that are particularly helpful to you in the development of "new forms"*?
4. What advantages and disadvantages do digital models offer you compared to analog models in your design process?
5. What influences (other than the given task) guided you during the form-finding and design process?
6. How did you deal with computer-aided manufacturing methods in the design process?
7. Define the influence of computer-aided manufacturing processes on your design work within this project and on your design work after this project.

* Definition "new forms" / form finding:

The terms "form finding" and "new forms" (developed through form finding) can be summarized by means of the definition of form language. Form language describes the constellation and combination of basic elements such as bodies, lines, and colors to and with each other to create a defined impression of a room. The way of getting there or the actor's search for this constellation and combination of the various elements can be described as form finding and produces new forms (c. f. VON BORRIES 2019). According to Weber, two overriding/overarching influences or objectives can be identified: Beauty or expression can determine and steer the process in a detached way. A focus is defined by the respective actor or task (c. f. WEBER (1982) 2019).

The transcribed interviews were presented to the designers for review and approval and form the basis for analysis.

6 Analysis

In this section, I will use certain categories as a basis for structuring, analyzing, and summarizing the above-mentioned questions along with the answers that were collected from the designers in the interviews.

The following categories were defined in advance and described in detail with anchor examples and coding rules according to Mayring (Table 1) (MAYRING 2015, 97/113). Only the respective overarching categories are explained, not their gradations up to level 3 (no agreement or dependence). These are only characterized by a weak expression of the respective content statement. The contents of the interviews were assigned to these categories and further categorized according to their characteristics using an anchor example.

Table 1: Deductive categories for structuring and qualitative content analysis

Category	Definitions	Anchor Samples	Coding Rules
KR.1	High dependency on manufacturing processes in the realization of the project. • Acceptance of digital data from companies for the execution • Realization of special combinations of forms by computer software • - Design and planning parameters can only be changed by outsiders using digital data	"It was the use of computer-aided manufacturing processes that made the realization of the project possible in the first place."	All aspects of the definition must be fulfilled; otherwise encoding towards KR.2.
KE.1	High knowledge of the influence of tools on the individual's own work and the development of designs, and curiosity to learn about other tools • Form, construction, composition developed from the tool, ... • Openness towards unconventional design tools (conventional = sketch) • Reflective use of design tools	"Computer-aided manufacturing processes have led to the development of the significant form of the design in the first place." "There are many ways I can do it and many ways I want to do it." "I'm interested in exploring and learning about new tools."	All aspects of the definition must comply with the view; otherwise encoding towards KEW.2.
KEW.1	• Computer-aided manufacturing processes that can create or edit physical objects from digital models (e. g. additive, subtractive manufacturing processes) • Model, both analog and digital • Computer software (Vectorworks, etc.) • Sketch,are considered relevant and are regularly used	"Knowledge of computer-aided manufacturing techniques and the physical model enabled us to further develop our design."	All aspects of the definition must be considered as design tools; otherwise encoding towards KEW.2.

Category 1: Realization (KR) is defined by a high dependency on computer-aided manufacturing processes based on the transfer of digital data for execution within the project. The statements answering questions 4, 5, and 7 can be assigned to this topic theme because of complete conformability with the anchor examples. Salient for this is the reproduction speed and precision of digital models and their physical equivalents via computer-aided manufacturing processes. The dependency is perceived by the designers. However, at the same time, the technical advantages are exploited and augmented through expert knowledge in order to utilize them for the project. Over the course of the project, the need for reorientation was determined: the production of mold elements for casting the surface covering was changed

from a targeted additive to a subtractive production. This was not considered a failure but rather an increase in knowledge (Figs. 5 + 6).

"We haven't taken the leap yet to really use 3D-printed elements. But considering 3D printing, it probably won't be far off" (THEIDEL 2019, 11).

Fig. 5:
Mold prototypes produced with the help of additive manufacturing processes (Source: WEINSBERG (2018, May 13), personal communication May 13, 2018, Image © BRYUM)

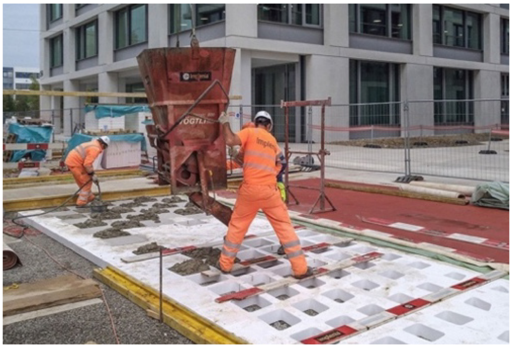

Fig. 6:
Mold prototypes cut from polystyrene with a water-jet cutter (CNC-controlled) (Source: WEINSBERG (2018, May 13), personal communication May 13, 2018, Image © BRYUM)

Category 2: Design (KE) is paraphrased by the designers' high level of understanding of the influence that tools have on their own work and the development of designs. In this context, open-mindedness and the general and reflective use of design tools are significant. The answers to questions 2, 3, 4, 6, and 7 apply to the definition of this category to the full extent. They indicate a reflective use of digital practices and computer-aided manufacturing processes. Parametric software has proven to be particularly capable of creating "new forms"* (see definition above), but only if it can be actively influenced. Furthermore, the knowledge of how to produce physical models or prototypes from digitally created models is (very) important, requiring additive and subtractive computer-aided manufacturing processes such as 3D printing or CNC. However, the decisive factor is the designers' aspiration not to copy or imitate, but to creatively apply the extension of the technical possibilities up to realization.

Category 3: Design Tools (KEW) are defined by the research horizon of the paper and include computer-aided manufacturing processes (additive, subtractive), models, sketches, and computer software. Answers to questions 1, 2, 3, 4, 5, and 6 can be categorized into first or second quality, due to the fact that the designers had not identified computer-aided manufacturing processes as design tools. Nevertheless, the additive and subtractive manufacturing processes and the knowledge of the possibilities proved decisive for the project process. The computer-aided manufacturing methods had also been questioned throughout the project, but never entirely rejected, as the advantages for the implementation of the basic design idea outweighed the disadvantages. New knowledge was generated regarding the manufacturing processes, both additively and subtractively, e. g. by experimenting and working together with experts from other disciplines.

> From the [external 3D printing expert who was supposed to make molds for Bryum] we actually learned that 3D printing can be more than just prototyping; it can be mass production. […] And not just on a small scale, but that you can actually theoretically use it 1:1 (THEIDEL 2019, 14).

7 Results

The summary and analysis of the interviews (Section 6) form the essence of the recorded material. In this section, the findings of the interviews will be considered and reflected upon in the context of the previously generated question.

Most of the answers given by the interviewed designers can be classified into the previously defined categories KR.1, KE.1, and KEW.1. Accordingly, the following findings can be identified for the Pocket Park project and the interviewed designers involved in the design and implementation process:

1. Digital practices influence the designer.

The use and knowledge of specific design tools, particularly computer-aided manufacturing processes and the corresponding software, influenced the design of the Pocket Park in Kaiseraugst (Switzerland) in a significant way. Without their knowledge and combined use of different tools and computer-aided additive and subtractive manufacturing processes, it is clear that the designers would not have considered the concise forms of the square surface (see Fig. 3). In this context, the software knowledge of the individual designers is of subordinate importance. They were able to recognize and communicate all important aspects of the knowledge they had gained, in terms of both design and technology.

This fact is particularly apparent in the answers to question 2:

> There you come up against limits (in terms of working with the industry standard software solutions, e. g. Vectorworks, Rhinoceros, Grasshopper). If you are only able to work with 2D and CAD, you stop and think: “This is not plannable” (irregular expansion of the surface covering). But if you know that there are tools, then it is somewhat different. You don’t have to be able to do it yourself. You don’t have to be able to use Rhinoceros or Grasshopper, but you have to know that they exist and that there are people who can do it and who can help you (THEIDEL 2019, 3).

This statement suggests that there is a perceived direct relationship between tool, design process, and result.

2. Computer-aided manufacturing processes may encourage the renunciation of standardized results.

In this context, the question of whether the use of computer-aided manufacturing processes enables or creates "new forms"* (see definition above) needs to be considered in a more differentiated manner. Despite the (at least) theoretically smooth interaction between software solutions and the materialization of the data generated through them, the designer still remains the decisive factor. She pools all the information. She interprets the knowledge and transforms it into a design solution. The appearance of this solution is dependent on many factors – not only subjective factors related to the designers but also objective ones. Bryum's Pocket Park serves as an example demonstrating that computer-aided manufacturing processes encourage the abandonment of standardized design components, in this case ground coverings. This is how these processes have been able to contribute to the creation of a designed landscape with greater variety.

3. Curiosity and openness lead to innovation.

The open-mindedness of the interviewed designers towards technical innovations, in combination with the standards they set for themselves and the existence of an open-minded, solvent (building) contractor made it possible to enter new territory and generate new knowledge beyond the scope of the project. Throughout the process, knowledge was consistently contributed by the participants. The created space is a very highly frequented site, according to the number of users, and therefore attracts the interest of experts.

4. New styles can result from digital or physical-digital workflows.

With respect to the question asked at the beginning "What influence do computer-aided manufacturing processes in combination with digital practices have on design?", it became apparent that the digital workflows are intertwined, (consequently) leading to a new style. This fact is demonstrated by the individuality of the space and the renunciation of standardized components. In the spirit of Aicher, it can be said that "technology (...) sets free a wealth of new aesthetics" (AICHER 1991, 86).

Although similar parametric digital models are not uncommon, the Pocket Park stands out among similar projects owing to its implementation. Only when a project has been implemented can it be innovative. Otherwise, it is only fiction and, in my view, less relevant.

The design approach refers to the formal design and production of the surface of an (outdoor) space using parametric software and computer-aided manufacturing processes. The approach of the designers was also included in the design process. However, the use of digital practices – such as a digital parametric model and the creation of digital and physical models through computer-aided manufacturing processes – does not provide any information on how the designers arrived at the basic form of the area's surface. Only the repetition, modification, and production of this form is addressed and facilitated.

8 Discussion

The discussion will be divided into two parts: method and results.

First, the applied method will be considered.

With the aim of generating specific knowledge on the basis of a practical case study, experts were interviewed, and their answers were deductively categorized according to Mayring's qualitative content analysis. The qualitative content analysis method was supplemented by a content summary, which was again verified by the interviewees. In my view, this approach made it possible to take into account aspects that are generally difficult to identify through design research. The recorded facts have been counterchecked by the interviewees to ensure a higher level of reliability.

The applied method of project analysis through guided interviews combined with a final analysis of these interviews is in principle well-suited for application in similar projects.

Methodical risks arise if existing knowledge cannot be correctly captured by the guiding questions prepared in advance. This problem can be prevented by asking the questions in a generally less rigid interview, which allows for more flexibility in reaction to unforeseeable situations.

The results are based on the case study as well as the interviewed designers. They will require further consideration, especially from the field of landscape architecture, in order to derive generally valid conclusions regarding design processes. Projects like the one used for the case study are still rare. Due to the ongoing prototypical intertwining of computer-aided design and computer-aided manufacturing – from the model to the implementation of projects – I would argue that examples of related design-based disciplines should be taken into consideration as reference objects. The ETH Zurich project "Urbachturm" for the Garten Schau Ramstal in Switzerland (Fig. 7) can be seen as a relevant example. The created forms are based on a computer-controlled process of drying the wooden panels that are being used.

Fig. 7: The "Urbachturm" for the garden show in Ramstals, Switzerland (Image © ICD/ITKE University of Stuttgart; Source: https://www.holzbauaustria.at/architektur/2019/06/selbst-ist-das-holz.html (30.12.2020)

These technology-based possibilities point the way to formal opportunities that may be inherent in the use of computer-aided design practices and manufacturing processes. In the presented context, it would seem reasonable to make certain processes possible by automating and thereby accelerating them. Furthermore, based on the specific results of this study, it is possible to derive research interests that also have a bearing on the subject of the design process. This raises the question as to whether the use of computer-aided manufacturing processes and the associated closed digital workflow leads to a higher frequency of reflection in the design process and thus to “better” results.

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Report of a Remote Participatory Design Process to Renew a Schoolyard during COVID-19

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Abstract: The aim of this paper is to share the experiences of an ongoing remote co-design process. With an inductive research approach, analysing the experiences of an ongoing case study, the research presents the challenges of remote collaboration such as the changed spatial understanding, transformed rules in communication and online community experiences. Pandemic circumstances allowed us to discover how remote settings can bring new rules and dynamics to participatory design processes. The research offers guidelines and solutions on how digital tools and online platforms can add value to community design processes.

Keywords: Online public involvement, youth engagement in landscape planning, digital toolbox, schoolyard co-design

1 Introduction

Discovering online platforms and remote working methods have become an important task with the spread of COVID-19. Among other professions, landscape architects are also facing many challenges of which participatory processes are just one. As community engagement processes also had to move to online platforms during the pandemic, it became a relevant and important landscape research topic. Some papers emphasize the role of participatory planning to create local strategies to cope with the pandemic crisis (BARBAROUSL 2020), some try to present hands-on ideas and practical guidelines for remote tools and methods (UDC 2020), and others try to highlight the unexpected benefits and opportunities such solutions can offer (HOWARD & ROBERTS 2020).

Although the importance of using digital tools in participatory processes such as virtual simulations, visualization, presentations or digital games was already growing before the time of COVID-19 (DEZUANNI 2018), remote participation was rarely conducted. Besides providing alternative ways of having meetings and technical help in exchanging ideas, remote design processes and digital participatory planning tools must pursue the qualities of meaningful face-to-face participation. Digital participation must not only collect data from participants and inform planning, but also develop social bonds and reorganize power relations of the community, as well as engage participants in a fun and exciting way (RUGGERI & SZILÁGYI-NAGY 2019).

2 Objectives

The objectives of the current research are to utilize the knowledge and experiences generated in the field of remote and online participatory planning in the LADDER Living Lab run by

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the authors and propose directions for the further development of digital and online tools in this field.

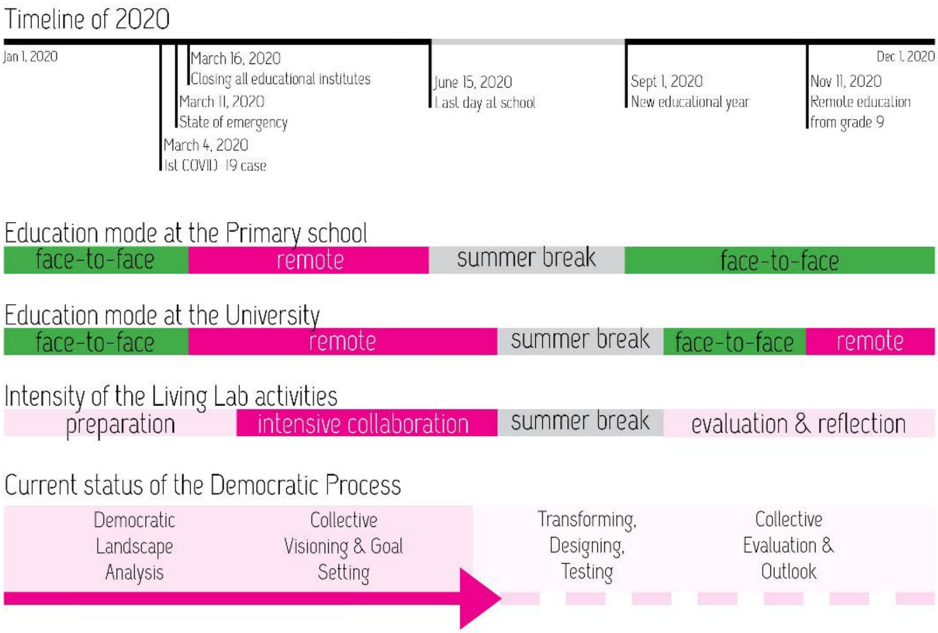

Fig. 1: Living Lab's participatory process in relation to the pandemic circumstances

Research is carried out in the LADDER Living Lab – a Laboratory with Students for Democratic Environment –, which is an exploratory collaboration space that allows continuous reflection and improvements of participatory methods through the combination of research and innovation processes within a mid-term partnership among the Landscape Architecture Faculty of Szent István University of Budapest, the NGO kultúrAktív and various local school partners[1]. The Lab is a user-centred, open-innovation ecosystem, operating in a territorial context of Hungary and with the thematic focus on democratic school environment redevelopment. Living labs operate with Participatory Action Research that repeats the following cycle for providing solutions for locally identified issues: co-creation, exploration, experimentation and prototyping, and evaluation (LED2LEAP 2019, PALLOT et al. 2010). Current research reflects on the experiences gathered in the first cycle of operation of the living lab and evaluates the remote participatory planning process carried out in the Elementary School no.1. of Budaörs. Figure 1 shows the timeline of the year 2020, how the Living Lab activities were embedded in the different educational systems operations. The education

[1] The Living Lab was born under the framework of the Landscape Education for Democracy – Learning, Empowerment, Agency, Partnership project. This international ERASMUS+ Strategic Partnership Programme aims to build long-term partnership between the academia and local community in order to create policies and processes related to democratic landscape change. To implement this approach, Living Labs are created locally where groups of actors in a community can be brought to form their landscape together.

modes of the university and the primary school gave the main framework of the collaboration which became completely remote.

This research (1) illustrates the findings related to the advantages and disadvantages of the online and digital tools used in the LADDER Living Lab and based on these first-hand experiences, it (2) outlines future development directions for digital and online tools for remote participation processes for further research.

3 Research Method

In order to identify the characteristics of remote participation, we decided to implement qualitative research (HOQUE et al. 2007) using semi-structured interviews. Experiences and observations of our living lab participants were analysed, systematically categorized and coded using the principles of Grounded Theory (FLICK et al. 2010) to generate a theory about the future development directions of remote participation. As we reached out to 23 participants directly with two online workshops (Round Table Discussion, Nominal Group Technique), and indirectly to more than 150 school community members (through questionnaires, mapping and drawing exercises), we decided to conduct 10 interviews that represent every role in our planning process: coordinators, parents, teachers, students, university students. We aimed for equal representation for all the perspectives (2 of each role), genders and age groups, and also direct and indirect involvement in the process.

Scope of the semi-structured interviews included three sets of questions: (1) influence of COVID-19 on the context of participation such as school environment, community, planning traditions in Hungary; (2) experiences and role of the interviewee in the participatory planning process; (3) opinions, advice related to the remote participatory process. Questions guided our interview process but allowed flexibility to adjust the scope, structure and depth of the interview when it was necessary. Interviews were conducted online via Zoom. These were recorded and then transcribed which was the basis of our qualitative data analysis.

In the analysis phase we identified in the transcript “key phrases, terms, and practices that are special to the people” (PATTON 2002) and marked the perspective of our interviewees about the phenomena, attitudes, challenges and benefits of remote and digital participation. Interviews confirmed already known evidence in remote and online participation (e.g. generational difference between digital competences), and they provided practical guidelines about how to organize remote participatory planning processes (DEMÉNYI & SZILÁGYI-NAGY 2020).

In this research, we discuss only three returning motifs that mark important development directions for digital and remote landscape architecture tools with the potential to elevate remote participatory planning to the next level. The three motifs are the following:

Spatial understanding of the design site: includes the advantages and disadvantages of technologically mediated or narrative-based mapping methods implemented in the project.

Communication in online workshops: includes our participants’ perception of verbal and non-verbal communication, flow of dialogue and discussions, relating to others and building human connections in the online environment.

1) Team experience in remote participation: trust building, dedication to teamwork, as well as positive equal representation of team members are in the focus of this category.

The three categories are explained through illustrative quotes from our interviewees that pinpoint the most important advantages and disadvantages of remote solutions implemented in our Living Lab. The specific experiences of the living lab are used to generate theory about the potential development directions of remote tools and provide the basis of our Chapter 5 Discussion. Furthermore, quotes include a reference to the roles and perspectives of our interviewee which can be tracked through the corresponding Interviewee Code. Interviewee Codes consist of two parts: the letters stand for their role, and the numbers specify which person we talk to. The following codes are implemented:

- COO – project coordinator from the university and the NGO
- PAR – school parents
- TEA – school teachers
- STU – primary school students
- UNI – university students

4 Results

4.1 Spatial Understanding of the Design Site

Personal site visits were not possible due to the pandemic therefore there was a need to find remote ways to achieve a common understanding of the characteristics, challenges and potentials of the design site. The first-hand experiences were replaced by methods such as video walk, oral discussions in round table sessions, drawing from memory and evaluating the site on digital maps. Participants reported that this led to the disadvantage of *"not being inspired and affected on-site, only relying on your or others' memories"* (PAR-1). *"[Video] doesn't convey the mood at all as if we go there, we can't hear the sounds, can't feel the wind"* (UNI-2).

On the other side, the fact that planners were not able to visit the design site and were completely relying on the information provided by the local community helped to prevail the community's perspective over the designer's: *"landscape architects did not personally see the school. However, perhaps this was not such a problem since it is one of the basic approaches in community planning to understand what the community sees, feels and hears, and so in our case this has been absolutely achieved by the applied methods. I think in our collaboration the professional eyes remained closed, while the eyes of the community were open and sharp."* (COO-1) School community members on the other hand reported a better understanding of the various perspectives related to the site: *"Teachers and students have a completely different view of the schoolyard because students only see how they can play, while teachers see how they can most effectively oversee the children, [...] parents see it differently yet again because children are happy to [...] slip down on the muddy hill, but the parents have to wash their pants."* (STU-2) Interviewees also mentioned that that *"geography has a great potential [for remote technics], and digital space can be used better in this field"* (TEA-2) meaning that with the available visual digital materials it is possible to explore sites that would need a lot of effort to visit otherwise.

4.2 Communication in Online Workshops

Interviewees who participated in at least one of the online workshops expressed that they had trouble perceiving the emotions of the others, *"personal interactions did not come through"* (UNI-1); non-verbal information *"when you meet someone in person, the charisma, behaviour and reactions present in that situation give you an opinion about the person"* (STU-1); as well as eye contact: *"Now I find myself constantly looking down here and thinking how weird it is not to look people in their eyes, and even if I look into the other's eyes, he doesn't see me looking into his eyes, that was disturbing in a way but you have to let this feeling go."* (UNI-2). The otherwise natural flow of conversations took a monological turn and immediate feedbacks were missing: *"I think if we're next to each other [...] we can react much more effectively [...]immediately to each other and we don't have to wait for our turn to speak because [in the online environment] only one person can talk at a time."* (STU-2). They also missed the opportunities to engage in parallel and informal discussions which would be otherwise possible in personal settings: *"from this more casual atmosphere [in the offline environment], there are side conversations, which cannot be created online"* (UNI-1).

Several interviewees also mentioned that the online environment was more comfortable: *"in general, my girls don't like to go to school, but when the school went into online mode, they said they felt less stressed [...]and they liked this setting more so they actually performed better because of it"* (PAR-2). Another interesting phenomenon was reported by the participants who emphasize visual communication: *"I like the Mural platform, that I got to know through [the project]. I think it was good for brainstorming"* (PAR-1). *"We used a platform, [it was] like a digital board that could be edited by many at once. And there were some different games [we played]. There was also an opportunity to express an opinion in writing, on small post-it notes"* (UNI-1).

4.3 Team Experience in Remote Participation

Team experience and the sense of a community were seen as challenging aspects of remote participation because the online environment could not replace personal connections, leading to struggle in building trust: *"It's basically trust building, which again has to be the starting point of any community design, or even any community, […] and that was a lot harder [to achieve] in the online environment"* (COO-2); or working as a team: *"we inspire each other less in the online environment"* (UNI-1*), "sometimes it was hard to stay focused and don't open any other platforms or apps while somebody else was speaking"* (UNI-2), *"I noticed that I'm not so motivated in the whole thing, I don't feel it belongs to me so much"* (UNI-2). In such a team constellation there is a place for team-building exercises, although *"we have many more tools to build trust in a personal setting"* (PAR-1).

On the other hand, interviewees highlighted that the online environment can have a positive effect on the atmosphere of the meetings and help achieve a more friendly environment for collaboration and breaking the hierarchy. This effect was associated with the fact that teachers, parents and students were equally inexperienced in using online technologies and with the fact that school students helped teachers with technical questions and problems: *"everyone was a little lame, and that dissolved the whole thing a bit. [...] there were smiles and weird names [on Zoom], [...] and it simply eased the mood a bit in my opinion, adults could have been much more relaxed, more direct."* (UNI-2) Participants perceived each other as equals due to the visual representation of the Zoom environment: *"Doesn't matter who is the* *parent, the student or the teacher, everyone appears on the same platform in the same size of squares, having equal opportunity to have a say."* (COO-2) *"I had a good time during the calls because I could really have a say and share my opinion at any time and it wasn't that you are just a kid and you couldn't intervene because you don't understand what's going on and what it's all about, but I was really involved like a design partner."* (STU-1)

5 Discussion

Our findings outline three important fields in which digital and online landscape architectural tools could be developed:

Elevating spatial experience: technical solutions could be developed for elevating the experience of getting to know the site. Besides the experimental quality of these tools, they would also need to focus on a comprehensive understanding and enabling the discovery of various qualities of the space. Creating immersive experiences through incorporating challenge-based, sensory and imaginative technologies into participatory platforms (GORDON et al. 2011), as well as solutions that help to enliven, record and use the physical, social, cultural and symbolic aspects, subjective and objective dimensions of the space.

Encourage non-verbal communication and visual experience: even if we find the best tool for a specific design method, an online environment brings instant challenges that can influence effectiveness and the final result of the method. Changed perception and unnatural flow of conversation, as an interviewee pointed out, might be addressed by facilitation methods and strategies: *"And there was a moment I realized that people need to be motivated and approached so differently online. [...] and after this occasion I really thought about how to make this [remote process] lively and vibrant, how to make a good meaningful conversation in the online environment at all, that is not like consecutive monologues, but a real dialogue"* (COO-1). Can technology have mediated dialogue work as natural? What are the other non-verbal tools that could help to negotiate discussions? There is a need for such technologies that build on non-verbal communication and visual representation, like immersive technologies – especially in processes where the Z-generation appears who is considered to be the visual-driven generation with an image-based communication (MC CRIDLE & FELL 2020) and solutions that incorporate meaningfully inefficient moments of sharing and exchange with the intention to bond participants and deepen dialogue (GORDON & WALTERS 2019).

Maximize team experience: while it must be stated that the role of the facilitator is crucial in remote participation in terms of designing and facilitating the participatory process in a way that it includes team building and icebreaker exercises that bring back the feeling of community, there might be a niche for online and digital tools and platforms that (1) enable activities that support good collaboration, team building interaction; (2) use an audio-visual language that contributes to a friendly and non-hierarchical atmosphere; (3) seem to contribute with their representation system to the democratization of the workshop atmosphere, redistributing power relations, a topic which is frequently discussed in participatory planning. Mural and Zoom are pretty interesting from these perspectives but what are the criteria of friendly and non-hierarchical platforms? These are questions proposed for further research.

In addition to the three fields of development that were identified in our research, an additional point must be made on the accessibility of the tools: we envision a development of creative common tools that are intuitive and allow self-organization. Tools that support cheap and easy to use solutions for communities willing to create participatory processes could contribute with added value to participatory planning processes in the following three fields.

6 Conclusion

In conclusion, remote solutions can actually give additional value to landscape architectural participatory processes, however, turning the whole engagement process into online platforms is not very realistic as personal and physical connections are basic values in such methods. Online platforms and remote solutions can release the pressure of having everyone in one room at the same time which can be valuable even after the pandemic. Considering the fact that youth feel more comfortable in the online environment can be priceless in a design process where we want to engage them.

Our case study points out important directions for the future development of digital and online tools in landscape architecture to support participatory planning processes. We state that from an organizer perspective, remote and in-person participation processes require the same mindset – to think about the transformative aspects of participatory process that contributes to individual learning, community development and the physical change of the place (DE LA PEÑA 2017), or aims for a deep engagement on the ladder of participation (ARNSTEIN 1969) – but different skills and technical proficiency from the participants involved. While technical issues can be solved, and necessary skills can be learned, there is a need to develop and put technology at the service of participation and create meaningful and engaging experiences for the participants (RUGGERI & SZILÁGYI-NAGY 2019).

In order to understand and learn how remote settings and digital tools can have an increased value in engagement processes, carrying out case studies and sharing present experiences are extremely important. There is no one-size-fits-all method for participatory processes and the main challenge is to find the right tools and methods for the right purpose which needs education and a lot of testing. COVID-19 made it clear that there are other ways to do things – it is our responsibility how we use the learned experiences and how we use digital tools and remote collaborations even after the pandemic.

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Algorithmic Design and Analysis Landscapes

A GIS-based Algorithm for Visual Exposure Computation: The West Lake in Hangzhou (China) as Example

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Abstract: Visual perception is crucial in landscape experience. Therefore, visual landscape research is an important field of inquiry that needs further development and applications (NIJHUIS 2011), and visibility analysis is the basis for further research. There are many methods and applications of landscape visibility analysis that have been developed and applied in the past decades. The pioneering work of Llobera explores the concept of "visual exposure". He defined the visual exposure (V-E) as a measure of the visible portion of whatever is the focus of the investigation, which is about the surface area covered on the retina (LLOBERA 2003). In this research, a newly developed V-E computation algorithm for complex environments has been developed, which enables the analysis of views from multiple viewpoints. The West-Lake, a UNESCO world heritage site in Hangzhou (China), is used as a case study to compute the V-Es' value for viewpoints on routes beside and around the lake. Finally, the method's accuracy and the algorithm's adoption potential have been evaluated.

Keywords: GIS-based visibility analysis, Visual exposure, the West Lake Hangzhou, V-E computation algorithm

1 Introduction

Visual perception is crucial in landscape experience. Therefore, visual landscape research is an important field of inquiry that needs further development and applications. Visual landscape research entails an interdisciplinary approach that combines (a) landscape planning, design and management concepts, (b) landscape perception approaches, and (c) Geo-information technology. When psychological knowledge of landscape perception, the technical considerations of geomatics, and landscape architecture and urban planning methodology are integrated, a solid basis is provided for visual landscape assessment in cities, parks, and rural areas. It offers great potential for acquiring design knowledge by exploring landscape architectonic compositions from the "inside out" and possibilities to enrich landscape character assessment with visual landscape indicators (NIJHUIS et al. 2011). Visibility analysis is an important and primary element in visual landscape research. Referring to the methods for visibility evaluation, a line-of-sight algorithm was invented by Ford in 1959 to compute the visibility of the terrain surfaces and was first applied in military fields (FORD et al. 1959). Later, visibility computation has been utilised in many other fields and disciplines, such as architecture and urban planning (WILSON et al. 2008), geographic study (GOODCHILD et al. 1990) and archaeology (LLOBERA 2003). Within the discipline of architecture and built environment, two major categories of methods have been developed, including the concept "isovist", initially put forward by TANDY (1967), and various algorithms for viewshed computation based on different GIS platforms. Though the purpose of visibility computation is to provide ways to research the relation between landscape and human beings' perception,

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the traditional visibility analysis methods, neither viewsheds nor isovist, could provide effective means to depict the composition of views from specific viewpoints at eye-level, because these visual mapping methods are focussed on the "overlooking" views instead of "perspective" views (DOMINGO-SANTOS et al. 2011).

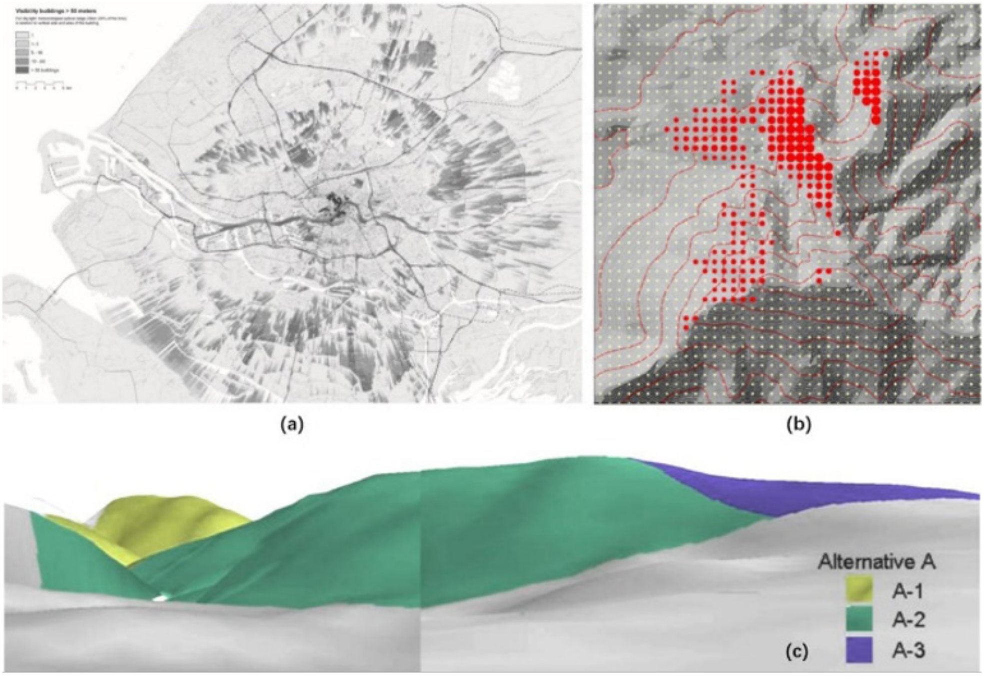

Fig. 1: (a), (b) Typical viewsheds computation and visual landscape mapping, which relates the visible portions to the observed objects in an "overlooking" plan (source: NIJHUIS & VAN DER HOEVEN 2018, ZHANG 2014); (c) a graphic presentation for V-E analysis, and the computing outcomes are the measurements of the occupied areas within perspective views (source: DOMINGO-SANTOS et al. 2011)

1.1 Visual Exposure (V-E) Computation

Common visibility methods often result in maps and numerical tables, but these are complicated means to delineate the view's composition from a horizontal perspective. To address this problem, lots of efforts have been made. The pioneering work of Llobera defines and explores the concept of "visual exposure". He defined visual exposure (V-E) as a measure of the visible portion of whatever is the focus of the investigation, which is about the surface area covered on the retina (LLOBERA 2003). Since the concept of "visual exposure" has not been widely accepted, many other similar definitions, such as visual magnitude (CHAMBERLAIN et al. 2015), visual perception sensitivity in VIEWIT program (TRAVIS et al. 1975), are also employed to conduct similar research. In general, two types of algorithms can be distinguished: (a) Indirect-computing methods, in which the distance and aspect relative to the observer are considered, are usually applied to estimate the one specific region's V-E for single or multiple viewpoints. The indirect-computing methods can be adopted in huge, complex environments with many viewpoints, but the accuracy of the calculation would be relatively low; (b) Direct-computing methods, such as the GIS-based algorithms developed by Domingo-Santos, which calculates the visual exposure of the terrain surfaces for several viewpoints (DOMINGO-SANTOS et al. 2011). The visual quality computation methods developed by the Lin's enable accurate calculations for different objects in the observers' fields of view using the parameters like distance, solid angle, and visual fields (LIN & LIN 2017). The accuracy of direct-computing methods has been scrutinised. However, these methods are ineffective and time-consuming in complex and extensive digital environments with many viewpoints to analyse. Many studies based on photography are employed, digitally analysing and quantifying the composition of views based on photographs. For example, this type of analysis is recently used to monitor park structures' changes by calculating the percentages of the landscape elements in multiple photographs from the same view (NIEDŹWIECKA-FILIPIAK et al. 2020). This method is practical and easy to implement, but difficult to apply in forecasting the visual impacts of proposed spatial developments. It is also not flexible as the analysis relies on the taken photographs, making it difficult to change the views under investigation. However, GIS-based V-E computation methods are based on accurate digital landscape models and allow rapid and flexible analytical procedures from a multitude of viewpoints.

1.2 Using West Lake as a Case Study

This paper takes the West Lake, Hangzhou, as an example. The West Lake is famous for its intricate and articulate relationship between the lake and its surroundings, consisting of an aesthetically pleasing hilly natural landscape with green forests, villa and garden complexes, pagodas and a vast urban landscape. From the 1980s, rapid urbanisation started to change the West Lake's scenery dramatically and urged the government to develop policy regulations to protect the scenery. Two policy documents for protecting the scenery and aesthetics of the West Lake and surroundings have been adopted. The first one focuses on the landscape planning and design for the West-side of the West Lake (2003) and especially elaborated on the importance of the eco-environments in the western parts of the lake. The second document focused on an urban planning and landscape design strategy for the West Lake's East bank (2009) and elaborated on the urban area's visual management on the Eastern bank. This document includes guidelines for the city's skyline development, restrictions on high-building development, the visual protection of critical views, etcetera. Several analytical methods were proposed and applied, such as sections, picturing from selected viewpoints, and sketching the skyline. This policy exerted a significant favourable influence on the protection of the lake's visual-aesthetic qualities, which led to UNESCO's recognition.

From a more technological perspective, the employed methods are time-consuming and imprecise. To advance digital methods for understanding and planning the visual-spatial characteristics of the lake is of crucial importance.

1.3 Research Objective

The objective of this paper is twofold: (a) to showcase a novel, time-saving and easy-taking algorithm, which is useful and accurate in a large and complex digital environment with many viewpoints to analyse, and compute the V-Es of the lakes; (b) to explore the possible application of the method in urban planning or visual management for the West Lake. The paper is organised in three parts. The first part addresses a novel algorithm for V-E computation. The second part focuses on the application of the method using the West Lake as a case. Finally, the outcomes are discussed, and some potential applications identified.

1.4 Limitations

Concerning recent visibility research and studies, one of the critical promotions is the possibility to use high-precision geodata, such as the LiDAR or so-called point cloud technology (VUKOMANOVICA et al. 2018). However, gaining high-resolution data and developing DEMs is time-consuming with high cost, and sometimes not possible because of security reasons or technical limitations. Therefore, it is vital to develop methods for situations without such data, like West Lake. Consequently, the proposed methods and their outcomes will have limitations, as the quality of any analysis depends on the data quality. For instance, the lack of detailed data on vegetation has a significant influence on the analysis outcomes presented in this paper (VUKOMANOVICA et al. 2018). Additionally, the scope of the site under investigation is also restricted by the availability of geodata. For example, the mountains and hills around the lake are not fully covered. Finally, the geometric distortion caused by the perspective projecting process is unavoidable, which might be not accurate in presenting the observer's views. Though these flaws exist, with regards to the computing efficiency, the presented method is relatively accurate in acquiring the visual characteristics within the eye-level perceptual views.

2 Methodology

2.1 Data and Modelling

In the West Lake data model, the lake's water surface plays a significant role, as well as the green spaces and hills around the lake, the eastern part of the wetland, and the western section of the urban area. The study region's data, being surveyed and mapped in 2008, was provided by the local government. A few types of data are available, including data on elevation (elevation points and contour lines), data of buildings and other structures (master plan and the number of stories for each building), data for roads (bolder and central lines for each road), data for land use (border and properties). GISs consider two main classes of digital elevation models (DEM): triangulated irregular networks (TINs) and regular square grids (RSGs) (KUMLER 1994). In this study, we employed RSG. The modelling process included four steps: (a) to establish a model for the bare earth with elevation data (the raster resolution of the model is 0.5m); (b) to model the buildings and structures, the floor height has set as 3.5m; (c) to fit the two models and merge them; (d) to classify the surface of the combined model with five different properties, including West Lake, the other water bodies, green space, buildings and structures, and paved grounds or undefined terrain areas.

2.2 V-Es Computation Algorithm

As the V-Es could be measured with the occupied areas of the objects' projections on the retina, the essential process is to depict the coverages of the target on the projected plane. In the previous studies, the viewed objects are mostly regarded as a surface. Therefore, the researchers were trying to obtain the "shape" of these objects on observers' retina, which cause obstacles to abstract the exact borders and distinguishing the blank areas to covered areas. In this study, we used the "point-to-point" method, instead of the previous "point-to-surface" method, to obtain the visual-spatial relationship between surroundings and eye points, since the relationship between two points could be more straight-forward and easier to be formulated than the relationship between one point and several surfaces. Additionally, the usage of perspective projecting is the key to this new method, which solves the problem of transferring the dots in a 3-dimensional (3D) modelling space to a 2-dimensional (2D) plane. The final V-E assessment algorithm follows several steps as below: (a) preparation works; (b) viewsheds computation and outputting the results with GIS software; (c) measuring the V-Es.

2.3 Preparation Works

This step could be done within the GIS-based software, including five sections: (a) Setting the viewpoints. Three different types of roads, including five segments (L_1, L_2, L_3, L_4, L_5) of the main roads surrounding the lake (most important traffic streamlines around the lake), two segments (L_1', L_2') of the causeways (historical and distinctive routines in the lake) surrounded by the lake, and three segments (L_1'', L_2'', L_3'') of the walkways beside the lake (the popular footpaths for the tourists and local citizens), have been selected as research sites. To ensure that there would be one for every 50 meters, and 1.6 meters higher than the surface of the ground, viewpoints have been set on the central lines of these roads: 233 viewpoints (V_1, V_2…V_{233}) on the main roads, 72 viewpoints (V_1', V_2'…V_{72}') on the causeways, and 126 viewpoints (V_1'', V_2''…V_{126}'') on the walkways. The sights' directions for all the viewpoints have been defined as the vectors normal to the roads and pointing to West Lake. (b) Setting the D-Ms for the DEM. The D-M density would influence the results' accuracy, while too many dots might cause a massive challenge for the computation procedure. Therefore, we set three D-Ms with different grid density: 5*5m, 10*10m, and 50*50m. Then, all the dots have adhered to the surface of the DEM. After a few attempts, we decided to use the D-M with a grid of 10*10m to complete the computation, and the other two would be used as comparative samples. (c) Setting the fixed dots for buildings and structures. Since the master plans of the buildings and structures have been collected, we set the dots on the plans' edges. Then, the dots were duplicated as the stories increased in the DEM. The buildings and structures could be classified as two types: the buildings located close to the eye points (distance shorter than 30m) and the others. For the first type, the dots were set more intensive, and there is one for every 2m on the edge of each story. For the second type, the dots were set sparser, and there is one point for every 5m. (d) Setting the D-Ms for the roads and the surface around them. According to the perspective principle, there would be denser dots reflecting the adjacent areas to the viewpoints; thus, we set three D-Ms belts with more elaborate resolutions besides the researching roads. 4m-belt with 1.5*1.5m D-M, 10m-belt with 2.5*2.5m D-M and 30m-belt with 5*5m D-M are included. (e) Classification for the dots. We classified the dots into five different types according to the property of the surface they are adhered to.

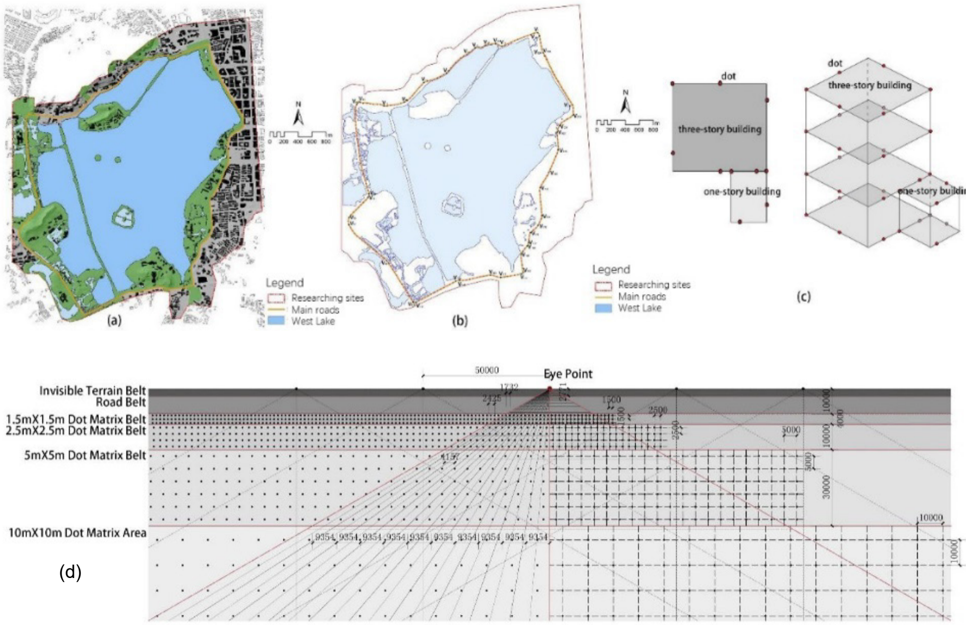

Fig. 2: (a) Classification of the land use; (b) the selected roads and set viewpoints on them; (c) setting the dots on buildings; (d) setting D-Ms for roads

2.4 Measuring the V-Es for the Viewpoints

The initial procedures are performed with ArcGIS 10.2 with a few standard algorithms. While, in a later process, the newly developed methods programmed in Python were applied. Measuring V-Es consists of two major stages, (a) transaction of the coordinates data and (b) computation of the V-Es.

In step (a), the perspective projection has been chosen to deal with this issue, which was recognised as one of the foundational visualisation technologies (TANKUS, SOCHEN & YESHURUN 2005).

Firstly, we had to translate the visible dots' spatial data in the 3D world coordinates (X_w, Y_w, Z_w) to the 3D coordinates (X_e, Y_e, Z_e) with the viewpoint as a new origin point and the vector of sight as a new X-axis. This process could be realised by moving the origin of the world coordinates to the viewpoint and rotating the coordinates with the angle, defined as θ, which is between the axis (X_w) and the sight vector. As for the dots within the coordinates space, their new coordinate value (x', y', z') could be gained with the following group of equations and the usage of the former coordinates value (x, y, z).

A plane, which is 1m away from the viewpoint and normal to the axis (X_e), has been defined as the projecting plane, also used as the replacement of the retina's surface. Those points behind the observer can be easily eliminated because their x-values are below 0. Either one of the remaining points Q (x_1, y_1, z_1) could be projected onto the plane, and a projected point Q' (x_1', y_1', z_1') would be obtained. The new coordinates values of Q' could also be gained by using the equations below. Only the "Y" values and "Z" values are kept; thus, the dots in a 3D coordinates space are projected onto a 2D coordinates plane.

Table 1: Equations for coordinates transactions and projecting transactions

Equation Set 1:	Equation Set 2:	Equation Set 3:	Equation Set 4:
$Cos(\theta)=(x_m-x_n)/d$ $Sin(\theta)=(y_m-y_n)/d$ $d^2=[(x_m-x_n)^2*(y_m-y_n)^2]$ $(d>0)$	$x'=x-x_n$ $y'=y-y_n$ $z'=z-z_n$	$x''=x'cos(\theta)-y'sin(\theta)$ $y''=x'sin(\theta)+y'cos(\theta)$ $z''=z'$	$x_1'=1$ $y_1'=y_1*x_1'/x_1$ $z_1'=z_1*x_1'/x_1$

Finally, to simulate the visual range of an observer, a view-frustum is created as an ideal rectangular pyramid, and the apex of the hypothetical geometry is set at the observer's eye point. To be in accord with the sight of an observer, the vertical angle (β) of the pyramid is set at 60°, the horizontal angle (α) is set as 120°. Therefore, the projection plane and the frustum would have an intersection face, which could be regarded as the approximate model of the retina surface and defined as face SOR (surface of retina). As Table 2 shows, the points out of SOR could be eliminated by comparing coordinate values.

Table 2: Equations for coordinates transactions and projecting transactions

horizontal edges	vertical edges	the range of Y-values	the range of Z-values
$Y_{rmax}=tan\ (\beta\alpha/2)$ $Y_{rmin}=-tan\ (\alpha/2)$	$Z_{rmax}=tan\ (\beta/2)$ $Z_{rmin}=-tan\ (\beta/2)$	$Y_{rmin}\leq y_r\leq Y_{rmax}$	$Z_{rmin}\leq z_r\leq Z_{rmax}$

In step (b), measuring the V-Es on the SOR is hardly available by counting directly, because points, mathematically, could be on a surface but cannot occupy any areas of the plane. Therefore, the SOR needs to be put into rasterization, so that we are accessible to count the cells which contain different classes of dots. Moreover, the number of cells containing one property dots could measure the V-E value of this kind of surfaces. For instance, if the number of the cells with the property of West Lake's surfaces is 80 out of 800 divisions, which means the lake would occupy the 80/800, equal to 10.0%, of the field of view for this viewpoint, and the V-E value of this class is 10.0%. Two things were carefully considered: the number of the divisions (for cells) and the method to count them. A proper dividing method needs to ensure that at least one point is located in any cell under the skyline. Therefore, the procedure to divide the SOR has a close relationship with the density of the points. In this study, we divided the SOR into 800 cells: 20 divisions horizontally multiply 40 divisions vertically, which is sufficiently accurate and easily operated for computers. Though it is easy to accomplish the counting, a problem still challenges the program. There may be more than one type of points belonging to one cell. We divide the cells into several equal "shares" according to the number of types to solve this. For instance, a cell might include three types of points, and we would "divide" the cell into three equal shares. As a result, each type of points occupied one-third of the cell. Finally, we could measure the areas for each type of points by adding up the numbers of entire cells and dividing cells. In this way, the V-Es, not only of West Lake, but also other four types of surfaces, could be gained, and the results would be visualised with different histograms in six different colours.

3 Results

All the V-Es of different surfaces have been measured for all the viewpoints. As the graphs indicate, six types of columns in different colours are applied to present V-Es' proportions for each viewpoint. The yellow columns are applied to present the V-Es of the West Lake's surface. They are outlined with red edges to emphasise the significance. A higher yellow column also equals a better vision for the lake. The lighter grey columns are used to show the empty cells on the SORs, the green spaces are shown in green, the buildings and structures are in black, the other water surfaces are in blue, and the paved or other undefined terrains are in darker grey.

(a) V-Es for the viewpoints on the main roads. As the result shows, the north shore roads are better viewpoints for observers to appreciate the West Lake. 51 of 59 viewpoints could view the lake, and 22 viewpoints (the V-Es for the lake is higher than 10%) of them have prominently sweeping sights of the lake. The viewpoints on the west shore mostly have greener sights. Only 5 of 67 viewpoints own the sights, where the coverage of green spaces is lower than 10 per cent, and there are 15 viewpoints with the V-E for green spaces higher than 20%. The V-Es of other water surfaces also play an essential role: the water surfaces of the wetland, as only 14 viewpoints could not see them. The western section of the north shore could view the lake, while green spaces or hills cover the eastern sections' sights. The east shore results are more complicated than the other sections; the V-E values for empty cells and buildings change dramatically. As for the northern segments, 17 of 26 viewpoints could have a relatively expansive view of the West Lake.

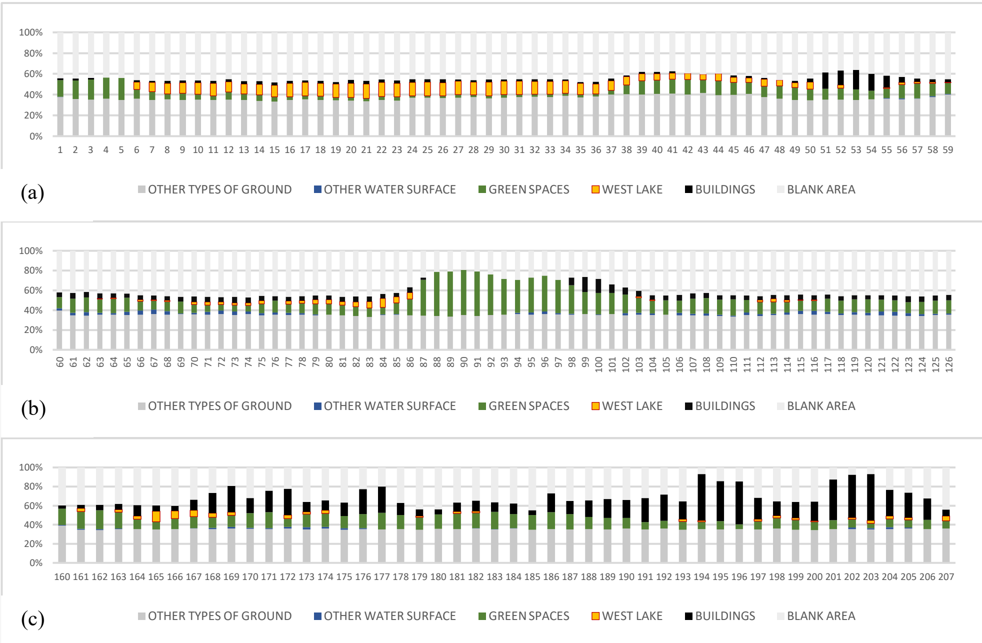

Fig. 3: (a) V-E value for viewpoints on L_1; (b) V-E value for viewpoints on L_2; (c) V-E value for viewpoints on L_4

(b) V-Es for the viewpoints on the causeways. Since the causeways' viewpoints have double views of the lake, the V-Es would be calculated twice to match with the two views. In general, the value of V-Es of the lake is relatively high for these viewpoints, ranging from 6% to 8%, while the V-Es for the lake is too high, like over 30% when the viewpoints are on the bridges.

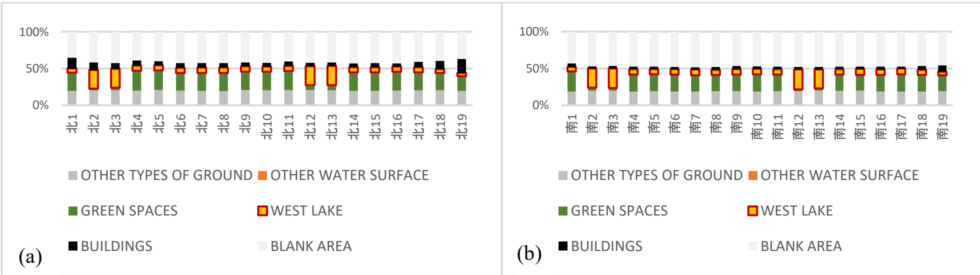

Fig. 4: (a) V-E value for viewpoints on L_{N1}'; (b) V-E value for viewpoints on L_{S1}'

(c) V-Es for the viewpoints on the walkways. The V-Es for the lake fluctuate dramatically, ranging from 0 to over 30%. The viewpoints on L_1" own the best views to the lake, and the average value of the V-Es for the lake is over 29%. While the viewpoints from L_3" could hardly view the lake, the V-Es' average value for the lake is merely around 3%.

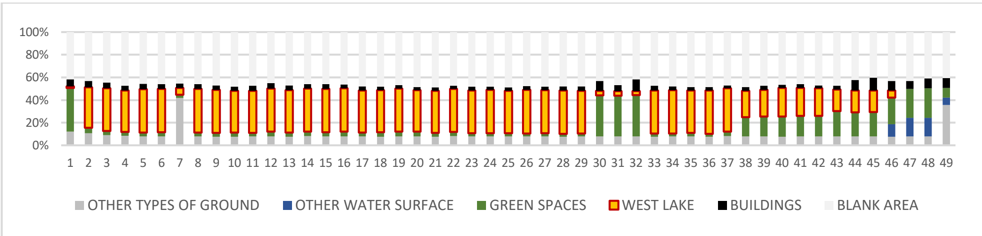

Fig. 5: V-E value for viewpoints on L_1"

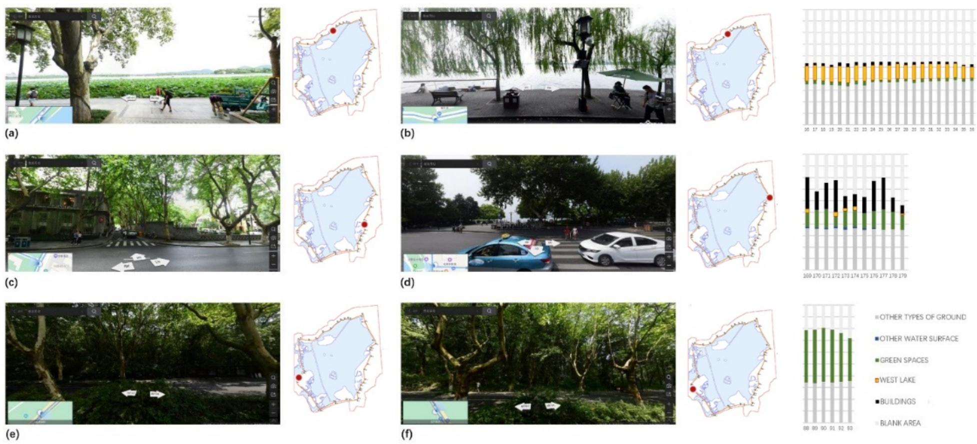

Fig. 6: (a) (b) the viewpoints where the V-E value for the lake is relatively high, around the V10-V36; (c) (d) the viewpoints where the V-E value for the buildings and structures is relatively high, around the V168-V174; (e) (f) the viewpoints where the V-E value for the green spaces is relatively high, around the V87-V93

4 Discussion

4.1 About the Algorithm

One effective way to verify the new V-E algorithm's computation results is to visualise views and compare them with the real situation. We used the Matplotlib toolkits for Python, which provides a pack of tools to translate the digital data into a 2D raster or vector graphs. One of the tools named seaborn could produce "heatmaps". We assigned values for the cells according to the type(s) of D-M they include so that these values could be adopted to create a raster graph to visualise the perspective FOV (field of view) for each viewpoint. There are 30 different classes for all the cells with permutations of the five properties, and their given values and colours are shown in the table. Five viewpoints were selected, and the visualised graphs for views are similar to reality; thus, the algorithm for V-E is reliable and accessible.

Table 3: The values for different classified cells. L=the surfaces of the West Lake; W= the other water surfaces; G= green spaces; O=paver or other undefined grounds; B=buildings and structures

class	L	LW	LG	LO	LB	LWG	LWO	LWB
value	1	2	3	4	5	6	7	8
class	LGO	LGB	LOB	LWGO	LWGB	LWOB	LGOB	
value	9	10	11	12	13	14	15	
class	W	WG	WO	WB	WGO	WGB	WOB	
value	16	17	18	19	20	21	22	
class	G	GO	GB	GOB	O	OB	B	EMPTY
value	23	24	25	26	27	28	29	0

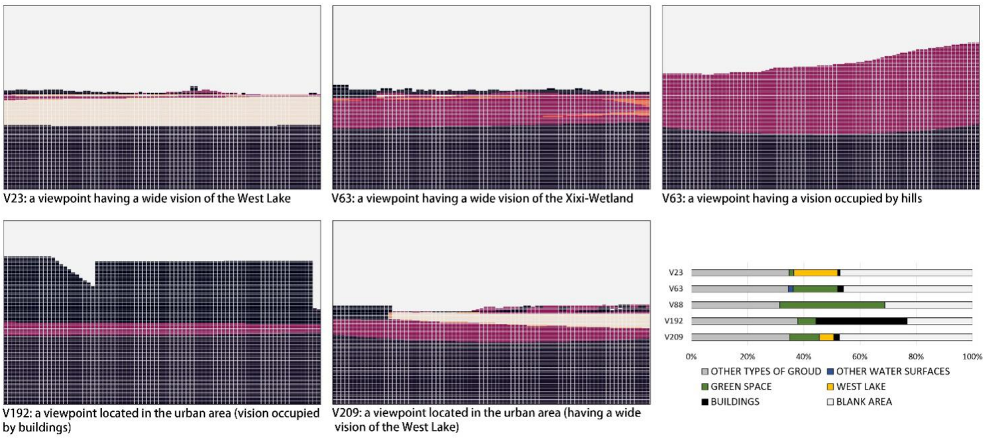

Fig. 7: Visualisation for the sights and V-Es for those viewpoints

The histogram of the V-Es for all possible pairs was juxtaposed to explore the impacts of the parameters' resolution. It could be seen that both the division of cells and the D-M metrics have significant influences on the accuracy of the computation. Besides, the impact is not a single functional factor. We could notice that the two conditions are mutually dependent, which means that for each resolution of D-M, there should be relatively suitable SOR divisions matching with it.

4.2 Possible Applications

Nowadays, many researching or planning projects are merely based on the outcomes produced by GIS-based viewshed analysis, which sometimes might have blind points on design for the perceptual visual environment. Therefore, one of the method's potentials is obvious. By combining the viewsheds analysis with V-E analysis, both the "overlooking" visual-spatial relationships and the "perspective" perceptual visual connections could be considered in the design and planning process.

Firstly, V-E computation could be an effective way to reveal the visual characteristics from a perceptual perspective. For example, by merely comparing V-Es' average value for viewpoints from different roads, we could find that the L_1' causeway has "greener" views. The green spaces make up considerable proportions in the views (Fig 4). We could also find that the L_1" walkway has the best views to the lake in these 10 segments (Fig. 5). In addition, with a few statistical processes, more visual characteristics could be analysed. For example, by adding the V-Es value together, all the occupied areas of the retina are counted, thus the rest empty areas must be the coverage of the sky. Besides, the variation in amounts of empty cells of different viewpoints could be applied to explore the changes of the skyline. The computation results also support this idea. Seeing the top of the columns in the L_2, the "curve" is near to the shape of the hill in front of the observers (Fig. 3). What's more, the variations of the V-Es' value from one viewpoint to another could be a possible way to evaluate the variation of visual environments among different viewpoints. The hill's shape V-Es reflect the sights viewed. Therefore, we employed the Standard Deviation method to calculate the variations among the viewed sights for different roads. Finally, the L_4 was identified to be the road with the most variable sights (Fig. 3). This fits the fact that the L_4 locates in a semi-urban situation where the views on buildings and green spaces shift dramatically.

Secondly, the V-E computing method has the potential to be useful in many aspects. For example, planners or designers could apply this visual impact assessment method to new constructional projects. By using the visibility analysis with viewsheds, the range of impacted areas could be quickly gained. Then the viewpoints could be set in the influenced areas, and the V-E data could be collected with this algorithm, which would indicate the possible visual impacts on those viewpoints. The evaluation results could be more reliable and more reasonable than merely using the viewshed analysis since the perceptual environments' effects are also presented. Finally, looking back to the mentioned urban design project for Hangzhou in 2009, the improvements could also be easily reached. The high-rises' possible visual impacts were not merely gained by sketching the sections for several so-called essential viewpoints. However, by evaluating their visibility, the impacts on the V-E values for numerous viewpoints within the influenced viewshed portions could be analysed. The visualisation of V-Es' computation could also help analyse the skyline. The so-called "rhythmical architectural variations" of the skyline could mathematically be discussed instead of empirical and fuzzy description by sketching.

5 Conclusion

Visual perception is essential for landscape experience. Before planning and managing visual elements for the built environments and natural landscapes, it is core to evaluate their visibility. Previous methods are usually stressing viewshed computation, while this research proposed a V-E computation method to assess the visibility of a scenic landscape with a "perspective" perceptual angle. Empowering the planners and city managers to consider the visual environment at different scale levels is of crucial importance and the presented method offers great potential for that.

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Evolution of Historical Urban Landscape with Computer Vision and Machine Learning: A Case Study of Berlin

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Abstract: Previous studies of historical urban landscape usually focused on the qualitative analysis of city planning and development with the social, economic, and political context, but overlooked quantitative analysis from human perceptions. In this study, we objectively measured the seemingly subjective qualities of the eye-level urban landscape perceptions with computer vision and machine learning technologies. We then explored correlations between the measured perceptual qualities and characteristics from the historical context. We chose Berlin as a research object because it is a capital city that owns a rich history of division and reunification, as well as a variety of residential zones built at different periods. We extracted 30 street features from the 150,000 Google Street View Imagery (SVI) dataset with a computer vision algorithm and evaluated eight perceptual qualities including typology, order, ecology, enclosure, aesthetics, richness, accessibility and scale with a machine learning method. Then we defined seven residential districts in Berlin, according to their spatial distributions and construction periods. Through a systematic comparison of perceptual qualities of the seven residential districts, we find perceptual qualities of ecology and enclosure have been improved a lot over a hundred years in Berlin. The housing policies and design codes in different social, economic and political contexts evolved to end overcrowding living conditions, create more open spaces, and develop a better ecological environment. This study enriches our understanding and application of subjective measures of human-centred built environment perception to the evolution of the historical urban landscape. The proposed quantitative framework of subjective human perception measures provides great testimony to evaluate the effects of the implementation of housing and other urban planning policies. Such an automated, multisource, high-throughput and scalable framework can be applied to other cities to determine the personality of the city and assess the impact of urban design and planning policies in streetscape improvement.

Keywords: Computer vision, machine learning, Google street view image, perceptual qualities

1 Introduction

Inspecting the development of urban landscape and investigating influence factors has long been a vital topic in the study of urban history. A variety of methods and data sources have been adopted to analyze the urban historical environment in urban studies. For example, historical maps have been scanned and digitized for long-term spatial change studies (TUCCI et al. 2010, LLOYD et al. 2012, KIM et al. 2018). Modeling software has enabled comparisons of built environments in three-dimensional space (ARNOLD & LAFRENIERE 2018). Satellite images have been utilized for examining the historical development of urban landscape structures and their dynamic changes (GUO et al. 2020, TANG et al. 2008, WENG & LU 2009).

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However, previous studies have almost exclusively focused on qualitatively describing historical changes in cities from a macro perspective, but overlooked nuanced and subjective perspectives on the human experience of place.

Previous studies of subjective perception of the built environment relied on traditional methods such as visual collages, interviews, field surveys, and virtual audits (LAAKSONEN et al. 2006, OGUZ 2000, SÁENZ DE TEJADA GRANADOS & VAN DER HORST 2020) to collect people's overall perceptions. These measurements have problems in consistency, reliability of the operation and limited application to larger geographic contexts. With multi-source, open data especially the Street View Imagery (SVI) and advanced technologies of artificial intelligence, it becomes possible to quantify how cities are perceived by their inhabitants with more human-centered and eye-level experiences and on a large scale. New analytical frameworks show great advantages in efficiency and accuracy over traditional methods. For example, NAIK et al. (2014) used Place Pulse data to train a computer vision algorithm called Streetscore that accurately predicts human-derived ratings for the perception of a streetscape's safety. Some authors have driven further development of crowdsourcing and computer vision methods to calculate the green view index of the streetscape. LI et al. (2015) explored Google Street View (GSV) images as an urban greenery assessment tool on street-level and modified the Green View Index (GVI) formula. LI et al. (2019) further utilized panorama images to predict the occurrence of sun glare from street-level. DOERSCH et al. (2014) analyzed street view images and attempted to extract characteristic features, such as windows, balconies, and street signs, that are most distinctive for a certain geospatial area. TANG and LONG (2019) measured the characteristics of Hutongs, typically representative of historical streets in Beijing, from the perspectives of greenery, openness, enclosure, street wall continuity, cross-sectional proportion, and stay willingness. This also allows them to analyze differences between physical and perceived qualities and evaluate the level of urban renewal in Hutong during recent years. Another study identified important indicators from both human-centered street scores as well as the more objective street feature measures with positive or adverse effects on property values based on a hedonic modelling method (QIU et al. 2020). The above-mentioned studies show that the SVI dataset has unique advantages in human-scale street perception measurement, quantitative urban landscape studies, and urban renewal performance assessment, which can compensate for the limitations of past historical landscape studies. However, the application of new data source and new analytical tools in the historical urban landscape contexts has not been addressed adequately. Few studies have systematically investigated and evaluated how and to what extent the citizen's human perception of the built environment changed as a result of various planning policies.

Against the backdrops of the existing literature, this study aimed to incorporate human perception in historical urban landscapes by utilizing computer vision and machine learning technologies. Berlin, a capital divided and governed by Capitalist and Socialist ideologies historically, was chosen as a research object. Its uniqueness not only represents different aesthetic preferences and morphological characteristics between East and West Berlin, but also reflects their changes during a long history of division and reunification. With computer vision and machine learning technologies, we extracted more than 30 street view features and estimated 8 perceptual qualities scores from 150,000 Google SVI images. We examined the spatial formation, landscape elements composition, and landscape perception through data mining and visualization of the SVI image dataset. We further compared human perception in different historical districts to find correlations between perceptual qualities and historical context. This study achieved three key contributions: (1) it offered a test of how these digital technologies can be used to quantify physical features and perceptual qualities; (2) it quantified the differences in human perceptions of the built environment under the impact of major historical events; (3) it revealed the correlations between perceptual qualities and historical context and interpreted it from the perspective of Berlin's planning policy. This study will help urban designers and planners understand the historical development of urban landscapes from a human perspective, as well as the influencing factors and driving mechanisms, which sheds light on future urban policies and urban design of an integrated city.

The rest of the paper is organized as follows. In section 2, we provide the definition of perception qualities and introduce the proposed methodology. Section 3 presents the result of the perceptual qualities score and discusses its correlations with historic context and planning policies. The conclusions and future work are given in Section 4.

2 Methodology

2.1 Definition of Perceptual Qualities

Perceptual qualities, affected by physical features, urban design qualities and individual reactions to the built environment, can be assessed objectively by observers. EWING and CLEMENTE (2013) used traditional research methods, such as observing, counting, and manually rating, to establish relationships among physical features, urban design qualities and perceptual qualities. In our research, we added an individual reaction process – 300 training samples derived from a random survey with 50 people – to predict the perceptual qualities of the rest SVI dataset with a machine learning algorithm.

We set up eight perceptual qualities for further study based on a review of classic landscape architecture and urban design. They are typology, order, ecology, enclosure, aesthetics, accessibility, richness, and scale. (1) Typology is the arrangement of physical elements which evoke people's impressions of land use and urban characters. They cover five common types: residential, office, commercial, suburban, and rural. (2) Order refers to the geometrical, sameness or presence of repetitions observed in an urban area. (3) Ecology indicates the detection of living organisms, including animals, plants and humans, and the physical environment around them. (4) Enclosure refers to "the degree to which streets and other public spaces are visually defined by buildings, walls, trees, and other vertical elements." (EWING & CLEMENTE 2013) It is strengthened by continuous building fronts of rough height, while being eroded by breaks in the vertical elements. (5) Aesthetics presents the overall visual quality of a street being comfortable and distinct (EWING et al. 2006). (6) Accessibility is about people's ability to reach geographically dispersed activities, attractions, and amenities (SOLÁ et al. 2018). (7) Richness (or complexity) refers to the complexity of a place depending on the variety of the physical environment, such as the numbers and kinds of buildings, landscape elements, street furniture, signage, and human activity (EWING & HANDY 2009). (8) Scale refers to human scale here, which means "physical elements to match the size and proportions of humans" (EWING & CLEMENTE 2013). It is an innovative method to quantify ecology and aesthetics with machine learning since they are closely related to the landscape architecture field but have been neglected in previous urban studies. The rest of the six perceptual qualities are also important in the literature of urban design as well as the landscape architecture field.

2.2 Methodology

The proposed methodology includes four processes: SVI sampling, SVI perception data acquisition, street features extraction and ML model training. We also zoned historic residential districts for comparative studies. The whole framework of the methodology is shown in Figure 1.

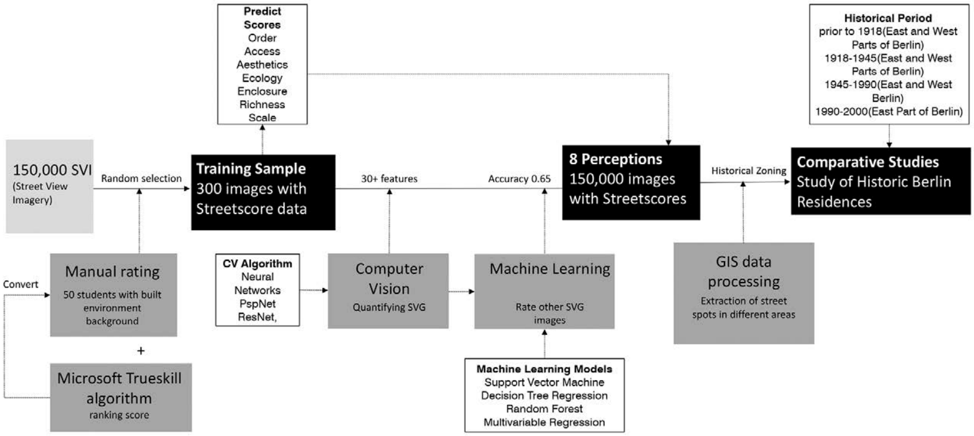


Fig. 1: Workflow of technology

2.2.1 Street View Image Sampling

Street View Imagery (SVI) provides a horizontal view of the street environment that is closer to the perception of pedestrians, making it an ideal data source for measuring a streetscape environment. Most Google Street View (GSV) images are taken by GSV cars along streets with 15 cameras that snap 360-degree views at a height of 8.2 feet (RICHARD 2012). It is considered as an accurate and efficient dataset by a great number of studies focused on the streetscape, for instance, GONG et al. (2018) verified the accuracy of the GSV-based method by comparing sky, tree and building view factors measured by GSV with field surveys. We sampled points every 50 meters along public streets in Berlin and downloaded 150,000 pictures of Berlin streetscape from Google Street View API. We set up angles as heading forward, pitch (0°), horizontal field of view (120°) and size (900 by 600 pixels) to ensure the consistent perspective. 300 SVIs were selected randomly for perception scoring as a training dataset (Fig. 2).

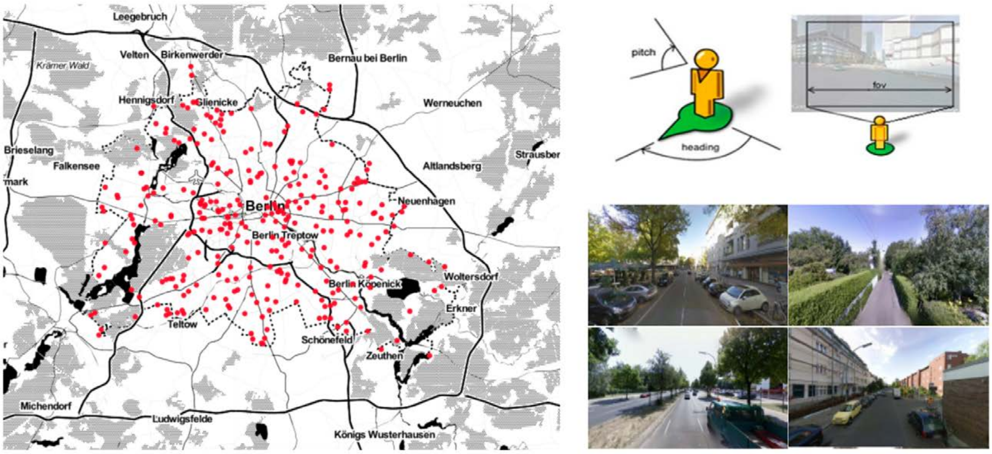


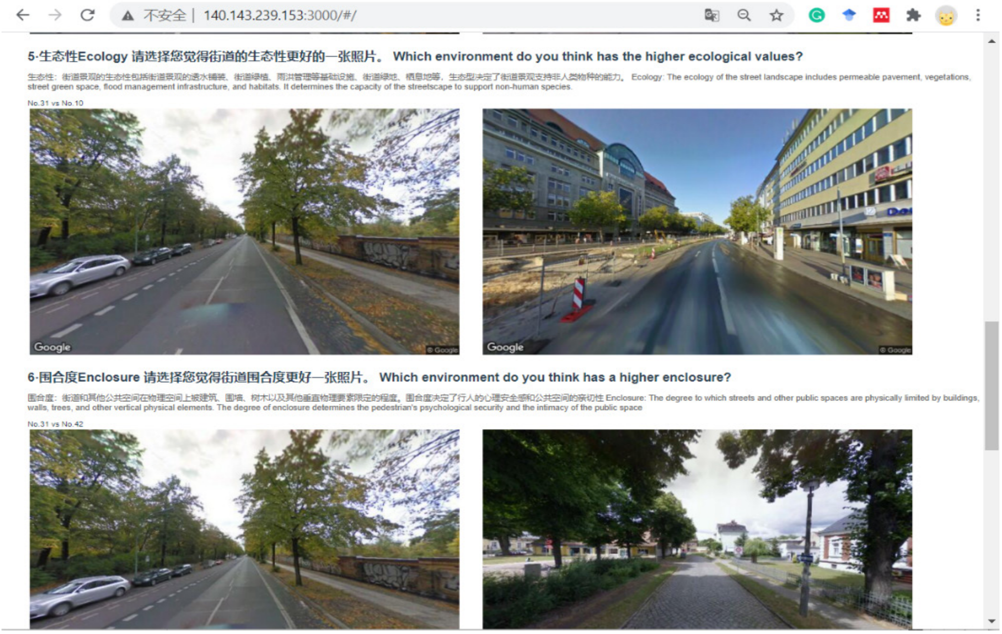
Fig. 2: A random sample of 300 street view image points across Berlin as the training dataset; Downloaded street view images from Google Street View API

2.2.2 Street View Perception Data Acquisition

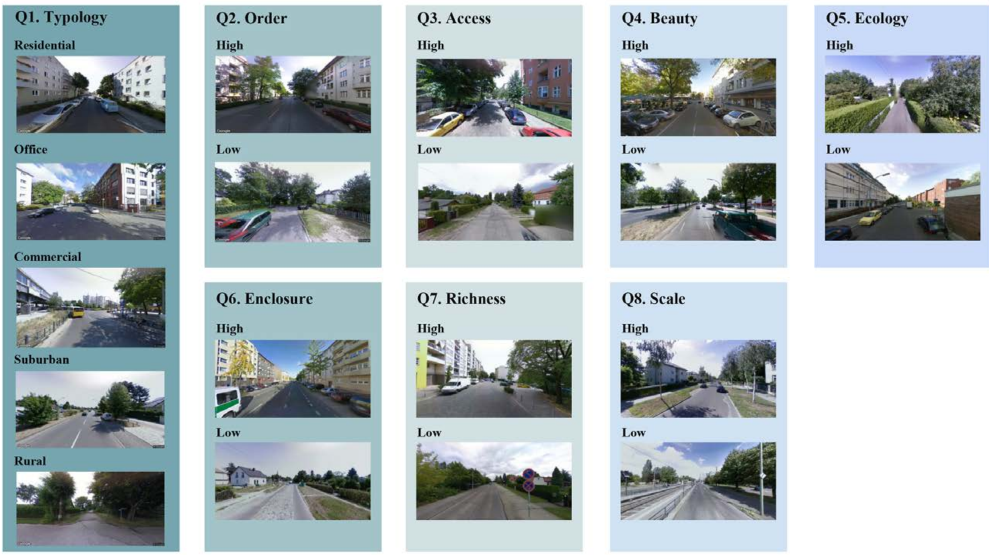
To obtain training data on people's streetscape preferences from SVIs, we used a high-throughput approach developed in emerging research (NAIK et al. 2014, SALESSES et al. 2013). Specifically, we developed an online survey platform where participants were presented with two images randomly selected from the Berlin SVI dataset. Participants were asked to click on their preferred SVI to answer eight evaluative questions about eight perceived street qualities (Figure 3). For example, a short definition of "ecology" was given. Then, we asked the participants the question "Which place do you think has a higher visual ecology?" Notably, to ensure that the training images covered a variety of street scenes from the city center to the suburbs to the outskirts, these preferences were converted into a ranking score (range 0-10) for each image by the Microsoft Trueskill algorithm (NAIK et al. 2014).

2.2.3 Street Features Extraction

After acquiring the perception scores, we quantified the proportion or number of pixels of 30 street features using a pre-trained Computer Vision model. Pyramid scene parsing network (PSPNet) is one of the most well-recognized image segmentation algorithms as it won ImageNet Scene Parsing Challenge 2016 and its research study is highly cited by the computer vision community (ZHAO et al. 2016). Through training on the PSPNet network, we performed image segmentation and element detection on 150,000 streetscapes, and ultimately extracted a proportion of more than 30 streetscape features as evaluation indicators, including building, sky, tree and so on (Figure 4). Instance segmentation with Mask R-CNN algorithm (Figure 5) can generate a segmentation map for each detected instance of an object and accommodate multiple classes and overlapping objects (HE et al. 2017).



(a) Online survey system asking participants to click on one of a pair of SVIs in response to evaluative questions



(b) Evaluation examples of 8 perception factors

Fig. 3: Online survey system and perception factor

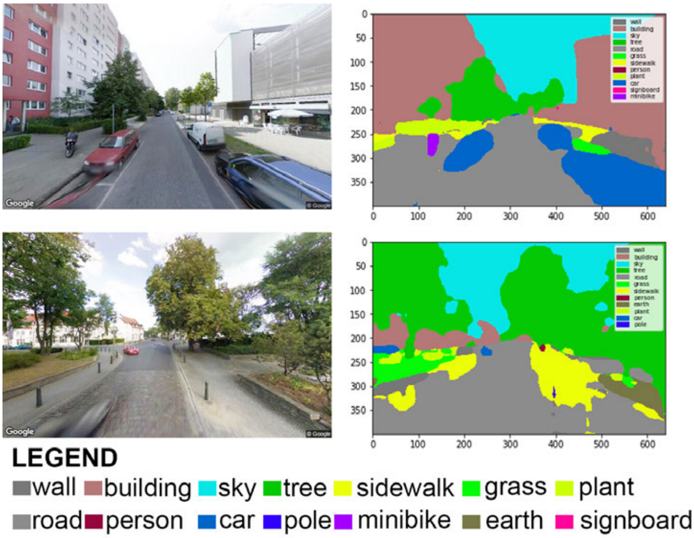


Fig. 4: Semantic segmentation example of physical features

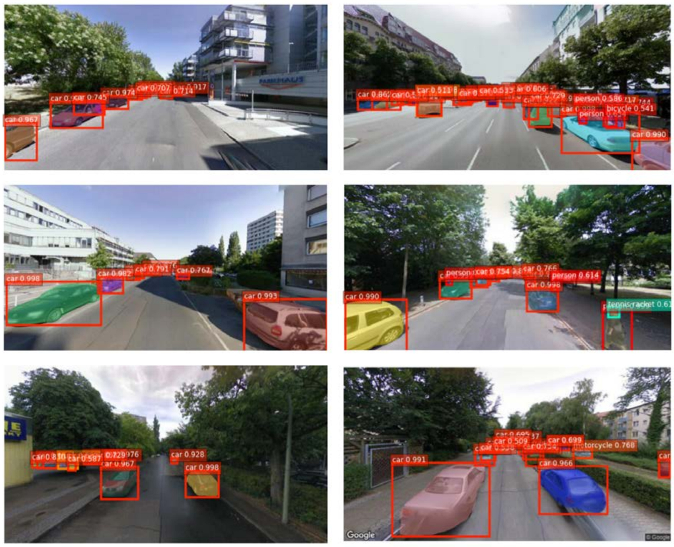


Fig. 5: Instance segmentation example of counting the number of cars

2.2.4 Machine Learning Models Training and Perceived Scores Estimation

We trained ML models including K-nearest neighbors (KNN), support vector machine (SVM), random forest (RF), decision tree, and gradient boost (GB) to estimate eight perceived scores from the 30 features extracted from SVI. The 300 labelled images from the online survey were split into a training set and a testing set. The input of the ML model is 30 street view features, and the output of the ML model is the eight perceived scores. To choose the optimal model, we compared model performances regarding the R-square, the Root Means Square Error (RMSE) and the Mean Absolute Error (MAE). RF performed best in predicting all the scores (Table 1). Then, using the random optimization method (LIU & SUN

2019, SMITH 2010), we further improve the RF model by optimizing the two parameters, the number of branches in the forest structure and the maximum number of levels in each decision tree. RF accuracy reached 0.65 after improvement and the accuracy of ML model was considered acceptable, limited by the small training dataset. Therefore, we considered the obtained street-perception data to be accurate. The final improved RF model was applied to estimate the perceived scores of the rest of the 150,000 SVI of Berlin streetscapes.

Table 1: Comparing the accuracy of different ML algorithms

ML Models	Q1_Type	Q2_Order	Q3_Access	Q4_Aesth	Q5_Eco	Q6_Enclo	Q7_Rich	Q8_Scale
KNN	0.47	0.36	0.40	0.38	0.48	0.44	0.49	0.41
Random Forest	0.60	0.48	0.55	0.54	0.56	0.59	0.59	0.51
Decision Tree	0.59	0.49	0.50	0.54	0.52	0.56	0.53	0.49
Gaussian Process	0.58	0.44	0.51	0.52	0.55	0.53	0.58	0.45
GradientBoosting Regression	0.58	0.46	0.52	0.49	0.52	0.57	0.54	0.48
ADA	0.56	0.47	0.51	0.49	0.53	0.54	0.53	0.48

2.3 Historic Residential District Zoning

We divided the existing residential area into seven districts according to every national government based in Berlin (BODENSCHATZ 2010): Mass housing, Mietskasernen, was built in the east area (E1) and west area (W1) between the German Empire of 1871 and the Weimar Republic of 1918, though nothing was built during WW1 from 1914 -1918. The apartments of new modernism were built in the east area (E2) and west area (W2) from 1918 to the end of Nazi Germany (1945), with little estate development during WWII from 1939 to 1945. Later, reconstruction occurred in East Berlin (E3) and West Berlin (W3) during the 1945-1990 period as a divided city. And 1991-2000 was the redevelopment period (E4) after reunification in East Berlin.

According to the interactive map of residential districts built in different periods (Figure 7), we selected the streetscape data that is closest to chronological age through an image calibration operation in Geographic information system (GIS) and divided them into E1-4 and W1-3 sections. E1 and W1, built in the early age, take up the central area of Berlin, and E4 is mainly located in the eastern suburbs of Berlin, while all other periods are distributed surrounding the centre (Figure 8).

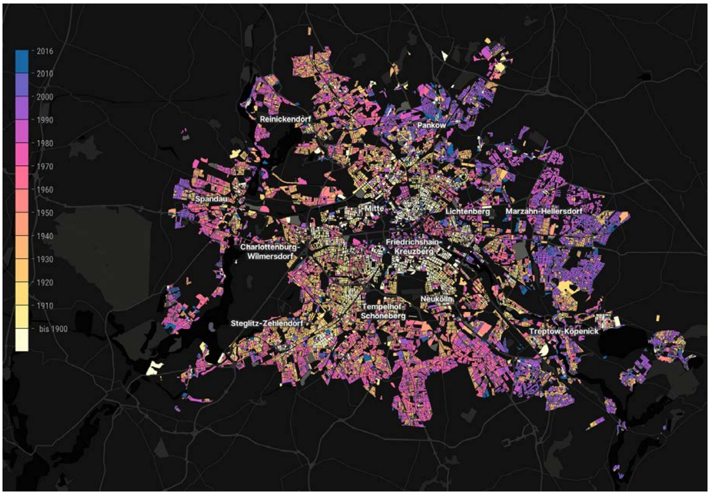


Fig. 6:
Distribution of residential areas in Berlin at different historical times (Source: Berliner Morgenpost, https://interaktiv.morgenpost.de/so-alt-wohnt-berlin/)

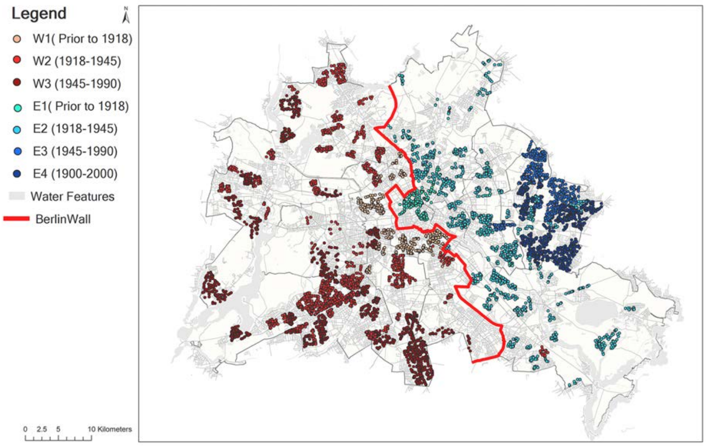


Fig. 7:
The distribution of observer spots in different periods extracted by GIS

3 Analysis and Discussion

3.1 Street View Perception Data Visualization

With the computer vision and machine learning technology introduced above, we extracted more than 30 streetscape features and acquired 8 perceptual qualities scores from 150,000 SVI images. The streetscape features provide quantitative support for predicting perception scores. For instance, there are four key streetscape features, namely sky, tree, building, and road taking significant fractions in a SVI image. Through visualization of data from GIS, we find that the building visibility is high in the center of Berlin, while high tree visibility is more distributed in the north and south outskirts, such as Frohnau and Lichtenrade and high sky visibility can be found in the east and west outskirts, such as Hellersdorf and Neustaaken. Correspondingly, the perception score of the enclosure is positively correlated to building visibility and tree visibility, but negatively correlated to sky visibility (Figure 9).

3.2 Analysis of Perceptual Qualities in Different Historical Districts

According to the seven historical periods in chronological order, we selected several representative clusters of residential districts of each period. By overlaying the histograms of predicted perceptual scores at seven historical periods, we found that the shapes of curves fell into three main categories. Firstly, data are moderately skewed at certain periods. Take the perceptual score of Ecology as an example, the E1 and W1 periods have a right-skewed distribution while the W3 and E4 periods have a left-skewed distribution. Secondly, the datasets are close to a normal distribution, such as the perceptual score of Aesthetics. Lastly, the data are evenly distributed with no clear pattern, such as the perceptual score of Enclosure (Figure 9). To compare the data more precisely, we selected the median score from each period and region to represent its score in the middle (Table 2). E1 and W1 districts share a lot in common in every perception evaluation: high score in access and order but low evaluation in perception score of ecology and aesthetics. E2 and W2, overlapping with each other at a high level, show relatively even performance in each perceptual score. W3 has a low evaluation of order though, better performance in the evaluation of scale and enclosure, compared to the buildings' low evaluation of enclosure in East Berlin (E3) during the same era. E3 also has a low evaluation of scale and enclosure, but a fair evaluation score of ecology. E4 district inherits a low evaluation of order and enclosure from the E3 district, but a better performance of ecology and aesthetics. Through comparison, we find ecology, enclosure and scale are the critical perceptual qualities to reflect the historical development of the urban landscape.

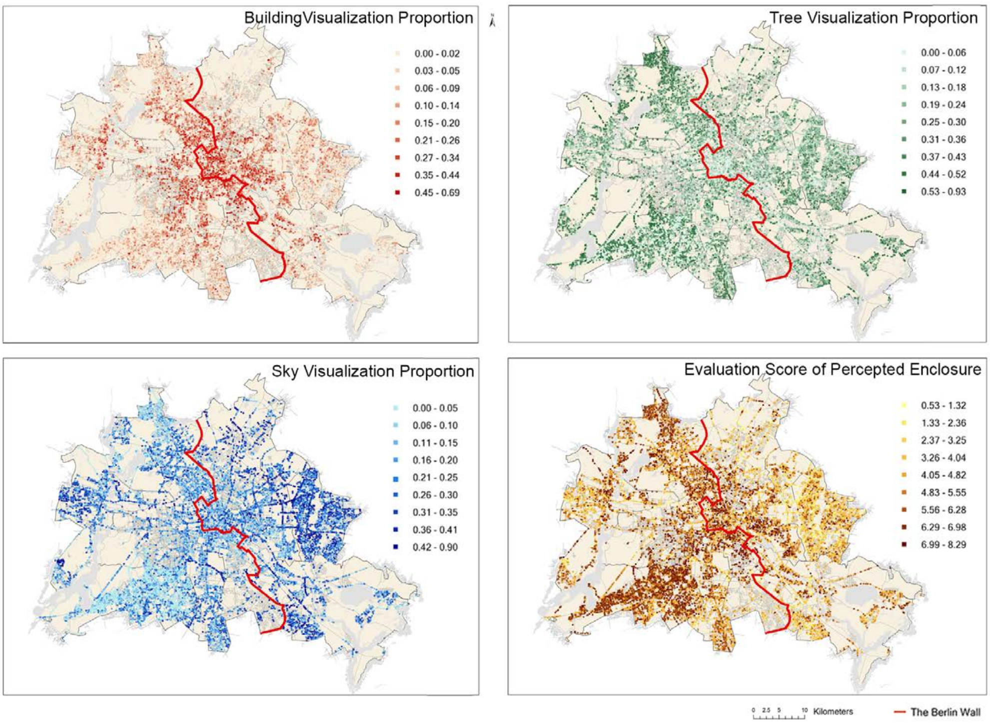


Fig. 8: Visibility of key streetscape features and perceptual qualities of enclosure

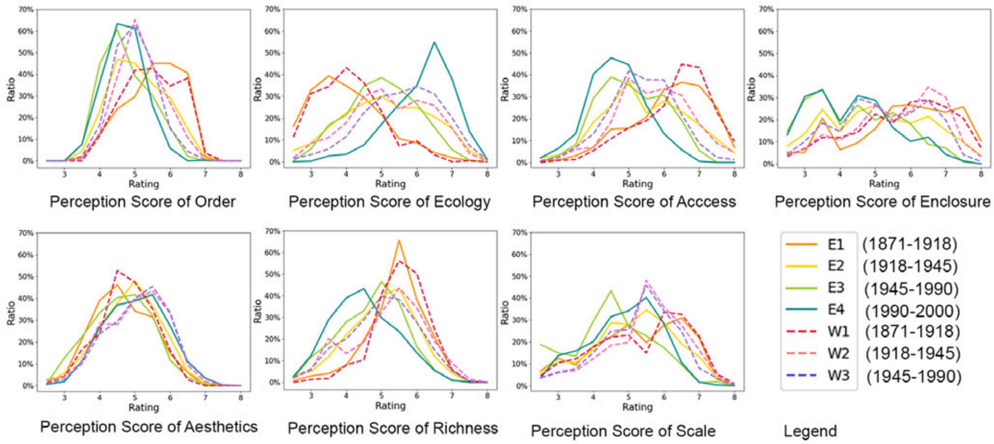


Fig. 9: Histograms of prediction perceptual score in 7 historical districts

Table 2: Comparing Prediction Perception Median Score in different periods and regions

Comparison of Perception Median Score							
Perception / Time	Order	Ecology	Access	Enclosure	Aesthetic	Richness	Scale
East1 (1871-1918)	5.61	3.92	6.32	5.87	4.64	5.49	5.32
East2 (1918-1945)	5.03	5.11	5.38	4.84	4.90	5.11	5.23
East3 (1945-1990)	4.62	5.02	5.04	3.74	4.65	4.82	4.46
East4 (1990-2000)	4.70	6.31	4.62	3.74	5.00	4.41	5.02
West1 (1871-1918)	5.46	4.02	6.51	5.89	4.76	5.59	5.59
West2 (1918-1945)	5.08	5.22	5.69	5.72	5.11	5.34	5.58
West3 (1945-1990)	4.95	5.68	5.38	5.06	5.17	5.11	5.44

3.3 Perceptual Qualities to Historical Context and Planning Policies

We attempted to explain these variances among the seven districts in Berlin from the perspective of historical contexts and planning policies. The analysis estimated the potential effects of individual policies on the perceptual qualities as below.

Berlin experienced rapid growth in population and economy in the mid-nineteenth century, with a perceived need for housing units for new immigrants (ARANDELOVIC & BOGUNOVICH 2013). Engineer James Hobrecht, appointed by the Prussian government, drew up a zoning plan (Hobrecht Plan), encompassing the existing city like a belt, for large residential districts in 1862. The Hobrecht Plan established limits between public spaces and private spaces and left the development to individual property owners since Hobrecht didn't think the aesthetic design was a task of planning (BERNET 2004). However, the loss of regulation within the blocks resulted in a high parcel density: these units were followed by a sequence of rear buildings where factories were located and most courtyards within buildings were used for industry instead of green space until the 1920s (BENTLIN 2018). This may explain why these planning policies had a negative effect on the perceived ecology and aesthetics of the built environment but are associated with a positive effect on the perceptual score of access and order in the E1 and W1 sections.

The Weimar Republic, declared in 1918, began a vibrant period of "Golden Twenties" in the history of Berlin. The 1925 Building Code put an end to the high density of buildings with rear blocks and limited accessibility only through the courtyards (BENTLIN 2018). In the building reform movement for improving housing and living conditions, Martin Wagner as the city planner with Bruno Taut and Walter Gropius as leading architects, set the style for social housing with spacious green areas and openings to light and air. The housing estates reflect the highest degree of quality, the combination of urbanism, architecture, garden design and aesthetic research of early 20th century modernism, as well as the application of new hygienic and social standards (URBAN 2018). Six representative "Berlin Modernism Housing Estates" were listed as UNESCO World Heritage Sites (PUGH 2014). The high quality of the housing standard might provide theoretical support for no apparent shortage among each perceptual score in the E2 and W2 sections. Few constructions, especially housing estates were preserved from the Nazi Germany era (1933-1945), so we did not evaluate the influence of the megalomaniac planning in that period.

Berlin suffered enormous destruction during World War II. In 1949, two German governments were constituted and separated the country into East and West over the next forty years. The influence of Soviet urban planning was evident in East Berlin, such as Karl-Marx-Allee, with wide boulevards and grandiose plazas to praise its social system. 'Plattenbau' (prefabricated concrete slab building) as a typical style of a residential building, was built to curb the country's severe housing shortage in East Berlin since the 1970s. However, 'Plattenbau' are often not desirable, due in part to their rapid deterioration caused by cheap and quick construction methods (PENSLEY 1995). A 1975 report to the top leader Gerhard Trölitzsch's office pointed out that the low aesthetic quality of East German housing blocks seriously endangered the citizens' identification with the socialist state (BAUWESEN 1975). Such planning policies and design standards represent a negative effect on the perceived scale, enclosure, and aesthetics of the built environment in the E3 section. But its grand scale of public space leaves potential for green areas, which contributes to the perceptual score of ecology.

To respond to construction projects in East Berlin, Hansaviertel residential complex (Hansa District) was the showcase of German design in West Berlin at the Interbau 1957 International Building Exhibition, which is an important testimony to the modern architecture and urban planning of the 1950s. The "star architects" as well as urban planners, engineers, public transport experts, sociologists and economists built this "City of Tomorrow" in West Berlin (WAGNER-CONZELMANN 2018). The Hansaviertel residential complex improved the dwelling conditions to a level that was unprecedented in history and set the design standard for later housing estate development. The planner Edgar Salin and the sociologist Hans Paul Bahrdt promoted the new urban planning paradigm Urbanität durch Dichte (urbanity-through-density) in West Berlin's large estates around 1960. Märkisches Viertel, Gropiusstadt and Falkenhagener Feld, which aimed at urbanity in this sense, were modelled after the principles of the Athens Charter such as functional separation, separation of traffic flows and predominance of light and air (URBAN 2018). Such planning policies probably have positive effects on perceived scores of Ecology, Scale, Richness and Aesthetics in the W3 section, relatively low performance in score of access and enclosure. Generally, the W3 section inherited good performance of perceptual qualities from the W2 section (Figure 10).

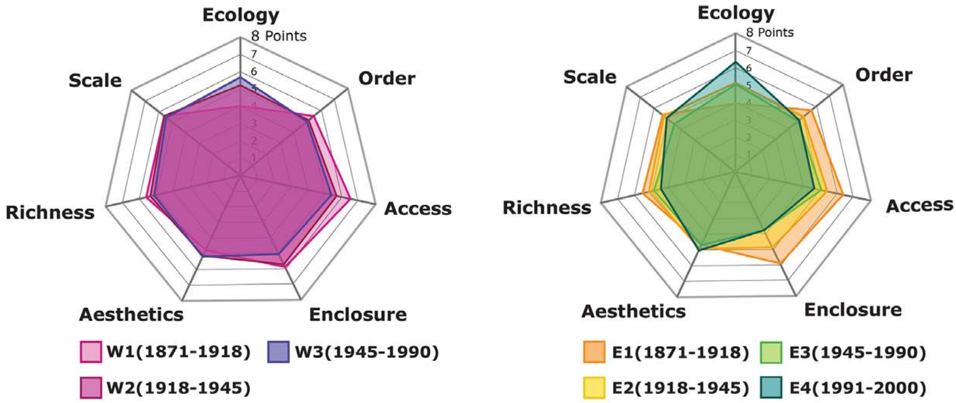


Fig. 10: Median score chronological change in 7 historical districts

After unification into the Federal Republic of Germany in 1990, the government attempted to integrate the urban streetscape of East Berlin to West Berlin in three ways: (1) visually change Plattenbau facades to a more Western face; (2) reconstruct the central city according to existing urban fabric (COBBERS 2011); (3) develop single-family houses and smaller apartment buildings in previously undeveloped areas. We took a cluster of residential developments, which are mainly single-family houses in Kaulsdorf, as an example to evaluate perceptual qualities. A low perceptual evaluation of order and enclosure, but a better performance of ecology and aesthetic prediction might be associated with the planning policies for the suburban new developments.

4 Conclusion

This study introduced a scalable, automated and high-throughput framework to apply machine learning and computer vision methods to publicly available SVI. The framework objectively measured eight perceptual qualities of the urban streetscape, and applied the result to comparative research of seven residential districts in Berlin. We compared the results from two perspectives: by chronological order and by geographic locations. First, in the chronological order perspective, we found perceptual qualities of ecology and enclosure have got significant improvement from the German Empire, the Weimar Republic, the divided city of West and East Berlin to a reunified Germany. The increase of ecology and enclosure evaluation evaluations represents housing policies and design codes have improved overcrowding densities, created more open spaces, and developed a better ecological environment since the post-war period. Second, the evaluation of perceptual qualities in the west part of Berlin showed consistent results with the east part at the same period until Berlin was divided into West and East Berlin in 1945. The housing estates built in the East Berlin period (E3) represents a low evaluation of enclosure, aesthetics, richness and scale. Though the Federal Republic of Germany government attempted to integrate the urban landscape of East Berlin to West Berlin after the reunification, people's perceptions can still tell the difference of the urban features which respond to their construction characters and historical contexts. The quantitative analysis of human perceptions provides great testimony to evaluate the effects of the implementation of planning policies and design codes.

This study presented a novel approach to interpret people's perceptions of the urban built environment, then date it back to the context of previous policy, society and economy. For a city with a long and rich history like Berlin, it explains the context of historical events and planning policy's impacts on the urban streetscape in a quantitative way. This digital city model technology can calculate various metrics to describe and quantify diversity or similarity of urban landscape from a human perception. It can help the local government to determine the personality of the city and assess the impact of policies in streetscape improvement.

Several limitations should be noted. First, with limited data acquisition and time, the small sample of 300 SVIs for the training set might bring bias to the machine learning model. Second, the training model is built based on evaluations from students with a built environment background. To a certain extent, it does not represent the public's perception. Lastly, the points we selected come from certain representative residence clusters. In other words, they do not cover all the areas built in that historical period. Future work includes zooming in specific residential districts of Berlin and analyzing their perceptual qualities more precisely.

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Pursuing an AI Ontology for Landscape Architecture

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Abstract: Technological advancements have become ubiquitous within landscape architecture. One of the latest advancements is in Artificial Intelligence, including techniques such as Machine Learning, Artificial Neural Networks and problem optimization. These advancements have already worked their way into landscape architecture. In this theoretical paper we briefly identify what the state of the art in AI is, as well as its potential and limitations in the discipline. Specifically, we argue for the need to create a disciplinary ontology to make knowledge explicit and shared amongst humans and machines.

Keywords: Artificial intelligence, computational design, landscape architecture practice

1 Introduction

Landscape architecture has taken advantage of computation algorithmic and information models, embedding them into curricula, professional workflows and experimenting with design processes such as terrain modelling (HERMANSDORFER et al. 2020, HURKXKENS et al. 2017), monitoring public spaces for design assumptions (ZEIGER 2019), modelling uncertainty in a 'synthetic' ecology (CANTRELL & HOLTZMANN 2014), and reflecting temporality in CAD workflows (TEBYANIAN 2016). The use of computation in landscape design is burgeoning and shows signs of sustained growth in the future (GEORGE & SUMMERLIN 2019). Some landscape architectural researchers and practitioners have begun imagining the potential for a greater disciplinary discourse on computational design and parametricism (CANTRELL & MEKIES 2018), proposing that landscape is a profoundly more complex system than that of a building or singular piece of infrastructure and thus needs to construct a system more responsive to the many factors and contexts in which it is embedded (CANTRELL & HOLTZMANN 2015). Yet because landscape is such a fundamentally expansive medium, the array of possible computational tools to apply to its design is also much more vast than the more manageable scope of something like architecture, and can thus lead to digital overload (FRICKER et al. 2013).

For all the diverse ways designers engage with other disciplines, most simply do not have the time, knowledge, or cognitive capacity to account for the range of intersectional aspects of today's design problems. To this end, there is new discourse emerging around the potential of artificial intelligence to help facilitate such limitations. It includes topics like laying the historical groundwork for AI so as to create better understanding in the profession (ZHANG 2020), proposing machine learning primers and ontologies for landscape design (ALINA et al. 2016, TEBYANIAN 2020), gauging the potential for AI in coastal adaptation design (ZHANG & BOWES 2019), and even envisaging an automated, post-human ecology (CANTRELL et al. 2017). As the trend of AI takes hold in design disciplines, there is an essential need to build a shared language between humans and machines, especially ensuring that assumptions, vocabularies and knowledge are explicit. This paper lays a theoretical foundation for the development of an information science *ontology* in the landscape architecture domain. Ontologies can improve problem solving because they make knowledge explicit, open and reusable by

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AI systems (and humans). The development of a landscape architecture ontology will enable an AI system to more easily gather and synthesize knowledge while elucidating domain assumptions and philosophies of design.

2 Developing a Landscape Design Ontology for AI

2.1 Clarifying the Term Artificial Intelligence

When the term 'artificial intelligence' is presented to a general audience, it is more likely to elicit troubling images from Sci-Fi movies than a basic understanding of AI research (FAST & HORVITZ 2016). Thus, before we delve into the research questions, it is important to understand what AI is, how it works and why it might make us feel simultaneously excited and a little uneasy. The Oxford Dictionary defines Artificial Intelligence as "…computer systems able to perform tasks that normally require human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages." Though the concept of it has been in development for centuries (BUCHANAN 2005, POOLE & MACKWORTH 2010), the beginnings of modern AI computing are often understood to have spawned in 1950 when Alan Turing posited: "can machines think?" and while he soon discovered that they could indeed, the bigger question he came away with was whether or not machines are capable of thinking like humans (TURING 2009). This highlights an important distinction often overlooked by the AI layperson; AI capability is different from AI functionality. Before AI attains human capabilities like abstract thought, empathy, and understanding meaning, it has to master the basic functions that build those capabilities. Functions include effective use of limited memory, reaction to stimuli, and real-time decision making (TECHLIANCE 2020). Some of the latest inquiries into the state of the field claim there are still many barriers to crash before reaching that milestone (MITCHELL 2020).

Nearly every branch of research or application of AI requires creating ontologies, methods, data mining or expert-based learning and developing statistical approaches to facilitate reasoning. In each instance, humans are involved in building and maintaining these systems, but the key defining element is that machines are the curator of learning. This is done through language and computational methods (e.g. statistics) that can amalgamate large datasets and be trained (using humans to fill gaps of learning). For instance, the detection of cancers can be done by allowing a computer to read radiological images and statistically characterize them to identify anomalies (AMERICAN ASSOCIATION FOR CANCER 2018, [1]); learning reinforcement happens when the computer is trained by a human to identify that the anomaly is a cancer. The more images read and correct detections made, the better the statistical models become. In this case reasoning is a statistically based outcome of learned information. However, such outcomes are not possible without abundant data, a clear language, and a reliable set of rules to follow.

2.2 What is an Ontology?

Ontology, philosophically understood, is the study of the nature of being or existence. When applied within the context of computer science and artificial intelligence, an ontology is a noun rather than a state; a formal structure of definitions, components, concepts, entities and the relationships between these that work to form an AI reality (CIMIANO 2006). Thus, creating an ontology necessitates the creation of language (syntax and semantics), rules, knowledge and their relations (POOLE & MACKWORTH 2010). Human knowledge is gained by an experiential and intentional process of being in existence (e.g. a radiologist seeing imagery of cancer and discovering that cancer is present). Just as we each gain knowledge as a result of our learned language and experiences, an AI system must also have an explicit structure of language and experiences in order to learn (e.g. exposure to statistical properties of cancer in an image). The act of building an ontology can be likened to an act of teaching definitions and relationships between phenomena (or *things*). Teaching definitions, however, do not always provide critical nuance and context; instead, that is learned by process.

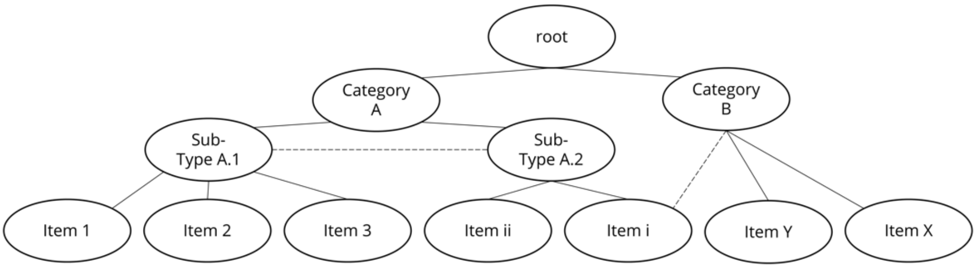

Fig. 1: Abstraction of ontological framework showing nested hierarchies and illustrated relationships (dashed lines). In a developed ontology, each oval would have a definition including syntax, unit, description, properties and synonyms.

For AI to develop it requires access to an ontology, which is often implicitly created by the programmer at the time of development. When programming an AI system, programmers develop classes, functions, variables, units and naming conventions in code. The creation of these is often done within a well-defined conceptual framework that has multiple degrees of formality from informal naming conventions to predefined reserve variables, functions and constants. An ontology is a formal way to express definitions and linkages between terms. It also enables AI systems and human coders to use, reuse, redefine and expand upon the ontology. The building blocks of an ontology often begin through an abstraction of key concepts, items, categories, et cetera, that are depicted through a hierarchical structure, as shown in Figure 1 (a practical example is shown later in Figure 2). The hierarchy provides an explicit rule of how *things* are connected, enabling the system to learn these connections and be connected to other published ontologies. For instance, a landscape architecture ontology could reuse a plant ontology developed by biologists, or a geoscience ontology that provides properties of soils, minerals and geophysical history. A relationship between these three ontologies means that an AI system would instantaneously have access to knowledge from each of these systems, analogous to Neo's rapid skill acquisition in *The Matrix.*

Crafting an AI ontology is at its core an act of assemblage. Rather than working from a tabula rasa, the program is nearly always built by explicitly remixing existing frameworks and applying them to problems in new contexts (JOHNSON-EILOLA & SELBER 2007). Such reproduction is considered best practice and often even a requirement if different applications are to communicate with one another (NOY & MCGUINESS 2001). A work of landscape architecture is no different. A site with all its components is shaped physically, culturally and functionally by remixing known ontologies of design processes and applying them to the problem at hand. Yet, understanding of these ontologies is markedly more implicit in practice than we often realize. For example, when a human designer composes the planting design for a pocket park, they generally go through the motions of analysing site conditions, developing the planting concept, selecting a plant palette (perhaps organizing it using the usual categories trees, shrubs, forbs and grasses, etc.), laying out a configuration for the selected plants in plan view diagram, and making a schedule for the implementation of the design. If the average entry-level designer were instructed to carry out these steps, the end goal would seem relatively clear. However, for an AI the goal would need to be more clearly defined. For instance, the AI needs to know what plants are, how to categorize them, what properties are important and what site conditions they thrive in. In this case, the fundamental questions of what, how, where, when, and why are procedural rather than theoretical.

2.3 Translating Practice into Language: The Question of an Ontology for Landscape Architecture

Developing a landscape architecture ontology may be a unique challenge because it hardly fits into the structured framework of a definition. This happens because the design process is culturally influenced and steeped in qualitative interpretation. Thus, a general glossary of landscape architecture terms would need to include cultural nuances in the meaning of such terms in different places as well as the interdisciplinary ways such terms can be measured (HERRINGTON 2013). John Stilgoe's "What is Landscape?" (2015) tackles such a task by revealing the complexity embedded in the attempt to understand what landscape (and therefore, landscape architecture) is. His tracking of the etymology of the word landscape across cultures and ages gives a sense of the vastness and extent of such nuances.

However, despite such hardness in defining landscape in a non-reductive way, such activity exists, and is practiced daily by designers around the world. How is that possible? As researched extensively in the field of cognition and cognitive science, the design process relies on unwritten knowledge, something practitioners learn by experience without referring to extensive verbal codification. Donald Schon used to call it "reflection in action" (SCHON 1983). As mentioned, AI requires an ontology, a syntax or a clear definition of the activity in order to automate it. Considering the complexity of the landscape architecture practice, what would be the ontology of landscape architecture, and how does one embark on the process of developing it? As we consider the development of a landscape architecture ontology, we must also explore our existential framework as designers - are we unique, a mere construct of other existing ontological domains or some combination thereof? If we assume disciplinary uniqueness, a direct adoption of other ontologies may not be compatible with our own. The ontology of landscape architecture must then include terms, associations and concepts endemic to practice and not just those borrowed from others. Thus, the *pursuit of an AI ontology for landscape architecture*, that is comprehensive and interdisciplinary, needs to be carefully crafted for AI functionality to be fully integrated into practice.

3 Example Ontology Using Fresh Kills Park Master Plan

With this understanding, we propose assembling a more explicit and programmable ontological structure for landscape architecture. One that compiles the already rich and diverse frameworks of the discipline and defines them procedurally so that the all but inevitable creep of AI applications into landscape practice evolves with, rather than supplants the role of the designer. To demonstrate the complexity of this task, we construct a sample ontology for one section of a well-known, well-documented work of landscape architecture: the Fresh Kills Park Draft Master Plan. The plan was developed over five years following the closing of New York City's Staten Island's Fresh Kills Landfill in 2001. The plan document continues to guide the phasing of the project today. Its conceptual framework, known as Lifescape, has become one of the most highlighted and critiqued poster children of the Landscape Urbanist movement, whether for its socio-ecological implications as a large park, its conceptual centring on cutting edge theories of ecological succession, or the role it played pushing the discipline into a new chapter (BEARDSLEY 2007, CORNER 2006, WALDHEIM 2016). Lifescape is defined in the report as the following:

> "Lifescape is an ecological process of environmental reclamation and renewal on a vast scale, recovering not only the health and biodiversity of ecosystems across the site, but also the spirit and imagination of people who will use the new park. Lifescape is about the dynamic cultivation of new ecologies at Fresh Kills over time – ecologies of soil, air and water; of vegetation and wildlife; of program and human activity; of financing, stewardship and adaptive management; of environmental technology, renewable energy and education; and of new forms of interaction among people, nature, technology and the passage of time."(FIELD OPERATIONS 2006)

This narrative statement is both broad and encompassing. It holds within it a variety of terms and concepts that would create a vast network of possible ontologies spanning far outside the scope of this exercise. For our purposes, we will focus on deriving a hierarchal ontology for just one aspect of the Master Plan which we consider to be a major driving force of the Lifescape concept, the Landscape and Habitat Plan; more specifically, the planting palette of that plan (see Draft Master Plan, Section 2.13, [2]). In it, there are three major landscape types proposed (wetlands, grasslands, woodlands) each with its own subsets of habitat types (e.g. salt marsh, fens, eastern dry prairie, birch thicket, etc.). For each habitat type, a palette of plants was selected to fit the priorities of low maintenance and ecological appropriateness.

In Figure 2, we have taken some of these elements and organized them into the beginnings of a legible hierarchy where a thing is the root, habitat types are the categories and subtypes, and the plants the items. This framework would then be discretized using descriptors called object properties, which delineate the relationships within the hierarchy as well as those between different sets of hierarchies. An AI would learn from this ontology, for instance, that a Morainal Oak plant community is a subtype of the habitats which make up the landscape category Woodland and is comprised of trees such as oaks, beeches, and hickories (with specific species denoted) and shrubs like arrow wood and spice bush. These connections might utilize a property like 'is part of' or 'develops from' to give meaning to their place in the hierarchy. Now that this habitat type is explicitly defined, it can be reused, modified, augmented and adapted to other design opportunities by an AI. Yet, it also provides benefits for human users to more quickly observe and understand the elements that make up this specific habitat type. This same process is done for every habitat type, where some plants are also "Part of" other habitat types.

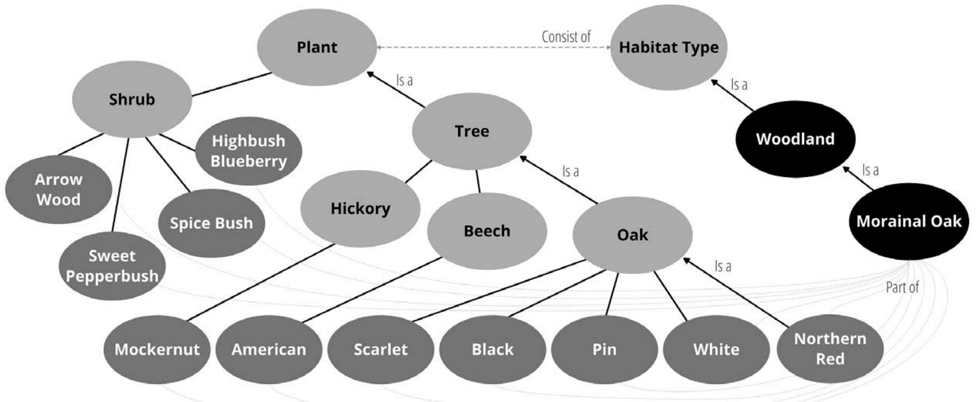

Fig. 2: Abstraction of ontology for Morainal Oak Woodland from the Fresh Kills Park Habitat Plan. Solid lines are hierarchical, light grey dashed lines are relational.

While assembling this habitat ontology, it quickly becomes clear that, given the available information in the master plan, it can only apply to that specific context and that the context itself is sparsely defined. The text provides no adjacent ontological contexts with which to associate it because it assumes an implicit understanding of its components e.g. the landscape architects assume the readers can reasonably know what a landscape is, what a plant is, what a tree is, where each these come from, how they relate to other examples of the same and what makes them specifically relevant to their prescribed type. A machine cannot know these things unless it is taught by a human expert (even through the reuse of other ontologies). Such an exercise offers an opportunity not only to lay out the terms of AI's engagement with practice but also to self-reflect and clarify what we understand practice to be and how we think it sits in relation to other disciplines.

4 Reflections: Limitations, Futures, Expectations

We recognize that an effort to assemble an entire ontology of landscape architecture in one paper or proceeding would be futile. Our intent is merely to initiate a call to attention toward the need for an explicit definition of terms and relationships of things within the landscape architecture domain. As digital landscape architecture professionals, we can be leaders in the AI-LA dialectic and lead the way in constructing language, skill sets, ethics, and best practices for environmental design. It should be emphasized that an appeal for further ontological structure in our digital practice does not diminish current or former structures of landscape practice; in our view, adapting the programmer perspective of reusing and expanding existing ontologies (e.g. building our framework utilizing the vast and well-established repositories in venues like AberOWL or GitHub and then building it right back into those repositories so it can be added to by the community at large) only deepens respect for them and affords an opportunity to better understand their nuance.

This is not a modernist call for historical erasure, nor is it a postmodernist plea for refracting our practice into endless language games. It is a challenge we extend to all in the discipline to have more organized and direct discourse on the application of artificial intelligence. The intent of this process is not to facilitate reductionism, on the contrary discourse facilitates clarity of our own language. Further, while AI in landscape architecture may be perceived as nascent within practice, if we do not lead this discourse we risk letting it be defined by those who lack knowledge of our practice and thus lack of embodiment of our language. Rather, taking the reins on developing an ontology enables landscape architects to facilitate control of our own language evolution. A clear, yet flexible structure of language allows us to challenge and anticipate the impending pervasion of AI into the industry rather than be blindsided by it. To this end, control of language begets control of agency guiding the design of new AI tools that take our work to places never before imagined, while still governing the creative process and avoiding a banalization of the landscape designer's role. This inevitably means reassessing the creative process itself and our role in it.

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Teaching Digital Landscape Architecture

Remote Wayfaring and Virtual Fieldwork

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Abstract: Regular users of the methods and techniques of digital landscape architecture (DLA), were presumably little disrupted by the paralysing impact of the current Covid-19 pandemic. But these digital operators have a front row seat in seeing how the global virus vaulted the field in a forward direction, rapidly increasing its prevalence. It was not only those in the business community that stopped travelling, became home-bound, and were tied to their desktop and computer screen. The scientific and academic communities were in the exact same position. Digitizing a workspace does not affect everyone equally, but it is particularly restrictive for landscape architects where "groundtruthing" is fundamental. It is not possible to completely replace real-world action and mobility with digital technology. However, with few options left, alternatives are necessary for those who usually develop their project and research work based on fieldwork, associated with travelling. A notable developmental leap in digital technologies in landscape architecture thus came in the most trivial and mundane form thinkable. In this paper, we describe how we conducted fieldwork in places that could not be reached without travelling, using commonly accessed digital tools as our forms of wayfaring.

Keywords: Remote wayfaring, fieldwork, digital landscape architecture

1 Context

Six years ago, daring statements were written like *fieldwork is not optional; it is mandatory* (REKITTKE 2015). The author now works with master's students of landscape architecture at the Norwegian University of Life Sciences (NMBU), who chose their study programme, amongst other motives, for the opportunity to conduct fieldwork in a global context. As researchers, we are, inter alia, embedded into a department research group in 3D visualization, and, as designers, we are standing for an outdoor profession – landscape architecture. It is a faculty and study programme that is aspiring to global relevance. The university reputes itself as a *sustainability university*, and therefore is looking to minimize travel activity in the future. This strategy began before and is independent of the current Covid-19 pandemic. But due to the pandemic-related ban on travel, a decision had to be made for this year's master's students as to whether the fieldwork component would be abandoned. We considered this to be a unique chance to test an inchoate approach that we refer to as remote wayfaring and virtual fieldwork. We refer to Olson's understanding that remote work is performed outside of the normal confines of space and time (OLSON 1983).

2 Research Forerun

Pandemic alarm hadn't yet begun during the developmental phase of the new international master's programme in Landscape Architecture for Global Sustainability (GLA) at NMBU in Ås, Norway. This phase included a pilot study with undergraduate and graduate students travelling to the Greek island of Lesvos to conduct analytical fieldwork. We named the pilot study NYMORIA – The Moria Project. Migration was the thematic subject, and we used a processing centre for asylum seekers and other migrants in Moria as a first study and design

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case. The Moria camp was hopelessly overcrowded. In April 2020, an estimated 21.000 people were insufficiently sheltered and served in squalid living conditions, because the premeditated facilities had been laid out for 3.000 people. Our assignment was to design an adequate reception and identification centre structure, in order to make humane living conditions possible. Ten days of fieldwork in February 2020 were allotted for this, in and beyond the Moria camp. Our post-pilot-study plan was to spend twenty-eight days of fieldwork in September 2020, together with the first cohort of GLA students, focusing on the Moria Camp once more, as well as conduct research on efforts and patterns of urbanization already made by the many migrants and refugees. Due to the persistent pandemic protective measures, this plan was not approved by our university management. Interestingly, our decision to conduct the pilot project in Greece and on the Moria Camp, was already an evasive manoeuvre from our first idea to work in, and on, Palestine. This was also not approved by the university due to safety concerns despite us having colleagues, such as NMBU's Ramzi Hassan and Karsten Jørgensen, with long-established academic relationships in Palestine. In fact, they almost succeeded in establishing a joined MLA Program, together with the Palestinian Birzeit University, located near Ramallah, West Bank (JØRGENSEN & HASSAN 2014).

3 Foreboding Self-Restraint

A distinct cohesion exists between the NYMORIA project loop ways and a concept titled *Convergent Digitality for Design Action in Obstructed Landscapes*, a paper published and presented in June 2020, at the 21st Annual International Digital Landscape Architecture Conference, hosted by the Harvard Graduate School of Design (GSD). We wrote: "Obstructed environments, often hold problems that landscape designers should be interested in. Investigating and making these problems visible, creating awareness, developing related design proposals, and initiating preferable change, forms the core of our design efforts" (REKITTKE 2020). The concept of Convergent Digitality constitutes a compromise of field presence and remoteness: "Not only due to the institutional, ecology-minded default, that travelling may not be obligatory for students in the future, we refrain from the assumption that all participants of our studios or projects will or can be present in the field, for fieldwork. As a basic principle, we plan for having a field team on site (Team 'Field'), and, at the same time, having a second team in a 'ground control' function, home on campus. To this group, we refer to as Team 'Houston'" (ibid.). We consider two persons in the field, they may be staff or students, as minimum requirement for adequate operability, the provision of expert testimony, as well as ground-truth. Real-world problems still make real-world contact and experience expedient, if not indispensable (ibid.). As if we had had a presentiment of what would follow, we hypothesized that the hand-in-hand collaboration between a team in the field, and a team in a control-room on campus, could result in significant additional benefits for globally operating landscape architects. We did not yet get an opportunity for adequately testing the respective self-restraint for its operability and efficiency, because not even the smallest team could travel for fieldwork after the concept had been published, due to the raging pandemic.

4 All-Digital and Stationary

Cancellations or prohibitions sometimes feature a good side. Suddenly, we were free to tackle our work and the world under changed conditions. Being not allowed to travel anyway, we chose places that are truly contested and obstructed, and – would we be physical travellers – entirely out of reach for us. The locations for the studio were related to our pilot Moria project and the guiding subject of migration and refugees: 1) war-affected Syria; 2) crisis-stricken Lebanon; 3) despaired Gaza. We set out for our fieldwork destinations as digital travellers, or remote wayfarers. These countries respectively subareas (Gaza) were our remote (virtual) travel and fieldwork destinations, our starting points for defining problem statements, and the sources of inspiration for migration-related design efforts in the course of our studio. Although none of the students moved from anywhere to anywhere, physically, the fieldwork led, for all intents and purposes, to meaningful design thinking and project work. We exemplify this by using two specific works for our paper. The remote wayfaring approach constituted a high risk of failure, but the results of the students were promising, well-grounded, and serious. It was genuine all-digital landscape analyses and design work, involving everything conceivable and accessible, from GoogleEarth to the CIA Fact Book, from popular Instagram to respectable university libraries, from pen-on-paper sketches to Geodesign approaches (PATTERSON 2007, FLAXMAN 2010, STEINITZ 2012). Three important things happened during our month-long virtual fieldwork. First, on the night of September 8th, the Moria camp burned down completely (AL JAZEERA 2020). Second, after returning from the field without having been to the field, we made a discovery worth reckoning with – a complementary method of landscape design related analysis and research. This method is minimally invasive spatial knowledge acquisition for global empiricism, or, in simple terms, remote wayfaring and fieldwork. Third, as academics, we realized, that the almost exclusive use of digitally accessible, secondary material of others – maps, videos, photos, texts, etc. – formed an ideal opportunity for deploying and teaching the unconditionality of sources in a scientifically correct way. This, though trivial, is not necessarily a matter of course for every design student in their daily practice. The students were taught to document their references using the NMBU-specific Harvard Referencing System, accessible remotely via their website, of course (NMBU 2020).

5 From Oslo to Bar Elias in Bekaa Valley

We chose two samples of works authored by studio participants, to exemplify possible approaches to the difficult task of travelling and field working without moving. The first work leads us from Norway to Beirut, Tripoli, and Bekaa Valley in Lebanon. Each leg of the trip happened as authentically as possible – 'see' the scenery en route to the airport with Google Street View (GOOGLE MAPS 2020), 'fly' on real, bookable flights and monitor them in live mode (FLIGHTRADAR24 2020), and 'reserve' real accommodation (AIRBNB 2020). Slowing down the pace of the digital travel to everyday speed and using ordinary online tools mimicked authenticity and reflected that travelling is continuous, unlike Google Earth's jumps suggests. The assignment was freely interpretable and gave no introductory site information. Without the student knowing anyone or anything about Beirut, she landed in the city and began. A shuttle took her to her hostel (BEIRUT AIRPORT TRANSFER 2020), and she began systematically walking Beirut's warm streets (YR 2020) via the unglamorous imagery of Google Street View (GOOGLE MAPS 2020). Beirut was an ideal starting location both as the capital and as one of the three densest locations of refugees (DIONIGI 2016). Facebook gave a voice to Beirut residents (FACEBOOK 2020a, b, c) and Snapchat informed her on local food and music (SNAP MAP 2020). The sensory information combined with news and articles began to shape a realistic depiction of everyday life while the news informed her of the current events (SHERLOCK 2020), something reinforced by her sketches. The early phase of the digital travel was defined by informal information sources, and was recognized as having distinct biases, but nonetheless useful for providing introductory information.

Fig. 1: Remote wayfaring from Norway to Lebanon. Left: Overview graphics by Kristin Lee Pedersen, 2020 (based on GOOGLE EARTH 2020). Right: Traveling from Beirut to Nahr El-Bared, through Tripoli (Graphics: Molly Andrews 2020. Photo: GOOGLE EARTH 2020).

The Beirut case study of refugees began with a host family in the Palestinian camp of Burj al-Barajneh (STEFANINI 2018). They spoke extensively about their experience as part of a diaspora and the intense restrictions that they face from the Lebanese government. Their lives and their conversations, regardless of being indoors or out, were defined by enclosure – homes were small and lacked natural light, corridors outside were tight, balconies or small roofs blocked much of the remaining light, and the jungle of cables finished the framing. While it was possible to find open space, it was limited to the few shopping streets, mini plazas, and a cemetery (GOOGLE MAPS 2020). The camp visit was supplemented by a visit to the American University of Beirut and their various ongoing research on the environment and refugees (AUB 2020).

Fig. 2: Virtual (remote) fieldwork photography. Left: Burj al-Barajneh, Lebanon (Photo: EID 2019). Right: A wedding party celebrating in the street in Nahr El-Bared (Photo: NO REFUGE LEBANON 2015).

In a moment of reflection, she paused to ask three questions: What have I seen? What haven't I seen? And most significantly, who haven't I seen? Much of the available information in Beirut, and later Tripoli – either academic or informal – was focused on Palestinians (BRITISH COUNCIL 2021, KNUDSEN 2007, FIDDIAN-QASMIYEH 2015), thus highlighting a clear bias and void. There are overwhelmingly more Syrians than Palestinians nationally – an estimated 1.500.000 Syrian refugees (UNHCR 2021b) compared to 500.000 Palestinians (UNHCR 2021c). This expedited her final case study in rural Bekaa Valley where over one-third of registered Syrian refugees reside (UNHCR 2021a). The town of Bar Elias in the Bekaa Valley governate is situated at the convergence of the extremely polluted Litani River and several of its tributaries (USAID 2012). It has as a high proclivity to flood (Jesuit Refugee Service 2019, Reuters 2019) along with seasonal water shortages (USAID 2012), something expected to worsen with climate change. Many Syrians have historically worked in Bar Elias in agriculture and construction (Alsheikh Kheder & Ibarra Sanchez 2018), an attracting point for refugees. Since the beginning of the Syrian war in 2011, it has more than doubled its original 50.000 residents (Francis 2017). Its rapid growth resulted in the urban sprawl of informal tented settlements that are shelter to over half of the refugee population (UN-HABITAT 2018). And while not every town has tolerated the presence of refugees (Frelick 2018), Bar Elias residents are open because they feel that their community benefits from the presence of NGO (Knowles 2019). Still, no place wants to host the refugees permanently (Al Ayoubi 2018). A mapping analysis identified the first project problem: too many refugees are living indefinitely in tents. Various reports on the Litani River informed on the second problem: severe degradation of water quality coupled with inadequate management. The third problem is a common thread in the debate about refugees: complicated social relations with locals. The three problems were distinctly intertwined. Combining maps of informal settlements (Zoom Earth 2020) and flood zones (USAID 2012), showed a large overlap that highlights the compounded vulnerabilities of refugees.

Fig. 3: Virtual (own) fieldwork sketching. Left: Bar Elias, Lebanon. Sketches by Kristin Lee Pedersen, 2020. Right: Shatila Camp, Lebanon. Sketches by Molly Andrews, 2020.

The resulting two-fold project addresses these problems in short and long-term scales. The student first defines appropriate urban development zones. A pilot project on 3.9 hectares (Zoom Earth 2020) proposes block housing with a large, protected interior plaza on a current tented site. It accommodates 330 families (Housing Agency 2018), or 2100 Syrian refugees (UN-HABITAT 2018). The outdoor space is left mostly open for self-defined use but incorporates elements that refugees miss from their homes. Sensitive to the flooding issue, the plaza stores rainwater. The second part of the student's project addresses the vacant agricultural land as refugees are relocated. Farmers that converted their plots into informal settlements will most likely not have the resources to remediate it (Nassif et al. 2020). This is a valley-wide problem. A land reallocation scheme frees up space adjacent the Litani River and upstream from Bar Elias and provides indebted farmers a pathway to continue their livelihood. The vacated land is converted into a wetland. It resituates materials on site to alter and slow the river flow, so it strategically floods into a designated plain. Excavated informal settlements become retention and treatment ponds. Trenches that already exist between the fields connect these ponds and encourage water to spread further, hopefully resulting in an aesthetic that hints at local agriculture as well as the refugee crisis. But it importantly protects Bar Elias from costly and regular flooding. Feedback on the student's work suggested real-world plausibility, but there are distinct shortcomings for fully digital fieldwork. Most significantly, images and narratives can be misleading and often capture an exaggeration of reality. There is no on-site presence to moderate this, only cross-referencing. This student's project was highly reliant on the accuracy of mapping informal settlements. Large groupings of tents are easy to identify from satellite imagery, but there is certainly room for error in the visual analysis. The sources used by the student began as very informal, shifting to academic literature, and lastly organizational reports as the fieldwork continued. This was not a coincidence, since her investigations and reflections led her to an area that is information-rich because of scientific, political, and NGO pursuits. While her first assumption was that Bar Elias was an unknown place, the reality is far from that and shows limitations in accessibility in truly remote, digital wayfaring.

Fig. 4: Left: Growth of informal settlements in Bar Elias, Lebanon (Photos: ZOOM EARTH, 2020). Right: Nahr al-Bared, Lebanon (Graphics: Molly Andrews 2020. Photo: GOOGLE EARTH 2020).

6 From Oslo to Nahr al-Bared in Lebanon

The second work sample leads us from Oslo Airport to Beirut, Tripoli, and Nahr al-Bared in Lebanon. She spent the first day and a portion of the following days exploring Beirut to begin to understand the extents of the digital fieldwork tools available. Through initial Google Maps and Facebook searches, the student discovered the Beit Beirut Cultural Centre, a former control point and sniper location that was positioned on the Green Line that divided Beirut during the civil war (BEIT BEIRUT 2020). This cultural centre has an active Facebook page where visitors can share their own images and experiences. Online travel blogs such as Runway27 (ibid.), allow the virtual traveller to read the personal experiences and opinions of the visitor alongside the visitor's images of the place. Beit Beirut hosts a series of fine art and photography exhibitions. The exhibitions have been photographed similarly to Google Street View so that the viewer can move about the building, even with a VR headset (HOBGOOD 2019). These exhibitions, such as Hala Younes' Lebanese landscape showcase', are usually documented by press (EL HAJJ 2018) and visitors (YOUNES 2020, ARIDA 2020), allowing to virtually attend an exhibition. The project offered 'a deep exploration of Lebanon's geography and landscape' (ABDEL-RAZZAQ 2020) which the student felt would help her to build a greater understanding of the subsequent fieldwork. She found footage of the respective 3D video installations on Instagram. Having tested a few digital wayfaring tools, she then intended to begin researching the Shatila Refugee Camp located within Beirut. However, rather than beginning a blind search for any information, she decided to investigate a for her familiar field of work. A golden rule applies to remote wayfaring and virtual fieldwork – we see what we know, and we find more than usual once we decided for a certain focus. Previously trained in textile design, the student found an embroidery studio operating in the camp. The Shatila Studio provides jobs for refugees in the camp, preserves traditional skills whilst also creating the opportunity to express a narrative of life in a refugee camp in the form of illustrative embroidery. Similar to Beit Beirut, the Shatila Studio has its own Facebook page which links to their Instagram site. Here they promoted one of their stockists on their Facebook page through a video (SHATILA STUDIO 2019). The video is an ordinary, unspectacular, informal piece of information. Although it is only a secondary source, it authentically shows an episode of daily life in a small boutique in Lebanon. The Shatila Studio has been featured in a short documentary by Tania Safi which was uploaded to YouTube (SAFI 2019), containing a great deal of footage and imagery that displays daily life in the Shatila Camp. The student paused Safi's video and sketched some of the visible landscapes, taking a pointed interest in the amount of light which is visible at street level. She then decided to search for additional existing projects taking place within the Shatila Refugee Camp. Recalling sources that she used when researching textiles, she was keen to explore the British Victoria and Albert Museum's online database (VICTORIA AND ALBERT MUSEUM 2020). The museum has a vast catalogue online which can be refined by country or region, materials and format.

Fig. 5: Left: Informal settlement in a vacant lot in Bar Elias, Lebanon (Photo: ALSHEIKH KHEDER & IBARRA SANCHEZ 2018). Right: The Shatila Camp in contrast to the reconstructed Nahr El-Bared Camp, Lebanon (Graphics: Molly Andrews 2020. Photos: SWANSEA CITY OPERA 2019, FREARSON 2013).

Through the Victoria and Albert Museum website the student found the *Culture in Crisis programme* (CULTURE IN CRISIS 2020). The site acted as a catalogue of projects taking place internationally and could be filtered by location. Within the Shatila Camp, she found a project called the *Swansea City Opera Lebanon Heritage Project*. The project organized a festival in which local dancers and singers could participate, they emphasized the importance of preserving traditional skills and events that were significant to the heritage of the inhabitants of Shatila. The Swansea City Opera project has stored much of this material with the American University of Beirut in an online archive which is available to the public. The student conducted more research into Palestinian refugee camps and read about the Nahr El-Bared Camp in the north of Lebanon near Tripoli. This camp had been almost totally destroyed in 2007 through conflict, and it had been decided that the camp would be reconstructed on the same site and restored to how it had been before 2007 (THE AGA KHAN AWARD 2011, RAMADAN 2009, UNRWA 2020). The intentions behind this were to preserve the social fabric of the site by learning from the inhabitants where their homes had been and who their neighbours were. The designers also had a goal of improving the quality of life in the camp by increasing the amount of open space (FREARSON 2013). This was achieved by reducing the footprint of each building, building higher, and making rooftops accessible spaces. Once in Nahr El-Bared, this location was explored through the lens of information from UNWRA, an article on Dezeen (ibid.), and the Aga Khan Awards web page (THE AGA KHAN AWARD 2011).

Fig. 6: Left: Regional-scale project area, Bar Elias, Lebanon (Graphics: Kristin Lee Pedersen 2020. Photo: ZOOM EARTH 2020). Right: Neighbourhood-scale project area, Nahr al-Bared, Lebanon (Graphics: Molly Andrews 2020. Photo: GOOGLE EARTH 2020).

An insightful source and design impuls came from *No Refuge Lebanon* which is the personal blog of an aid worker visiting the camp in 2015 (NO REFUGE LEBANON 2015). He documents the day-to-day events and community life. There is also mention of wedding party celebrations with people dancing traditional *dabke* along the narrow streets. (CARSON 2020). This insight built up a clear image of the significance of the outdoor spaces to the Nahr El-Bared community, and the student decided to investigate its spatial history through Google Earth Pro, where one can explore the historical aerials of a location. An aerial image from 2007, taken before the destruction of the camp, highlighted the density of the original camp. The 2020 aerial, showing the reconstructed version of the camp, provided a powerful contrast. Through the Daskara App (DASKARA 2020), a mobile application for tourists in Lebanon, the old quarter in Tripoli was explored as a design reference. This old quarter constitutes a model for successful refugee relocation (MAGUIRE et al. 2016), and the preservation of cultural landmarks (CULTURE IN CRISIS 2020). The student also discovered a link to drawings and plans of the Nahr El-Bared camp reconstruction. However, it was difficult to discern if these plans were created by the official project team, or maybe an independent theoretical project. Nonetheless, these plans did offer an insight into density reconfiguration and the design principles for the new camp.

For the final reflection on the spaces of Nahr El-Bared, the student chose an existing plaza and designed the space with a concept that sought to conserve a space for leisure and celebrations by formalizing movement routes around the designated area. Buffers provide distance between busy paths and the leisure area, thus sheltering the users of the space and limiting contact. The choice of materials in this plaza were informed by her fieldwork: the leisure area is denoted by an embroidery pattern across the floor; the plants reflect the culturally significant species to encourage a sense of connection and ownership of the space; the layered, stepped seating provides the opportunity for people to have a clear view over the space to watch celebrations; and lighting masts would allow for additional decoration for significant holidays or celebrations.

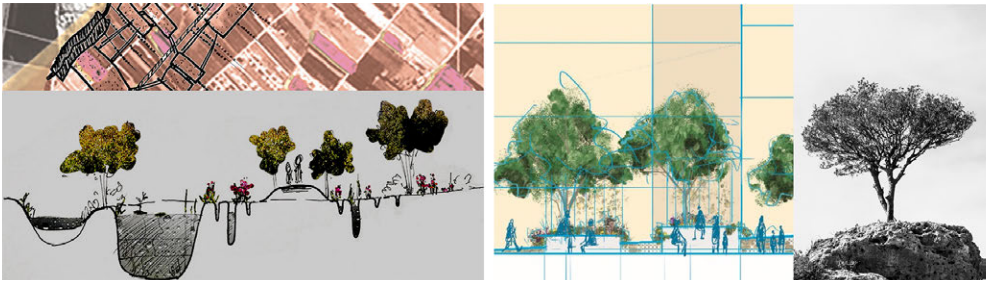

Fig. 7: Left: Constructed wetland proposal, Bar Elias, Lebanon (Graphics: Kristin Lee Pedersen 2020). Right: Neighbourhood square proposal, Nahr al-Bared, Lebanon. An olive tree, a tree of significance to Palestinian culture (Graphics: Molly Andrews 2020. Photo: CEBECI 2016).

7 Digital Sobering and Catharsis

There was nearly no use of sophisticated digital armamentarium during the uncommon studio course. This was limited to GIS-based maps for defining study areas as well as programs for designing presentations and exhibitions. We found that it was not needed for the unprecedented and challenging act of remote wayfaring and virtual fieldwork. This is presumably utterly disappointing insight, but simultaneously a very encouraging finding. We were not able to move in the field, this time, but did we need to use any different digital instruments than we would use during a physical trip or fieldwork mission? The answer is no, to a large extent, there were no outstanding differences. Even if we had been physically present in Beirut, or somewhere else in Lebanon, or any other place in the region, we would have used the same canon of catch-all digital applications, probably sitting on our hotel room sofa or in the breakfast room, before leaving for fieldwork: the standard Google applications or similar for orientation and navigation; the standard online social media and social networking services that almost everyone uses every day, in any case; and all other services and portals that can be retrieved online. The physical fieldworker typically takes numerous own photos when driving and walking around. This essential action from stroller's perspective could be astoundingly effectively substituted by the cornucopia of images and videos on Facebook, Instagram, YouTube etc. For many places there might be no image or angle of vision that had not been taken by someone before, and publicly posted on some internet platform. Exploiting these openly accessible informational treasure troves, may become a very serious element of future research methods, no matter if done by researchers themselves, with a longer corresponding reference list, or by machine-learning software. The informational amalgam of such existent, multifaceted mass information, may potentially contain much more truth, than from the personal photo or video of the individual fieldworker on site, who considers such piece of individual information as particularly authentic and true. What struck us, was the awareness that the great secondary digital information pool – *the internet* – provides insights in places and situations that we, an academic fieldwork group, would most probably never be able to visit or experience. We would not be able to visit Gaza during an airstrike and take footage of such hellscape. The people who live there do exactly that, and then subsequently post this material from their mobile phones on Facebook, Instagram, YouTube etc. Working on any design project in Gaza without considering such relevant detail of reality – recurring airstrikes – would be naive. This means for the designers and researchers, that they must, to an increasing degree, include the secondary but rich information that the World Wide Web provides. Formerly as exclusively physical travellers and fieldworkers, the forced remote wayfaring and virtual fieldwork constituted the important recognition that real fieldwork is not optional but mandatory, but that virtual fieldwork should become a self-evident complementary instrument in the course of any landscape design studio beyond one's own nose. Nevertheless, the virtual form of fieldwork is not made to supersede or replace the real one in the long term, even if some eager university treasurers may hope for that. Scientific work, also in the design fields, depends on verifiability and provability, and secondary material published online, can of course be false or misleading. Photos and videos can be manipulated, maps and other documentation can be propagandistic, and testimonies can be fake. Every secondary material has to be carefully interpreted, and, in case of doubt, be checked against further sources. However, crowdsourcing meanwhile became a serious and solid method in many areas of digital ventures. In his Wired article titled 'The Rise of Crowdsourcing', published in 2006, Jeff Howe reported of a project at the National Health Museum in Washington, DC, where information about potential pandemics like the avian flu had to be illustrated by pictures of sick people. Instead of hiring a photographer to take shots of people suffering from the flu, pre-existing images – stock photography – had been used in a successful and cost-saving way (HOWE 2006). Our approach of remote wayfaring and virtual fieldwork is to be classified as a form of academic crowdsourcing. We are aware of the related risks and shortcomings. It is primarily the banal web browser that is needed by both the remote wayfarer and the real traveller to prepare and perform systematic and serious work in the field. The difference between remote wayfaring and real travelling remains considerable, because the virtual fieldworker cannot produce what is called groundtruthing (HARTEN et al. 2020), the on-site verification of information. That said, the students' studio work accomplished through virtual fieldwork was well-founded and serious, by judgement of the related academic tutors and reviewers. Before the pandemic, the manageable community of digital landscape architecture sometimes had difficulties living down the prejudice of constantly chasing for the next sophisticated digital method, application, or workflow.

In landscape architecture, a true digital breakthrough had not yet happened, but has now materialized. Not in the form of a revolution, but quietly and silently, as an inevitable result of a worldwide crisis, and in the most self-evident and unsophisticated garb. *Being digital* (NEGROPONTE 1995), in every imaginable form, was the collective reflex during pandemic shut-downs, travel bans, etc., and, in an economic sense, epitomized the great crisis profiteers. We hope that the community of Digital Landscape Architecture (DLA) is ready to extend this once-in-a-hundred-years stimulus.

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Virtual Studio 1.0: A Virtual Tacit-forward Learning Management Framework

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Abstract: The purpose of this paper is three-fold. First, it documents the creation of a Virtual Studio learning management system that supports formal and informal tacit learning. Second, it provides a faculty reflection, and third, it presents student perceptions of the Virtual Studio in supporting an online planting methods course during COVID-19 restrictions. Survey results demonstrated strong support for using the Virtual Studio. However, students do not perceive it as a replacement of in-person instruction. Future Virtual Studios should explore the inclusion of real-time verbal communication to deepen social- and co-presence.

Keywords: Tacit learning, virtual studio, learning management system, studio presence

1 Introduction

This paper describes the creation and student perceptions of a Virtual Studio learning management system (LMS) that supports formal and informal tacit learning. The virtual studio LMS supports all the standard functions of a traditional LMS – course administration, documentation, tracking, reporting, automation, and delivery. The virtual studio LMS differs from a conventional LMS in two ways: facilitating presence and live desk critiques. The purpose of this paper is threefold. First, to document the technologies used to model and host the Virtual Studio, including the underlying instructional support technologies. Second, to provide faculty reflection on, and evaluation of, the process and workflow, and assess to what degree it supported student engagement. Third, to document student perceptions and experiences of learning within the Virtual Studio environment. The length of this paper and the structure of the research design does not allow for an in-depth discussion of virtual versus non-virtual learning management systems. Instead, we focus on developing a virtual tacit-forward learning framework and students' perceptions of a pilot Virtual Studio LMS.

Studio. The word alone has a deep meaning within the design professions. Studio is a place where students research, propose, develop, interrogate, present, and reflect on design propositions that synthesize material from a diverse range of sources, both inside and outside the curriculum. However, in online education, design students lose some of the formal and informal tacit learning opportunities typically afforded by their physical studio environment. Indeed, the switch to online modes of learning halfway through the 2020 spring semester due to COVID-19 did not always effectively facilitate interaction in our tight-knit studio groups – what WENGER (1999) refers to as 'communities of practice.' Specifically, Zoom and Canvas at best only moderately supported peer-to-peer and engaged approaches discussed by SHALINSKY and NORRIS (1986) and BROOKS et al. (2002). Similar challenges were met by most other online studios in our graduate and undergraduate programs. With that hindsight, we critically discuss constructing a virtual tacit learning management system for our Fall 2020 studio.

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1.1 Planting Methods (Course Background)

The Virtual Studio supports the 2020 Fall Planting Methods (LArch 335/837). LArch 335/837 is a three-credit, technical implementation course within the Department of Landscape Architecture at Penn State University. The course enrolls 41 3rd year undergraduate bachelor of landscape architecture (BLA) and three 2nd year master of landscape architecture (MLA) graduate students. LArch 335/837 meets six-hours per week and runs for 15 weeks. Both the BLA and MLA are accredited professional degrees prerequisite to the licensure needed to practice in most U.S. states and Canadian provinces.

1.2 Course Goals and Pedagogical Foundation

The authors leverage both explicit and tacit learning theory because the primary goal of Planting Methods is to facilitate learning about plants and planting implementation in the designed landscape. Objectives promoting this goal were to i) gain experience in the horticulture and "ecoculture" of contemporary planting genres ii) develop technical abilities in specie selection, planting establishment, soil improvement methods, plant installation details, and adaptive management of planted landscapes iii) gain fluency in contract documentation iv) bolster progressive planting design theory that addresses aesthetic, ecological, and functional factors, and v) continue the development of digital design software (e. g., AutoCAD, SketchUp, Adobe Creative Suite, and Lumion) for conceptualization, visualization, and contract documentation. The course aims are accomplished through scaffolded learning (WOOD et al. 1976) through three applied projects: a mixed planting bed, a treed plaza, and a planted meadow ecosystem. Scaffolding refers to how an instructor systematically builds on students' previous experiences and knowledge. As students' knowledge grows and they transition from lower learning levels (skills and knowledge acquisition > concrete conceptual > abstract thinking) to higher learning levels (problem-solving > problem finding), the instructors shift from direct knowledge-based instruction to providing guidance on complex, nuanced, and principled approaches to solving real-world problems (TAMMINGA & CIANTIS 2014). In essence, the student progresses from structured and instructive learning to more constructive, experiential and self-guided learning where socially-engaged judgment, empathy and even wisdom factor into the process.

As outlined above, the course structure reflects our belief that design students are well served by tacit knowing, or embodied knowledge, a constructivist approach to learning (JOHANNESSON & PERJONS 2014, POLANYI 1966). Essential to the constructivist approach is that learners feel they are active participants in directing their educational process, and that learning is a social activity where students are empowered to share technical and creative problems with their peers as they use various modes of representation. Tacit knowing is supported by manipulating the tools of practice, a process called reflection-in-action, as students iterate their drawings and models (SCHÖN 1985). However, we cannot ignore explicit knowing within this course – what DE JONG and FERGUSON-HESSLER (1996) call procedural knowledge. Students need a base knowledge of key facts regarding plant characteristics and associated environmental needs for healthy plant communities (e. g., soils, climate, hardiness zones). Additionally, students must be introduced to professional standards of contract documentation and construction procedures and protocols. The course activities, processes, and learning modalities, then, must blend formal and informal explicit and tacit learning. In other words, both tacit and explicit knowledge is scaffolded within the course. Throughout the course students are guided through basic concepts of creating human-scale environments with plants, infrastructure, built form, landform, and ecological processes, while concurrently introduced to the information and skills needed to prepare plant palettes and seed schedules. Additionally, these concepts are paired with visual communication, technology, and technical construction documentation skills; for example, three-dimensional modeling and CAD planting plans and drafting standards. As this is the first and only planting methods course in Penn State's curriculum, our intent is to guide students from knowledge to applied thinking and then translate this constructed knowledge to subsequent design studios.

In the Fall 2020 virtual version of the course, explicit knowledge modalities included faculty-to-student instruction such as conventional online lectures, technology demonstrations, and discussions – all formats that students were used to. But as the semester loomed, we realized we were on course to repeat our Spring 2020 shortcomings on the tacit learning side of the spectrum unless studio format changes were made. Our LMS, Canvas, was largely closed to the students; it required faculty facilitation, which is counter to a constructivist approach to education. Hence, a virtual studio LMS needed to remain open to student directed and facilitated modes of learning. We invited our colleague, emeritus professor and digital design visualization expert Tim Johnson, to interweave several emerging virtual environments to craft a novel Virtual Studio that would accommodate both explicit and tacit styles, and that hosted collaborative whiteboarding, video conferencing, and video technologies. While the resultant model accommodated virtual explicit modes, such as formal desk critiques, presentations, and open document caches, they also embraced vital peer-to-peer learning modalities: small group pin-ups, peer critiques, and two extended design charrettes. Importantly, we soon realized that this de-facto virtual community of practice could also support peer-to-peer co-learning (SCHWEITZER et al. 2008) in ways that encouraged informal, non-class time browsing of peers' work left on virtual desktops – much like the analogue studio settings that students and faculty alike cherished.

Also critical to the Fall 2020 version of the course was maintaining individual student presence in studio, as we wanted to avoid a repeat of the Spring 2020 transition to online instruction that witnessed a drop in student engagement. While some of this drop could be attributed to the worldwide anxiety of the pandemic, post-course evaluations showed that a portion of the decrease in Spring 2020 course engagement can be attributed to the loss of the dynamic nature of the physical studio environment, or "studio presence". Studio presence is a broad concept and has a variety of meanings; however, for this research, the term refers to three concepts: telepresence, social presence, and copresence.

Telepresence is the LMS's capacity to give the learner a feeling of "thereness" or studio embeddedness (SCHROEDER 2002) – a sense that Canvas and Zoom cannot adequately provide. Telepresence is intended to enhance engagement through effective nonverbal communication and visual interaction by establishing student comfort and familiarity within the virtual space.

Social presence is the degree to which students feel they have access to each other's design ideas, technical development, and digital representation strategies (RICE 1993). This form of presence in face-to-face classes is typically supported by the physical spaces we inhabit, e. g., desks or drawing pin-up walls, which can be self-organized by students and changed as needed during and after studio. Research has shown that access to their peers' work reduces learning anxiety by showing that they are not alone and are supported by others, thus improving mental health which, in turn, facilitates even deeper course engagement (JIN 2011). However, as we found in Spring 2020, this was difficult to accomplish within the Canvas LMS because students could not self-organize peer-to-peer critiques and drawing. While it is true that students could self-organize using other technologies, the fragmentation of their efforts produced barriers in smoothly moving between one community of practice to another. Therefore, the Virtual Studio designed for Fall 2020 includes collaborative whiteboard technologies that mimic the availability and self-organization capabilities of our in-resident studio desks and pin-up spaces.

Copresence refers to a psychological connection to and with another person. Copresence requires that students can actively sense interacting partners and that these partners can reciprocate in sensing them (NOWAK 2001). Copresence is essential in forming and maintaining interpersonal relationships within communities of practice. The Virtual Studio environment supports copresence through video conferencing and collaborative white boards. The white boards support synchronous, multi-user, named cursor tracking and named asynchronous comments. Collectively, these technologies can increase social and copresence.

1.3 Previous Virtual Learning Environment Efforts

Virtual learning environments are not new to the landscape architecture academy. Indeed, research has explored the use of virtual environment and gamed supported pedagogies using SimCity (CHAMBERLAIN 2015) and Second Life (THOMAS & HOLLANDER 2010). Additionally, virtual environments were created to teach targeted concepts such as grading (LI 2016) or to visit inaccessible places through virtual field trips (HUANG 2020). While these efforts have pushed the boundaries of landscape architecture pedagogy, they have also necessitated specialized hardware and fast network connections (CHAMBERLAIN 2015). Additionally, these tools often introduced novel workflows or means of interaction and design visualization that precluded other forms of media (e. g., hand drawing on tracing paper), a necessity for some students without the technological capacities to support specialized virtual interactions. Finally, they also facilitated specific design assignment and tasks and were not intended to serve as the studio itself. Hence, the need for a Virtual Studio that becomes the context for an interactive and blended approach to both tacit and explicit learning and the associated wide array of project deliverable media.

2 Methods

2.1 Virtual Studio Technologies

The virtual studio consisted of four areas: studio desks, lecture hall, pin-up spaces, and lounge. Studio desks consisted of two critical components, a virtual whiteboard and video conferencing (Figure 1). Conceptboard was chosen as the whiteboard software because it is perpetual and provided the ability to upload multiple file-formats: JPEG, PNG, AI, PDF, PSD, DOC, XLSX. Additionally, Conceptboard accepts embedded audio and video files. Conceptboard's drawing tools were useful because they allowed for varying colors, line weights, and recognized mouse and pen-based inputs. Zoom enabled video conferencing. Each student's desk contained direct links to each faculty's Zoom sessions for easy access. The capabilities mentioned above were vital because they supported desk critiques, a central pedagogical class activity. Synchronous desk critiques require redlining and drawing construction documents, details, and complex construction notes. Additionally, the combination of Conceptboard and Zoom facilitated copresence and social presence during class time.

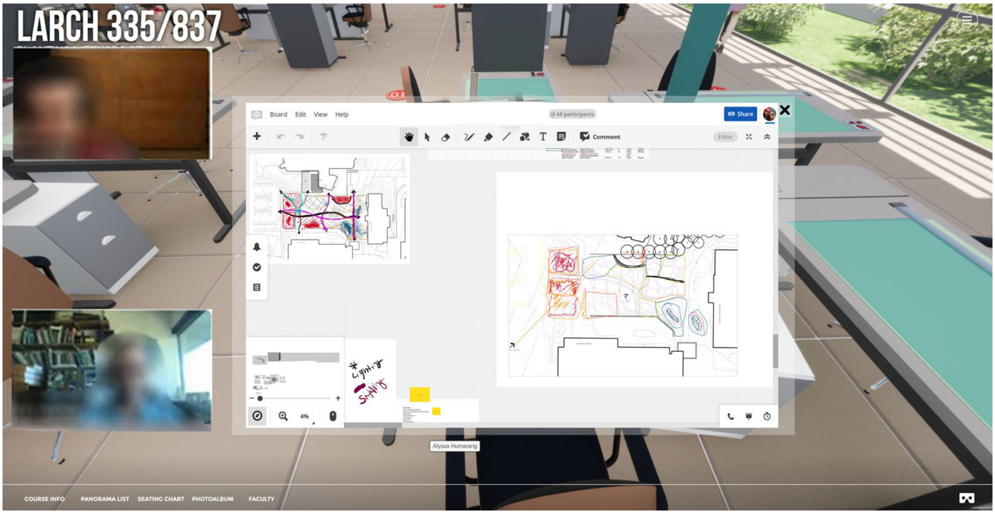


Fig. 1: The Virtual Studio video conferencing desk critique space

The virtual lecture space facilitated explicit knowledge transfer through links to live Zoom lectures and a YouTube repository of pre-recorded technology demonstrations, course materials, and past lectures. Pin-up spaces were created using embeded Conceptboards to facilitate group critiques and discussions. Conceptboard supported copresence during pin-ups through synchronous, multi-user, named cursor tracking, named asynchronous comments, and presenter controls, in addition to the benefits outlined for desk critiques. A lounge was created

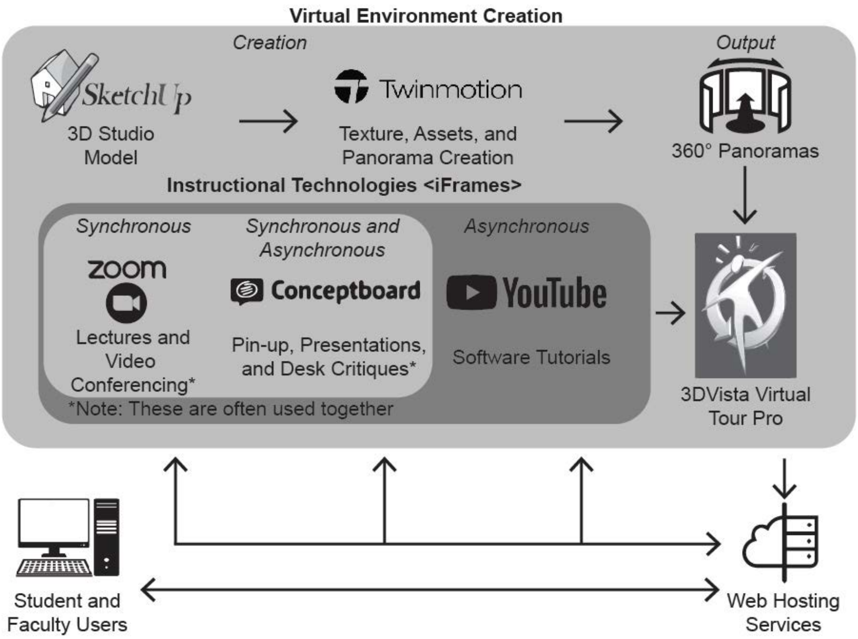


Fig. 2: Virtual Studio workflow and technology integration

to support student mental health and relaxation. Embedded within the lounge were links to local food delivery services, movie watch parties, and music.

The Virtual Studio was modeled in SketchUp 2020. Twinmotion 2020.2 was used to texture and add additional assets (e. g., people, display walls, skylights, plants, sounds) to the model. The studio was built using 120 unique panoramas exported from Twinmotion and imported into 3DVista's Virtual Tour Pro 2020.4.1, an interactive 360-degree virtual tour authoring software. Students and faculty navigated the studio using clickable hotspots to move from panorama to panorama. Hyperlink shortcuts also allowed users to immediately jump to any panorama within the studio. The completed Virtual Studio model contained 175 media objects and over 1,000 images. Learning technologies included Conceptboard, Zoom, and YouTube. Figure 2 outlines the workflow and integration of technologies.

2.2 Survey

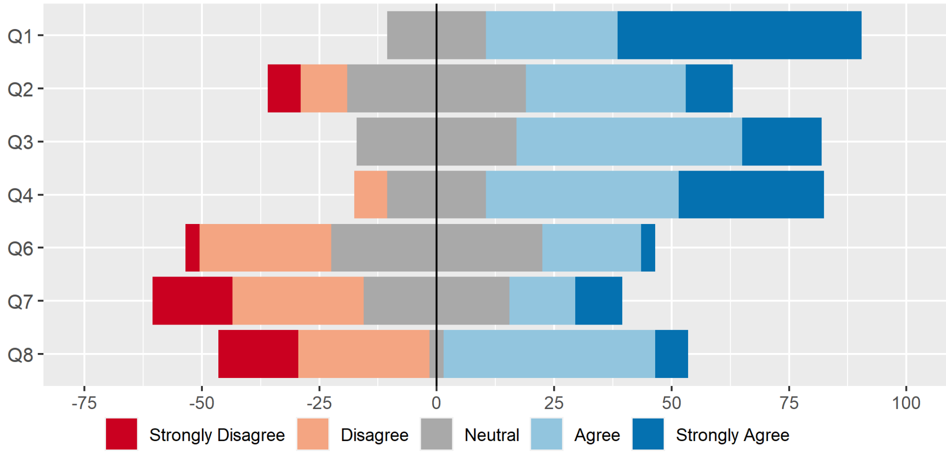
Student perceptions and Virtual Studio experiences were collected through a fifteen-question survey using a mix of five-point Likert scale rating system and open-ended questions. The survey had three parts. Part I questions sought to understand how the students expected the Virtual Studio to affect their learning. Part II sought to understand how students felt about using the Virtual Studio. Qualitative responses to survey questions were coded to identify prominent themes in student responses. Part III documented students' usability and internet connectivity issues, which could have impacted their experiences documented in Part II of the survey. The survey was administered in the twelfth week of the semester. Part III's data was used to identify correlations with perceived effectiveness and technological issues. Collectively, the survey sought to elicit the level to which students felt that the Virtual Studio replicated the interactive and synergistically creative conditions that are hallmarks of an effective, non-Virtual Studio setting. The survey was administered to all 41 undergraduate and three graduate students during a class Zoom session. As the three authors were engaged in the course and determining student grades, an external faculty member held the survey responses until final course grades were submitted.

3 Results

Thirty-three students responded to the survey request, with 29 students fully completing the survey. The response rate was 65.9%.

3.1 Survey Part I – Student Expectations of Learning within the Virtual Studio

Figure 3 presents the Likert-scale survey question results. Part I survey results show that, before the semester, a significant proportion of the students felt nervous about engaging online (52% strongly agreed and 28% agreed). Forty-four percent of the respondents thought the Virtual Studio would increase their learning, compared to Canvas and Zoom alone.



Q1. Before the course, I was nervous about remaining engaged in online learning.
Q2. My learning in this course will increase because of the Virtual Studio.
Q3. I enjoyed using the Virtual Studio.
Q4. It was a good idea to use the Virtual Studio in this course, and it should be expanded upon and used in future virtual courses.
Q6. The Virtual Studio improved social interaction with my peers.
Q7. The Virtual Studio gave the course a continuing presence, similar to face-to-face, which made it easier to stay engaged during and outside of class time.
Q8. The Virtual Studio is a useful learning mode and should become an integral part of mid-level to advanced studios even during non-pandemic times.
Note: The survey had eight questions, presented in the same order here. Question 5 was excluded from analysis due to wording ambiguities that were not detected until after the survey was administered.

Fig. 3: Summary Table of Likert-Scale Survey Question Results (results presented as a % of total respondents; n=29)

3.2 Survey Part II – How Students Felt About Using the Virtual Studio

Part II consisted of several Likert-scale questions (Figure 3) and several open-ended questions. Overwhelmingly, 72% of the students thought using the Virtual Studio was a good idea and recommended it to be used in future virtual courses. However, when comparing the Virtual Studio to face-to-face studio learning, students were split as to what degree the Virtual Studio improved social interaction, with 31% saying it did not, 24% saying it did, and 45% remaining neutral. Additionally, only 15% thought the Virtual Studio created a sense of continued engagement, similar to face-to-face, while 45% did not, and 31% were neutral. However, 52% of the students thought the Virtual Studio was a useful learning mode and that it should be integrated into mid- to advanced-level studios, even during non-pandemic times.

Students reported that the desks linked to individual Conceptboards allowed for favorable synchronous desk critiques and peer reviews (22 students). Additionally, students appreciated the synchronous availability and personal archival aspects of the Virtual Studio space (10 and eight students, respectively). Students liked that the virtual studio "acted like a real classroom" in that it was a space – albeit a digital one – that served as a better learning management system than a series of links in Canvas (10 students).

The coded results of the Part II open-ended question "How did your student-student learning change (either positively or negatively) because of the use of the Virtual Studio" produced several themes. A majority (67%) of students enjoyed using the Virtual Studio, while only seven percent did not. Part II question coding also showed students thought the Virtual Studio was user-friendly (15 students). However, the students did not like the panorama node-based navigation that 3DVista's Virtual Tour Pro requires, suggesting further work is needed to ensure more fluid or direct ways of accessing their desks (six students). Students repeatedly made this point; for example, Student 24 noted:

> Moving to my desk is not that smooth. It is annoying how you move around and can't just click on my desk from the plan view. The same goes for going to someone's desk across the studio.

In response to, "What were your least three favorite features of the Virtual Studio", students predominantly focused on node-based navigation frustrations (19 students). Students noted that instead of navigating the studio space, they relied on the panorama student name list available in the menu below the virtual studio window. However, they still found this less than satisfactory since it was ordered spatially, rather than alphabetically or by a stratified system of locations (six students). Additionally, students noted frustrations with logging into Conceptboard, as it occasionally would require multiple efforts to achieve access successfully. Finally, students indicated that peer-to-peer communication was not as easy as accessing the professors via Zoom.

The coded results for the question, "Describe what features and functions you would like to see added to the Virtual Studio", produced two strong themes: proximity-based peer-to-peer communication (13 students), and live avatars with gaming-like, fluid movement and verbal communication (six students). However, not all students suggested the same communication method: some students suggested proximity video like Gathertown, while others wanted instant messaging, audio, or a notification center.

3.3 Survey Part III – Correlations with Perceived Effectiveness and Technological Issues

Survey results showed no correlation between students' home internet bandwidth speeds and technical glitches and crashes with negative Virtual Studio experiences, although a few students did note minor interruptions. However, for many students, the Virtual Studio provided a stable platform, as 41% of the students never experienced a technical glitch or crash, and 28% only experienced a few instances during the semester. Comparatively, the faculty's experiences were glitch-free.

4 Discussion

Prior to the semester the students were deeply concerned about the prospects for sustained engagement in an online design course format. The Virtual Studio more adequately facilitated informal and formal asynchronous and synchronous peer-to-peer design critiques than Canvas and Zoom alone. The faculty noted increased course engagement compared to the previous semester's online instruction initiated at the start of the pandemic. Additionally, we have some confidence that the Virtual Studio created greater telepresence and social presence than Canvas or Zoom because the technology allowed the students to engage with each other on their own terms, both during studio and after hours, using their own design processes and media. Indeed, students noted that telepresence was improved over previous online experiences because of the inclusion of familiar materials and spatial qualities within the Virtual Studio. As one student summarized, it "is better than a bunch of links." Additionally, social presence was also notably improved. Students specifically highlighted how the Virtual Studio desks served as a hub for conveniently accessing their Conceptboards and faculty Zoom links. Two specific benefits were noted. First, the Virtual Studio allowed students to collate a visual record of all peer and faculty critiques throughout the semester in a single, navigable space. Due to physical space requirements in face-to-face modes of class, this is often impractical to facilitate. Second, it allowed students to see the cumulative work of their peers. The resultant deeper engagement was also noted by JIN (2011).

Collectively, telepresence and social presence improved students' engagement in the course compared to the previous semester's partially-virtual classes. However, the Virtual Studio in its current form also somewhat limited social presence. First, students noted that not all their peers engaged with the Virtual Studio equally. Unequal engagement quite likely left gaps in tacit peer learning experiences. Several students suggested, and we agree, that more intentional requirements of uploading in-progress work could foster additional peer-to-peer engagement. However, while mandated interim submissions and reviews would increase peer-to-peer engagement, we are not sure if this would lead to deepening tacit peer learning experiences. Required, top-down engagement is counter to the spontaneity and self-organization of democratic communities of practice discussed by SHALINSKY and NORRIS (1986), BROOKS et al. (2002), and WENGER (1999). This suggests a heightened role for student-led peer-to-peer norms, in addition to faculty expectations.

It is unclear if the Virtual Studio created or reinforced copresence, since the subject cohort of students has been matriculating together through the curriculum for several semesters. Therefore, it is difficult to determine if the Virtual Studio supported the creation of deeper communities of practice or if it served to maintain the communities of practice that already existed. Despite these uncertainties, many students discussed copresence limitations. Two specific copresence issues emerged: an inability to know who was actively using the Virtual Studio in real time, and an inability to engage in verbal peer communication intuitively and seamlessly. Finally, most students noted that while the Virtual Studio is a step forward in online learning support, it is not an adequate replacement for in-person studio.

Future research-based development should be able to improve all three forms of presence within the Virtual Studio. Replacing the static panoramas of the Virtual Studio 1.0 with an open world, multi-player gaming environment could improve telepresence, social, and copresence and tacit learning in two ways. First, a more deeply immersive learning experience could be created through the introduction of dynamic movement, lighting, and textures. Second, gaming engines could support the students' ability to inhabit the studio through avatars, as opposed to the current Virtual Studio's node-to-node based movement. The use of avatars could also deepen social and copresence by removing the barriers to initiating video conference and leveraging proximity video chat that supports real-time facial expression animation. Whether students' remote bandwidth and hardware setups could accommodate all these enhancements are open to further investigation.

5 Conclusion and Next Steps

The Canvas LMS + Zoom context is not an effective substitute for face-to-face studio experiences because it does not adequately support tacit learning and studio presence. New LMSs are needed. The Virtual Studio 1.0 supports an emerging framework using a virtual "physical space" that serves as a hub for tacit learning technologies. Additionally, the Virtual Studio begins to create studio presences, specifically telepresence, a critical piece of studio culture. However, copresence is not fully developed within the Virtual Studio space, and future iterations should leverage the open-world, multiplayer game engines for their dynamic and real-time engagement support.

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Tangible Landscape: A Waterway Design Education Tool

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Abstract: This study proposes the specification of a Tangible landscape (TL) to be used in the educational setting of a landscape design atelier. The main learning outcomes are to design alternative waterways in a riverine area taking into consideration the impact of waterflow on the landscape as a result of the designed waterways. TL is a projection-augmented sandbox powered by a Geographical Information System (GIS) for real-time geospatial analysis and simulation by coupling a mock-up with a digital model in near-real time by using 3D sensing, enabling users to apply geospatial simulation and visualisation. Notwithstanding the proven qualities of using TL in an educational setting, some obvious topics are addressed regarding the role of TL in educating waterway design. These topics are; how to realize a reusable and semi-realistic mock-up, in what way could waterways be designed without disrupting the mock-up, and how to give appropriate feedback during the design of waterways regarding the impact of waterflow change. The specified TL includes a thread-based approach that enables the student to design without disrupting the mock-up. Besides near real-time iterative results – both visually and numeric – it shows the hydrologic impact of the designed waterway. The expected outcomes of the current TL in education may stimulate topological thinking and insight into riverine geomorphology, it fosters representative and integrative thinking because of the near real-time relation between the design (form, scale, size) decisions and hydrologic process impact which makes the impact of design decisions on hydrological processes more illustrative and tangible.

Keywords: Tangible User Interfaces, hydrological modelling, geospatial modelling, education, landscape architecture

1 Introduction

Tangible Landscape (TL) is a projection-augmented sandbox powered by a Geographical Information System (GIS) for real-time geospatial analysis and simulation (PETRASOVA et al. 2018). TL couples a mock-up with a digital model in near-real time by using 3D sensing, enabling users to apply geospatial modelling, simulation and visualisation. The visualized elevation data is altered by changing the mock-up. TL is an example of a Tangible User Interface (TUI). A TUI enables users to physically interact with the digital environment (ISHII & ULLMER 1997) by removing the need for interaction with a mouse and keyboard by shifting to manipulation by touch and feel. TL has proven to be an effective tool for accurately modelling topography, to shape ideas, to perform quantitatively testing and to use an iterative design process to model topography using a digital reference (HARMON et al. 2018). It increases the understanding of geomorphology, of damming on historical flood landscapes (RENGIFO 2018), the course of waterways (HARMON et al. 2016, WOODS et al. 2016), changing hydrological conditions (RAHMAN et al. 2017), and the understanding of the difference between real and abstract representations (JERMANN & DILLENBOURGH 2008). Using TL, waterways could be designed by providing near real-time analyses and feedback. We propose

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TL in the educational setting of a landscape design atelier of which the main learning outcomes are to design alternative waterways in a fluvial area taking into consideration the impact of waterflow as result of the designed waterways on the landscape. Notwithstanding the proven qualities of using TL in an educational setting, such an approach has not been applied. Regarding such a TL some specific topics were not yet addressed, (HARMON et al. 2016 and 2018, RENGIFO 2018, MILLAR et al. 2018, RAHMAN et al. 2017) which can be answered by the following research questions:

1) How to create a reusable and valid near-realistic elevation model which has not to be constructed after every design session within a design atelier?
2) What design tool will not disrupt the mock-up and does support shape and size characters of a waterway?
3) Which numeric and visual feedback mechanism will support waterway design with specific – numeric and visual- information regarding the waterflow impact?

2 Methodology

To create a near-realistic elevation model, a mock-up of the study area was created using magic sand and a mould. The mould of 100 x 75 cm was based on a national DTM. To create the mould, the elevation of the DTM was inverted to correctly model the topography of the resulting mock-up. The elevation of the DTM was exaggerated 8 times, increasing the height differences, making it more easily distinguishable by the human eye and the scanner. The mould was constructed using CNC routing. To create the mock-up, the mould was placed into a rectangular frame (Fig. 1). Magic sand was placed into the rectangular frame, on top of the mould, uniformly filling it to the top. A plate was fitted on top of the levelled sand bed. Next, the frame was flipped upside down. Finally, the plate and mould were removed to reveal the mock-up. The experimental set-up of TL is depicted in Figure 2.

To enable the reuse of the mock-up, a non-disruptive design approach was applied by using a thread to 'design' the new trajectory of a waterway. By doing so, several interventions were simulated without distorting the mock-up. As a trajectory only defined the length and shape of a waterway, a newly developed feedback mechanism was applied that computed and visualized the effect of an intervention on the hydrology for a given flow rate. The development of this mechanism was split up into two parts. First, the centre line of the proposed waterway was constructed (Fig. 3, steps 1-5). Second, a raster representing the waterway was constructed (Fig. 3, steps 6-10). Finally, parameters for design such as the length of the trajectory, wavelength, sinuosity and amplitude were calculated. Initially, the flow rate and composition of the sediment were defined as model inputs. DEN BERG (1995) found that these parameters – in combination with the valley gradient – determined the geometry of braided and meandering waterways.

Fig. 1:
The mould; an inverted DTM of the study area which was used to create the mock-up. Z-values were exaggerated 8 times

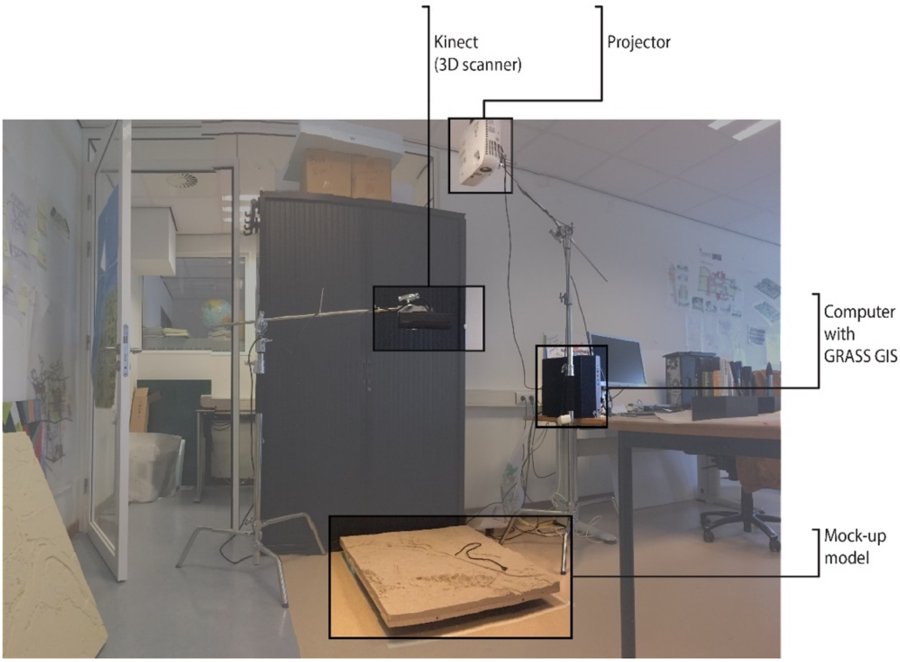

Fig. 2: Experimental set-up of Tangible Landscape at the *atelier* at *P4*. The hardware components: 3D scanner, projector, computer with GRASS GIS are depicted as well as the mock-up.

The geometry was predicted by using hydraulic-geometric equations (LEOPOLD & MADDOCK 1953) which relate the flow rate *Q* to a certain *width* and *depth*, according to following relations:

$$width = a * Q^b \quad (1)$$

$$depth = c * Q^f \quad (2)$$

with the coefficients a, c, and the exponents b, f being dependent on the type of river and climate. The hydraulic-geometric relations have been used for the design of waterways before with little variation in the exponents, for which in most cases $b = 0.5$ and $f = 0.4$ were used (MAKASKE & MAAS 2015). HOBO (2006) used a value of $a = 4.0$ and $c = 0.58$ for clayey banks in the study area.

To describe the shape of the proposed waterway a centre line was constructed. First, the raster cells representing the thread were filtered out (Fig. 3, step 2). A growing algorithm (LARSON 2019) was used to fill possible gaps. Next, a thinning algorithm was applied (Fig. 3, step 3) (JANG & CHIN 1990). The thinning algorithm used an iterative process, peeling off the outside pixels after each iteration. A cleaning algorithm was used (GERDES et al. 2016) (Fig. 3, step 5) to remove small spurs. Finally, the multiple vector lines were converted into a single polyline.

Using the constructed centre line, a waterway raster was constructed using the flow rate dependent width (Fig. 3**,** steps 6-7). Next, the depth of the design was calculated and integrated into the scanned DEM (Fig. 3, steps 8-10). The depth given by the hydraulic-geometric equation (Equation 2) indicated the depth of the waterway bed in relation to the top of the waterway, not the actual depth in relation to the scanned DEM. To calculate the actual depth more processing was needed (Fig. 3, step 8). Water flows from high to low elevation following the valley gradient. To simulate this, a raster plane was constructed according the valley gradient, length of the river, and aspect. The gradient was calculated as; $valley\ gradient = 180/(\pi * arctan2(\Delta h/\Delta d))$ where Δd is the Euclidean distance and Δh the height difference. The Euclidean distance, Δd, was calculated using the Pythagorean formula. Then, the aspect was calculated as $aspect = 180/(\pi * arctan2(\Delta x/\Delta y))$ where Δx and Δy are the differences between respectively the distinctive x-coordinates and y-coordinates.

From this raster plane the depth calculated by the hydraulic-geometric equation (Equation 2) was subtracted to derive the actual depth of the waterway (Fig. 3, step 9). Using the previously calculated waterway raster as a mask, the calculated gradient raster with the designed depth was re-sampled. A composite raster was created by patching the scanned DEM and the re-sampled waterway raster Fig. 3, step 10). Finally, this composite raster was projected on top of the mock-up.

Design parameters were calculated for each iteration. A schematic overview is depicted in Figure 4. Wavelength and amplitude (LEOPOLD & WOLMAN 1960) were calculated according to Equation 3 and Equation 4, respectively:

$$wavelength = 11 * w^{1.01} \quad (3)$$

$$amplitude = 3.0 * w^{1.1} \quad (4)$$

With w denoting the width of the river. The hydraulic radius, which can be used as a good estimation for the depth for design (MAKASKE & MAAS 2015) is described as (BROWNLIE 1983):

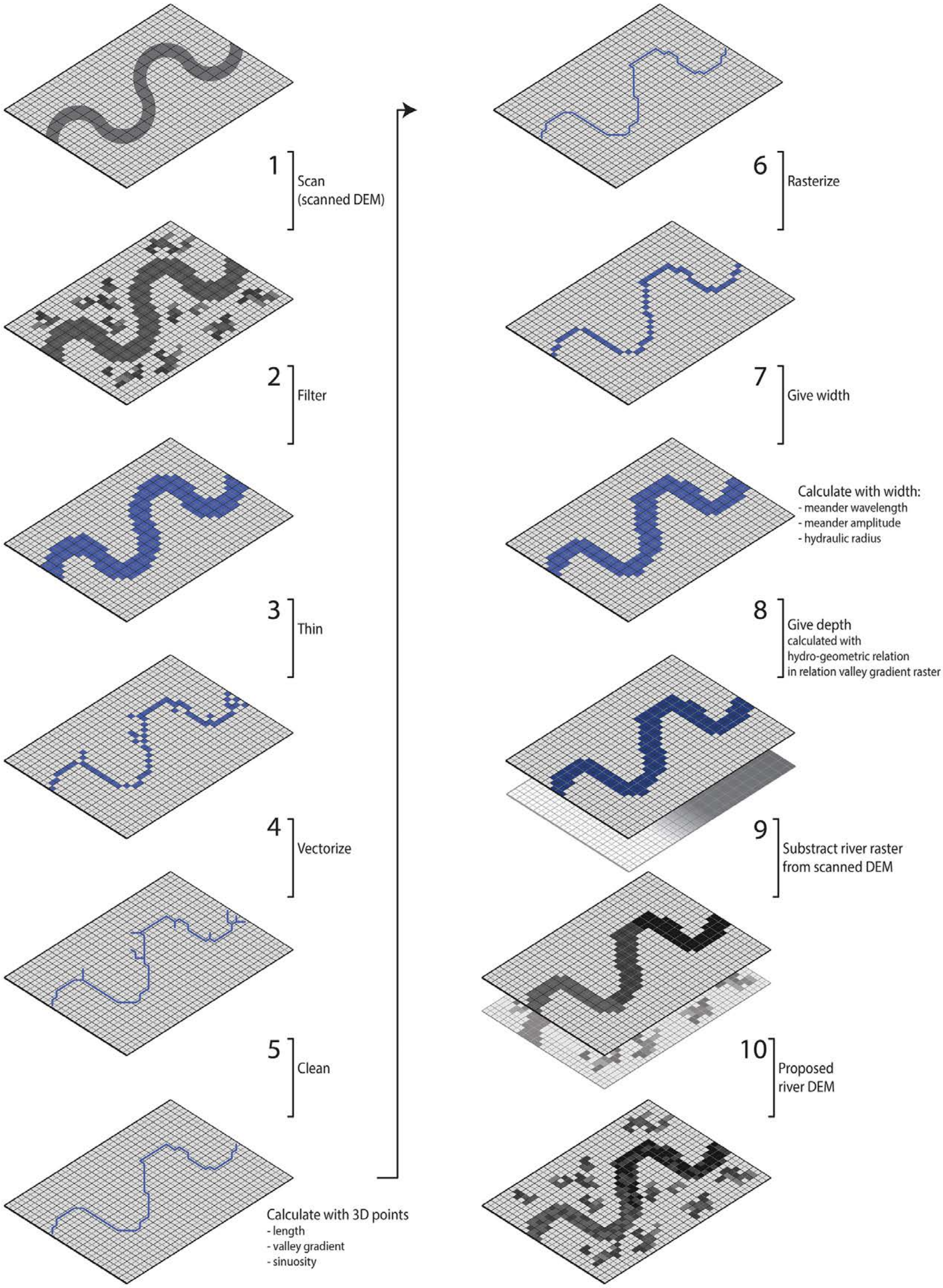

Fig. 3: Schematic overview of the process of designing a waterway using a thread

$$Hydraulic\ radius = S^{-0.2542} * 0.3724 * D_{50} * Q *^{0.6539} * \sigma_s{}^{0.1050} \quad (5)$$

With S denoting the gradient of the waterway, D_x (x = 16, 50 or 84, see below) the grain size in a grain size distribution for which x percent of the weight has a smaller grain size, Q the flow rate and σ_s the composition of the soil defined as $\sigma_s = \sqrt{(D_{50}/D_{16} + D_{84}/D_{50})}$. The hydraulic radius described the ratio between the cross-sectional area (hatched area, Fig. 4), and the wetted perimeter (red outline, Fig. 4).

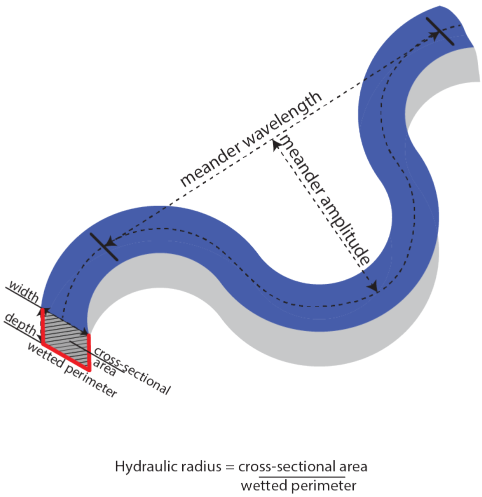

Fig. 4:
Schematic overview of the above mentioned relations: width (Equation 1), depth (Equation 2), wavelength (Equation 3), amplitude (Equation 4), hydraulic radius (Equation 5)

Another describing parameter for design is sinuosity, or tightness of the meander bend, which is expressed as the ratio of the length of the waterway in a given curve to the wavelength of the curve (LEOPOLD & WOLMAN 1960). In other words, the ratio of the length of the centre line of the waterway and the Euclidean distance between the start and end point of the waterway (WILLIAMS 1986).

3 Results

In an educational setting we proposed to use a 3D mould created out of the inverse of elevation data to deposit a mock-up to represent the study area. Waterway design was conducted by using and placing a thread on the mock-up. Regarding the placing of the thread the width, depth, numerical parameters for design, and course of the waterway were calculated and the georeferenced raster cells, as result of the calculation to coincide with the designed waterway changed accordingly. The geometrical changes increased with increasing flow rate. The change of geomorphology, depth and width of the waterway, was indicated by increasingly darker colours. The developed algorithm was carried out for several flow rates (Figure 5A1, B1, C1) and presented results (close-ups in Figure 5A2, B2, and C2 respectively). The developed algorithm proved to work consistently while alternating the placement of the thread. In doing so, different cases with changing geometry; length, direction and degree of bending were tested. In all cases the width of the modelled waterway was larger than the calculated hydraulic-geometric width. At higher flow rates, the difference was found to be larger. The depth of the waterway was observed to follow the calculated gradient of the valley as was intended. In all cases, the resultant length was larger than the calculated length. Both the meander length and meander amplitude increased with increasing flow rate as expected. A final design was realized by taking away sand or adding sand on specified areas. The specific areas were visualized on top of the mock-up as a guide. Positive (blue) values indicated that sand had to be removed while negative (red) values indicated that sand had to be added. White indicated that no sand has to be removed or added.

4 Discussion

Designing with a thread proved to be a straightforward process and may stimulate representative and integrative thinking, and insight into riverine geomorphology, because of the relation between the design (form, scale, size) decisions and hydrological impact. Using a thread-based approach enables the user to design, supported by near real-time iterative results – both visually and numeric – decreasing the needed effort and time, making hydrological processes illustrative and tangible. In our current approach we visualized the new situation as result of the thread-based design, to foster reflection upon design. To support didactics, we believe showing only changes regarding elevation and waterflow between designs offers more input for different adjustments of the final design. To support this, threads of different colours could be used to indicate the used flow rate, eliminating the need to define this manually.

This study assumed that realizing a waterway design by a non-disruptive change of a mock-up will be possible by using additional tools like threads and feedback by visualisation. However, in practice the resolution of the scanner was too low. The resolution of the scanner must be close to the resolution of the raster data to be processed, and to visualize the required changes on the mock-up imposed by the proposed design. Decreasing the extent of the study area would increase the size of the proposed changes, yet decreasing the insight into the larger context. Changes were difficult to interpret due to the small size of design proposals, including the small change in depth compared to the vertical scale, which was already exaggerated 8 times to give greater emphasis. By exaggerating the height, features otherwise not perceptible given the Dutch context and scale of the mock-up could be recognized. However, this could lead to unintended impacts on topological thinking and a possible false perception of the represented landscape.

The thread based approach could be applied as a Research Through Design method, which is applied in engineering-oriented landscape designs where models or simulations are tested and evaluated until an optimised solution is found (VAN DEN BRINK 2016). Our approach enables iterative, and quick simulations accompanied with numeric parameters for evaluation.

Designing with a thread entailed drawbacks as well. Intuitively, the problem with representing the trajectory with a thread is that the physical representation itself is the complete opposite of the phenomena that is represented. While a thread is an elevated structure, a waterway is an excavated structure. Moreover, the thread obscured the visualized results as both covered the same extent. It remains questionable if the calculated depth represents well the intended change as the height of the thread was scanned as well, This caused the surface of the thread to be the initial elevation, instead of the surface level of the mock-up. Fortunately, under-sizing a design leaves room for the waterway to shape itself via morpho-dynamic processes (MAKASKE & MAAS 2015).

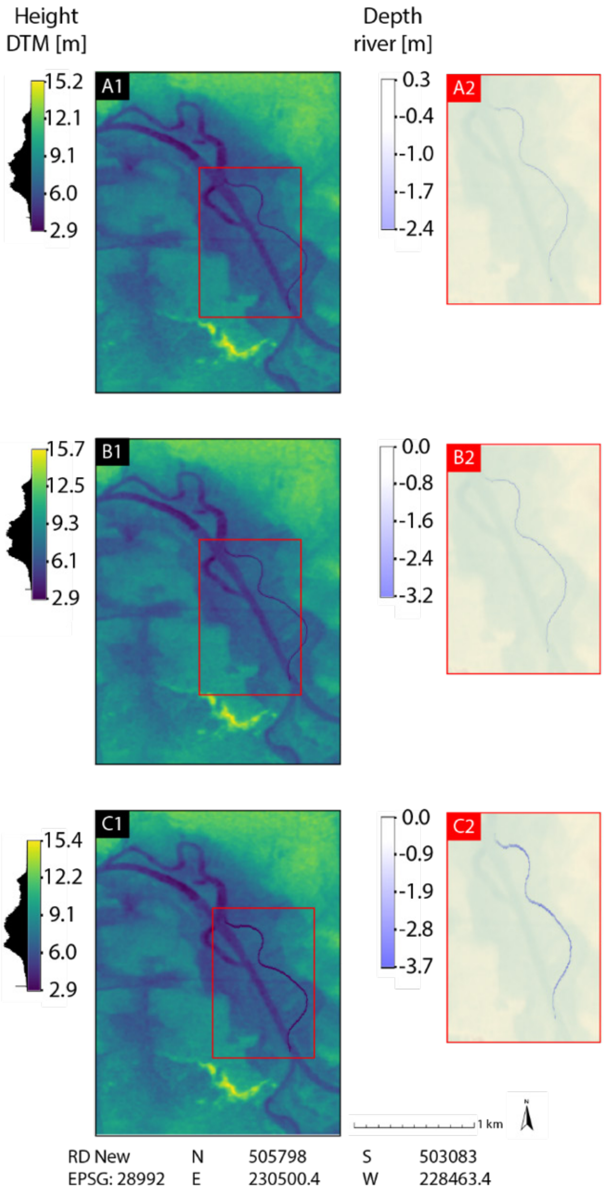

Fig. 5: A1-C1: the waterway design integrated in the scanned DEM is shown. A2-C2: a detailed view of the designs is given as well as the raster values only for the raster cells of the waterway. From top to bottom, the waterway is designed for a flow rate of 3 (A1), 9 (B1) and 15 (C1) cubic meter per second respectively.

5 Conclusion and Outlook

This study presented a specified TL making use of a valid near-realistic mock-up that represented a real world riverine landscape. The developed thread-based design approach enables iterative waterway design and a mean to realize designs by altering the mock-up. TL and the developed thread-based design approach fosters representative thinking, and ultimately makes the impact of the designed waterways on the hydrologic regime by near real-time calculation more illustrative and tangible.

In 2015 a waterway was realized in the study area that was designed with the same principles as applied in this study. The measurements and data of this realized waterway, and of the monitoring afterwards could be used as "ground truth" to further calibrate and validate the functioning of the developed algorithm.

The developed TL will become an instrument in landscape design education after testing the application with professional designers in the setting of projects regarding the redesign of waterways. In the context of education monitoring student experiences and reflections by using this TL is essential to become aware of the added didactical value. Especially the (un)intended impact on topological thinking regarding the change of geomorphology visualised by the projection of the (re-calculated) elevation on the slightly exaggerated height of the mock-up could be nicely studied by using this TL.

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Teaching Urban Landscape Microclimate Design Using Digital Site Visits: A Mosaic Method of Embedding Data, Dynamics, and Experience

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Abstract: This paper presents a methodology for creating a multi-modal digital site visit as a tool for teaching urban microclimate design. The approach draws on traditional site visit methodologies including walking and data capture and positions these within a curated digital environment to produce a 'mosaic' of critical data, representations, design theory and research. The construction of the digital site visit further applies principles from game-design to promote students' engagement and creative exploration. By producing an exploratory interactive digital site, the tool seeks to engage students with the complexity of microclimates in the early stages of the design process.

Keywords: Site visit, simulation, design pedagogy, gamification, landscape architecture

1 Introduction

Prior to 2020, interest in creating digital sites and virtual field trips for teaching design highlighted the many potentials of digital tools but also reported hesitations in translating studio methods to an online environment (BENDER 2005, GEORGE 2017). However, with the COVID-19 global pandemic and the shift to more online delivery, design educators have had to rapidly overcome these uncertainties. While the abundance of online data and digital resources have been invaluable for communicating spatial information to students, the previous hesitancy in using digital site visits has left gaps between these resources and disciplinary-specific pedagogical methods. For landscape architecture, this is evident in how sites are introduced to students in the early stages of a design process.

Landscape site investigations have traditionally used physical site visits, experiential recordings, and data collection as part of the early stages of design. For example, exploring a site through walking, surveying and site-specific embodied practices are common methods for understanding the special qualities, topography, materials, usage, and spatial scale of a place. However, it is difficult to substitute such place-based investigations in an online environment (DE WIT 2016, SCHULTZ & VAN ETTEGER 2016, WINGREN 2019). The broad range of existing research into creating digital sites has largely focused on technical aspects of recreating space. For example, using virtual or augmented reality to reproduce an immersive visual experience or communicate design concepts (LI et al. 2018, PORTMAN et al. 2015, TOMKINS & LANGE 2020). These approaches do not explicitly connect digital spatial replication with teaching generative design. Within educational research, there is an acknowledged need for online tools that more directly connect with the pedagogy of design studio (DREAMSON 2020, FLOHR et al. 2020, GEORGE 2017, PIPAN 2019, MILOVANOVIC 2020).

These challenges are further highlighted when teaching generative methodologies for microclimate and atmospheric design. In addition to understanding stable physical spatial characteristics, students must learn to work with fluctuating environmental phenomena such as temperature, wind, and solar exposure (LENZHOLZER 2015, WALLISS & RAHMANN 2018). Static

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representations and numerical forms of environmental data can be difficult for students to interpret as dynamic conditions which operate in time as part of a designed space.

Although digital experiences are common, there are gaps in structuring these resources for learning outcomes specific to design teaching. Particularly for students who are learning to work with data and digital tools, who need strategies engaging with the content, alongside explicit connections to design techniques. This paper describes a methodology that was developed in the move to fully online studio teaching. The digital site visit was produced for an interdisciplinary master's design studio working with microclimate design in inner-city Melbourne, Australia. The 2020 pandemic lockdown in Melbourne imposed severe restrictions on public movement and congregation. This resulted in students not being able to access outdoor sites and having to work from home using personal computers. While completely immersive digital experiences have been found to improve student's engagement and interest with site conditions, these often require access to specialised hardware in laboratories (FISCHER et al. 2020, FLOHR et al. 2020, PORTMAN et al. 2015). In this instance, teaching remotely meant that the digital site visit had to be accessible and functional from a range of home devices whilst also introducing students to the diversity and variability of designing with urban microclimate phenomena.

2 Capturing and Revealing Microclimate Dynamics

The methodology begins with capturing and curating material to populate the digital site visit. The range of material is gathered to fulfil two purposes: to expose site-specific microclimate phenomena and further to demonstrate landscape design site investigation methods. The site recordings and data were captured using three established techniques – data logging, photography and sound and video recordings. These techniques are widely used in traditional physical site visit analysis and here they continue to be employed as the primary devices for capturing spatial, visual, and audio observations for informing the early stages of design.

The framework for capturing site information is based on explicitly revealing microclimate dynamics within the site. The aim is to highlight localised microclimate and atmospheric behaviours by exposing environmental differences and revealing comparisons. To do this, two walkable transects across the site are chosen to create critical parallels which can demonstrate microclimate fluctuations within close spatial proximity. Data is captured by physically walking the transects while logging environmental information using air temperature, humidity, and air flow sensors. In this example, iButton temperature and humidity sensors and a handheld digital anemometer were used concurrently. Capturing microclimate variance through physical walking and wearable data tools has become increasingly common in recent years and there is a wide range of suitable tools for the task (CHOKHACHIAN et al. 2018, DZYUBAN et al. 2020, NAKAYOSHI et al. 2015, TOH & WALLISS 2016).

The organising principle for collecting data is further informed by the timing of the data recordings. Data loggers are programmed to take readings at regular intervals, for example, every minute. Subsequently, the act of walking is necessarily matched to the selected timed intervals. The walk is broken into a series of timed stops in a rhythm. This generates a sequence of regular moments or *key points* along the transects. This structuring device works to create a simple comparative spatial matrix of different microclimates within the larger site. The same transect walks, stopping at the key points are repeated on separate days, times and in different conditions, producing a set of environmental data which deliberately exposes the microclimatic patterns and variance at the site.

Each key point, where the environmental data has been collected, is further illustrated with video recordings and photographs to highlight the spatial and environmental phenomena in context. Street-level video recordings are used to demonstrate microclimate phenomena in action. For example, the sound and influence of wind moving through space, rain fall or visually tracking the changes to sun exposure and shade. Video is also used to record demonstrations of the data logging and field observations methods. This includes the instructor speaking to the camera, demonstrating the equipment and 'talking through' the process. By incorporating the demonstration videos into the digital site visit, students are provided with both the microclimatic material but also insight into the methods of how it was produced. Photographs are taken to highlight very specific site features or moments in time. While these cannot capture dynamic qualities, still images can be easily annotated to draw attention to precise details. Static panorama and 360° photographs are also used as the primary orienting and direction-finding visuals within the digital interface as these allow the user to pan and zoom as they choose. These direction-finding decisions become important as operational distinctions in navigating the digital site and investigating the site information.

3 Assembling the Mosaic – Compilation and Navigation

In assembling the material, the method draws on two compilation strategies: highlighting the deliberate contrast in the site data and the application of navigational *flow* from game design theory. Flow is described in game design as managing the user experience so that is not too easy and resultingly boring but equally not too difficult and frustrating (URH et al. 2015). In this case, creating appropriate *flow* is used as a playful mechanism for engaging students with discovering the nuances of variable microclimate conditions. In the digitally reconstructed site, the environmental data and recordings are embedded at different locations, some more evident than others. In effect, creating a virtual 'treasure hunt'. Through applying the principles of flow, the treasure hunt becomes progressively more challenging as students become more familiar with the site and the digital interface. By hiding and revealing the content, students are encouraged to pay close attention, investigate the material widely and open their investigations beyond the immediate and most obvious aspects of the site.

Creating the interactive and exploratory digital site utilises the H5P platform. This is an open-source HTML content editor which can host a variety of media to create interactive presentations and videos within a web-browser. The interface can accumulate information types and overlap multiple recordings of experiential qualities with data and other spatial information. Being web-based also overcomes some of the issues of accessibility for a student cohort who are working from home without access to specialised hardware or software.

The initial entry point to the digital site uses an aerial plan view which can be 'zoomed' into at the key points generated from the data collection along the two orienting transects (Fig 1.) Once zoomed into, the points are digitally viewed as a sequence of 360° ground-level site photographs that can be freely navigated to 'look around', pan, and zoom.

Fig. 1: Diagram explaining the structure of the digital site visit. Within the digital space site images are embedded with navigation arrows alongside spatial and microclimate details including temperature data, timestamps, and other media.

The street level images are further embedded with other resources such as readings from design theory, scientific research, and larger-scale meteorological data. The resulting mosaic of information offers a spatialized mode of exploring a site which is enriched beyond the existing capabilities of Google Street View or Near Maps.

The transects can be virtually traversed at street level by clicking navigation arrows which recreates 'walking' through the site. In moving along the transect from point to point, the sequence of images purposefully changes the representations of the temporal conditions that affect the microclimate. Thus, the student might virtually 'walk' from a rainy morning into a bright, sunny afternoon. While the static structures of the site remain as they do in real life, the changing atmospheric, weather and microclimates are revealed by moving and exploring the digital space. The changing visual representations are directly annotated with the site microclimate data alongside the other resources. This allows students to align the numerical data with explicit spatial and environmental characteristics and to associate invisible changes such as air temperature within the more obvious visual changes.

As the navigation is not prescribed, the virtual space can be fluidly moved through. The layering of information can highlight site phenomena or strategically hide details within the images. By constructing the digital site visit as a microclimatic treasure hunt or mosaic, the pieces exist concurrently where students must unpack and explore the range of information within the constructed visual-spatial representation (HOLLAND & ROUDAVSKI 2016, SEZGIN & YUZER 2020).

4 Application to Design Teaching

The method described here does not aim to produce a 'digital twin' of the site or a real-time virtual experience. Beyond simply packaging and providing the material to the students, the digital site visit aims to engage students in a deeper investigation of working out why the site microclimate behaves in particular ways. By structuring the material using game theory, the exploratory aspect of the digital space also allows students to make discoveries and further develop their observations. The game-like device of presenting the site and microclimate information to be discovered aims to foster curiosity and exploration towards exposing opportunities for design rather than reducing the site to single or static conditions (KAMUNYA 2020, MAJURI 2018, MARSANO 2019, TURAN et al. 2016).

As a teaching tool, the digital site visit can be configured to focus on specific points whilst also allowing students to seek out details and 'hidden' data. Whereas this library of information could be presented to students as an unstructured resource, by associating the material within the site's spatial conditions, students are offered an important set of connections between resources and site. The mosaic of information created by the digital site visit produces an effective lens for directing student focus – in this case on the role and effects of microclimate phenomena. This is useful for landscape architecture students who are just learning to interrogate microclimatic behaviours, where visually locating and connecting data overcomes some of the initial difficulties of interpreting numerical representations of environmental phenomena. Simultaneously, the careful curation of material provides important guidance to students through ensuring the quality of information and resources.

While there are clear opportunities in this method, there are also limitations to the approach for both design instructors and students. From the instructor perspective, there is a considerable amount of time and some expertise required in creating the entire resource. The full process of capturing suitable recordings through compiling and curating the media and further aligning theory and research is both labour and time intensive. Similarly, the method described here requires some physical site visits by at least one person and adequately capturing environmental variance entails multiple visits. While there are examples of remote site-based investigations produced by harvesting social media recordings from Instagram or Snap Chat, largely these studies offer a different focus to a designer-led site analysis. Many are framed around the user and audience perceptions and the emerging practices of consultation through digital storytelling and ephemeral communications (GEROS 2020, KAUSEN 2018, SONG & ZHANG 2020).

In the initial applications of this method to design studio teaching, students have demonstrated a complex understanding of site-specific microclimate dynamics in the context of landscape architectural design. However, without a physical site visit, there have been fewer opportunities for these students to engage with broader contextual site information that would usually inform their design work. In addition, under the instructor-led gathering and curation of information, students do not get to participate in the methods of site analysis themselves. While the site analysis techniques are demonstrated through recordings within the digital site visit, this does not equate to students applying the methods themselves – a potential gap that must be filled later in a student's landscape design education.

To further develop the method, there is a clear need for proper evaluation and comparison with other remote teaching tools and techniques. Particularly as design teaching and learning continues to transition into hybrid forms of remote learning. There may be opportunities for this method to be used in concert with more advanced digital experiences. Similarly, it is important to further develop the links between a digital site visit and the unique pedagogy of landscape design studio.

5 Conclusion

Undoubtedly for landscape design, having students visit a site themselves will always have an embodied benefit. By physically experiencing a site, students can position and make sense of a space directly through the tactile and haptic phenomena of real conditions. However, the events of 2020 have highlighted the need for diversity in design teaching methods and approaches. Physical site access will not always be possible. With increasing numbers of students choosing to study remotely, having alternative methods for providing site-specific information will continue to be beneficial.

The mosaic method described here has been most useful to early-stage students who need very specific direction or focus on topics and has proven valuable in teaching urban microclimate design to a remote cohort. The curation and assembly of material within the flexible digital space allows students to practice aligning different media and numerical information. Further, the method promotes engagement with the material by enhancing the playful aspects of navigating in digital space. By making the material exploratory as well as informative, the tool aims to motive students to explore in a way that might be closer to a physical site visit.

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Acknowledgements

We wish to give special thanks to the JoDLA Board of Editors, and to the members of the Review Board of the Journal of Digital Landscape Architecture.

The Board of Editors helps promote the quality and interests of the **Journal of Digital Landscape Architecture (JoDLA)**. This includes advising the editors on the policies of JoDLA and its future direction, and recruiting appropriate submissions. A group of experts in the areas of New Media and Landscape Architecture, mostly from the Board of Editors, but completed by additional specialists, serves as **Peer Reviewers for the Journal JoDLA**. The contributions to the journal are the result of a two-phase blind peer-review process.

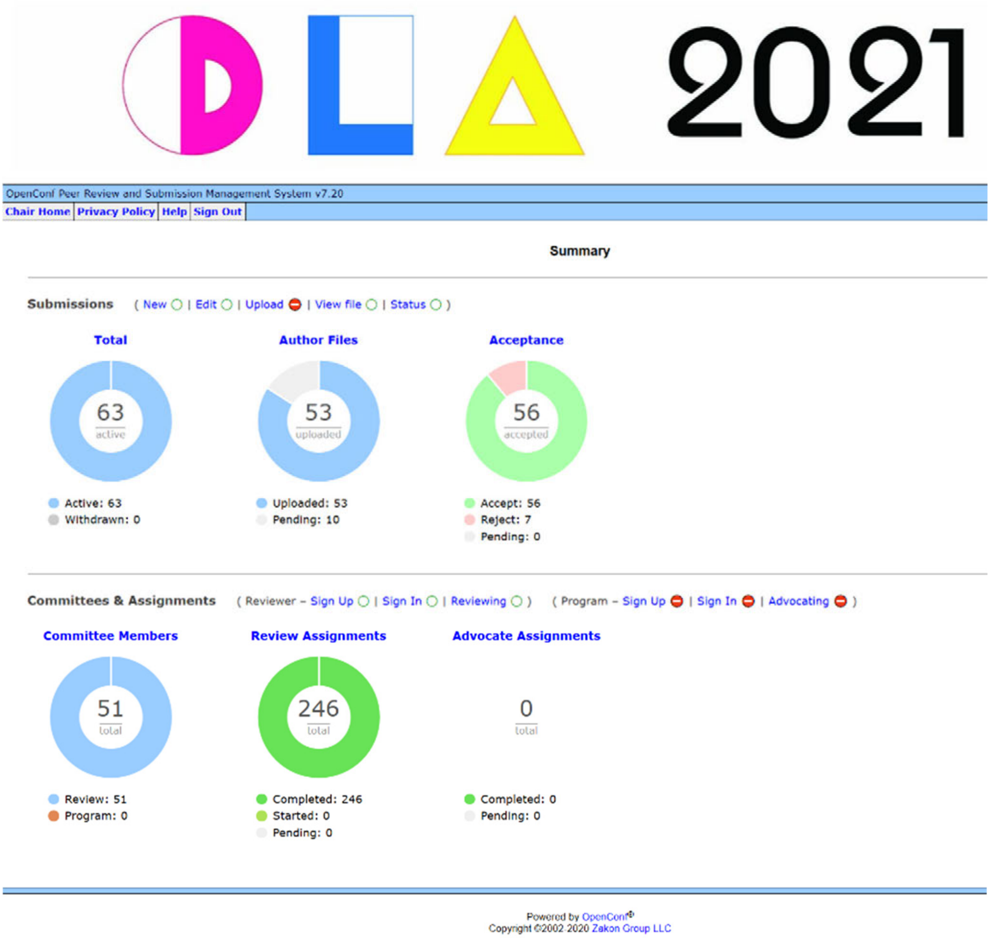

Fig. 1: Sixty-three submitted extended abstracts reviewed by fifty-one blind reviewers led to fifty-six accepted abstracts for submission of full papers for JoDLA 6-2021 – graphics provided by OpenConf

The anonymous peer-review process of the sixty-three extended abstracts led to fifty-six being accepted for full paper review and finally to fifty-six full papers accepted for publication as peer-reviewed papers. Every paper accepted as a full paper for the journal publication was rigorously reviewed by at least two peers from the international panel of scholars listed below.

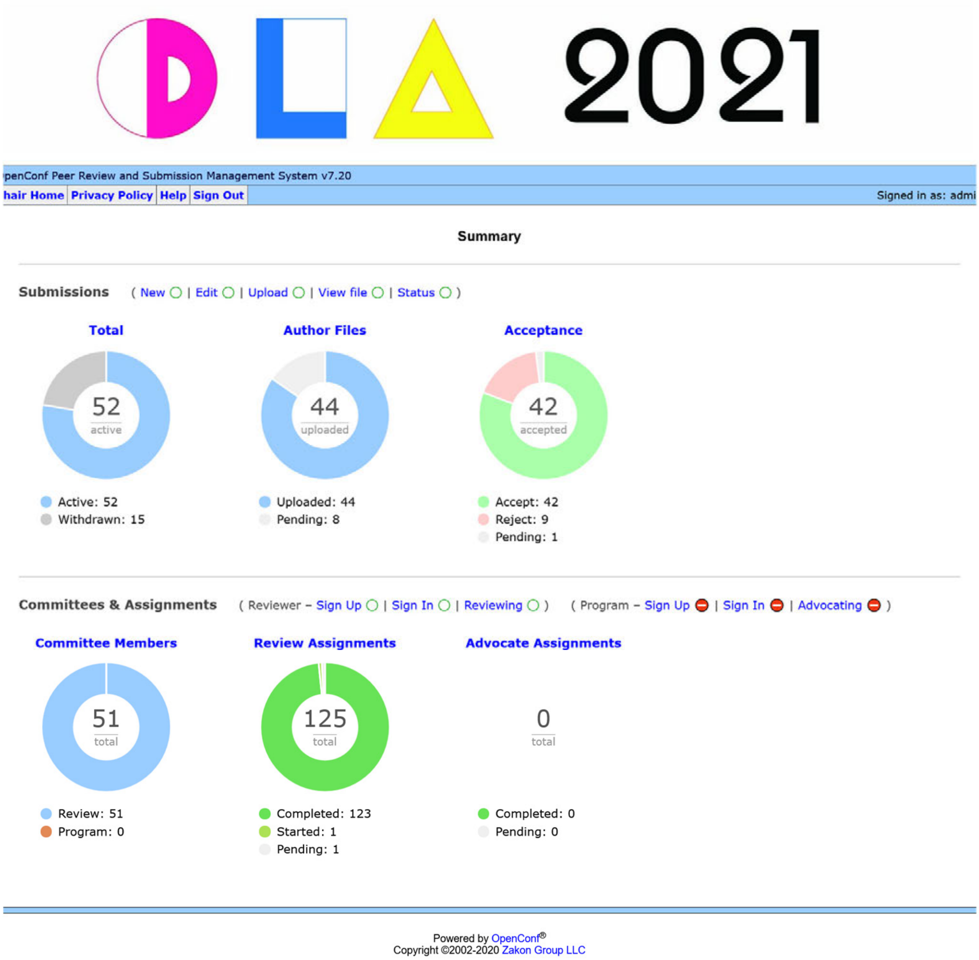

Fig. 2: Fifty-one accepted full papers for JoDLA 6-2021 after 125 blind full paper reviews by fifty-one reviewers – graphics provided by OpenConf

The full paper submission of accepted abstracts came from fifteen countries: thirteen full paper entries each from the United States, and Germany, four full papers each from South Korea and Switzerland, three entries each from China, Hungary and the United Kingdom, two entries from the Netherlands. And from the following countries we received one full paper entry each: Australia, Canada, Armenia, Czech Republic, Finland, New Zealand, Norway, and Turkey.

The high standards of the reviewers assure that the papers in this sixth issue will advance the theory and application of digital methods in landscape architecture.

The reviewers listed below spent many hours on extended abstracts and full papers. Many of them also wrote expert recommendations on how to improve the papers. **Without voluntary academic contribution, we could not develop this academic journal. Thank you JoDLA reviewers!**

And we sincerely hope that the reviewers will also find time to help us in the future.

Ackerman, Aidan – SUNY College of Environmental Science and Forestry, USA
Bishop, Ian – University of Melbourne, Australia
Campagna, Michele – Università di Cagliari, Italy
Canfield, Tess – London, United Kingdom
Conrad, Max – Louisiana State University, United States
Danahy, John – University of Toronto, Canada
Döllner, Jürgen – Hasso-Plattner-Institut, Germany
Donaubauer, Andreas – TU München, Germany
Douglas, Craig – Harvard University GSD, United States
Ervin, Stephen – Harvard University GSD, United States
Esbah Tuncay, Hayiye – Istanbul Technical University, Turkey
Formosa, Saviour– University of Malta, Malta
Fricker, Pia – Aalto University, Finnland
Gilbey, Eric – Vectorworks, United States
Haase, Andrea – Rainer Schmidt Landschaftsarchitekten, Germany
Hasbrouck, H. Hope – University of Texas at Austin, United States
Hehl-Lange, Sigrid – University of Sheffield, United Kingdom
Heins, Marcel – Anhalt University, Germany
Chamberlain, Brent – Utah State University, United States
Ikwan, Kim – Istanbul Technical University, Turkey
Ikhwan, Kim – Istanbul Technical University, Turkey
Kieferle, Joachim – Hochschule RheinMain, Germany
Kim, Mintai – Virginia Tech, United States
Kolbe, Thomas – TU München, Germany
Kowalewski, Benedikt – ETH Zurich, Switzerland
Lange, Eckart – University of Sheffield, United Kingdom
Lammeren, Ron van – Wageningen University and Research, Netherlands
Lovett, Andrew – University of East Anglia, United Kingdom
Mach, Ruediger – mach:idee Visualisierung, Germany
Mattos, Cristina – GAF, Germany
Melsom, James – UTS – University of Technology Sydney, Australia
Monacella, Rosalea – Harvard University GSD, United States
Mertens, Elke – Hochschule Neubrandenburg, Germany
Orland, Brian – University of Georgia, United States
Örnek, Muhammed – Istanbul Technical University, Turkey
Ozdil, Taner – The University of Texas at Arlington, United States
Ozimek, Agnieszka – Cracow University of Technology, Poland
Özkar, Mine – Istanbul Technical University, Turkey
Paar, Philipp – Laubwerk GmbH, Germany

We would like to summarize the phases of the specific review process that we apply during the review for the Journal of Digital Landscape Architecture. The seventy reviewers from different areas of IT in landscape architecture, as well as all the authors, used OpenConf, an efficient online conference management system.

Prof. Joachim Kieferle from Hochschule Rhein-Main operated the management system this year, as he has so faithfully done for many years. **We would like to offer Joachim Kieferle our greatest appreciation for his long-term commitment**.

In the first step of the blind-review process, four to five blind reviewers are asked to give an initial evaluation for each of the anonymous abstracts assigned to her/him and place it into one of six levels of evaluation. The average score derived from these evaluations and the written evaluations of the reviewers is the basis for accepting a paper for full paper submission.

In the second step, the blind review of the full papers, only two reviewers with in-depth knowledge of the subject matter are assigned per paper. These second reviewers are usually selected from the original group that evaluates each initial abstract, and they are asked to consider recommendations already made.

In the written suggestions, the reviewers are also asked to check for

- missing references to the literature, and
- irrelevant or mistaken assertions

The reviewers are usually able to make several suggestions for improvement. All further accepted authors are given enough time to rework their full papers according to the recommendations of the two reviewers. In this second review phase, only very few authors of full papers are asked for a complete re-submission for a later issue.

Each author receives the comments of the reviewers and additional comments by the editors for revising the full paper. When necessary, papers are returned to authors for revision until accepted by both reviewers. In some cases, additional anonymous reviewers are also asked to comment.

Over one hundred authors and co-authors of forty-two papers received a final confirmation letter that their contributions would be published in the sixth issue of the Journal of Digital Landscape Architecture, 6-2021, Herbert Wichmann Verlag, VDE VERLAG GMBH, Berlin and Offenbach, Germany.

We would like to give special thanks to all our colleagues who serve on the Review Board and by doing so further develop the level of scientific standards of peer-reviewed proceedings of this conference. We thank all of them for the extensive time spent in reviewing the abstracts and the papers for this journal**.**

The quality of the peer-reviewed papers benefits greatly from the extensive advice given in comments by the blind reviewers to the anonymous authors. We are very flattered by the academic support given by the reviewers of JoDLA.

We thank all fifty-one reviewers who helped with their recommendations during the two-phase review process and we compliment the authors for their SCIENTIFIC EXCELLENCE!

The outstanding contributions of the reviewers to this Journal may be best described by looking at the volume of recommendations given by the reviewers to the authors. The 500,000 words of blind recommendations given in the comments on the papers would fill over 100 pages of this journal! Thank you for taking the time and making the effort to share your knowledge with the authors!

The Journal of Digital Landscape Architecture Award 2021 for
HIGHEST LEVEL OF COMMITMENT IN THE REVIEW COMMITTEE
are given by the editors to

Ian Bishop, University of Melbourne
Brent Chamberlain, Utah State University
Andreas Donaubauer, TU München
Pia Fricker, Aalto University
Andrew Lovett, University of East Anglia
Brian Orland, University of Georgia
Olaf Schroth, Weihenstephan-Triesdorf University
Hans-Georg Schwarz von Raumer, University of Stuttgart
Verena Vogler, Bauhaus Universität Weimar
Ulrike Wissen Hayek, ETH Zürich

who each wrote more than 5,000 words in recommendations as guidance for the authors submitting full papers for review. A number of other reviewers came close to this volume of recommendations, while others kept their valuable advice to the point. They all gave helpful anonymous input to the authors as well as to the editors aiding the decision on which papers to accept for publication.

We are also pleased to announce three authors and their co-authors who received the highest possible rating by both of their blind reviewers for their full paper contributions to the 6-2021 edition to the Journal of Digital Landscape Architecture.

The awards are given for the highest possible score of the review process for full papers.

The Journal of Digital Landscape Architecture award 2021 on SCIENTIFIC EXCELLENCE is given to

Prof. Aidan Ackerman, SUNY College of Environmental Science and Forestry
Ashley Crespo, SUNY College of Environmental Science and Forestry
John Auwaerter, SUNY College of Environmental Science and Forestry and
Eliot Foulds, Olmsted Center for Landscape Preservation, Boston

for their article

"Using Tree Modeling Applications and Game Design Software to Simulate Tree Growth, Mortality, and Community Interaction"

and to

Ilmar Hurkxkens, ETH Zurich
Dave Pigram, University of Technology, Sydney and
James Melsom, University of Technology, Sydney

for their article

"Shifting Sands: Experimental Robotic Earth-Moving Strategies in Dynamic Coastal Environments"

We are also pleased to announce those who received the second highest rating for their full paper contributions. Each of the following papers was given the highest score possible by one of the blind reviewers and the second highest score possible by the other blind reviewer.

The Journal of Digital Landscape Architecture award 2021 on SCIENTIFIC MERIT is given to

Prof. Dr. Allan W. Shearer, The University of Texas at Austin, Texas
Dr. David J. Kilcullen, Cordillera Applications Group, Colorado and
Gordon Pendleton, Cordillera Applications Group, Hampshire

for their article

"Conceptualizing a Model of Antifragility for Dense Urban Areas"

Laura Wilhelm
Dr. Andreas Donaubauer and
Prof. Dr. Thomas H. Kolbe, all Technische Universität München

for their article

"Integration of BIM and Environmental Planning – The CityGML EnvPlan ADE"

Isaac Seah, University of Toronto
Prof. Fadi Masoud, University of Toronto
Dr. Fabio Dias, University of Toronto
Aditya Barve, Massachusetts Institute of Technology
Mayank Ojha, Massachusetts Institute of Technology and
Prof. Miho Mazereeuw, Massachusetts Institute of Technology

for their article

"Flux.Land: A Data-driven Toolkit for Urban Flood Adaptation"

Prof. Emily Schlickman
Nikita Andrikanis
Corbin Edward Burns Harrell and
Prof. Peter Nelson, all University of California

for their article

“Prototyping an Affordable and Mobile Sensor Network to Better Understand Hyperlocal Air Quality Patterns for Planning and Design”

Dr. Johannes Gnädinger and
Georg Roth, both Prof. Schaller UmweltConsult (PSU)

for their article

“Applied Integration of GIS and BIM in Landscape Planning”

Chaowen Yao and
Prof. Dr. Pia Fricker, both Aalto University

for their article

“How to Cool Down Dense Urban Environments? A Discussion on Site-Specific Urban Mitigating Strategies”

Hui Tian, Independent
Prof. Dr. Ziyu Han, Tongji University
Weishun Xu, Zhejiang University
Xun Liu, University of Virginia,
Waishan Qiu, Cornell University and
Dr. Wenjing Li, The University of Tokio

for their article

“How to Cool Down Dense Urban Environments? A Discussion on Site-Specific Urban Mitigating Strategies”

Congratulations to all!

Jeanne Colgan, who has been on board since the very beginnings of the DLA, was once again responsible for English language proofreading. As native English speaker she enables the English language editorial work hosted in Germany. She was supported by Stephen Colgan and Laurie Whittaker, while Jana Ekman and Anna Meïra Greunig checked and improved all the layouts of the contributions as during the last years.

This year our great thanks goes to Anhalt University. Prof. Erich Buhmann, the Chair of DLA is being assisted by Prof. Dr. Matthias Pietsch and his team for preparing this year’s virtual options for the DLA conference. Prof. Dr. Steffen Strauß of the Anhalt University in Media Technology is supporting the video production of live panels. The videoconference provider STEAVENT will optimize the interactive participation and social networking during the virtual conference.

We also thank Anhalt University for having supported the international conference series Digital Landscape Architecture DLA for the entire 22 years.

We very much look forward to the second effort to hold the DLA in-person at the GSD at Harvard in 2022. As there is still a lot of uncertainty until next summer we are not yet able to set the exact dates. Please put DLA 2022 in your agenda for June 2022. We are very grateful to Dr. Stephen Ervin for taking on this (now hybrid) conference for a second time. We truly hope to see many of you in person again.

The JoDLA will continue to be organized in Bernburg by Prof. Erich Buhmann and Jeanne Colgan. We are looking forward to receiving many papers for the JoDLA 7-2022 which will then be presented at Harvard in Boston.

Harvard University
Graduate School of Design

June/July 2022, TBA
Harvard GSD
Cambridge Mass, USA

DIGITAL LANDSCAPE ARCHITECTURE
DLA 2022

EARLY CALL FOR PAPERS and POSTERS

23rd International Conference on Information Technologies in Landscape Architecture

The 23rd annual International Conference on Information Technology in Landscape Architecture, Digital Landscape Architecture DLA 2022, will be held at the **Harvard Graduate School of Design, Cambridge MA USA in June 2022, date TBA (hybrid format with virtual attendance option).**

We invite you to contribute to this conference on all aspects of technologies in landscape architecture. The "Extended Abstract" should have a minimum of 1200 and maximum of 2000 words including key references and additional selected graphics as attachment.

Submit the abstract as a pdf file online via the web-based submission system at:

→ **https://www.dla-conference.com/ > "Review system" by November 1, 2021**

Accepted abstracts are invited to be submitted as a full paper for a second fully blind peer review. Accepted papers will be published as fully blind peer-reviewed papers in **Journal of Digital Landscape Architecture 7-2022** by Wichmann, Berlin · Offenbach: www.JoDLA.info.

Main Theme and Suggested Topics:

For the 23rd Digital Landscape Architecture Conference, the Editors and the Editorial Board of the **Journal of Digital Landscape Architecture** cordially invite you to submit abstracts for original, unpublished presentations focusing on the conference's main theme:

Analog: Digital: Hybrid; the next normal

Abstracts are encouraged for this theme or from one of these related areas:

1) **Resilient Landscape, Global Change and Hazard Response**
2) **Landscape and Building Information Modeling (LIM + BIM)**
3) **Geodesign Approaches, Technologies, and Case Studies**
4) **Socio-political Responses of Digital Landscape Architecture**
5) **UAV Imagery and Remote Sensing in Landscape Architecture**
6) **Mobile Devices, Internet-of-Things, and 'Smart' Systems in Landscape Architecture**
7) **Algorithmic Design and Analysis of Landscapes**
8) **Visualization, Animation and Mixed Reality Landscapes (VR, AR)**
9) **Teaching Digital Landscape Architecture**
10) **Digital Landscape Architecture in Practice**

Journal of Digital Landscape Architecture · 7-2022

Important dates for the review process are:

Abstracts due:	**November 1, 2021**
Notification of acceptance:	December 1, 2021
Full manuscript draft due:	January 05, 2022
Revised manuscript due:	February 15, 2022
Conference:	June/July, 2022 TBA
Opening of Call for Posters:	February 1, 2022

Keynote speaker(s) will be announced by February 2022.

The conference language is English. The DLA 2022 conference will be held at
Harvard Graduate School of Design (GSD), Cambridge Mass, USA.
(Hybrid format with virtual attendance option.)

We are planning this conference in cooperation with the American Society of Landscape Architects (ASLA) and the Boston Chapter (BSLA).

For further information on the DLA 2022 conference please contact:
Stephen Ervin, DLA Conference Local Host
DLA2022@gsd.harvard.edu | https://2022.dla-conference.com

JoDLA Review Process: www.dla-conference.com | atelier.bernburg@t-online.de

Profile

The Journal of Digital Landscape Architecture addresses all aspects of digital technologies, applications, information, and knowledge pertaining to landscape architecture research, education, practice and related fields. The journal publishes original papers in English that address theoretical and practical issues, innovative developments, methods, applications, findings, and case studies that are drawn primarily from work presented at the annual international Digital Landscape Architecture conference. Its intent is to encourage the broad dissemination of these ideas, innovations, and practices. The Journal of Digital Landscape Architecture is indexed in the international citation database Scopus.

More information on our series of conferences on Digital Landscape Architecture at
www.dla-conference.com

Master of Landscape Architecture

The Master of Landscape Architecture Program seeks highly qualified applicants of Landscape Architecture or associated planning disciplines such as Architecture, Environmental Planning or other who are interested in an English-language based graduate education for Master of Arts (M.A.) in Bernburg/Saale, Germany.

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Language:
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Tuition fees:
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- Design approach and planning instruments with European focus and reflecting different planning cultures
- Leadership skills (project management, communication skills, English and German language elective courses)
- Application oriented projects
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The Journal of Digital Landscape Architecture addresses all aspects of digital technologies, applications, information, and knowledge pertaining to landscape architecture research, education, practice, and related fields. The journal publishes original papers in English that address theoretical and practical issues, innovative developments, methods, applications, findings, and case studies that are drawn primarily from work presented at the annual international Digital Landscape Architecture conference. Its intent is to encourage the broad dissemination of these ideas, innovations, and practices.

This issue of the Journal of Digital Landscape Architecture, 6-2021, presents contributions from the 22th annual conference at the Anhalt University, Dessau, Köthen and Bernburg, Germany, (May 26 to May 28, 2021), covering nine broad topics:

- Defining Digital Landscape Architecture
- Resilient Landscape, Global Change and Hazard Response
- Visualization, Animation and Mixed Reality Landscapes (VR, AR)
- UAV Imagery and Remote Sensing in Landscape Architecture
- Geodesign Approaches, Technologies, and Case Studies
- Landscape and Building Information Modeling (LIM + BIM)
- Digital Landscape Architecture in Practice
- Algorithmic Design and Analysis Landscapes
- Teaching Digital Landscape Architecture

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