Regenerating the City
Performance-driven and Simulation-based Computational Design for Sustainable Cities and Communities

Proceedings of the 9th Regional International Symposium on Education and Research in Computer Aided Architectural Design in Europe

Tallinn University of Technology
15-16 June 2023

Edited by: Francesco De Luca, Ioannis Lykouras and Gabriel Wurzer

eCAADe RIS 2023

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Tallinn University of Technology
Department of Civil Engineering and Architecture
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Tallinn, Estonia

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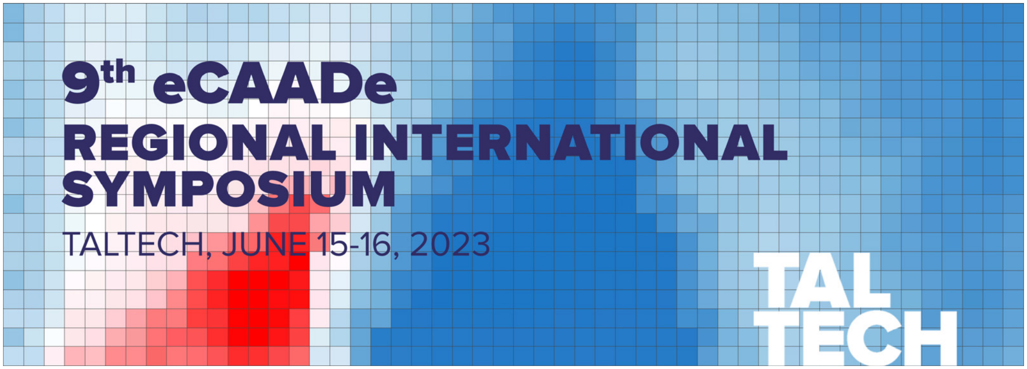

Theme

Nowadays, sustainability is in the agenda of most of the countries and international organizations. Among the 17 Sustainable Development Goals of the United Nations, Goal 11 Sustainable Cities and Communities sets specific targets for cities to adopt solutions for inclusion, safety, resource efficiency, resilience, mitigation and adaptation to climate change. Furthermore, it is increasingly evident among designers and researchers that design methods and solutions doing less harm or with a neutral effect on the environment are not sufficient anymore. A holistic approach is necessary in designing for a positive effect on climate change, resource depletion, human health and natural systems as a whole to develop sustainable architecture design solutions as well as regenerative and resilient cities.

Computational design allows us to develop workflows considering the built environment, humans and natural systems as a whole, by integrating simulations such as climatic, environmental, materiality, energy, behavior and use, and performances such as energy balance, usability, structural, fabrication, comfort, health, and costs, at multiple scales. The symposium and workshops reflected and experimented new concepts, methods, and solutions to create a positive impact on the urban environment and the city, but also on humans and the natural environment, taking advantage of the potential of computational design to integrate performance-driven and simulation-based workflows.

Furthermore, the objective of the symposium was to explore the potential of computational design in proposing a new architectural paradigm through performance and simulation. Particular emphasis has been given to research showing innovative holistic, multi-disciplinary, multi-domain, multi-scale, and multi-objective approaches to guide and support the scientific and design community at large to design sustainable cities and communities.

Francesco De Luca and Ioannis Lykouras
Conference Chairs
Tallinn, November 2023

Acknowledgements

Our sincere thanks go to the eCAADe Council that invited us to present a proposal and allowed us to organize the 9th Regional International Symposium on Education and Research in Computer Aided Architectural Design in Europe at Tallinn University of Technology (TalTech).

For the organization we received the support of several persons and institutions, to whom we owe a debt of gratitude. Our sincere thanks go to the members of the eCAADe Council, Joachim Kieferle who supported and guided us during all the organization phases, José Duarte and Bob Martens who also supported us during the organization and participated in person to the symposium, Rudi Stouffs who helped during the organization, Martin Winchester who helped for matters related to the OpenConf system, and, last but not least, Gabriel Wurzer who guided and helped us in the realization of the proceedings.

We want to especially thank Prof. Kimmo Lylykangas who welcomed the idea of hosting the eCAADe RIS 2023 at the Academy of Architecture and Urban Studies of TalTech, and gave us the possibility to organize it, and Mariann Lugus and Eliisa Metsoja of the TalTech Conference Centre who took care of several organizational aspects. We also want to thank the keynote speaker Jenni Partanen for her enlightening presentation, the invited presenters Helen Sooväli-Sepping, Jaan Kuusemets, Viktorija Prilenska and Esther Linask for presenting the perspective of institutions, professionals and policy makers, and the moderators Ergo Pikas, Abel Sepúlveda and Mar Canet for triggering interesting discussions.

Finally, we want to express our sincere gratitude to the scientific committee members who took on the burden of reviewing the papers, the workshop tutors Abel Sepúlveda and Rossella Siani for their tireless and great work, and to the authors and participants, on-line and in presence, for their amazing contribution that made the symposium a moment of exchange and growth for all of us.

Organization

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All the information relative to the theme, organization, dates, contacts and detailed program of the symposium are availabe at: https://taltech.ee/en/ris2023

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Keynote

Jenni Partanen

Navigating the sea-change of data-driven design

Jenni Partanen, Dr SC (Arch), is a Professor of Future City at TalTech, Estonia. She has previously worked at the Urban Institute of Aalto University, and at the School of Architecture of Tampere University, Finland. Her research focuses on self-organizing socio-economic processes in technology-mediated urbanity and on the impacts of digital technology on urbanity. Partanen leads the research group 'Urban Spatial Analyses' exploring how digitalization changes cities' configurations and dynamics using spatial analytics, simulations, and machine learning. She holds a PhD from Tampere University of Technology and is currently a visiting scholar at Tampere University, Finland.


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Invited Speakers

Helen Sooväli-Sepping

Strive towards climate neutral university: Tallinn University of Technology in action

As Vice-Rector for Green Transition at Tallinn University of Technology, Helen Sooväli-Sepping supervises the incorporation of sustainable development and green capabilities into university curricula, research, and campus growth, using TalTech campus as a testbed. She has worked as professor in environmental management and lead several European and Nordic sustainable development projects.

Jaan Kuusemets

Augmented creativity in conceptual design: Examples from DAGOpen practice

Jaan Kuusemets is an Estonian architect (Qualified Architect-Expert 8) and a professor of contemporary architecture at Tallinn University of Technology, Academy of Architecture and Urban Studies. He is partner and chief architect of the architecture office DAGOpen. With his practice, he has an extensive portofolio of realized buildings and he obtained prizes at several international architectural competitions.

Viktorija Prilenska

GreenTwins: A collaborative planning support ecosystem for better decisions in urban green

Trained as an architect, urban planner and researcher, Viktorija Prilenska shifted to project management and innovation development in the Smart City field. Her professional interests and competences span from architectural design and spatial planning to agile methodologies and enterprise data strategies. Her design background helps her to develop innovative solutions, and focus on the value-creating results.

Esther Linask

Tallinn GIS solutions for a better city

Esther Linask is part of the Tallinn Strategic Management Office geoinformatics team. Using the data for smarter decisions and better communication is a key for better city management and her main attention goes to automating data flows and analyzing processes to make use of the data colllected by the different departments and other institutions, offering better solutions for working with the data.

Workshop Tutors

Abel Sepúlveda

Human-centric design techniques for resilient future cities

Abel Sepúlveda is a researcher and lecturer in Karlsruhe Institute of Technology. He has proposed several design workflows to ensure visual and thermal comfort in buildings, studied the applicability of daylight standards for buildings in cold climates using mixed-methods. Currently, he applies experiment-based methods to develop fundamental research involving visual and thermal comfort in buildings.

Rossella Siani

MATTER IN CODE: Algorithmic design + digital fabrication workshop

Rossella Siani is an architect and researcher in Architectural Technology at the University of Parma, Italy, and director of VAHA (www.vaha.it). Expert in algorithmic design and digital manufacturing, she creates experimental works of architecture and digital craft, pavilions in DigitalBamboo, artificial reefs in additive manufacturing in collaborative gropus in Europe, United States, Japan, and Africa.

The workshops took place on June 15th at TalTech campus, Department of Civil Engineering and Architecture.


TALLINN (ESTONIA)

Contents

SIMULATIONS, DATA AND PARAMETRIC DESIGN FOR SUSTAINABLE AND LIVABLE URBAN ENVIRONMENTS

Methodology for Improving Wind Comfort in a Cold Region Through Modular Urban Elements

Nasim Eslamirad[1], Francesco De Luca[2], Abel Sepúlveda [3,4], Kimmo Sakari Lylykangas[5]
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This paper discusses wind comfort improvement strategies as a crucial microclimatic issue in urban planning. The investigation used pergolas as a wind catcher/breaker element to improve wind comfort at the pedestrian level in Tallinn, Estonia, during extraordinarily windy and cold times of the year. We analyzed the impact of buildings and other surrounding elements on wind flow to design pergolas as windbreakers. Case studies include three urban areas. The wind flow has been simulated using Computational Fluid Dynamics (CFD) on the micro-climate scale using ENVI-met. The CFD analysis allowed us to understand urban wind flow phenomena and apply solutions to mitigate distress and guarantee more comfort. According to the CFD results, the urban zones show a high rate of wind speed under different meteorological conditions and, consequently, extreme wind discomfort. The analysis results of 48 scenarios based on different meteorological cases were used to select the most performative retrofit solution and provided insight into windbreak pergolas' size, layout, and location to provide comfort. Thus, improved geometrical models of case studies were simulated and analyzed. The results showed that the designed pergolas offer high wind comfort at the pedestrian level, especially in open urban areas, and could assist municipalities, city planners, and urban designers in creating more comfortable and sustainable urban environments.

Keywords: *Sustainable urban environment; Computational Fluid Dynamics (CFD) analysis; Wind comfort; Wind chill; Windbreaker element.*

INTRODUCTION

The world is experiencing enormous urban development and rapid urbanization (Erell, et al., 2011) (Xiaolu & Yi-Chen, 2011). At present, half of the world's population lives in cities (Chokhachian, et al., 2017), and it is expected that by 2030 the population of urban areas will reach almost five billion (Erell, et al., 2011).

Moreover, nearly 73% of the European population lives in cities, which is anticipated to reach 82% (Akbari, et al., 2016). In addition, many modern cities do not incorporate resilience principles in their design (Chokhachian, et al., 2017). The quality of life of city dwellers can be improved by controlling the factors that impact the urban microclimate condition (Erell, et al., 2011), while poor urban design increases the impact of climate change on cities (Akbari, et al., 2016).

In addition, individuals living in urban areas face many challenges influencing the quality of life in cities. Thus, public spaces in cities provide essential places for rest, leisure, and commercial activities of city dwellers (Johansson & Yahia, 2018). In recent years, urban planners are continuously endeavoring to optimize the well-being of city residents by implementing various design principles and solutions to create invigorating and agreeable public spaces (Eslamirad, et al., 2023). Nevertheless, despite the accumulated knowledge of sustainability and mitigation solutions in the built environment, mitigation still needs to develop scientific research products.

The study has three main objectives:

1. To study the wind speed and wind comfort of three urban study areas in Tallinn, Estonia, during extreme wind conditions and low levels of wind comfort. The aim is to identify the problematic urban zones where discomfort areas exist, and wind comfort improvement is needed.
2. To apply redesigned landscape strategies by adding wind catcher or wind shelter elements to these problematic urban zones. The objective is to mitigate wind chill and improve the level of wind comfort for pedestrians.
3. To assess wind comfort in the redesigned urban areas and demonstrate how adding wind obstacle elements offer better wind comfort at the pedestrian level. The study uses CFD simulation in the ENVI-met environment and applies the Lawson wind comfort criteria to assess the level of wind comfort in each zone.

The structure of this paper is the following: Overall, the study aims to enhance Tallinn's urban livability and sustainability by improving wind comfort during extreme wind and cold conditions in urban areas.

The remainder of this paper is arranged based on the following sections:

The second section gathered background information on wind comfort improvement strategies in urban planning. The following section is related to the material and methods employed in the study. The CFD simulation and numerical study of case studies follow in the next section. This section describes the simulation methodology, including the input parameters and the numerical models used to simulate wind flow in the study areas. The numerical study may involve testing several design options or scenarios to determine the most effective wind comfort improvement solutions. The results section presents the study's findings on wind comfort assessment and applying wind obstacle elements at the pedestrian level. Finally, the conclusions section summarizes the key findings of the study and their implications for urban planning, while the limitations section discusses any potential limitations of the study's methodology or results.

BACKGROUND

The outdoor wind comfort level is essential for assessing the urban wind environment (Zhen, et al., 2012). According to Blocken (2016), an evaluation of wind comfort should be conducted through a combination of three data sources: statistical meteorological data, aerodynamic information, and a comfort criterion. The aerodynamic information transforms the statistical meteorological data from the weather station (meteorological site) to the building site location. The transformed statistical data and the comfort criterion are then used to assess local wind comfort at the specified location (Blocken, et al., 2016).

Current standards for evaluating wind comfort are based on the correlations between wind characteristics, human activity intensity, and wind comfort level categories. These criteria differ in different climates and regions, and they are impacted by meteorological conditions and human wind adaptation environment (Zhen, et al., 2012). Furthermore, while factors such as thermal comfort, humidity, solar radiation, and precipitation have been identified as necessary for human comfort, wind comfort generally only encompasses the mechanical effects of wind on people (Blocken, et al., 2016). The design-related contribution of wind flow conditions to the design of buildings in the urban area is determined through wind-tunnel testing or

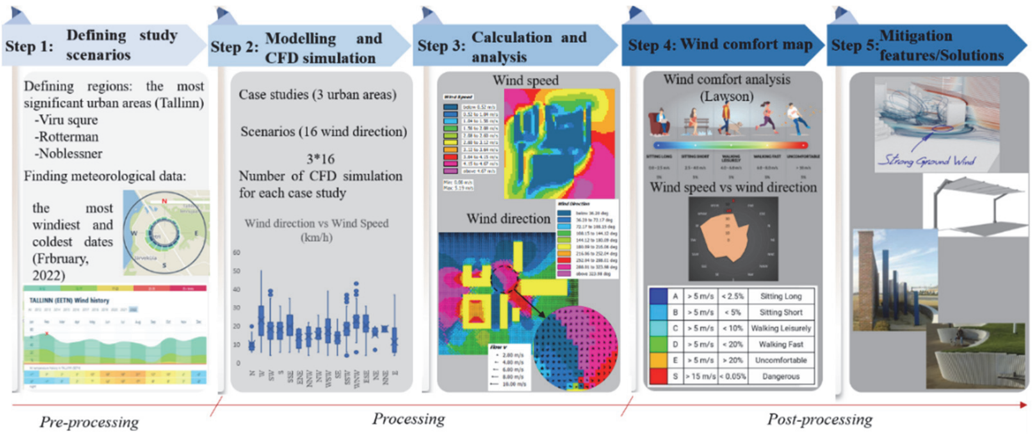

Figure 1
The framework of the study.

numerical simulation utilizing CFD (Blocken, et al., 2016).

Accordingly, wind-tunnel measurements or CFD simulations can obtain information on the pedestrian-level wind (PLW) speed for wind comfort assessment (Blocken, et al., 2016).

Based on the study of Johansson and Yahia (2018) in southern Scandinavia, cold solid winds constitute a problem, even if wind speeds are lower in urban areas.

These winds are particularly troublesome for neighborhoods situated on the outskirts of cities or along the coast (Johansson & Yahia, 2018).

The study methods for evaluating wind comfort at the pedestrian level by comparing different comfort criteria investigated (Hemant, et al., 2018). Indeed, Kim et al. assessed pedestrian wind comfort and pointed out that the wind speed in the winter season could cause discomfort for pedestrians (Kim, et al., 2018).

In the other study, wind speeds and direction were analyzed in the ENVI-met environment, and the result used to evaluate and assess wind comfort (Park, et al., 2014).

MATERIAL AND METHODS

Accordingly, the research is CFD simulations that can obtain information on the pedestrian-level wind (PLW) speed for wind comfort assessment methodology, which was composed of five steps, as illustrated in Figure 1.

Subsequently, scenarios were defined in 16 different definitions based on 16 wind directions and diverse weather conditions in Step 1. Thus, step 1 involved identifying regions in the city to be studied and the meteorological data and weather parameters essential for quantifying extreme wind discomfort in urban settings. In addition, geometric modeling and CFD simulation of case studies were conducted in step 2. Moreover, section 3 is related to the wind speed and wind direction as the results of CFD simulation in the ENVI-met environment. The wind comfort analysis of the case studies is performed in step 4. Finally, step 5 involves applying wind catcher/wind obstacle elements added to the wind discomfort areas.

The CFD simulation and wind comfort evaluation in the final step shows how the wind comfort level of the public areas in the case studies was improved.

Study urban areas

Tallinn city (59°26'13.1'' N and 24°45.212' E) is the capital city of Estonia, which has a humid continental climate with gentle summers, as mentioned in the Köppen-Geiger classification Dfb (Peel, et al., 2007).

Figure 2
Three case studies in Tallinn,
(a). case study 1, Rottermanni
(b). case study 2, Viru
(c). case study 3, Noblessner.

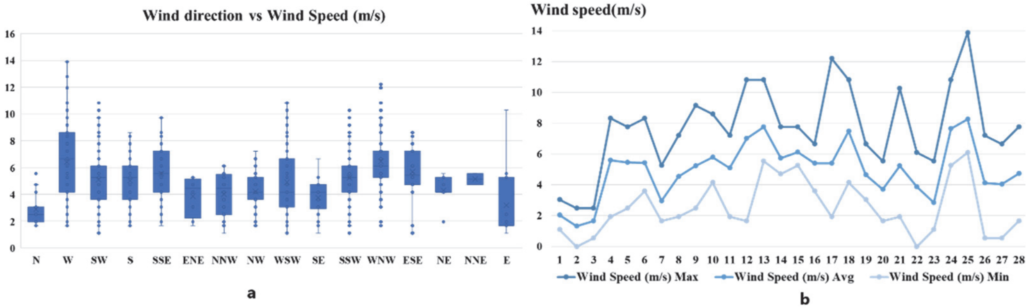

Figure 3
The daily weather data of Tallinn, February 2022.
(a) The box plot of wind speed in 16 wind directions.,
(b): The daily wind speed.

This study selected three urban areas in Tallinn for wind analysis where people are more likely to spend their time (Figure. 2).

Case study 1 is an urban area in Tallinn named Rotermanni, as Figure 2a shows.

Figure 2b shows the Viru square in Tallinn, with the surrounding buildings and open space areas. Moreover, the area next to the sea is the new port of Tallinn named Noblessner, as Figure 2c shows.

Local Meteorological Data of Tallinn

To analyze pedestrian-level wind and wind comfort, CFD simulations and wind speed assessment need to be performed for many (e.g., 12 or 16) wind directions (Janssen, et al., 2013).

Thus, 16 scenarios were defined for CFD simulation and wind comfort analysis. The reason to choose scenarios is that they represent days with cold air temperatures and extreme winds, creating even more cold in winter.

The section relates to the CFD simulation and the numerical analysis to assess wind speed in the studied areas. The modeling and simulation processes are based on three case studies that modeled and simulated sixteen wind directions in the weather conditions of February 2022.

Figure 3.a shows the wind speed data of Tallinn in and Figure 3.b shows the wind direction in February 2022.

All simulated scenarios illustrated in Table 1 are based on the weather data of the coldest and windiest month in 2022.

CFD SIMULATION AND NUMERICAL ANALYSIS

CFD is crucial for comparing wind comfort conditions (Janssen, et al., 2013).

This approach allows us to comprehensively analyze the effects of different wind directions and meteorological conditions, such as wind speed, air temperature, and humidity on the performance of the urban areas being modeled.

Table 1 shows more detailed information about the scenarios of the study.

Table 1
Defined scenarios in the study in February 2022.

	Date (day)	Time	Air temperature (°)	Relative humidity (%)	Wind speed (m/s)	Wind direction
S1	21	12	-1	93	10.3	E
S2	19	9	0	100	5.3	ENE
S3	21	11	-1	93	8.6	ESE
S4	22	10	0	93	5.6	N
S5	19	14	1	93	5.6	NE
S6	19	15	0	100	5.6	NNE
S7	22	13	-2	93	6.1	NNW
S8	8	23	1	93	7.2	NW
S9	25	2	2	87	8.6	S
S10	4	14	-4	86	6.7	SE
S11	25	12	3	81	9.7	SSE
S12	24	13	5	70	10.3	SSW
S13	13	15	2	81	10.8	SW
S14	25	17	0	100	13.9	W
S15	17	22	0	100	12.2	WNW
S16	12	17	2	87	10.8	WSW

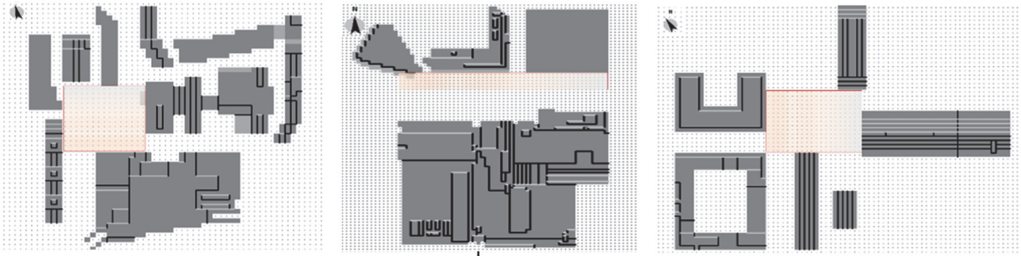
a b c

Figure 4
The used urban areas in the studies cases,
(a): Case study 1,
(b): Case study 2,
(c): Case study 3.

These case studies were simulated with the highest wind speed at the exact date and time.

Therefore, 48 simulations are conducted during the study.

This approach allows us to comprehensively analyze the effects of different wind directions and meteorological conditions on the performance of the urban areas being modeled.

Wind analysis in urban areas

For each case study, the more populated areas and where people prefer to spend their time were selected for the CFD simulation and analysis.

Figure 4 shows the used areas for analysis in case studies 1, 2, and 3.

In the case of case study 1, the analyzed area is located in the urban area as a central plaza or square, a popular spot for people to pass through or spend their time.

The results of CFD simulation give us valuable information for understanding wind patterns in the studied areas.

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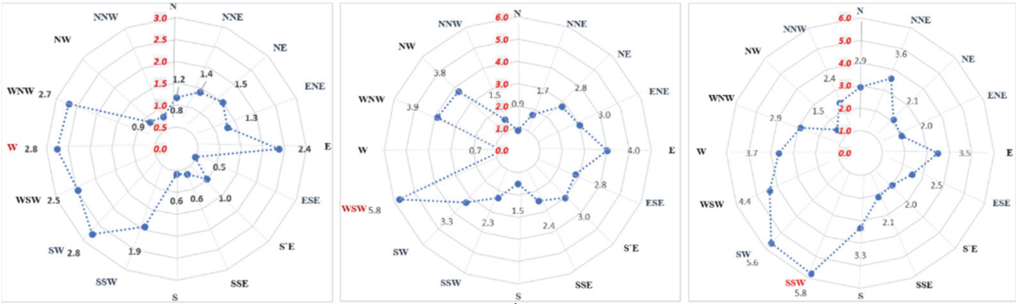


a b c

Figure 5
Analysis of wind speed in all wind directions, (a): Case study 1, (b): Case study 2, (c): Case study 3.

Figure 5.a shows the windiest scenarios of case studies. Based on the CFD simulation and wind analysis results, scenario 14 has the windiest conditions in the selected urban area, with an arithmetic mean wind speed of 2.8 m/s in the W direction. The worst-case scenario with the highest wind speed in case study 2 is scenario 16, with a wind speed of 5.8 m/s in the direction of WSW, since Figure 5. b shows. Furthermore, Figure 5. c shows the windiest of Case Study 3, with a wind speed of 5.8 m/s and a wind direction of SSW.

The results of wind analysis studies can be affected by many factors, including meteorological conditions. Analyzing the wind speed in these areas is essential to identify potential issues and improve the pedestrian level wind comfort.

Therefore, it is essential to carefully consider factors when interpreting the results of wind analysis studies.

In order to assess wind patterns accurately, it is necessary to consider the scenarios defined before conducting the analysis.

Moreover, Figure 5 gives information about the scenario and condition causing the highest rate of wind speed in the studied area of case studies to assess wind comfort.

Wind comfort assessment of scenarios

The results of CFD simulation in the ENVI-met environment were used to define wind comfort by applying the Lawson wind comfort assessment method and the LDDC variant of the Lawson comfort criteria (Lawson, 1978, Lawson, 1990) through the Wind Comfort Level (WCL) method. This method involves combining statistical meteorological data with aerodynamic information and a comfort criterion to assess the wind comfort level in a given area using a score with an adimensional number from 0 to 100 (De Luca, 2019).

This method uses a set of comfort criteria to evaluate the level of wind comfort in a given area based on parameters such as wind speed, turbulence intensity, and air temperature (Janssen, 2013).

Wind comfort was then determined using the LDDC Lawson criteria (Table 2).

Table 2
LDDC Lawson comfort criteria (Lawson, 1990).

Comfort activity	Threshold Wind velocity(m/s)
Sitting	4
Standing	6
Walking	8
Business walking, cycling	10
Uncomfortable for all activities	>10

The Lawson wind comfort criteria are primarily used to assess the level of wind comfort in urban areas and do not directly provide information about wind danger.

However, it can be used to weigh areas with different wind speeds to highlight more or less comfortable pedestrian areas.

Table 3 provides an evaluation of wind comfort in all 16 case study scenarios.

Table 3
Results of arithmetic mean of wind speed and wind comfort in case studies, in different scenarios.

	Case study1, Rottermanni		Case study2, Viru		Case study3, Noblessner	
	Wind speed (m/s)	Wind comfort*	Wind speed (m/s)	Wind comfort*	Wind speed (m/s)	Wind comfort*
S1	2.4	90	4	77	3.48	86
S2	1.3	100	3	99	2	100
S3	0.5	100	2.81	95	2.5	100
S4	1.2	100	0.9	100	2.92	96
S5	1.5	100	2.8	99	2.10	100
S6	1.4	100	1.73	100	3.6	93
S7	0.8	100	1.5	100	2.4	100
S8	0.9	100	3.75	84	1.5	100
S9	0.6	100	1.5	100	3.3	93
S10	1.0	100	2.99	82	2	100
S11	0.6	100	2.44	97	2.1	49
S12	1.9	94	2.29	97	5.8	49
S13	2.8	88	3.3	94	5.6	53
S14	2.8	81	0.7	100	3.7	82
S15	2.7	87	3.90	93	2.9	92
S16	2.5	88	5.8	52	4.4	92

* Wind comfort in an adimensional number (from 0 to 100)

The goal is to identify which scenarios require modifications to improve wind comfort. These modifications could include changes to the landscape or adding wind catchers, which are structures designed to redirect and capture the wind.

Therefore, in the assessment, not only the wind speed of the results of CFD simulation take into account (Eslamirad, et al., 2022), but also wind comfort value by implementing the LDDC variant of the Lawson comfort criteria considered.

According to Table 3, there are different wind comfort values in scenarios ranging from 52 to 100. In order to identify the worst-case scenarios, we need to consider both the highest arithmetic mean of wind velocity and the lowest wind comfort levels in the studied area.

By finding the scenario with the highest wind speed and the lowest wind comfort level, we can identify the scenario that poses the most significant challenge regarding wind comfort for pedestrians of outdoor spaces in the area.

Accordingly, in case study 1, the urban area of Rottermanni at the pedestrian level, the CFD simulation of S14 resulted in the highest wind speed of 2.8 m/s while the wind comfort was 81.

For the other case studies, the windiest scenarios with the lowest wind comfort levels are S16 in case study 2 and scenario 12 in case study 3, with a median wind speed of 5.8 m/s and wind comfort levels of 52 and 49, respectively.

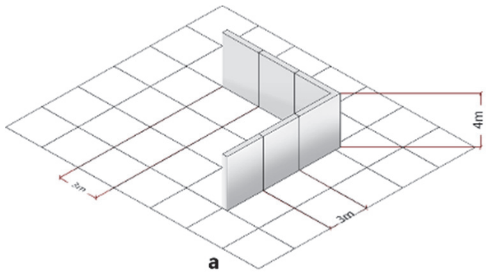
RESULTS

According to Table 3, there are different wind comfort values in scenarios ranging from 52 to 100. In order to identify the worst-case scenarios, we need to consider both the highest arithmetic mean of wind velocity and the lowest wind comfort levels in the studied area.

By finding the scenario with the highest wind speed and the lowest wind comfort level, we can

identify the scenario that poses the most significant challenge regarding wind comfort for pedestrians in the urban area.

In this section, wind catchers were added to the 3D geometric models in the case studies to improve the wind flow in urban areas. These wind catchers are designed as vertical walls placed in areas with the recorded highest wind speed. Each vertical wall is a module in a 3-meter horizontal and 4-meter vertical expanded wall, with the bottom projected on the ground (Figure 6.a).



and 3, where wind comfort levels increased from 52 to 100 and 49 to 99, respectively.

The results of these simulations were used to find the new wind patterns and wind comfort in urban areas.

As a result, the previously uncomfortable areas for outdoor activities, including sitting, have become completely comfortable, even for activities requiring the highest level of wind comfort, according to the Lawson wind comfort assessment criteria.

Furthermore, applying wind catchers or shelters can be particularly effective in improving outdoor comfort levels in urban areas with high wind velocities, especially during cold winters when wind chill can significantly impact people's comfort and limit their outdoor activities. By reducing wind speeds and providing sheltered spaces, wind catchers and shelters can help create more comfort, encouraging people to spend more time outdoors and engage in a broader range of activities.

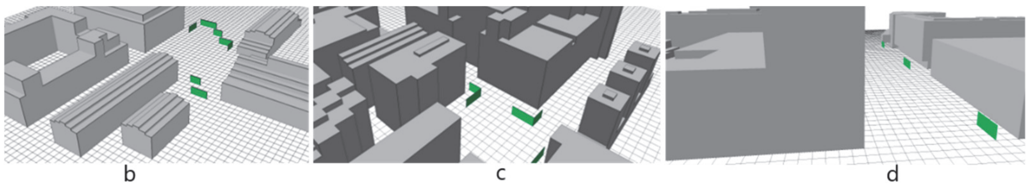


Figure 1
(a): The schematic of wind catchers to improve wind comfort in the studied urban areas.
(b): Case study 1 with the added wind catchers,
(c): Case study 2 with the added wind catchers, (d): Case study 3 with the added wind catchers.

Implementing wind shelters

Figure 6 shows the schematic of the design of wind catchers and improved geometric models simulated in ENVI-met to evaluate the wind flow in urban areas by adding these wind catchers. It is important to note that the worst-case scenario with the highest wind speed was considered for the simulations in this section.

According to Table 4, applying wind catchers or shelters in the geometric models of the scenarios with the highest wind speed and lowest wind comfort to the areas with the highest wind speed recorded has significantly improved the wind comfort levels in the studied urban areas. The improvement is most significant in case studies 2 and 3.

Furthermore, based on the results presented in Table 4, in case study 1, the urban area is fully enclosed by buildings, which increases the turbulence effect of urban wind catchers in improving wind comfort levels. However, in case studies 2 and 3, where the urban areas are more exposed to wind flow, implementing wind catchers and shelters has effectively mitigated wind speeds and improved wind comfort levels. In addition, Figure 7 shows the wind speed results of the worst scenarios in the base case and improved models by adding wind catchers in all case studies. Wind catchers and shelters can be particularly useful in urban areas that are more open and exposed to wind flow, where wind speeds can be higher.

Table 4
Results of applying wind catchers' scenarios.

	Scenarios	Wind speed (m/s)	Wind direction	Wind comfort*
CS 1	S14	2.8	W	81
	S14 improved	2.6	W	82
CS 2	S16	5.8	WSW	52
	S16 improved	1.3	WSW	100
CS 3	S12	5.8	SSW	49
	S12 improved	2.0	SSW	99

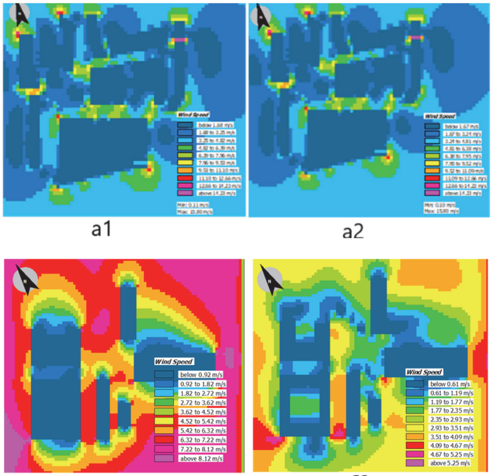
* Wind comfort in a dimensional number (from 0 to 100)

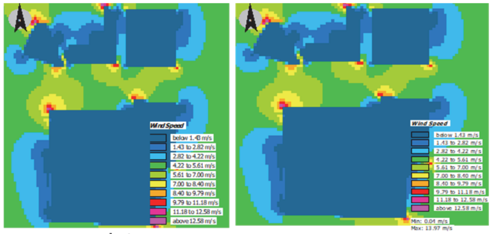
Implementing urban wind comfort improvement strategies can significantly benefit the health and well-being of local communities and the economic, social, and environmental sustainability of urban areas.

CONCLUSION

Wind comfort assessment studies can provide valuable insights into the level of wind comfort in a given area. They can help to make decisions related to urban planning and other aspects of development. However, it is essential to consider all relevant factors carefully and to use appropriate methods and criteria when conducting these assessments.

Figure 7
Bit maps show the results of CFD simulation and wind speed (a1): Case study 1, S14, (a2): Case study 1, S14 improved. (b1): Case study 2, S16, (b2): Case study 2, S16 improved. (c1): Case study 3, S12, (c2): Case study 3, S12 improved.


a1 a2 C1 C2


b1 b2

Overall, the effectiveness of wind catchers as a strategy for improving outdoor comfort depends on a range of factors, including the urban form, the prevailing wind conditions, and the specific preferences of people.

Therefore, by adopting a context-specific approach to urban design and planning, it is possible to create outdoor spaces that are comfortable, functional, safe, and inviting for a wide range of activities and users.

This study presented a concept of urban design optimization by considering wind comfort improvement analyzed at the pedestrian level in the cold season and imprint urban areas in three public areas in Tallinn, Estonia. In particular, we considered the worst-case wind scenarios among all wind direction cases in different scenarios based on the February 2022 meteorological parameters in the study area to mitigate the extreme wind and low level of wind comfort at the pedestrian level.

Overall, the wind comfort assessment aims to identify areas requiring modifications, such as applying wind catchers.

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Machine Learning-based Optimization Design Workflow based on Obstruction Angles for Building Facades

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This paper proposes a ML-based optimization design workflow based on obstruction angles for the optimization of building facades (i.e. g-value and window width). The optimization output consists of the optimal clustering of windows in order to ensure a desired level of daylight provision according to method 2 defined in the EN17307:2018 (i.e. based on Spatial Daylight Autonomy: sDA) and to not exceed a maximum level of specific cooling capacity (SCC). The independent variables or design parameters of the parametric model are: room orientation/dimensions, window dimensions, and obstruction angle (θ). The ML prediction models were trained and tested with reliable simulation results using validate softwares. The total number of room combinations is 61440 for sDA and SCC simulations. The development of reliable (90% of right predictions) ML predictive models based on decision tree technique were calibrated. The optimal clustering of windows was done first by floors and secondly by the designer's need to homogenize the external facade with similar glazing properties and window sizes, having impact on the annual heating consumption. The proposed method help designers to make accurate and faster design decisions during early design stages and renovation plans.

Keywords: *optimization, daylight, thermal comfort, cooling capacity, machine-learning predictive model, office buildings, cold climates*

INTRODUCTION

Buildings' energy needs account for 40% of the total energy consumed in Europe (Ahmad et al., 2014). Moreover, it is well-known for designers the importance of a suitable facade design to balance different building performances such as a combination between visual/thermal comfort (Sepúlveda et al., 2022a) and energy efficiency (Hoffmann et al., 2016). Nowadays, the application of Machine learning, which is a subdomain of Artificial Intelligence, has been widely used in building construction industry, especially in the field of architectural design and visualization (Baduge et al., 2022). In fact, there is a trend of using optimization algorithms based on machine-learning (ML) models to predict building performance while minimizing the conventional simulation approach based on time-consuming daylight-thermal modelling and simulations (Wortmann et al., 2022). In fields like civil engineering, the use of artificial intelligence algrotihms improve the expressiveness of traditional computational models, which are commonly based on phenomenological regressions (Wang et al., 2023).

Background

Most studies used supervised learning methods with artificial neural networks (ANN) to predict/optimize daylight provision in buildings (Ngarambe et al., 2022). Lin et. al could optimize with a ANN-based method 9 times faster than traditional simulations the selection of perforated facades with different positions and aperture change rate of circular patterns to balance annual daylight and solar exposure in an open plan office building located in Taipei, Taiwan (Lin and Tsay, 2021). A combination between multi-objective optimization method based on ANN (average accuracy of 89.9%) for finding the best building floor layout of high-rise residential buildings in Beijing, China was used to balance daylight provision, solar access, sky view, and outdoor thermal comfort (Wang et al., 2021). Other investigations proposed workflows of higher R^2 of 0.959 based on ML to predict dynamic daylight metrics from design variables such as room dimensions, thermal-visual properties of the windows and facade orientation (Han et al., 2021).

A vast number of investigations focused exclusively on thermal comfort and energy efficiency goals (Alsharif et al., 2023; Chegari et al., 2021; 2022; Hosamo et al., 2022). Digital twin models were combined with ANN to predict indoor thermal comfort under the influence of energy-saving strategies (Ma et al., 2019). Within the Morocco climatic context, the use of predictive ML models allowed to reduce the annual energy consumption a 74.5% by optimizing building envelope's thermal properties (Chegari et al., 2021), respectively. Als et. al proposed a framework that couples ML techniques and multi-objective optimization to find dimensions and rotation angle of fixed shadings in order to minimize thermal discomfort hours, energy consumption, and the total shading devices' surface area (Alsharif et al., 2023). Another recent investigation developed high accuracy a ML-MOO method and applied it to secondary school buildings located in Norway achieving an energy consumption reduction of 37.5% and a thermal comfort increase of 33.5% (Hosamo et al., 2022).

Some other investigations considered daylight and thermal comfort/energy design goals within ML-MOO methods (Kristiansen et al., 2022; Li et al., 2023; Xu et al., 2021). Design variables such as window-to-wall ratio (WWR), U-value of the opaque and glazing constructions, visible transmittance, PV-shading dimensions were optimized in primary and secondary education buildings located in China, finding a balance between daylight provision, thermal comfort, energy savings, and economy (Xu et al., 2021). Li et. al developed a designer-centric support tool that allow to balance in real-time energy consumption, daylight provision, and sunlight exposure during early design stages (Li et al., 2023). ANNs were used to predict annual daylight illuminance and operative temperature from room orientation, g-value, Tvis, and WWR within the Norwegian context achieving a computation time savings of 96% with respect to traditional simulation-based approaches (Kristiansen et al., 2022).

Novelty and aim of this investigation

Building performances such as daylight provision and thermal comfort depends strongly on the level of obstruction (i.e. obstruction angle) created by the surrounding buildings (Sepúlveda et al., 2022a). However, rules of thumb or prediction formulas (Sepúlveda et al., 2022a) could conservative and they might lead to very conservative design decisions. Thus, there is a lack of consideration of the level of obstruction in the ML-MOO workflows proposed by previous investigations.

In order to fill the above mentioned research gap, this paper aims to proposed a ML-based optimization design workflow based on obstruction angles for the optimization of building facades (i.e. g-value, Tvis, and WWR). The optimization output consists of the optimal clustering of windows in order to ensure a desired level of daylight provision according to method 2 defined in the EN1037:2018 (European comission, 2018) (i.e. based on the well-known

Spatial Daylight Autonomy, sDA metric) and to not exceed a maximum level of specific cooling capacity (SCC). Specifically, the objectives of the paper are as follows:

- To develop a reliable ML predictive method based on decision-tree algorithm for the obstruction angle-dependent metrics sDA and SCC;
- To find the optimal clustering for windows (Tvis, g-value, and WWR) of facades of a designed office urban quarter located in Tallinn, Estonia by applying the ML predictive method in combination with the GA technique.

METHODOLOGY

Parametric model for office rooms

The range for all the design parameters considered in the parametric model can be seen in Table 1. The independent variables or design parameters of the parametric model are: room orientation (ro), room width (rw), room depth (rd), window width (ww), window height (wh), and obstruction angle (θ). We used a building typology already used in previous investigation within the Estonian context (Sepúlveda et al., 2022a, 2020). The total number of room combinations 61440. The frame width and the number of vertical dividers (maximum width of the glazing pane was set to 1.75 m) for each ww was adjusted to ensure a constant frame ration of 12%, giving frame widths from 4.3 cm to 6.6 cm.

Metrics and ML-based predictive model

Although, good indoor environment requires careful design and proper installation of mechanical cooling, the prerequisite of assuring thermal comfort is well controlled SCC. Therefore, in this study the recommended thermal comfort levels are defined through SCC. The thermal comfort classes used in this investigations are based on the SCC metric: 80, 60, and 40 W/m^2 (annual peak load) for a minimum, medium, and high level of recommendation (Table 2).

Table 1.
Values considered for each design variable. Tvis= visible transmittance, ro= room orientation, rw= room width, rd= room depth, ww= window width, wh= window height, = mean obstruction angle.

Design variable	**Values**
Tvis (%)	40, 50, 60, 70
g-value (-)	0.20, 0.25, 0.30, 0.35
ro	S, SE, E, NE, N, NW, W, SW
rw (m)	3.5, 4.5, 5.5, 6.5
rd (m)	3.5, 4.5, 5.5, 6.5, 7.5
ww (m)	0.50*rw, 0.63*rw, 0.73*rw, 0.87*rw
wh (m)	2, 2.35, 2.7
$\bar{\theta}$ (°)	0, 5.5, 11, 16.2, 22, 27, 30.5, 35

Table 2.
Daylight provision classes (DPCs) definition based on the Spatial Daylight Autonomy (sDA) metric according to method 2 defined by the EN 17037:2018 and thermal comfort classes definition. SCC=specific cooling capacity.

Class	**Condition DPC / condition TCC**
Min.	sDA100,50 ≥95 AND sDA300,50 ≥50 / SCC≤80 W/m^2
Med.	sDA300,50 ≥95 AND sDA500,50 ≥50 / SCC≤60 W/m^2
High	sDA500,50 ≥95 AND sDA750,50 ≥50 / SCC≤40 W/m^2

Regarding daylight provision classes considered in this research, method 2 is based on the Daylight Autonomy (DA) metric during annual daytime hours

(Table 3). Specifically, these requirements can be expressed with the well-known Spatial Daylight Autonomy ($sDA_{x,t}$) with different illuminance thresholds *x* (100 lux, 300, lux, 500 lux, and 750 lux) and a constant value of the temporal threshold *t* of 50%. According to method 2, a minimum, medium, and high level of recommendations for daylight provision correspond to the simultaneous fulfillment of $sDA_{x,t}$ with different x and t thresholds (Table 2).

g-value (0-1)	0.2	0.25	0.3	0.35
ST (0-1)	0.17	0.21	0.25	0.3
Tvis (%)	40	50	60	70

Table 3. Windows glazing specifications. ST= solar transmittance, Tvis= visible transmittance.

Simulation settings

For daylight simulations, the reference plane was located at 0.85 m from the room floor level as defined by the EN 17037:2018. In addition, as recommended by the standard 0.5x0.5 m grid cells were considered for the calculation of horizontal illuminance values. The offset distance between the grid points and the room walls was 0.5 m. The reflectance of the window frame was set to 0.5 corresponding to a silver aluminum window frame. The reflectance values of the opaque surfaces were set according to standard values defined in the EN 17037:2018: 0.5, 0.2, 0.7, 0.2, and 0.3 for interior walls, floor, ceiling, external ground, and external facade/buildings, respectively. Moreover, we used the 2-phase method implemented in the Ladybug Tools component "HB Annual Daylight" for DA simulations (Radiance parameters: -ab 6 -ad 25000 -as 4096 -c 1 -dc 0.75 -dp 512 -dr 3 -ds 0.05 -dt 0.15 -lr 8 -lw 4e-07 -ss 1.0 -st 0.15) (Sepúlveda et al., 2022b).

All the combination rooms had heavyweight constructions based on concrete. Thus, the total thermal transmittance was 0.128, 0.2, 3.8, 2 for external walls, slabs, internal walls window frame, respectively. The glazing and frame U-value were constant and set to 0.55 W/m^2 and 2 W/m^2, respectively. The windows glazing specifications can be seen in Table 3. Occupied hours for Estonian office buildings are from 9:00 to 12:00 and from 13:00 to 16:00 (Estonian Government, 2015). The internal gain parameters for Estonian single offices and HVAC settings are: people density of 0.1 p/m^2 (1.2 met), equipment/lighting density power of 12/6 W/m^2, no dimming control, and target illuminance of 500 lux. Regarding HVAC settings, cooling/heating set point was 25/21 °C, mechanical ventilation air flow rate of 1.4 l/s·m^2, and supply air temperature was set to 17 °C.

Case study

The case study consists of two facades of a designed office building located in Tallinn, Estonia (Figure 1). There are 65 4x4 m office rooms oriented S and SE (Figure 1b).

Obstruction angle-based facade clustering algorithm

The metric to quantify the level of obstruction was the mean obstruction angle ($\bar{\theta}$), which is the arithmetic average of the obstruction angle associated to each horizontal angle (step of 0.5°) and a dead angle of 10° (Sepúlveda and De luca, 2020). In Figure 2, a random obstruction angle analysis is shown for a south-east oriented window. In this case, θ ranges between 0° and 42.5°with a $\bar{\theta}$ of 17.8°. In fact, we developed a grasshopper component to calculate the obstruction rays, θ profile and $\bar{\theta}$. Depending on the room orientation and $\bar{\theta}$, there could be several combinations between g-value, Tvis, and WWR that allow the fulfillment of certain level of daylight provision (Table 2) and thermal comfort (based on SCC). Thus, the prediction must be conducted by using ML classificators. If the prediction was made room per room, could lead to many different possible design solutions within the same facade. In practice, the selection of too many different glazing types and WWR could be economically unfeasible. Therefore, a clustering process is needed to minimize the number of glazing types that allows the desired level of combined fulfilment. Thus, once feasible combinations between Tvis, g-value, and WWR by using ML predictive models, the search of the optimal glazing types and WWRs for all windows located in each building facade is conducted by using a basic GA algorithm to generate high-quality solutions to optimization by relying on biologically inspired operators such as mutation, crossover and selection (Melanie, 1996).The objective formula to be minimize is the following one:

$$F = \sigma_{g-value}/0.35 + \sigma_{wfs}/0.87 \qquad (1)$$

where:

- σ_x is the standard deviation (Eq. X) of the design variable x,

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} \qquad (2)$$

where:

- n is the number of rooms per each facade,
- x_i represents each of the values of the data,
- $\bar{x}$ represents the mean of x_i.

Since $\bar{\theta}$ is highly dependent on the floor height and the surrounding buildings, the developed GA optimization algorithm (in python from the scratch using *numpy* and *random* libraries) was run per floor (1-5) and facade orientation (SE and S). The steps of the optimization algorithm for a desired DPC and TCC are as follows:

- Obstruction angle analysis for the case study
- Definition of design variables to optimize: g-value (0.20, 0.25, and 0.35) and wfs (0.50, 0.69, 0.87). With rw=rd=4 m and y0=0.15 (to maximize the view content) (European comission, 2018);
- Identification by using the ML predictive models developed in the previous section of all g-value-wfs combinations that make the room fulfill simultaneously a desired DPC and TCC;
- Genome generation per floor: 8 and 5 rooms for SE and S facades, respectively.
- Generation of the first population (size of 100 individuals) considering random individuals from the genome;
- Evaluation of the fitness value (F) for the first generation (Eq. 1) and sorting by lower F;
- Generation of the next generation considering the parameters mentioned above in the following order: elitism (15%), mutations (25%), reproduction (10%), and random individuals (50%);
- Evaluation of the fitness value (F) for the second generation (Eq. 1) and sorting by lower F;
- Evaluation of the best solution in terms of F, if F is higher than 0, the GA algorithm continues running generations and evaluating them until F=0 (i.e. $\sigma_x = 0$) or the number of total evaluations (Number of populations x 100) is lower than the number of size of the genome.

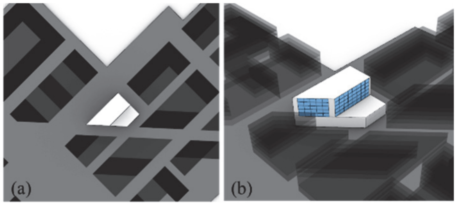

Figure 1.
Top (a) and perspective (b) view of the S and SE facades.

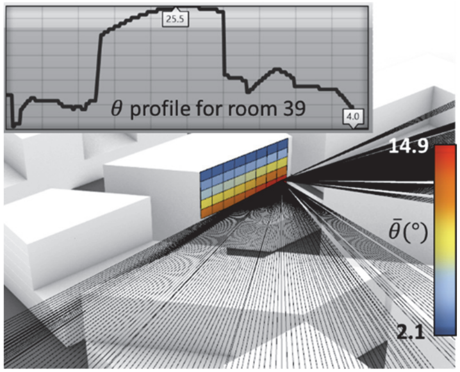

Figure 2.
Obstruction angle analysis for a facade partition in a generic office building.

RESULTS

Validation of the ML predictive model

Decision tree is among the most common and basic ML techniques to build up prediction models when the dependency between variables are not linear. The variables to predict in this investigation are the sDAx,t-based daylight provision class (DPC) shown in Table 2 and SCC-based thermal comfort class (TCC). The aim of this section is to find the maximum depth and size of the training datasets to predict DPC and TCC with an accuracy of 0.90 for both, training and test data sets. The python library *sklearn* (Brucher et al., 2023) was used to build up the multi-class decision tree classifier (0: below minimum level, 1: minimum level, 2: medium level, and 3: high level). Maximum depth of the decision tree is the length of the longest path from the tree root to a leaf. Since this parameter could depend on the relationship between DPC and TCC with the design variables (Table 1), we included these ones in the sensitivity analysis (Figure 3).

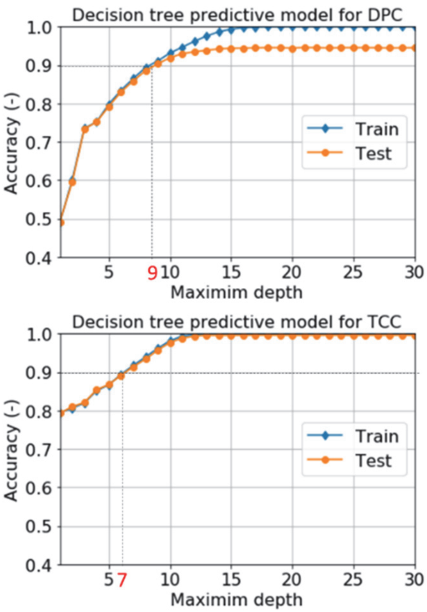

Figure 3.
Accuracy as ratio of right predictions (with size of the validation | training set=70% | 30%) of DPC (up) and TCC (down) depending on the maximum depth parameter (1-30).

As we considered a minimum accuracy of 0.9, the maximum depth of 9 and 7 were used to define the ML models to predict DPC and TCC, respectively. The need of a higher maximum depth for DPC than for TCC could be due to the lower correlation between sDA than for SCC and the design variables. The training of the ML prediction models required about 1 second (Intel(R) Core(TM) i7-8850 H CPU @2.60GHz 2.59 GHz, 32 GB of RAM memory).

Facade optimization using the proposed workflow

The aim of this section is to propose and apply an optimization method (Figure 4) to find the optimal combination of g-value and window width per facade orientation and floor of the case study.

The evolution of F with the number of generation and the optimal g-value and wfs values for each room of the same floor are saved for post-processing that is shown in Figures 4 and 5. The optimal combination (i.e. F=0) between g-value and window width for each floor is shown in Figure 5. The optimization process lasted 57 min, 16.1 min, and 0.9 min for required DPC of 1, 2, and 3, respectively (with a fixed TCC=1). The differences in terms of computation time is due to the lower number viable combinations between g-value (and therefore, Tvis, since we set Tvis=200*g-value in %) and wfs decrease when DPC increases.

When DPC is 1 (Figure 5a), the optimal g-value is 0.25 and wfs are different for middle floors. However, floor 2 is more obstructed than floor 3, meaning that a wfs of 0.5 would be enough to fulfill DPC and TCC in floor 3. Thus, with just a single glazing type (0.25) and WWR the design of the facade could be homogeneous. The optimization algorithm gives the first best design solution (F=0) per floor. However, there could be several design solutions that fulfill F=0 that are not given by the algorithm. This post-process decisions can be made according to the design criterion (e.g. aesthetics, scale economy, etc).

When DPC is 2 (Figure 5b), the optimal wfs is 0.5 for all the floors except for floor 1, which is 0.87. The optimal g-values are 0.35 for floors 2-3 and 0.20 for the rest of floors: 1, 4, and 5. Thus, last two floors are much less obstructed than the first floor, needing more protection against direct solar radiation in order to ensure TCC=1. This leads to a lower WWR than in rooms located in the highly obstructed first floor, where the available daylight provision is much more limited.

When DPC is 3 (Figure 5c), the optimal wfs is 0.87 for all the floors except for floors 4 and 5, which are less obstructed and therefore do not need such large windows. Floor 1 and 2 have the same optimal wfs but different optimal g-value. The most critical performance for floor 1 is DPC because is more obstructed, therefore floor 1 and 2 could be homogenized with a wfs of 0.87 and a g-value of 0.20 while ensuring DPC=3 and TCC=1.

Finally the selected final facade solution is displayed in Figure 5d, 5e, 5f. The mean WWR values are 49.4%, 46.4%, and 64.4% when DPC of 1, 2, and 3, respectively. In practice, facade C outperforms facade B, and this one is better than facade A in terms of daylight provision. However, the mean WWR is higher, which could have negative impact on heating the energy consumption (Thalfeldt et al., 2013). The final selection of the optimized facade should depend on the designer's final decision built up on the outputs of the proposed optimization workflow based on ML.

CONCLUSIONS

This paper proposed a ML-based optimization design workflow based on obstruction angles for the optimization of building facades (i.e. g-value, Tvis, and WWR). The optimization output consists of the optimal clustering of windows in order to ensure a desired level of daylight provision according to method 2 defined in the EN1037:2018 (i.e. based on the well-known Spatial Daylight Autonomy, sDA metric) and to not exceed a maximum level of specific cooling capacity (SCC), which has been proved to be related to thermal comfort within the Estonian context. The findings of this investigations are as follows:

- The development of reliable (accuracy of 0.90) ML predictive models based on decision tree technique to predict daylight provision and thermal comfort classes is possible by using maximum depths of 7 and 5, respectively.

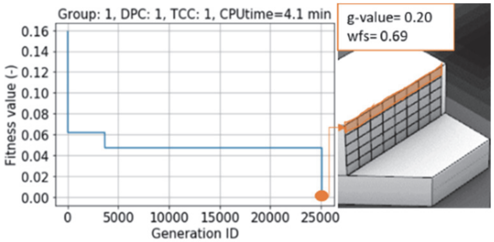

Figure 4.
Fitness value depending on the running generation for the rooms located at the last floor considering DPC=1 and TCC=1.

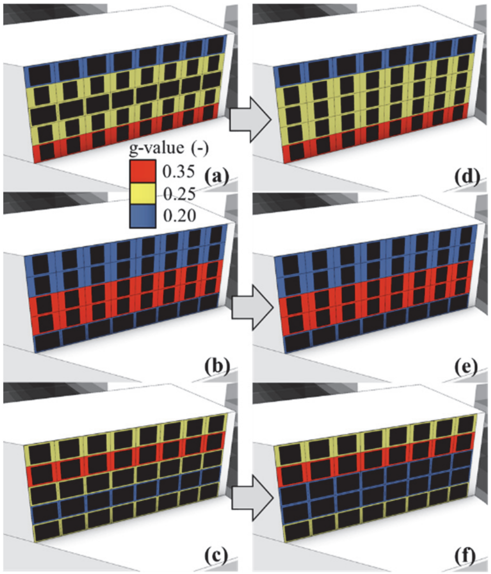

Figure 5.
Optimized SE facade in terms of g-value and window width when considering a minimum daylight provision class, DPC=1, and different thermal comfort classes: TCC=1, 2, and 3 shown in (a), (b), and (c), respectively.

- By using the proposed ML predictive methods in combination with a simple GA algorithm implemented in python the optimization of a SE facade (40 rooms) of an office building located in

Tallinn, Estonia conducted for three different design criteria (regarding daylight provision and thermal comfort classes) in an average of 25 min,

- The optimal clustering of windows were done first by floors and secondly by the designer's need to homogenize the external facade with similar glazing properties and window sizes, having impact on the annual heating consumption.

Only decision tree technique was considered to develop ML prediction models. Future research could be explore how different training strategies and ML algorithm could influence on the prediction of both daylight provision and thermal comfort classes. The GA algorithm could be optimized by conducting a sensitivity analysis of the parameters such as: elitism, mutation, reproduction, and random sampling ratios. This could lead to a faster convergence of the optimal solutions, which might not reach null values for the fitness formula because the variety of obstruction angles. Moreover, optimal solutions generated by the proposed method should be further validated with simulations. Future studies should focus on application to different climates and locations with different solar angles and outdoor temperatures, giving designers powerful tools to make more accurate and faster design decisions during early design stages and renovation plans.

ACKNOWLEDGMENTS

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A Data-enabled Participatory Application towards Better Engagement and Neighborhood Accessibility

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This paper presents a novel workflow for managing urban data and visualizing them with the use of a mixed reality interface for studying historic urban cores in participatory design scenarios, using as a case study the Strovolos historic core in Nicosia, Cyprus. The application provides a data-enabled interactive medium to measure key aspects of urban accessibility with real time data feedback, to test design hypothesis and record user input. The goal is the creation of a user driven urban database and facilitate decision making of urban scenarios in consideration of walkable cities.

Keywords: *Digital Twins, City Modeling, Smart Cities, Data-Enabled Participation, and GIS.*

CURRENT CHALLENGES IN CITIES

Negri (2009) suggests that a new type of emerging urban centrality can be observed in cities due to rising population trends. These trends put great strain on cities and their neighborhoods due to the increased needs in infrastructure and governance, attributing to the neighborhood unit high importance, since it "is one of the most critical elements for the spatial and functional organization of the city" (Pozoukidou et al 2021, p.1).

As a result, Bouzguenda (2021) notes that "governments are moving toward collaborative forms of governance", pointing towards a need for finding new ways to make citizen participation effective.

The value of participatory planning in shaping the neighborhood from within, can be seen not only as an elicitation and decision-making tool for the authorities, but also a placemaking tool addressing the inhabitants, as with," participatory planning, effectively engaged citizens can experience an increased sense of place" (Colantonio 2009, p. 2).

ICT integration and digitally enabled citizen participation

Recently, Digital Twin models, digitally enhanced decision-making and citizen participation practices are proposed to enrich traditional urban planning and design practices. As these processes are being enhanced by new tools and techniques, they are calling for new methodologies to be developed.

The current digitalization trend has steered governments and technology companies to invest in smart systems for the transformation of cities into data generating environments that adjust their performance and with the aim to provide better services to citizens. However, many believe that certain aspects of urban development are still underdeveloped, "do not support technological innovation and are often unsuitable for multi-stakeholder strategic collaboration" (De Lange 2019, p.5).

Another effect of the ICT transition of city management is the enhancement towards a digitally enabled citizen participation environment. Defined by Sanford and Rose (2007, p. 5), as "a technology-mediated interaction between the civil society sphere and the administration sphere, where the citizen's ability to participate in digital governance is at the epicenter".

The value of Historic Urban Cores

Recently, there has been a growing interest and pursuit of new policies in transforming historic city cores to car-free zones such as Paris and Berlin. Barcelona, is trying to completely restructure its urban grid with the "Superilla" initiative, whereby connecting the street network of its trademark superblocks strives to increase the citizen accessible space to 67.2% with superblocks (Roberts 2019).

French-Colombian scientist Carlos Moreno (2021) proposed a complete urban planning model that sets the foundations for a more sustainable human-centric urban environment, named "The 15-minute city". While not a new concept all together, it is one of the most recent frameworks that proposes a road map that is in line with the New Leipzig Charter (Godson 2020), to create pedestrian friendly neighbourhoods by addressing street network design and amenities management to bring activities to the neighborhoods, where daily necessities are within a 15-minute walking reach.

The value of this concept lies in offering to residents an opportunity to participate in the planning process of their area, which they know well by stating their needs and the problems, and for planners to act by locating facilities that serve multiple neighbourhoods based on relevant citizen input.

CASE STUDY: CHRYSALEOUSA-STROVOLOS, CYPRUS

To introduce the methodology and workflow in a real-life framework, we selected, a suburb of Nicosia, in Cyprus, the historic core of Strovolos, Chrysaleousa, as a case study. Nicosia, as of 2022, has a population of about 200.452 inhabitants (USOLVE-WP3 2022, p. 6). The key characteristics of Nicosia's urban form are low population densities, urban sprawl, and lack of street level green canopies and insufficient provision of public transport services. In addition, Chrysaleousa, suffers also from being a main street artery that connects the city to the west suburbs while presenting low levels of connectivity with the city's iconic linear park of Pediaios river.

The rapid urbanization of the mid-urban areas between the walled city of Nicosia and the surrounding settlements was due to the huge number of refugees, that needed urgently to be housed, after the events of the 1974 intracommunal war and the new status quo, that forced almost a quarter of the total population to become refugees due to the consequent division of the whole island and the exchange of populations.

Finally, within the historic core, based on Philokyprou (2013) "housing, and commercial uses (shops) coexist even within the same urban plot with direct contact with the road". This characteristic relates directly to the concept of the 15-minute city since the idea of working and living locally was an active ingredient of the city's urban heritage.

Research and Planning initiatives in Chrysaleousa

Strovolos attracted the interest of multiple stakeholders as there is ongoing research by Artopoulos (2022) about the reuse of the building stock of urban heritage through a digital twin platform that brings multiple stakeholders together. In 2016, the municipality of Strovolos held an architectural contest about the regeneration of Chrysaleousa, which the winning entry named "the Slow City" tried to implement design interventions based on the "slow city concept" (Slow City 2016), however implementation proved challenging due to multiple and diverse stakeholders at play.

Finally, the Cyprus Institute and the University of Cyprus, with the U-solve project, have been actively engaged in developing a comprehensive representation of all the stakeholders who can and have the power to influence urban sustainable development, that will lead in the establishment of a local hub for smart entrepreneurship, based on three main pillars, waste management, urban and transport planning, and innovation for sustainability.

CONCEPTUAL FRAMEWORK

In the context of the above local initiatives and European research, a conceptual model was developed that tried to link the existing small-scale businesses with the developing entrepreneurial ecosystem that could use the creative industries model as a driver to promote local entrepreneurship and in doing so to contribute to neighbourhood urban regeneration. The core of Strovolos, had historically mixed use of housing with local small businesses, and thus makes for a great candidate to promote an urban regeneration model based in the introduction of creative industries.

Creative industries are a new type of urban economy, that enhances the model living and working locally, by integrating with existing services, businesses, and workshops along with guidelines that are aligned with the 15-minute city concept.

METHODOLOGY OVERVIEW

In this framework, the paper presents a novel workflow of managing urban data and visualizing them with the use of a mixed reality interface for studying urban accessibility aspects of historic urban cores in participatory design scenarios.

The two tools developed, "Accessibility Mapper" and "Neighbourhood Mapper" offer the opportunity for users to highlight, using an interactive application, POI (places of interests), neighbourhoods, local workshops, existing or future creative industries sites, routes, and areas of importance.

The primary goal of the tools is for local stakeholders, local community groups and municipal officials and researchers, to be able to capture local sentiment, track local businesses and highlight best potential areas for installing new businesses alongside local residential uses.

The core functionality of the tool relies in providing isochrone analysis and visualization for the given street network. Previous publications by Düring et al (2019) and Bielik et al (2018), provided valuable insight on the use of a graph-based model for accessibility and the relation between amenities and walking patterns in a street network.

The proposed tools contribute to the area of digitally enhanced participatory processes by providing an interface for local stakeholders and inhabitants to engage in scenario testing and discussions that draw on expert data that typically are difficult to be integrated in city models and interpreted by non-experts.

Data Management Plan

For the development of the presented application, we used the 3d modeling software Rhinoceros and its parametric design plugin Grasshopper. Data collection and preparation was done in QGIS, where data from OSM or open access cadastral databases, were collected, cleaned, organized, and imported in Rhinoceros. The presented workflow consists of four main steps:

- Data preparation in QGIS,
- Data analysis and visualization of accessibility analytics in Rhinoceros and Grasshopper
- A custom-built user interface that enables collection from citizen data
- A postprocessing session where all data collected are exported back in QGIS in the form of a shapefile.

The main data required are the street network, an OSM or aerial map overlay and any POI (point of interest) that is available. Special care was made for simplifying the street network to single line components to facilitate future analysis such as space syntax. All data were then imported into Rhinoceros directly from the shapefiles with the use of either the Urbano plugin or the BearGIS plugin.

Isochrone Map functionality

According to Allen (2018), an isochrone map is a map that depicts the area accessible from a point of origin within a certain time threshold. In urban planning, isochrone maps are commonly used to depict areas of equal travel time and are great tools to easily visualize what is accessible in an area, in ideal conditions.

Isochrone visualization, if used in correlation with the 15-minute city concept, can be a great visual cue to help residents easily visualize and understand their surrounding area.

Time	1min	5min	10min	15min	20min
Range	80m	390m	780m	1170m	1560m

Table 1. Average distances covered in specific time intervals, based on an average walking speed of 1,3m/s (Alves et al 2020, p. 5).

From street network to graph

To create an isochrone map, the street network is transformed into a graph and analyzed with basic graph operations. In a street network, any street segment is translated into an edge, and every intersection or change in direction is modeled as a vertex.

In a street network graph, the cost between two intersections is the length of the street segment that connects them, measured in meters.

The core functionality of the tool relies in calculating isochrones for 1, 5, 10, 15, and 20 minutes thresholds. The plugin used to calculate a graph from the street network is the SpiderWeb plugin.

By using the "single source shortest path" component, SpiderWeb calculates the shortest path of each vertex in the graph to any given starting point within the street network. By calculating the shortest path for each vertex of the graph to every other vertex, the component works similarly as the betweenness centrality calculation used in Space Syntax.

The catchment area of the 15-minute walking distance, highlights the area that is accessible within that timeframe and is calculated by incorporating into the process the average walking speed of a healthy human being (approx. 1,3m/s) (Alves et al 2020, p. 5), that is translated into how far an average person can reach, in a 15-minute threshold (Table 1).

By providing appropriate visual cues and color codes, users can easily understand what areas are closer to their point of origin and what amenities are within reach.

User Interface

The proposed tools were developed to be used along with data-enabled planning practices (Lieven 2017), or participatory design methodologies (Our City Plans 2022).

All functionalities are being accessed through a custom user interface that is made available using the UI+ plugin. The combination of a custom interface that is easily operated by a non-expert user along with the ability for custom operations and functions to be easily programmed, makes the tool highly adaptable and reconfigurable to any given design scenario.

The visual interface is used to help users navigate in the map, change isochrone parameters and finally, provide feedback for any selected POI (point of interest). The provided feedback is then stored locally in Rhinoceros in the form of metadata along with the new user-generated POI and isochrones. Finally, all data collected are exported back into a shapefile, with the use of the BearGIS plugin.

FUNCTIONALITIES OF THE APPLICATIONS

Both tools use the same methodology and data management plan, but with a different focus. "Accessibility Mapper" or "A_Mapper", specializes in highlighting elements relative to the "15-minute city" concept, such as accessibility and amenities distribution, while "Neighborhood Mapper" or "N_Mapper" focuses on data collection of existing industries, possible locations of creative industries and the production chains that can be formed along. In both options, users are asked to also provide a series of qualitative urban data on comfort, accessibility, security, and urban form.

A_Mapper functionalities

"A_Mapper" offers 2 main functions. The first is "exploration mode", where users can pick a point on the map by using the appropriate button and attractor through the interactive interface and see what type of amenities exist in the selected area. Furthermore, by selecting the appropriate walking time threshold as seen in Figure 1 and Figure 2, the user can see how the accessibility isochrone map changes. Also, the user can select age group and gender as they slightly affect the resulting catchment area.

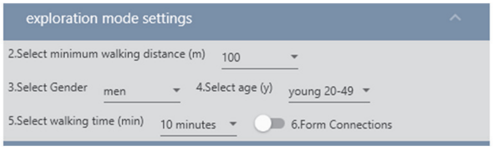

Figure 1. Isochrone Settings

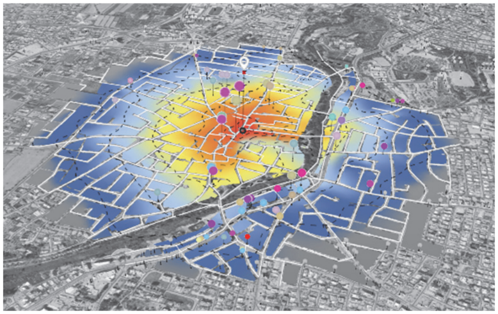
Figure 2. Isochrone Visualization

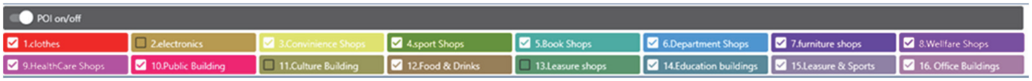

Figure 3. Amenities Selector User Interface

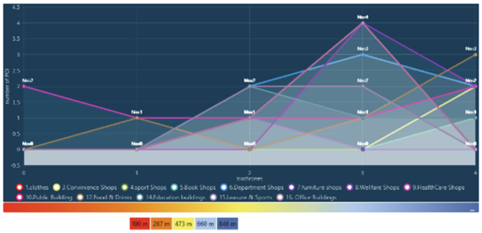
Figure 4. Amenities Population Statistics

The type of amenities that are depicted are based on the Open Street map categorization, such as shops, healthcare, food and drinks and leisure and sports.

All amenities are color coded and through a visual interface, the users can select the type of amenities that are turned on/off (Figure 3). Lastly, the application provides a visual line chart, that visualizes the population of each selected amenity in the selected catchment area. In Figure 2, having selected the 10-minute range, the isochrone provides POI data from 100m, up to approx. 780m, which is the max travel distance based on the selected exploration mode settings. (Figure 4).

The application also offers a visual interface that provides a mini map of the catchment area and the intersection density per 50 meters (Figure 5). Intersection density can be related closely with block size, as the greater the density the smaller the blocks. Based on a study by Ewing and Cervero (2010), intersection density has the largest effect on walking, as smaller blocks are more walkable. This metric relates also with research from Sim and Gehl (2019), in creating an attractive cityscape for walking, as the average person needs a new visual cue every 4 to 7.7 seconds and sound levels below 65db.

The application also provides a polar diagram based on research by Boeing (2019) of the mean street orientation, for the selected catchment area. Mean street orientation can be used as a tool to highlight which streets will be benefited most by the presence of green canopy during summer as examined by Sanusi et al (2016), as in the Mediterranean regions have the longest exposure to the sun.

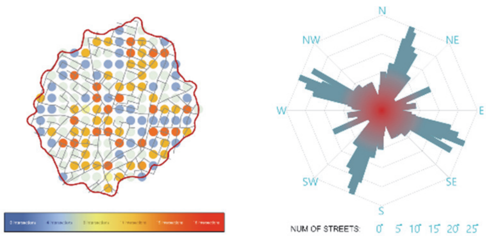

Figure 5. Intersection Density and Mean Street Orientation

The second mode of the "A_Mapper" is the "multiple points" mode. The user can place points directly on the map that are used as starting locations for the isochrone map. In that mode, we can see how a cluster of neighborhoods can benefit using Pediaios linear Park as a "slow" connectivity highway, connecting by walking or cycling, neighborhoods from the periphery up to the walled city of Nicosia (Figure 6).

N_Mapper functionalities

The purpose of "N_Mapper" is to map existing production and reprocessing activities, propose new locations for the installation of creative industries, and to map routes that users usually take for their everyday activities.

N_Mapper offers 2 core functionalities as well, "exploration mode" and "route planner" mode. "Exploration mode" works in the same way as in "A_Mapper", with slightly different visuals and without showcasing the included amenities. Furthermore, for each POI that the user selects, the isochrone interpretation relates to the maximum area (and residents) that the selected POI can service (Figure 7).

In "Route Planner Mode" users can track their walking routines or highlight a preferred path. By pressing the "Place Route" button, users can point and click to place points on the map, that will be connected into a polyline. The visualization that appears is highlighted by a 1min walking distance isochrone that corresponds to the area that is in the urban wanderer's immediate perception (Figure 8).

User input through the User Interface

Both "A_Mapper" and "N_Mapper" provide a user interface, that can be used to add information relative to the POI or route. The user data are broken down into 2 groups, in group A (Figure 9), users input information relative to the POI:

1.POI Name, 2.Address: the address of the POI or an "origin/destination" input. 3.Industry Type (N_Mapper only): the industry or creative industry type selected from the dropdown list, including a

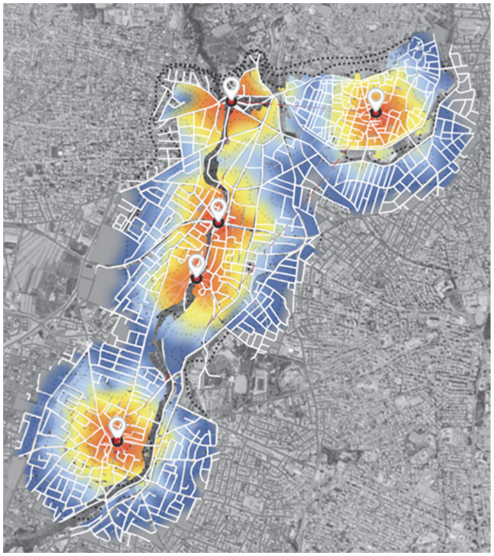

Figure 6.
Multiple Points
Mode

Figure 7.
N_Mapper
exploration Mode

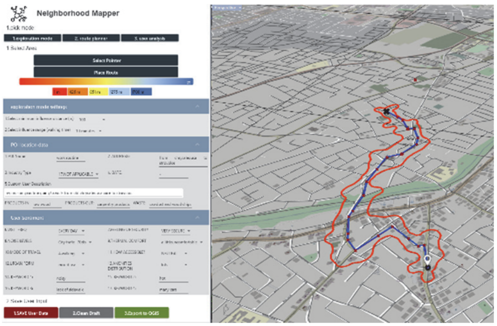

Figure 8.
N_Mapper route
Planner mode

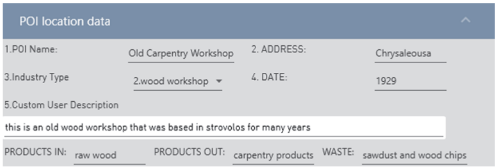

Figure 9.
User Input GroupA
POI Data

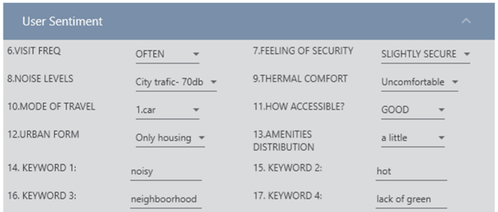

Figure 10.
User Input GroupB
User Sentiment
Data

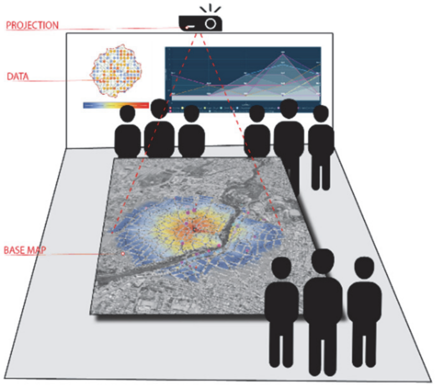

Figure 11.
Participatory Setup
Diagram with Data
projection on top of
map

"not applicable" option. 4.Date, A date option, that measures the age of the POI. 5.Custom user Description, a sort text description of the POI, route. 6.Products In/ Products out/ Waste (N_Mapper only): mapping of raw resources, produced products and produced waste to create a productivity map of the area, mapping possible local production chains (FabCity, 2016).

In group B (Figure 10), users can input their opinions for a given POI or route: 1.Visit Frequency: the frequency of visits or passing throughs. 2.Feeling of Security, the feeling of security for the given POI/ route. 4.Noise Levels, the perceived noise levels in the POI/ neighborhood or route. The scale is based on relevance to noise levels that can be easily translated to Db (Measuring Levels 2021). 5.Thermal Comfort, the perceived thermal comfort levels in the POI. (Zhang et al. 2007).

6.Mode of Travel, marking of the most frequently used mode of travel for the POI/ route such as car, bike, walking, or p. transport. 7. How accessible, marking of the ease of access to the POI/route. 8.Urban Form, marking of the surrounding urban form of the area and highlight the most significant land use. 9.Amenities distribution, marking of amenities distribution around the area, highlighting the availability of complementary services. 10. Keywords: marking 4 keywords that describe best the POI/ route.

Finally, all data can be exported, by pressing the button "Export to QGIS", to a shapefile that can be accessed in any GIS-type application, to be used along with other urban data or other types of urban or environmental analyses for correlation of data.

TOOL APPLICATION

The methodology and an early version of N_Mapper, was introduced and tested on site in the conditions of a workshop organized in the municipal library of Strovolos with the U-Solve project in 2022. The participants included academics, researchers, professionals, start-uppers, representatives of local groups, students, and residents.

In this early version of the interface, using only screen-based input, participants were asked to map their walking routines while interacting in real-time with the previously presented data visualizations. The goal of this experiment was to introduce participants in participatory planning and citizen science and to evaluate preliminary engagement with e-participatory tools.

The results showed that there is a need for a clear goal to be set in the participatory workshop setup, where the tools complement the participatory process, as engagement seems to require some sort of stake that the participant needs to bring along into the participatory setup.

The results of this preliminary evaluation session informed the development of a more complete version of the tools which was later presented in the 7th Conference on Sustainable Mobility & Intelligent Transportation systems (2023), informing technical experts of the local authorities).

FUTURE DEVELOPMENT OF THE TOOLS

The next version of the tools is planned to be tested in the context of the ERASMUS+ CLICHE project, where during a workshop session about urban health and urban sustainability in Strovolos, the methodology presented here will be compared with state-of-the-art decision-support systems used to guide public administrations in identifying development scenarios for sustainable urban and territorial transformations (Grifoni, Sargolini and D'Onofrio 2018).

In this setup, the tools aspire to provide a methodology in transforming qualitative-user generated data to quantitative geolocated databases. As data are geolocated and can be correlated with established methods of street network analysis, based on Stichler (2016), they have the capacity to become evidence of bottom-up input from various stakeholders and local neighborhood dwellers.

Therefore, the contribution of the proposed methodology is in bridging the gap between scientific data visualizations for expert analysis and the use of simplified, static illustrations of urban conditions in participatory planning processes, facilitating the communication between residents and policy makers. Better communication for this research is related to a continuously growing database of locally aware urban data.

The tool developed to support this methodology provides an interactive medium to measure key aspects of urban performance, focusing on accessibility, in an easy-to-understand way. The intended environment of application is to be used along goal oriented participatory workshops as data feedback and recording tool to test design scenarios in relation to data-driven visualizations of local urban conditions.

Accessibility_Mapper, will continue to be developed and enhanced with a mixed reality interface as part of the on-going research. By using a printed map and by projecting all accessibility data top-down, the tools strive to capitalize on the advantages in using a hybrid interface (Figure 11). That is physical interaction with a map, by using markers, post-it etc. and live update of projected accessibility data.

The currently under development mixed-reality interface uses the Fologram plugin. The users instead of using the Rhinoceros interface to move the attractor points they will use a physical aruco marker which can be identified in real-time by a tablet that is used along with a video projector, acting as the technological interfaces to enable the projection of the simulation results while interactive with the platform.

Preliminary test models informed the authors that both the tracking and the live feedback are within acceptable levels, since the recalculation of the isochrones won't require more that 5-6 seconds up to 12 in data heavy occasions, making the process almost real time, suggesting that the tool can be effectively used during a participatory process.

CONCLUSION

In this paper we presented a methodology and tools, with the goal to provide a data-enabled participatory medium to help with the creation of a user- driven database of citizen data to enhance user engagement and facilitate decision- making in neighborhood-scale design scenarios, specifically in the historic core of Chrysaleousa.

The strength of the methodology is that it relies in a hybrid setup where participation along with data collection is done on the same interface. However, as with most digital tools, it requires initial training of participants to feel comfortable in using the interface presented, as well as the communication of clear goals and a facilitation methodology to be set prior to the participatory session. Also, during the participatory process, it requires very specific rules of conduct, for the tools to be used effectively, as participants need to engage with a clear goal in mind.

Furthermore, for the database to become effective, it requires an iterative series of participatory sessions that could happen regularly to create a big enough dataset to allow correlations between parameters and scenarios to start forming. Finally, to become immersive, it requires a stationary setup primarily relying on projecting the data on top of a static map, for users to engage more actively, using physical markers on the map at the same time while modifying the variables.

The methodology hopes to contribute towards a new approach to citizen- engagement in participatory urban management processes by helping non-experts to interpret urban analysis (scientific) data and the complexity of implementing alternative design scenarios in urban environments through visualization and knowledge elicitation – a method that helps the citizens to feel ownership of the dialectic process.

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Parametric Design and Digital Fabrication of Temporary Pavilions for Resilient Historical Open Spaces

An Educational Experience in Parma

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The historic centers have maintained their structure almost unchanged throughout various eras, thanks to a conservative approach that preserves valuable architecture and urban systems. The preservation of pre-existing structures can maintain the identity of a place, but it may also limit the flexibility of urban spaces that evolve over time in response to changing climates and functions. The study aims to develop a systematic and holistic workflow for creating temporary architectures that enhance the climatic and functional resilience of historical open spaces. Several disciplines are brought together for project development, including historical and climate analysis, algorithmic design, fabrication, and digital prototyping. As both climate and cultural changes are occurring rapidly, it is essential to educate the younger generation of students on effective methods. The technologies of algorithmic design, combined with digital fabrication, enable the creation of customized solutions that are more effective than standardized construction models. This paper reports on a methodological experiment for developing temporary pavilions in the courtyard of the Cloister of San Sepolcro in Parma, Italy.

Keywords: *Algorithmic Parametric Design, Digital Fabrication, Laser Cutting, Prototyping, Temporary Architecture, Historical Spaces Space*

INTRODUCTION

Urban open spaces in historic centers are the result of a building stratification that has been consolidated over various eras. Typologies, methods, and building materials used in traditional architecture serve as valuable evidence of the past. In Italy, as well as in other countries, is preserved with great care and attention. The historic city faces the dual challenge of adapting to both climatic (Alcamo, 2012) (Kumar, 2021) and cultural changes, while simultaneously preserving its unique identity. The modifications allowed for open space designs are highly restrictive, necessitating the exploration of minimally invasive and temporary intervention strategies (Gherri, 2021).

The case study examines the courtyard of a religious building located in the city of Parma, Italy: the cloister of San Sepolcro. Previous studies analyzing the climate have shown that the San Sepolcro cloister courtyard experiences several critical climatic issues, particularly in terms of providing comfortable summer climate. Like many other historical cloisters, San Sepolcro is underutilized due to its secluded location and the absence of practical amenities for everyday use. This is mainly due to the fact that historical cloisters and courtyards are often overlooked as common public spaces, despite offering many thermal and functional advantages in the urban fabric. New infrastructure is instrumental in the readjustment of spaces. Permanent architectural interventions are prohibited; a low-impact approach to utilizing the courtyard is preferred. The courtyard typology, which is common in old town centers, exhibits similar climatic and functional discomfort characteristics. These findings can be applied to the entire typology.

The study aims to establish a workflow for designing and implementing temporary architecture that addresses climate adaptation, the repurposing of open spaces, and the relationship with building heritage. The available tools include algorithmic generative software and numerical control machines for digital fabrication. These tools can be used to systematize all data related to the identified themes, as well as for the development, prototyping, and production phases. The workflow was tested by Civil Engineering master's students, who had the opportunity to enhance their knowledge of both tool-related technologies and process-related methodologies.

BACKGROUND

The use of advanced design and construction processes is becoming increasingly prevalent in the field of architecture. These methods are expressed through architectural buildings, temporary structures, and street furniture. The benchmarks adopted for the morphogenesis of these architectures are primarily numerical and can be easily adapted to structural, climatic, or dimensional data of the context. Constructing qualitative relationships between visitors, new architecture, and pre-existing built environments, particularly in historical contexts, is a less immediate task.

OBJECTIVES

The study aims to enhance the resilience of open historical spaces by defining a holistic systemic workflow that creates a balance between various areas. These areas include the valorization of historical heritage, visitor experience, climatic adaptation, development of a repeatable building system for similar contexts, and scalability and adaptability of the project. Algorithmic analysis, design models, and digital fabrication technologies (Yuan, 2018) are the tools utilized to accomplish the research objectives.

Algorithmic design, which is used in compositional processes, defines complex relationships between the parts of architecture. A qualitative level of relationships, as opposed to a quantitative one, allows for the emergence of visual relationships and topological forms (Deleuze, 1994) (De Landa, 2000) rather than typological ones. The design structure of a space influences the relationship that visitors have with it. A temporary design structure can create new frames and viewpoints that highlight pre-existing elements in fragments. The solar radiation, which is partially filtered and partially obstructed by the loggia, creates both a sense of thermal comfort and an immersive experience.

Advanced technologies that work with numerical data are more easily utilized to obtain quantitative results. The effort to include non-quantifiable aspects broadens the scope and requires a holistic approach. The interplay of visual relationships through the fragmentation of the view, the creation of frames that incorporate the pre-existing architecture and portions of the sky, and the establishment of non-trivial analogies between the host courtyard and new construction are all factors that cannot be quantified but should be considered in the algorithm design process.

METHODOLOGY

The research methodology is divided into the following stages:

1. historical, environmental and climate analysis
2. definition of issues and strategies
3. choice of technologies, software and production tools
4. design morphogenesis

5. prototyping
6. construction of scale models

The historical analysis of San Sepolcro cloister aids in comprehending the identity of the location and its background. The climate analysis is conducted using simulation software such as Rhino, Grasshopper, and Ladybug (McNeel, R. & Associates, Rhinoceros, 2021). These data support previous studies that analyzed the microclimatic performance of the inner cloister using the Envi-MEt software. The analyses performed revealed an underutilization of the space in the courtyard inside the cloister of San Sepolcro, as well as critical issues related to thermal comfort during the summer season, in accordance with climate change. The UTCI and OTCA indices are used to evaluate thermal discomfort levels in the courtyard.

The strategy involves a temporary architectural intervention capable of reducing the summer thermal discomfort while also serving as infrastructure for visitors. The temporary architecture is developed using algorithmic design technology, the Rhino / Grasshopper / Ladybug generative software are adopted. Two sets of parameters are utilized in the development of compositional morphogenesis: those pertaining to climatic factors and those pertaining to the visitor's perspective. In the first scenario, the objective is to enhance the thermal comfort of the open spaces. In the second scenario, the goal is to create a dynamic interplay of perspectives that fragment and frame the pre-existing structure through the new construction. The prototyping phase involves a feedback process which first verifies the constructive feasibility of the architectural construction defined as described, then incorporates dimensional and quantitative changes in relation to the technical capabilities of the numerically controlled machines and the materials utilized. The design / production process culminates in the creation of a scale model, which serves to verify both the production process and the compositional aspects on a broader level.

Historical, environmental and climate analysis

The analysis of historical typology identifies the cloister of San Sapolcro (Melley, 2012) (Figure 1) as a recurring typology of an internal courtyard building, typical of ancient Italian centers. The San Sepolcro cloister features arcades on three sides and a spacious grassy courtyard. The original religious function is still maintained today; however, the spaces are now open to the public. Despite the potential for use as a public and communal space, the inner courtyard is rarely utilized.

The case study of San Sepolcro cloister is analyzed using simulation software such as Rhino, Grasshopper, and Ladybug. The same cloister underwent more detailed climatic analyses in a previous study (Touloupaki, Gherri, & Naboni, 2023), which utilized Envi-met software (ENVI_met, 2022). The climate simulations assessed the mean radiant temperature (MRT) values, wind speed, and air temperature, and evaluated the Universal Thermal Climate Index (UTCI) values, which revealed specific climatic issues resulting from the combination of the climatic zone and the typological conformation of the courtyard.

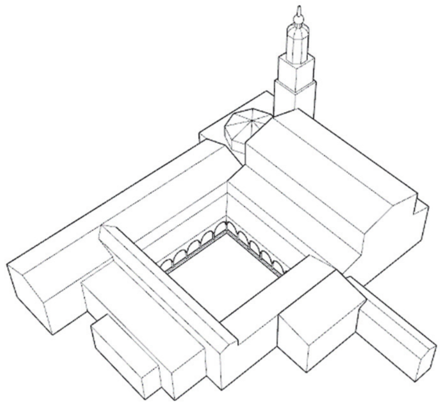


Figure 1
Closter of San Sepolcro

Issues and strategies

The climate analysis highlights some critical points. Firstly, there is a high concentration of solar radiation in the upper internal facades of the courtyard. Secondly, there is a lack of both vertical and cross ventilation, which contributes to high air temperatures and discomfort during the summer season. These findings are supported by the UTCI and OTCA indexes. The design strategy involves utilizing modular construction systems to control shading, which reduces solar radiation on the courtyard floor while still allowing for vertical ventilation. Two design solutions are proposed, each with its own set of unique characteristics. The two structures are composed of distinct modules and share topological characteristics with the courtyard that surrounds them. Like the courtyard, they feature a perimeter frame that is more or less solid and a central opening. However, the compositional style differs typologically from the pre-existing structures and plays a contrasting role, which emphasizes both architectural languages.

The modules have a variable orientation, designed to optimize thermal performance. The various inclinations of the buildings in the courtyard create a dynamic interplay of viewpoints and framing, resulting in a visually engaging narrative experience for visitors. One of the two structures optimizes this aspect in an interesting way by identifying a point beneath the construction where the view of the cloister is fully visible despite being fully covered. The only fragmentation in the view is caused by the necessary modules. The viewpoint is at ground level, so visitors are encouraged to lie down on the lawn to experience this optical game.

Design morphogenesis

The concept moment already contains an overall setting of functional, climatic and cultural relations, and even the type of material, the construction system, the production logic in relation to a specific CNC machine. This is a systemic and holistic approach, which requires an in-depth dialogue phase between various disciplines even before setting up the work.

The digital composition of the two proposed projects derives from a process of morphogenesis and algorithmic analysis using Rhino / Grasshopper (Oxman & R., 2014) (Pugnale A. & M., 2007) software tools. This process involves five subsets:

- morphogenesis of the control surface
- morphogenesis of the construction system
- optimisation of the structure in relation to climatic and cultural parameters
- climate analysis using UTCI and OTCA indices
- parametric prototyping

The two projects A and B follow the same procedure. The control surface and analysis part undergo the same morphogenesis process. Differences are evident in the morphogenesis of the two construction systems, resulting in project-specific parametric prototyping. This study focuses on developing algorithms for building systems and parameterizing the prototyping phase. The study also includes the realization of a scale model. However, the climate aspect, including both morphogenesis and analysis, will be addressed in a separate study.

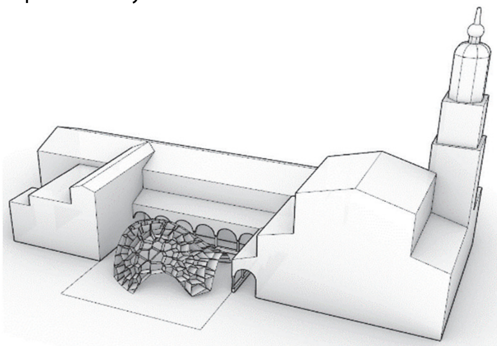


Figure 2
Project A in the cloister of San Sepolcro

In project A (Figure 2), the construction system is defined by dividing the control surface into irregular hexagons using a Voronoi algorithm. The extrusion of the different Voronoi segments on the surface creates a modular composition that is enclosed on the perimeter and open on both sides of each module. The composition of each module, as defined, has a topological structure similar to that of a court, with an opening on a closed perimeter. The perimeter enclosing the elements of each module has differently oriented positions in space, ranging from vertical to oblique. This arrangement is designed to optimize shading and consequent thermal comfort in relation to solar radiation.

The orientation of elements derives from a biomimicry process (Benyus, 2002) (Pawlyn, 2016). The composition of the Opuntia ficus-indica (Opuntia ficus-indica) (Anderson, 2001) (Figure 3) comprises vertically oriented and inclined flat elements, which bring shade to the body of the plant, but at the same time do not prevent the passage of vertical air. This strategy helps the plant to withstand the extremely hot and arid climate of its natural habitat. The same strategy can be effectively applied to an installation within a courtyard, providing shading without obstructing vertical ventilation. This is particularly important in the case of a courtyard building with a closed conformation, where vertical ventilation is the only option available.

Figure 3
Opuntia ficus-indica. Acatlán, Hidalgo, México,2013. Diego Delso.

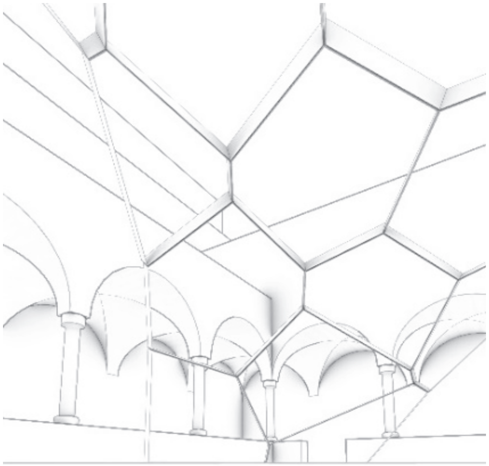


Figure 4
The vision of the cloister of St. Sepulchre through the modular structure of project A. Perspective game for the visitor.

The design incorporates compositional analogies with pre-existing structures and biomimicry climatic strategies inspired by cacti that thrive in extreme climates. A third objective is to establish a visual relationship between the visitor and the architecture. The temporary structure serves as both a closure and an opening to the surrounding context, which is defined by the building that borders the courtyard.

This game of perspectives involves multiple points of view that result in varying percentages of closure and aperture, with a specific point where the maximum visual opening is achieved. From one vantage point on the courtyard floor, the historic buildings are fully visible, while the temporary structure appears as a sparse grid, with each module serving as a frame (Figure 4). The visitor is invited to lie down on the grassy floor at the indicated point for the proposed immersive experience.

The described set of climatic and cultural characteristics is achieved through the implementation of algorithmic rules that guide the extrusion of modules towards a vanishing point. The amplitude of extrusion, however, is different for each module and is generated through morphogenesis optimization (Wortmann, 2017) (Rutten, 2010) from climatic parameters.

The construction system for project B (Figure 6) is defined by discretizing planar triangular modules of the control surface. Each module includes a triangular hole, which is created by offsetting the shape of the module itself. The size of the hole is determined by the morphogenesis of climatic parameters in order to optimize the summer thermal comfort of the courtyard spaces. In this project, the modules have a topological relationship with the courtyard's composition. They are delimited by a perimeter that delimits an opening.

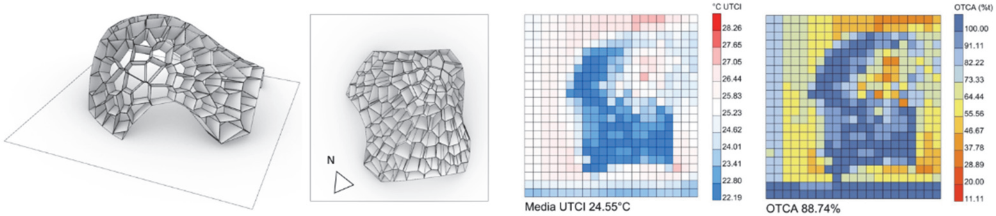


Figure 5
Climate analysis of project A. UTCI and OTCA

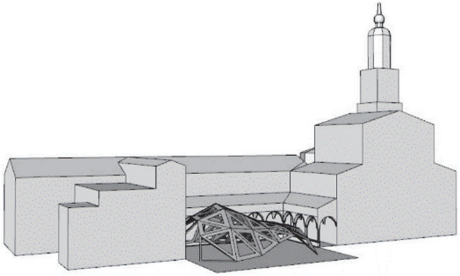


Figure 6
Project B in the cloister of San Sepolcro

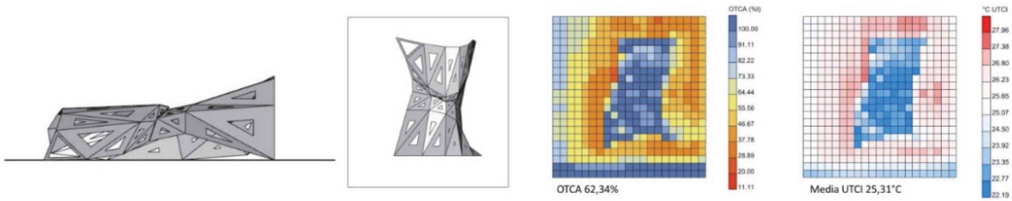


Figure 7
Climate analysis of project B. UTCI and OTCA

The alternation of empty and full spaces, created by the varying sizes of the modules and openings, results in a visual fragmentation of the area. As visitors cross the courtyard, they experience multiple perspectives of the same context.

Prototyping

The prototyping phase includes two moments, the first corresponds to the development of the algorithm and the second involves the scaling of the model in relation to the characteristics of the available CNC machines and the material. The CNC machine chosen is the laser cutter, the material for the scale model is corrugated cardboard.

For project A, the algorithmic process for prototyping involves combining all sides of each module into a single surface, which is then unrolled on the XY plane. As many surfaces are obtained as there are modules. An identification number marks the module and its corresponding unrolled surface. To close the surface, a flap is created on the corresponding side and folded over. The laser cutter requires a two-dimensional drawing with linear vector elements for both cutting and incisions. Therefore, the surfaces of the ashlars obtained as described are divided into two groups of linear vector elements: one for cutting, which corresponds to the external margin, and the other for incisions, which corresponds to the folding points (Figure 8). The cutting and incision work takes place on the extrados of the ashlar blocks (Figures 9, 10).

The size and number of modules, as well as the range of extrusion depth, are regulated based on the dimensional limits of the formats, the thickness of

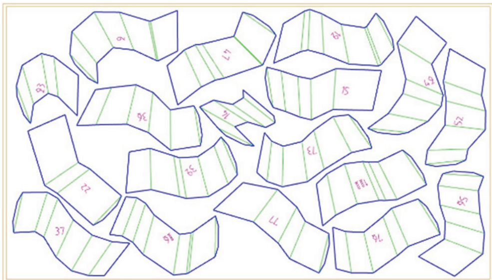


Figure 8
Project A. Nesting

the material, and the cutting plane dimensions of the available laser cutter.

Project B involves planar modules that are joined together on three sides. In this case, the prototyping algorithm transfers the surfaces of the numbered triangular perforated modules onto the XY plane. These modules begin with multiple orientations and are then arranged into a planar organization. The modules are connected by aligning and bringing together the sides that coincide with each other. To complete the task, you must create tabs with parametric dimensions on all three sides of each module.

The surfaces of the modules are arranged in vector lines on two layers to distinguish between the cutting and engraving areas for the laser cutter (Figure 11). The prototyping phase, although it occurs at the end of the process, requires a complete revision of the initial project setup. Prototyping (Figure 12, 13) is an active phase of the project that involves more than just translating compositions into production schemes. It involves modifying the project itself to optimize dimensions and quantities, as well as improve assembly techniques. It is essential to consider the construction process and the subsequent logic of prototyping during the initial concept phase.

The nesting process (Figure 8, 11) for both projects optimize the organization of the modules in the material format. The production takes place through a laser cutting process of the cardboard. The assembly of the numbered modules returns the models on a reduced scale.

RESULTS

The research has resulted in a workflow for two building systems for temporary architecture that incorporate cultural aspects such as the relationship with historical heritage, interaction with visitors, functionalization of historical open spaces, climatic adaptation, and realisability through automated digital fabrication processes. The workflow, based on algorithmic processes, allows for a large family of solutions based on input parameters. This approach

Figure 9
Project A. Laser-cut modules

Figure 10
Project A. Modules

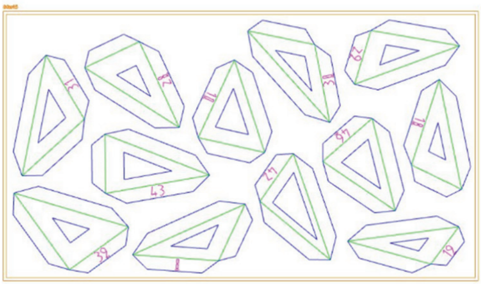


Figure 11
Project A. Nesting

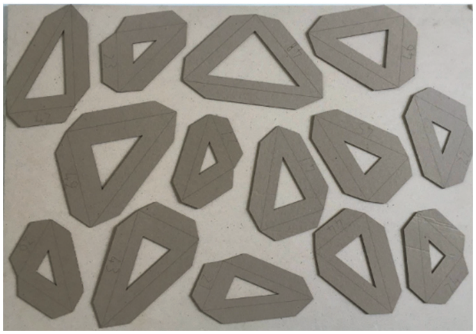


Figure 12
Project B. Laser-cut nesting

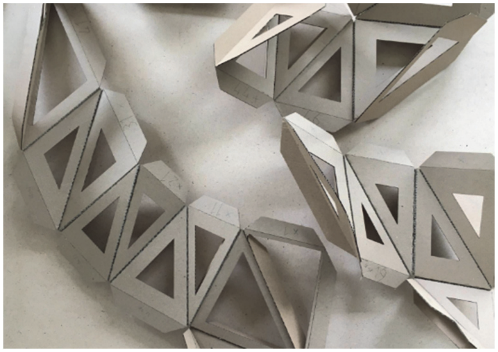


Figure 13
Project B. Modules

offers the advantage of generating various design variants that can be quickly adapted to the dimensional or functional differences of other historic open spaces and courtyards.

The realization of the two small-scale models (Figure 15, 16) demonstrates the feasibility of the full-scale models. In fact, the process is identical.

CONCLUSIONS

Adopting a process that incorporates both quantitative and qualitative multi-criteria leads to the development of holistic and systemic solutions. Algorithmic design and digital fabrication are valuable tools for creating temporary architecture that enhances historical open spaces, such as courtyards or squares. As part of a systemic approach,

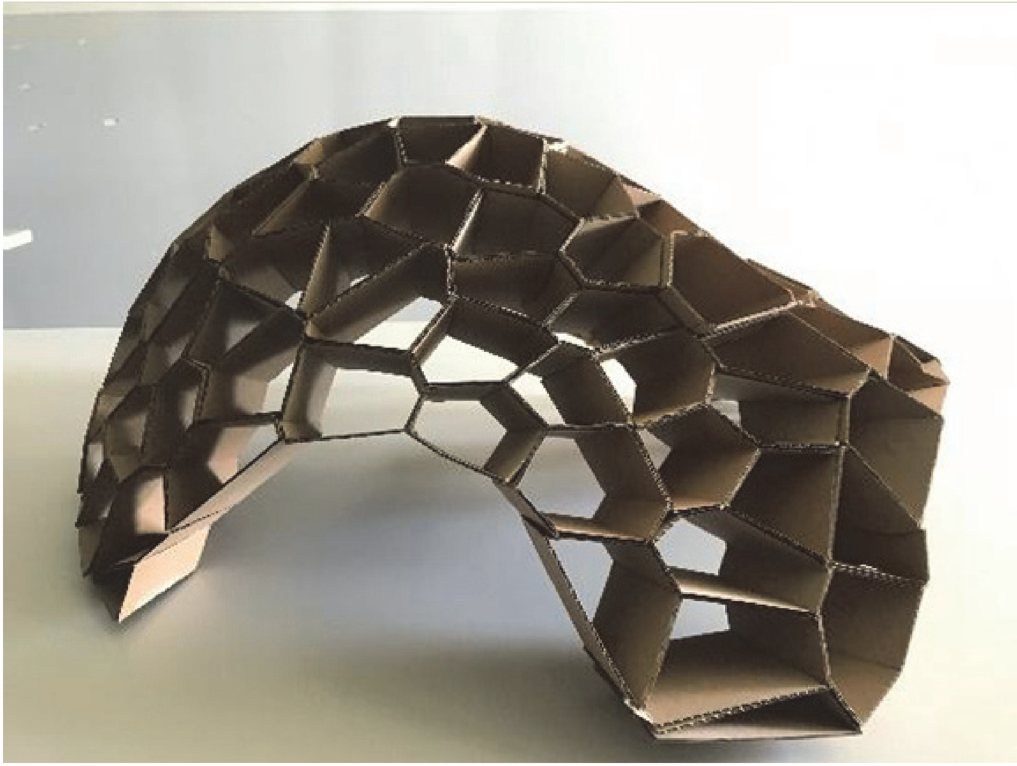
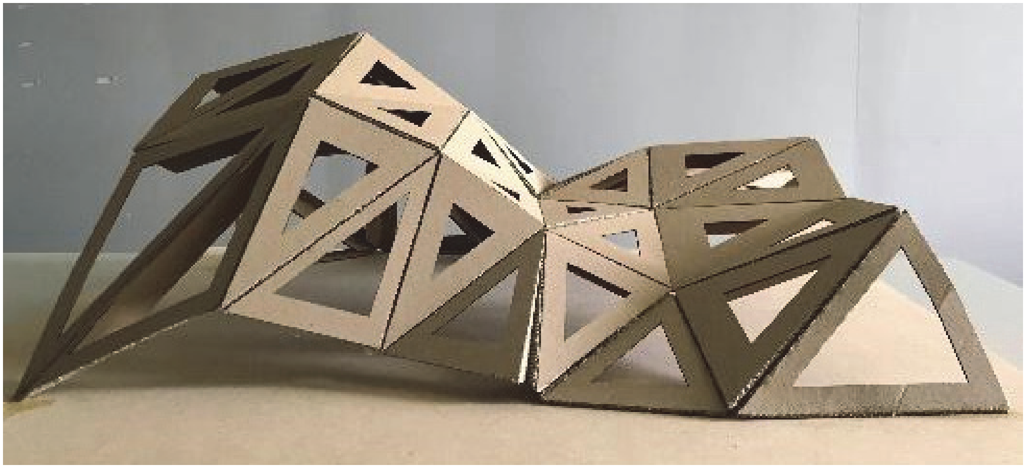


Figure 14
Project A. 1:30 scale prototype

Figure 15
Project B. 1:30 scale prototype



they can manage cultural aspects of the relationship with pre-existing architectures, experiential aspects of the relationship with visitors, and aspects of comfort in relation to climate. The result of all this is a resilience of historical open spaces.

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COVID-19 and the City

An Analysis of the Correlation between Urban and Social Factors and COVID-19 in Fortaleza, Brazil

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The COVID-19 pandemic has been the biggest sanitary crisis humanity has ever faced, the virus has contaminated 662.717.929 people worldwide and killed 6.701.270 people. However, these numbers were not distributed equally at international, national or urban scale. In Fortaleza, Brazil, city studied in this paper, data from 2021 and 2022 epidemiologic reports suggest a contamination pattern that starts in neighborhoods with higher Human Development Index (HDI) and then goes to lower HDI neighborhoods, however, throughout all of this cycle, low HDI neighborhoods tend to have a higher lethality rate. These facts raised the hypothesis that those neighborhoods have specific urban and social factors that affect the capacity to respond and prevent COVID-19. The main objective of this paper is to identify the correlation of some urban and social factors with COVID-19 data. To achieve that, the authors selected seven variables (access to water rate, literacy rate, waste collection rate, population density, access to electric energy rate, sanitation rate and average monthly income) to correlate with four COVID-19 indicators (total number of cases, total number of deaths, contamination rate and lethality rate). For this, it was chosen to apply Spearman's correlation coefficient and for the calculation the statistical software Jamovi was used. The results show that the literacy rate, the access to electric energy rate and average monthly income have a positive correlation with the contamination rate, however these same variables have a negative correlation with the lethality rate.

Keywords: *COVID-19, Urban Factors, Spearman's Coefficient Correlation, Public Health.*

INTRODUCTION

COVID-19 has been a notorious health and sanitary challenge worldwide, reaching 676.609.955 cases and 6.881.955 deaths. (*Johns Hopkins University* 2022) The brazilian context, however, as long as other Global South countries, had socioeconomic inequality as an aggravating factor. Unicef (2020) especially mentioned the lack of efficiency of the most common sanitary prevention methods, such as washing hands, in low income areas or slums, considering there's a lack of infrastructure for most of these areas, such as limited water access, poor sanitation and inadequate or inexistent bathrooms.

In Fortaleza, city studied in this paper, according to the Municipal Department of Health's reports (2021-2022), during the first and second wave of the pandemic, it's possible to perceive a contamination pattern. Higher Human Development Index (HDI) neighborhoods tend to start as larger contamination clusters, during the first month of the wave, they have a higher number of infections and deaths, nonetheless, once the sanitary issues start to aggravate, there is a shift, lower HDI neighborhoods, then, tend to become the higher contamination clusters for the remaining time the wave lasts, however with a higher lethality rate and a larger number of deaths.

This pattern evoked a couple explanations. One of the possible causes is that, in territories where COVID-19 tests are harder to obtain, the lethality rate will appear higher due to the underreporting of cases (Prado et al. 2020). The possibility explored in this paper, although, hypothesizes that certain urban and social factors affect the prevention of and action against COVID-19. Regarding it, this research questions: which of these urban and social factors could correlate with COVID-19's spread and lethality?

That being said, the main objective of this paper is to identify the correlation between determined urban and social factors and COVID-19 data in the neighborhood scale. This is intended to help urban planners understand which decisions can impact public health. This is, also, a part of another research, intended for the future development of an algorithmic indicator that can predict the disease impact on a smaller scale, inside of the neighborhood, so as to mitigate the lack of data in lower income neighborhoods.

METHODS

As mentioned in Introduction, the research presented in this article is the first phase of a three phase project. The first one, detailed in this paper, consists in identifying the correlation between urban and social factors and COVID-19 data in the neighborhood scale, because this is the scale with the highest amount of information available about urban infrastructure and COVID-19. The second phase will test the same correlation, but inside two neighborhoods, one with a higher HDI and another with a lower HDI, both being considered as contamination clusters at some point during the pandemic. The last phase will utilize the information obtained to develop an algorithm that can predict, based on the urban and social factors with higher correlation, which areas are more vulnerable and can suffer higher impact from COVID-19, using a CAD software with VPI software.

The phase discussed in this paper is divided in three steps:

1. Literature review. For this step, it was conducted a systematized review, which, according to Grant and Booth (2009), has the same elements of a systematic review, however, without the need to exhaust the search. The intention of this step was to understand which urban and social factors were usually picked to be analyzed considering COVID-19 data.

The authors searched for articles that contained "correlation", "COVID-19", "urban factors" and "low income areas" in either the title, abstract or keywords. The first screening consisted in checking if there were urban or socioeconomic characteristics being connected to COVID-19. The second screening consisted in filtering the results to studies that either talked about low income communities or were situated in countries from the Global South. By the end, 13 articles were selected.

From the selected articles, Lancaster et al. (2022), Wang et al. (2022) and Qanazi et al. (2022) mentioned that the number of hospitals was associated with better health care and lower COVID-19 indexes. Lancaster et al. (2022) also mentioned that the number of registered doctors and COVID-19 testing sites had a positive correlation with COVID-19 indexes. Wang et al. (2022) and Qanazi et al. (2022) also mentioned population density as a factor associated with better COVID-19 indexes, however Silva (2021) and Nunes et al. (2021) mentioned population density as a factor connected with worse COVID-19 results. Qanazi et al. (2022) mentioned population total as a factor with a direct relation with COVID-19.

Waste collection was mentioned as having an opposite relation with contamination indicators by Beckert and Barros (2022), Traesel et al. (2021) and Amankwaa and Fischer (2020).

Sanitation was one the most considered and mentioned variables, mentioned as having an opposite relation with COVID-19 by Traesel et al. (2021), Aquino (2020), França (2020), Amankwaa and Fischer (2020) and Nunes et al. (2021). Access to water was often associated with this variable and it was also mentioned by Traesel et al. (2021), França (2020), Amankwaa and Fischer (2020) and Nunes et al. (2021).

The income was the other most mentioned variable; three out of four papers said that income had an opposite relation with COVID-19, they were: Silva (2021), Nunes and Carvalho (2020), Nunes et al. (2021) and Santos et al. Sanhueza-Sanzana et al. (2021) also talked about income related to COVID-19, however these authors perceived a direct correlation of extreme poverty with COVID-19's lethality rates, they also perceived the literacy rates had a negative correlation with lethality.

Santos et al. (2022) also perceived the literacy rates had negative correlations with COVID-19 indexes.

2. Variables selection. In this step, the authors analyzed the previously selected articles and collected 9 possible urban and social factors that showed higher correlation in each article and it's incidence in all of the papers, they were: Amount of Hospitals; Registered physicians and COVID-19's test locations; Density; Waste Management; Population; Sanitation; Water Supply; Average Monthly Income and Literacy. After further research, three variables were eliminated and another one was added.

As it can be seen in Figure 1, Registered physicians and COVID-19's test locations was eliminated due to low occurrence, since it was mentioned once in a single article. The variable Population was eliminated due to an overall preference amongst the papers to utilize Population Density (hab/km²) in the analyzes. Lastly, Amount of Hospitals was the third variable to be eliminated, not because of irrelevance, but because this variable is usually evaluated in researches about access to basic health. Considering Fortaleza's context, quality of the health facilities seem much more relevant than the quantity of them, which means that this variable by itself wouldn't be enough to the analyzes and it would better work in a research specifically about access to basic health.

At last, it was decided to add the variable Access to Electric Energy, due to its connection with other urban infrastructures, such as Waste Management, Sanitation and Water Supply.

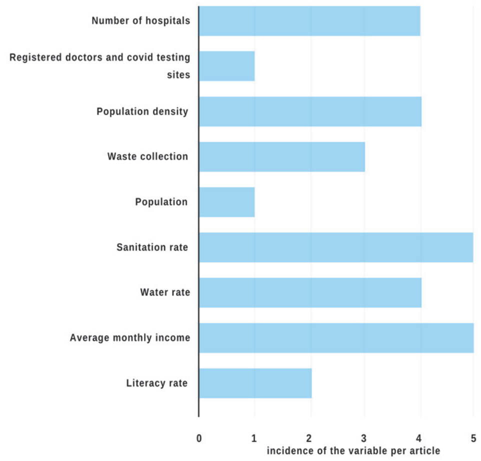

Figure 1
Incidence of variables per article

3. Correlation Matrix. The last step was to correlate the seven variables chosen (Access To Water Rate, Literacy Rate, Waste Collection Rate, Population Density, Access To Electric Energy Rate, Sanitation Rate And Average Monthly Income) to four COVID-19 related variables (Total Number of Cases, Total Number of Deaths, Contamination Rate and Lethality Rate) using Spearman's Correlation Coefficient.

Accordion to Mukaka (2012), Spearman's Correlation Coefficient is similar to Pearson's Coefficient, however, Pearson requires the variables to be normally distributed which was not the case with this study, Spearman, in other hand, allows variables to be skewed or ordinal, which is why it was chosen for this research.

The COVID-19 data was provided by the Federal University of Ceará Architecture Tutorial Education Program and it consisted in the number of cases and deaths for march, may, april and june of 2020 and the accumulated number of cases and deaths of the whole period. The contamination and lethality rate were calculated by the authors.

At last, the information was organized and inserted in Jamovi, a free statistical software, that provided a Correlation Matrix of the data, which results were then interpreted by the authors.

The initial intention to achieve the Correlation Matrix was to use a CAD software along with a VPI software to calculate the correlation coefficient, so that all phases of the research could use the same softwares. This was developed and achieved by the authors using Rhinoceros and Grasshopper, however, it was decided that, to achieve a higher level of precision it was better to use a statistical software and that's why Jamovi was used.

RESULTS AND DISCUSSIONS

As said in Methods, the seven variables selected were analyzed in relation to four COVID-19 variables: Total Number of Cases; Total Number of Deaths; Lethality Rate and Contamination Rate

As presented in Figure 2, the Total Number of Cases variable had only one correlation with an acceptable p-value, it had an insignificant positive correlation with the Sanitation Rate. The Total Number of Deaths didn't present any precise correlation with the variables selected, however it presented a high positive correlation with the Total Number of Cases, which means that territories with a high number of infections tend to have a higher number of deaths. (See Figure 2)

To discuss the Lethality rate correlations is first necessary to define it. In this paper, the authors use the definition that it corresponds to the percentage of deaths of a territory's total number of cases, which means that it measures how much lethal the disease is, how many infected people end up passing away. This variable presented three positive correlations with a p-value under 0.001 with the following variables: Access to electric energy rate; Literacy rate and Average monthly income.

Even though all the correlations were low, they were relevant to the research, because they suggest that the higher the Average monthly income, the Literacy rate and the Access to electric energy rate the lower the probability of death in case of infection. It's important to atest, however, that all of these three variables have medium or high positive correlation within each other, so it's possible that not all of these factors have, in fact, a relation with COVID-19, but only one or two of them.

The authors interpret that, about the Average monthly income variable, the higher income infected people have more financial possibilities to follow treatments, either because of their higher purchasing power of medicine or because of the possibility to pay for private health assistance. A possibility also mentioned and debated by Sanhueza-Sanzana et aL. (2021) This possibility is especially important considering the research's time frame. During March to June 2020, in Fortaleza, the average percentage of occupied ICU beds was 69,67%, the higher rate of this period, though, reached 90,94% on May 24th 2020. The average percentage of occupied beds in wards of this time frame was 45,61% and the higher rate of this period happened on May 14th 2020 and it reached 76,79% (*IntegraSUS* 2020)

About the Literacy rate variable, the results suggest that the higher the percentage of literate people the less lethal the disease is.

A lot of factors can have influence in this, however, the main hypothesis brought up by the authors is the illiterate people's susceptibility to be influenced by fake news, a recurring problem during the pandemic.

The Access to electric energy rate variable wasn't considered by the authors as a relevant factor to COVID-19 lethality rate, however, your correlation with the other two variables previously mentioned

Figure 2
Correlation Matrix

		Sanitation rate	Access to electric energy rate	Waste collection rate	Access to water rate	Literacy rate	Average monthly income	Population density (hab/km²)	Total number of cases	Total number of deaths	Lethality rate	Contamination rate
Sanitation rate	Spearman's Rho	—										
	p-value	—										
Access to electric energy rate	Spearman's Rho	0.391 ***	—									
	p-value	< .001	—									
Waste collection rate	Spearman's Rho	0.473 ***	0.597 ***	—								
	p-value	< .001	< .001	—								
Access to water rate	Spearman's Rho	0.022	0.128	-0.066	—							
	p-value	0.814	0.174	0.487	—							
Literacy rate	Spearman's Rho	0.511 ***	0.809 ***	0.643 ***	-0.029	—						
	p-value	< .001	< .001	< .001	0.756	—						
Average monthly income	Spearman's Rho	0.342 ***	0.671 ***	0.432 ***	-0.152	0.855 ***	—					
	p-value	< .001	< .001	< .001	0.106	< .001	—					
Population density (hab/km²)	Spearman's Rho	0.445 ***	0.052	0.360 ***	-0.055	0.070	-0.197 *	—				
	p-value	< .001	0.578	< .001	0.556	0.460	0.035	—				
Total number of cases	Spearman's Rho	0.185 *	0.116	-0.050	0.057	0.163	0.108	0.055	—			
	p-value	0.047	0.218	0.593	0.543	0.082	0.249	0.560	—			
Total number of deaths	Spearman's Rho	0.118	-0.079	-0.125	0.040	-0.054	-0.158	0.158	0.858 ***	—		
	p-value	0.208	0.399	0.184	0.672	0.565	0.091	0.091	< .001	—		
Lethality rate	Spearman's Rho	-0.072	-0.306 ***	-0.104	-0.009	-0.317 ***	-0.415 ***	0.187 *	-0.040	0.414 ***	—	
	p-value	0.443	< .001	0.269	0.924	< .001	< .001	0.045	0.669	< .001	—	
Contamination rate	Spearman's Rho	0.167	0.237 *	0.228 *	-0.192 *	0.383 ***	0.380 ***	-0.022	0.430 ***	0.151	-0.418 ***	—
	p-value	0.074	0.011	0.014	0.039	< .001	< .001	0.817	< .001	0.107	< .001	—

Note. * p < .05, ** p < .01, *** p < .001

Low negative correlation
Medium negative correlation
High negative correlation
Low positive correlation
Medium positive correlation
High positive correlation
Insignificant correlation
Correlations important for the analysis

strengthens the narrative that they are relevant in action against COVID-19.

At last, the Contamination rate is analyzed, which consists of the percentage of infected people in relation to the total population of a territory. This variable presented two low positive correlations with an appropriate p-value with the Literacy rate and with Average monthly income. That suggests that neighborhoods with higher income residents and with a higher literacy rate had a higher percentage of infected people, however, as presented before, not as many deaths as lower income neighborhoods. This may be explained by the first month of the time frame, March 2020, in this month, Fortaleza would reach community transmission only on March 20th, which means that a great portion of the data from this month had only imported cases from abroad. (G1 CE 2020) The authors hypothesize that higher income residents have a higher possibility of international mobility due to the prices of traveling abroad and this might explain the correlations.

The Contamination rate also presented a positive correlation with Access to electric energy and Waste collection rate and a negative correlation with Access to water rate, however these last three have a p-value higher than 0.01 and are all considered insignificant. These three insignificant correlations may exist, however, to certify it, it's necessary to increase the time frame and to seek more recent data about infrastructure.

CONCLUSIONS

It is therefore concluded that the literacy rate and the average monthly income are factors that are correlated with the contamination and lethality of COVID-19 in Fortaleza. Both are directly related to contamination and indirectly to lethality, which led the authors to interpret that neighborhoods with higher average monthly income and higher literacy rate are proportionally more contaminated, but die less, and neighborhoods with lower income monthly average and lower literacy rate are, proportionally, less contaminated, but die more.

For future research, it is recommended in addition to increasing the time frame and updating the infrastructure data to draw conclusions about the other variables, research that specifically studies the correlation between access to health, poverty and COVID-19. It is also recommended to continue the research and advance to a second phase of making predictions based on census tracts.

Finally, it is important to emphasize that the research was carried out during a political period in Brazil when there was a data blackout and suspension of the collection of new data for the census. These blackouts affected, in addition to census data, also COVID-19 data, thus being a context that hampered the progress of the work. However, it is foreseen that a new census will take place soon, which will make it possible to update the research.

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ENERGY, STRUCTURAL, FUNCTIONAL AND AESTHETIC PERFORMANCES. BIM AND DIGITAL CONFIGURATION IN EDUCATION

An Experimental Investigation of Latent Heat Storage for Solar cooling Systems using Paraffin Wax

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Latent heat thermal energy storage units employ phase change materials to store and release heat at a nearly constant temperature, ensure high heat transfer efficiency, as well as high charge and discharge capacity. Phase change materials (PCMs), allow a more compact, efficient, and therefore economical system to operate. Thermal Energy Storage (TES) systems are of growing importance within the energy awareness, because of TES can reduce the levelized cost of electricity of solar cooling systems. This paper proposes a comprehensive methodology where simulations were performed to demonstrate the phase change process of paraffin wax and to improve the effect of PCM modules on the heat transfer process. PCM modules were tested in the laboratory, then their impact on thermal energy storage were determinate. The rise of COP of solar absorption cooling system was calculated.

Keywords: *Solar Energy, Solar Cooling, Thermal Energy Storage, Phase Change Material (PCM); Latent Heat.*

INTRODUCTION

Demand for new technologies, linked to environmental problems, energy shortages and, over the last three decades, the cost of energy, has been the focus of scientists. In recent years there has been a demand for renewable energy, so a lot of attention is being paid to the use of solar energy. The use of solar systems is a promising way to reduce the consumption of fossil fuels and reduce CO_2 emissions into the atmosphere. Solar energy has two drawbacks: intermittency and diffusivity (Shehadi 2020). The most important factor in the use of solar energy is therefore efficient and economical heat storage. Phase change energy storage materials (PCMs) have been shown to have great potential for solar energy applications. Unlike sensible heat storage materials such as water, masonry, or stones, PCMs store much more heat per unit volume (Migla & Lebedeva 2021). Air conditioning is one of the biggest consumers of electricity, increasing fossil fuel consumption and consequently CO_2 emissions. Compared to electric vapor compression chillers, thermal cooling systems have a lower COP of between 0.6 and 1.8, but a higher solar collector efficiency of around 35 to 70% (Hirmiz et al. 2018). Since the COP of the chiller and the efficiency of the collector are inversed, the overall system efficiency is between 35 and 80% (Shirazi et al. 2018). It is important to mention that the increase in indoor temperature, when cooling is needed, mainly come from solar radiation or internal heat sources. Conversely, the more solar radiation is available, the more we can use it to generate energy to maintain the indoor climate (Zajacs, et al. 2020).

The aim of the study is to look for solutions to reduce the above-mentioned barriers to the use of solar energy in the economy, for example in solar cooling systems. The development of an optimized energy storage with integrated phase change material containers/modules, reduce auxiliary heater energy consumption, increases the COP of the solar cooling system, and reduces the environmental impact of the cooling system. The literature review (Vyshak & Jilani 2007; Shipkovs et al. 2015; Shehadi 2020) revealed that a solar LiBr-water absorption cycle provided the best coefficient of performance of around 0.77 with a relatively small solar collector area. The novelty of the study is the Lab-scale energy storage tank used to test containerized phase change materials to investigate the effect of PCM on energy storage efficiency and COP and electricity reduction of Solar Cooling systems. Solution should increase the efficiency of solar thermal energy storage when solar energy is available and use the stored energy when there is no sun.

METHODS

This paper experimentally investigates the effect of the encapsulation design on the performance of a lab-scale thermal energy storage tank. The constructive solutions of PCM cylinder modules with fins for integrating into the lab scale heat storage tank is examined in depth. In addition, the results were simulated in the validated simulation model mentioned in previous articles (Shipkovs et al. 2015), based on an existing solar cooling system in Latvia, to determine the COP of the system. The methods used are described in article in depth.

PCM for solar cooling applications

Based on the literature analysis (S. Seddegh 2017; Du et al. 2018; Millers et al. 2020; Abdolmaleki & Berardi 2022), the most commonly used PCM for single effect absorption solar cooling systems were summarized in table 1. As in general, paraffin waxes are safe (do not have the properties of fire hazard, toxicity, etc.), reliable, inexpensive, and non-irritating substances, obtained in a relatively wide range of temperatures. And it is proven that most technical grade waxes can be used as PCMs in latent heat storage systems. From the chemical point of view, paraffin waxes are inactive and stable. They exhibit moderate volume changes (10–20%) during melting but have relatively low vapor pressure (Vakhshouri 2019).

The Rubitherm RT90 was selected for this particular experiment because of the operating temperature required for the solar absorption system. It also has the following properties: heat storage and release occur in a relatively constant state, it means, there is no significant volume changes; no subcooling effect is observed, it is chemically inert, and it is a long-lasting product with stable performance during phase change cycles.

In addition to the advantages of paraffins mentioned above, they are also non-corrosive. The choice was also influenced by the fact that the other non-paraffinic PCM listed in the table 1 have subcooling effects.

Table1
PCM materials for solar cooling systems

PCM	type	Melting point °C	Heat of Fusion kJ/kg
RT110	Organic paraffin	112	213
Erythritol	Organic	118	339.8
$MgCl_2 \cdot 6H_2O$	Inorganic	115	165
RT90	Organic paraffin	90	197
RT80	Organic paraffin	79	209
RT65	Organic paraffin	64	154

Latent heat storage system model

The Lab-scale energy storage tank (see fig.1) consists of a hot water stratification storage tank made of galvanized steel and equipped with a 1200 W auxiliary heater. The hot water temperature in the tank is regulated to ensure a constant inlet water temperature in the tank. The power supplied to the heater is controlled via a voltage slider. The heat supplied to the tank is used to simulate the heat from a solar collector system. The overall size of the hot water tank is 500x1155 mm with 200L capacity.

Figure 1
Scheme of Lab-scale storage tank

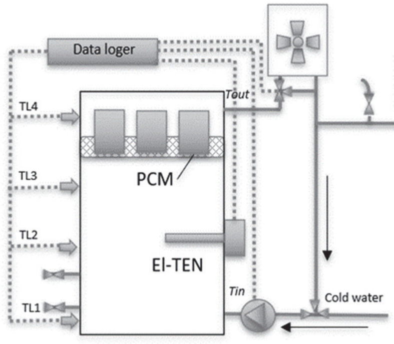


Figure 2
cross-sections of PCM modules

a) without fins b) with fins

To simulate consumption, a fan was used to cool the heat transfer fluid. The flow rate is measured using a simple method to fill a water tank to a given volume in a calculated time. This method ensures good accuracy as it is the traditional way used to calibrate rotameters. The calculated uncertainty was around + 0,01 kg/s.

In order to design a latent heat accumulator, the mass of the PCM, the number of tubes, the tube radius, and the mass flow rate of the heat transfer fluid (HTF) must be obtained, which are important parameters for the efficiency of the thermal storage and the melting and solidification time of the PCM. The test section where the melting processes take place consists of a specially designed wire basket in which the PCM modules are inserted. The tank is equipped with a flanged opening lid to allow the modules to be changed and the arrangement of the modules to be modified. The test section is designed to hold cylindrical PCM capsules in various arrangements. As it is known that cylindrical tubes are one of the famous forms of macroencapsulated PCMs forms. This type of encapsulation is going to be used for solar thermal energy storage systems. The test section is designed to hold a cylindrical PCM copper capsule with a wall thickness of 2 mm, inner diameter of 54 mm, and length of 50 cm. Capsules were filled with PCM.

Modules with four 1 cm wide fins stuck to the outer wall along the length of the tube were tested (see fig.2) to improve heat transfer and reduce the length of the PCM melting period.

Numerical model

The additional COP of solar cooling system shall be determined as follows (Agyenim 2016, p.87):

$$COP_{th.} = \frac{Q_{use}}{Q_{in}} \tag{1}$$

where Q_{use} – system's useful power, kW
Q_{in}- input power, kW.

In the case of using PCM (RT90, but in other studies it can refer to any PCM that affects the efficiency of heat storage) in thermal energy storage tank, an additional useful energy will be the energy from the PCM storage. The COP with additional power from hot water heating will be calculated by following equation (Agyenim 2016, p.87):

$$COP_{.mod.} = \frac{Q_{cold} + Q_{sp.heat} + Q_{PCM} + Q_{DHW}}{Q_{s.coll.}} \tag{2}$$

Where Q_{cold} – chiller output, kW, $Q_{sp.heat}$ – space heating output, kW, O_{pcm}- useful power from PCM, kW, Q_{DHW} – Domestic Hot Water (DHW) heating output, kW, $Q_{s.coll}$ – available solar power from solar collectors, kW.

With PCM COP of the system can be increased which ultimately leads to reduced collector size and cost. The objective of further study to investigate suitable PCM energy storage to improve COP was undertaken to assess how practical is the operation of the proposed system.

The cumulative energy of charging and discharging process, heat lost to the environment and thermal storage efficiencies were calculated using equations (Agyenim 2016, p.87):

Cumulative energy charged/discharged:

$$Q_{char} = \sum_{0}^{t} mC_{p,h}\,\Delta T \Delta t \quad (3)$$

Where ΔT=T_0-T_i for charged energy, and opposite ΔT=T_i-T_0 for discharged energy, ṁ - mass flow rate (kg/s), $\Delta\ t$ - change in time (s), ΔT- change in temperature (°C), $C_{p,h}$ - specific heat capacity of heat transfer fluid (kJ/kg °C).

With the enthalpy method it is easy to handle a PCM and its phase change range. The phase change range is introduced as follows (Esen & Ayhan 1996):

$$h(T)=\begin{cases} C_{ps}T \ \ if \ \ \ T < T_{m1} \\ C_{pl}T + \frac{\Delta H (T - T_{m1})}{\Delta T_m} \quad if\ T_{m1} \le T \le T_{m2} \\ C_{pl}T + \Delta H \ \ if \ \ \ T > T_{m2} \end{cases} \quad (4)$$

Where ΔTm=T_{m2}-T_{m1}, ΔH - latent heat, kJ/kg.

Cumulative energy heat lost Q_loss (J):

$$Q_{loss} = \sum_{0}^{t} \frac{(T_{i,ins} - T_{o,ins})}{\frac{ln(r_{0,ins}/r_{i,ins})}{2rk_{ins}L} + \frac{1}{h_0 A_0}} \Delta t \quad (5)$$

where $r_{i,ins}$ – inner radius (m), $r_{o,ins}$- outer radius (m), h_o - heat transfer coefficient (W/(m^2 °C)), A_o- area (m^2), L - length (m), k_{ins} - thermal conductivity of material (W/m °C), $T_{i,ins}$ - inner temperature (°C), $T_{o,ins}$ - outer temperature (°C).

Charging efficiency is calculated by the following equation:

$$\eta_{char} = \frac{Q_{char} - Q_{loss}}{Q_{char}} \quad (6)$$

Discharge efficiency:

$$\eta_{dischar} = \frac{Q_{dischar}}{Q_{char} - Q_{loss}} \quad (7)$$

So, it possible to calculate storage efficiency based on charged energy:

$$\eta_{store} = \eta_{char} \times \eta_{dischar} \quad (8)$$

A numerical model of a latent heat accumulator was developed. and implemented in MATLAB.

Validation

The thermophysical properties and the phase changing behaviour of RT90, as given by the manufacturer was independently validated by analyzing sample. The sample was melted under laboratory conditions, the melting point was determined, and the heat of fusion was calculated. The results differed from the manufactory data by less than 1%. The partial differential equations relating the PCM modules, and the heat transfer medium were solved numerically using the finite difference method and the enthalpy method. The values characterizing lab scale energy storage system and PCMs were inserted into the MATLAB numerical model, it was calculated that Δt - 112 min., as can be seen in the figure 3, the experimental data show that the melting period ends after reaching 110 min. Since the results are similar, a good agreement between the experimental results and the numerical results was obtained.

RESULTS

In order to design a latent heat storage, the mass of the PCM, the number of tubes, the tube radius, and the mass flow rate of the HTF, which are important parameters for the storage efficiency and the melting and solidification time of the PCM, are needed to be determined. The latent heat storage is considered to consist of 20 encapsulated modules. During the charging process, the PCM is assumed to be solid at 20 ℃ and HTF at 100 ℃ is flowing through the tubes. The PCM temperature variation, the average PCM temperature and the HTF outlet temperature are shown in Figure 3.

The study shows that the storage efficiency reaches maximum, when the whole PCM is melted and reaches the HTF inlet temperature.

Having established all the necessary values, and using the above numerical model, storage efficiency is defined as the ratio of stored energy to the maximum energy that could be stored in a latent heat accumulator. The maximum energy in the accumulator is when the entire PCM has melted and reaches the HTF inlet temperature.

Figure 3
Results of charging process

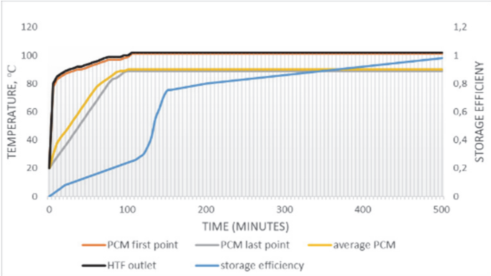
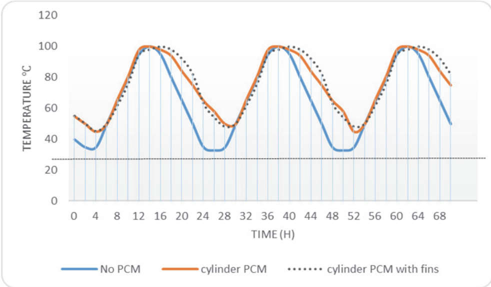


Figure 4
Temperature changes in the Lab-scale storage tank



Cooling demand has a direct relationship with available solar radiation. The more the space heats up, the more energy needs to be spent on cooling. Next, a laboratory experiment was carried out to simulate a daily cycle with a sensible heat storage tank and a latent storage tank. Visualized results are shown in Figure 4. It was determined that the cooling rate of the storage tank is much slower, because after a cooling period of 12 h, the temperature difference between the tank without and with the PCM modules was 25 degrees. so the temperature after a 24-day cycle is higher for the modified thermal energy storage tank. This was done to find out the amount of electricity saved by using an electric tank to heat water.

The results showed that there was at least a 21% reduction in electricity consumption. Based on the results of the study, a COP of 0.88 was determined for the original solar cooling system and a COP mod of 0.92 for the modified systems, which means that the COP increases by at least 4%.

CONCLUSIONS

The objectives of the study have been achieved, as improvements in the efficiency of modified energy storage using modules filled with paraffin wax have been found. An increase in the COP of the solar cooling system was determined, which gives the possibility to increase the use of solar energy for space cooling. In addition, it was determined that the amount of additional heat (in this case electricity) consumed is significantly reduced, so that the amount of primary energy consumed can be minimised and CO2 emissions decreased. The results show that using a smaller radius cylinder modules filled with PCM achieved a higher power, leading to a reduction in the charging and discharging time. The observed optimized performance given by the fin's arrangement achieved significant reduction of PCM's melting time compared to the heat exchanging without fins. The results obtained show that PCM modules have a specific impact on the solar cooling system efficiency.

The calculations and results of this study can also be used in other cases where the heat source is not solar energy, but another heat source of a non-permanent nature. This article is part of a larger study. In the following, a simulation model will be developed to simulate the charging of a modified energy storage under available solar radiation.

Acknowledgments

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Generative Methods in Kindergarten Designing

Movement as a primary driver

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There are many obese children worldwide, for which the lack of physical activity is the main reason. During early childhood, children spend most of the day in kindergartens. Many studies show that the kindergarten environment can form a suitable context for implementing interventions to engage in physical activity through its functional organization. This paper offers an algorithm for floor plan generation to ensure all necessary daily activities in the kindergarten with the increase of movement as a physical activity of moderate intensity with a tendency towards values recommended by the World Health Organization. Magnetizing Floor Plan Generator is chosen as a tool for generating floor plans with input data: space for each activity represented as a room with the area necessary for carrying out activities and the connections between them according to kindergarten guidelines. In the Galapagos component in Grasshopper, the fitness function will then be set to increase the corridor area, and finally, through iterations, a solution with the largest corridor area will be obtained, i.e., potentially the longest movement path.

Keywords: *Generative Design, Evolutionary Algorithm, Single-objective optimization, Floor plans generation, Magnetizing Floor Plan Generator, Movement*

INTRODUCTION

Nowadays, there are more than 340 million-overnourished or obese children in the world. It is alarming that this number has increased tenfold compared to the results of research conducted in 1975 (Abarca-Gómez et al., 2017). In addition to hereditary factors and unhealthy eating habits, insufficient physical activity in preschool children and the popularity of 21st-century technologies lead to negative consequences for children's physical health, psychological development and the development of cognitive abilities (Aivazidis et al., 2019). To prevent this problem, it is necessary to act in early childhood because then the foundations are laid for the behavior and upbringing of children for the rest of their lives.

It has been proven that movement, as a low-intensity physical activity, contributes to the child's overall development, enables research and learning about the world around him and creates the habit of including physical activity in everyday life. The World Health Organization recommends that children aged 5 to 17 be encouraged to engage in at least 60 minutes of moderate to vigorous and intense physical activity daily (World Health Organization, 2010).

During early childhood, children spend most of the day in kindergartens. Thus, these institutions can form a suitable context for implementing interventions to do physical activity (Aivazidis et al., 2019). Research reports (Huang et al., 2022) show that the kindergarten environment (space size, the layout of rooms, space equipment, sports games, teaching methods, etc.) and the family environment play an essential role in the development of children's health and physical condition, with the influence of the environment in kindergarten on the amount of children's physical activity (24%) was significantly higher than the influence of the family (14%).

MOVEMENT AS A PRIMARY DRIVER IN DESIGNING KINDERGARTENS

Kindergarten space affects children's development in all segments, so designing such institutions is always challenging for architects. Apart from the natural and created conditions of the specific location, legal regulations and regulations, designing spaces for children in the period of early childhood requires knowledge of the specifics of the physical, social and emotional needs of children, as well as their perception of the spatial environment because this is the only way to create an appropriate architecture based on qualitative criteria.

Olds (2001) believes that the four spatial needs of children (movement, comfort, competence and control) are crucial for the quality of space and are required in every aspect of designing children's places. The first design requirement is the design of spaces that encourage movement. Several researchers have proven that activity is primarily for children's knowledge of the world around them because it allows them to orient themselves in space and creates a basis for spatial conceptualization and the construction of adequate cognitive maps (Björklid and Nordström, 2007). According to Stanković (2009), the movement of children in space is positively influenced by the lack of emphasis on communications, a large area of free space, partially partitioned and equipped zones, horizontal and vertical structuring, niches and the curvature of vertical partitions and walls.

Stupar (2017) pointed out that qualitatively conditioned architectural and quantitatively conditioned physical comforts shape the structure of elements of the overall comfort of a kindergarten. Formal, functional and kinesthetic comfort is crucial for initiating children's movement in space:

- Formal comfort refers to the geometric properties of the space and is determined by organizing floor plans in terms of movement and use of space (in tracts, clusters, linear, central, etc.);
- Functional comfort refers to comfort that depends on how the organization of space and mutual connections define certain activities that take place in it (play, education, dining, sleeping, and hygiene-sanitary needs) and
- Kinesthetic comfort implies the potential of the space to engage body movements, depends on the parameters of connection, thresholds and unevenness of the section, and it is measured by the length and duration of the movement.

The geometry of the base is conditioned by the activities they perform in kindergarten and the movement of children by the arrangement of activity centers, which implies that all the previously mentioned comforts are mutually conditioned. Therefore, these comforts can be considered as a unity called comfort of movement, thus the following common characteristics can be defined:

- Rooms with a loose shape are suitable for simple organization of all activity centers;
- Centers of activity (play, education, dining, sleeping, and hygiene-sanitary needs) must be gathered around the central square together, building a unique unit of space;
- The premises of the associated activity centers must be connected, i.e., open to each other and
- The circular connection is the most important in kindergartens.

An example of good practice that highlights the potential of space to initiate children's movement is the Fuji Kindergarten in Japan, designed by Tezuka

Architects. On this plan, the boy's movement between 9:10 and 9:30 is marked (see figure 1). Considering that the perimeter of the building is 183 m, the boy covered 6 km in such a short time (Tezuka, 2014). Children in this kindergarten walk an average of 4 km per day (approximately the value of physical activity required by the World Health Organization), which makes them the leader in engaging physical activity among many kindergartens. With this way of organization and design principles, the movement of children can be initiated, i.e., physical activity that is necessary for children's health and their development in early childhood, which prevents the occurrence of various diseases, such as obesity in young children.

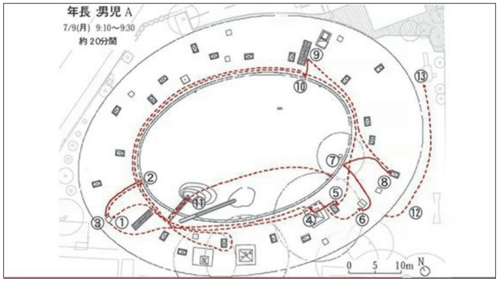


Figure 1
Movement of the child in kindergarten (Tezuka, 2014)

However, there are still few built kindergartens in the world where the movement of children is taken as a key factor in the functional organization of space.

The goal of this paper is to offer a sample for providing all the necessary daily activities in the kindergarten while increasing movement as physical activity of moderate intensity with a tendency towards the values recommended by the World Health Organization. This could be achieved by setting longer distances between activity centers when creating floor plans.

GENERATING FLOOR PLANS

Since the 1970s, much research has been conducted in the domain of computer-aided architectural design, where the primary focus is on the automatic generation of floor plans, where space layouts can be treated as an initial idea by the architect/designer with the possibility of later modification. Today in the literature, there are many proposed systems suitable for the automatic generation of buildings based on different concepts of geometry:

- Graph Teory (Shekhawat, Upasani, Bisht and Jain, 2022);
- Shape grammar (Gu and Amini, 2021);
- Generic algorithms (Bahrehmand et al., 2017);
- Neural networks (Wu et al., 2019);
- Cellular Automata, (Lazić, Perišić and Perišić, 2022) etc.

The mentioned approaches for generating floor plans are constraint-based, agent-based, physically-based, evolutionary algorithms, etc. However, the disadvantage of these approaches is that they cannot be used for buildings with more complex functional organization, and new solutions cannot be generated after changing the architectural program, but a new structure must be created.

The Magnetizing Floorplan Generator is a recent generator created by the author team Egor, Sven, Martin and Reinhard (2020), which opens up possibilities for new strategies for generating the foundations of objects based on the principles of flexibility (the ability to manage interactions and changes by the user at every step), ease of use by architects, developers and planners (Rhinoceros and Grasshopper were chosen as working environments), maximum versatility and speed of generation (intuitive and fast to use and manage a large number of values during the floor plan generation of a large building).

This generator also differs from others in giving importance to communications (corridor, hall, foyer, vertical communication core), i.e., movement inside the building, which is characteristic of public buildings. Therefore, the starting point in this design process is that every room in the building is accessible from any other room through the corridor. The simplified structure of this plan is identified with the creation of an evacuation plan, which can later be transformed into a more comprehensible communication corridor.

Communication structures are also needed when connecting children's activity centers in kindergartens, so this generator is considered suitable for the floor plan generation of a kindergarten unit. Each activity center is treated as a room with an appropriate area, while communications are defined as the paths that children take from point A to point B, i.e., from the center of one activity to the center of another. In this plugin, communication is defined by area, so the children's movement path will be seen as the length of the communication axis (see figure 2).

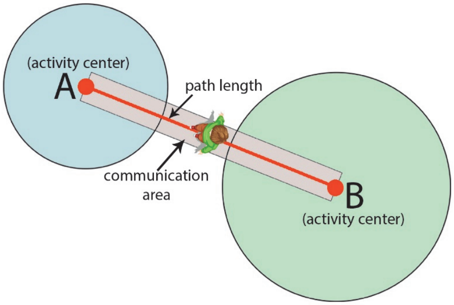


Figure 2
Scheme of movement of the boy from one activity center (point A) to another activity center (point B)

Assigning a larger corridor area means a larger area for children's physical activity and a potentially longer path of their movement, which is the goal of this research.

RESEARCH METHODOLOGY

This research project was conducted under the action design research framework methodology, where the author team implement their design practice and then evaluate it to identify its advantages and disadvantages. Those deficiencies are addressed to improve practice in subsequent project iterations or subsequent projects.

The focus of this paper is on the initiation of movement in children through the functional organization of space. To achieve this goal, it is necessary to propose the algorithm that can produce different floor plans while only focusing on one performance objective. Therefore, for defining the evolutionary algorithm, the Magnetizing Floor Plan generator is used as a plug-in for generating the floor plans and the Galapagos component for single-objective optimization, where the maximization of areas for communication between activity centers is taken as the performance objective.

To develop the concept, the subject of this research will be the generation of the possible floor plans of one kindergarten unit for 20 children (average number of children per one unit) with a multipurpose space. This research has the following methodology:

- Input data preparation – architectural program and its translation in Magnetizing Floor Plan Generator in Grasshopper;
- Floor plan generation by Magnetizing Floor Plan Generator and
- Optimization by the Galapagos component in Grasshopper with maximizing corridor area as a performance objective.

Step 1: Input data preparation – architectural program and its translation in Magnetizing Floor Plan Generator in Grasshopper

Defining rooms (activity centers) and their areas. Activities to do in kindergartens are play, education, eating, sleeping and hygienic and sanitary needs. The centers of these activities will be materialized and the optimal area necessary for their performance will be determined. All input data is entered in this order with the RoomInstance option in Magnetizing Floorplan Generator:

1. Multipurpose area (about 80 m^2);
2. Cloakroom (10 m^2-recommended value) set as Entrance;
3. Toilet (10 m^2-recommended value);
4. Dining zone (about 12 m^2);

5. Sleeping zone (about 30 m^2- area for beds and access to them) and
6. Play zone (about 40 m^2).

The room (area) for education is deliberately excluded because it can be done in the dining or play zone.

Determining the connections between rooms according to the daily plan and program of work in the kindergarten. According to the kindergarten guidelines that are valid worldwide, access to the living room is through the cloakroom. A multipurpose space will be placed as an entry point and a cloakroom as a hall because this room has the most connections with other rooms (activity centers). The toilet can only be accessed from the cloakroom, while all other activity centers are interconnected (see figure 3).

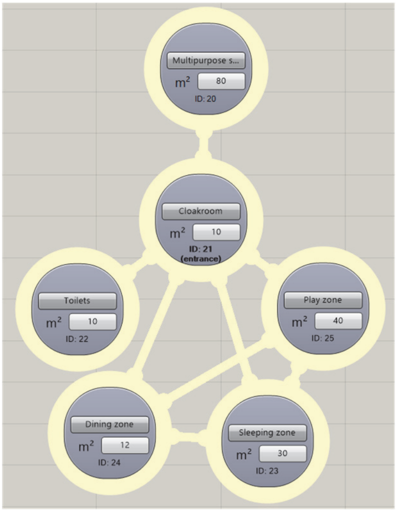


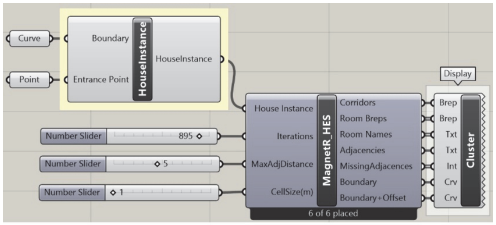
Figure 3
Input data in the Grasshopper environment

All the listed connections are achieved in this generator by simply connecting previously defined RoomInstances. After a successful connection, all RoomInstances will be marked with the same color.

Floor plan generation by Magnetizing Floor Plan Generator

After defining the connections between the rooms, the HouseInstance option is set, which takes Boundary, Entrance point as input data (their definition is not crucial now because the concept is being developed) and the connected RoomInstances scheme. Now the HouseInstance is marked with the same color as RoomInstances.

From the input data, MagnetizingRooms_ES takes House Instance (the result of the previous step), Iterations (the number of repetitions of the process to obtain a suitable solution - the recommendation of the authors Egor, Sven, Martin and Reinhard (2020) 300-900 iterations), MaxAdjDinstance (the maximum distance between two rooms - 5 m is taken) and CellSize (square grid - 1 m is taken for simple analysis). All output data is connected to the Cluster Display to enable a visual presentation of the generated solutions (see figure 4).



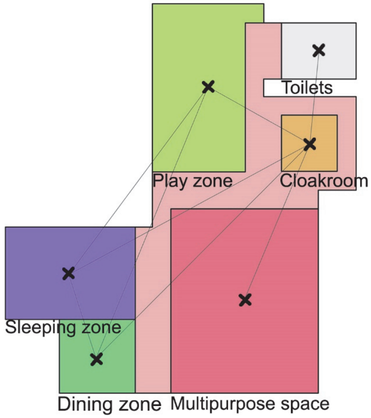


Figure 4
Visual presentation of the generated solutions in Grasshopper and Rhinoceros environment

Optimization by the Galapagos component in Grasshopper with maximizing corridor area as a performance objective

Several evolutionary design and optimization algorithm tools have been developed for performance-based optimization of building designs. Popular tools include Galapagos, Octopus and Opossum in Rhino-Grasshopper and Optimo in Revit-Dynamo. Using these tools, architects can set up a performance-based design optimization system to search for high-performance solutions without programming and coding knowledge (Wang et al., 2020).

This paper aims to find solutions with the maximum area of the corridor, which increases the space area for the child's movement and potentially its length. The Galapagos component was chosen as an evolutionary design and optimization algorithm tool because of setting single-objective performance.

In the next step, this component is used to optimize a shape for achieving a user-defined goal. The Galapagos component needs a series of options or genes (genome) to experiment and a defined goal or fitness value. In this task, the number of iterations is set as the genome, and the corridor area as the fitness function (Corridors - MagnetizingRooms_ES - List Item - Area) (see figure 5).

Double-clicking on the Galapagos component opens the Galapagos Editor. In the Fitness options, Minimize and Maximize appear by default. In this case, it is necessary to set Maximize because the goal for the given fitness function is to obtain maximum values. Finally, the optimization solver can start working. The bottom right diagram shows the best solutions at a certain point in time of workflow (see figure 6). By selecting one result from a diagram and clicking on Reinstate, the result will be visible in the Rhinoceros environment. The algorithm must run until changes between iterations (results) are minimized.

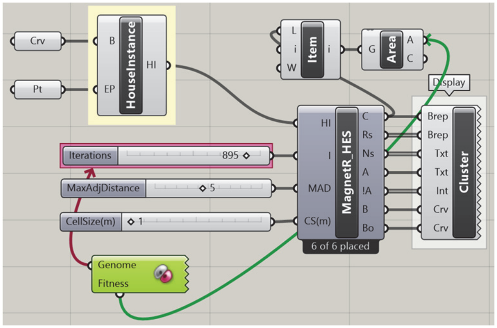


Figure 5
Galapagos component

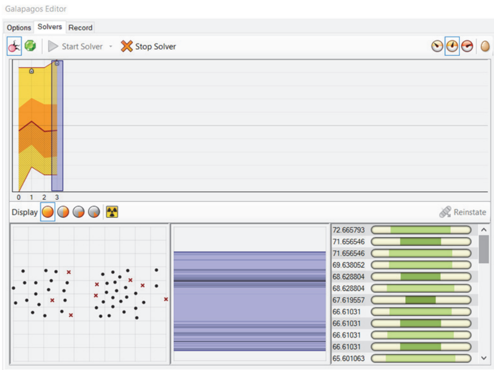


Figure 6
Galapagos diagram with the best solutions at a certain point in time of workflow

RESULTS AND DISCUSSION

After stopping the algorithm, alternative solutions can be seen at the beginning of the diagram (see figure 7). These are floor plans with maximizing corridor area (about 70 square meters) which emphasize the movement of children and, with their functional organization, influence the physical and psychological development of children in kindergarten. In this project, a primary driver is movement. However, generated plans should be evaluated according to different metrics. Together, they fulfill functional and formal comfort (Stupar, 2017), but here they will be evaluated according to the parameter of achieving a circular connection, which is most desirable in kindergartens.

All the activity centers must be grouped around the multipurpose space so that a circular connection can be seen. The most adequate floor plan according to the desired parameter is shown in figure 8 (see figure 8). The disadvantage of this solution is the position of the cloakroom due to the intersection of clean and dirty roads.

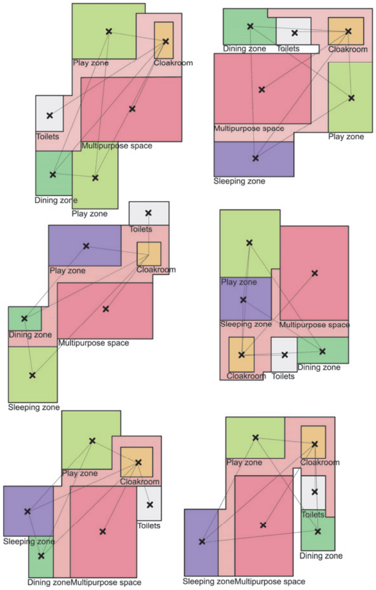


Figure 7
Some generation results of the Galapagos

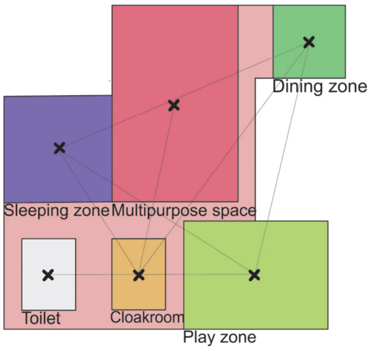


Figure 8
Selected floor plan

FUTURE RESEARCH

The Magnetizing Floor Plan generator served as a good tool for generating a floor plan solution for a kindergarten unit with a maximum corridor area, which would mean a larger space area for children to move around. However, setting the maximum area for children's movement does not necessarily mean the longest movement path. The optimization of the solutions according to this parameter will be the subject of future research.

CONCLUSION

Today, children do not engage in physical activity, which leads to various diseases. The environment of the kindergarten can help in this by increasing the movement of children with its functional organization. By assigning activity centers, which are performed daily in these institutions, and connecting them with communication structures, a scheme of children's movement is obtained. By application of Magnetizing Floor Plan generator and Galapagos component, a floor plan of one kindergarten unit with the maximum area of the corridor can be obtained, i.e., the maximum space area for children to move and potentially the longest path. A generative approach to solving problems can affect children's physical activity.

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A Novel Approach of Structural Modeling, Analysis and Optimization of Bearing Parts in Free-Formed Arc-Like Geometry Reconstructed from 4D Sketches

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Sketching is often used as the main approach in design of free-formed structures in very early stages of planning. Chosen materials for bearing and non-bearing parts and results of structural analysis can decisively affect the shape and form of planned geometry. The structural modelling, following finite element (FE) analysis and structural design can be very time-consuming due to still weakly regulated building information modelling (BIM) data exchange of free-formed structures. This paper describes a novel approach of structural modelling, analysis, and multi-objective optimization (MOO) of bearing elements of free-formed geometry sketched within a developed 4D semantic, mixed reality application MRSketch. The shapes of individual elements are computed from the recovered curve network and comprising boundary curves, aiming for smooth transitions and less deviation to the sketched strokes. The focus of this paper lays on the test case in which a free-form voluminous arc-like structure (similar to BUGA pavilion) has been thoroughly sketched in MRSketch. The computed geometry of the above-mentioned form is used for the structural analysis and MOO, whereby 3 different material and structure types are studied: monolithic concrete shell, plywood timber panels, and steel framework. The MOO process takes place with the goal of minimizing used material masses and deflection of the structure. The ultimate and serviceability limit state´s (ULS and SLS) criteria acc. to Eurocodes represent MOO-constraints. Lastly, a large-scale estimate of the CO2 balance of the 3 above-mentioned construction´s variants is compiled and compared.

Keywords: *Concept Design, Curve Networks, Parametric Modeling, Structural Optimization, Numerical Optimization.*

INTRODUCTION

Building Information Modeling (BIM) methodology of data exchange is widely used in the construction industry to improve collaboration, communication, and visualization among all project´s participants and stakeholders. With the development of Information and Communication Technology (ICT), many novel data exchange methods for BIM information have been discovered. However, digital data exchange between architectural design and structural analysis, when both domains use BIM authoring software tools, is still burdened with numerous difficulties, mostly caused by semantical problems and particularly challenging problems of geometric interpretation (Sibenik and Kovacic 2020). Little literature has attempted to review the current status of BIM data exchange methods (Lou, Lu and Xue 2021). The main critique for using the most popular BIM exchange format "Industry Foundation Classes" (IFC) lays on the data loss when sharing data from one application to another (Honti 2018). For example, existing methods for Cloud-BIM data integration face several challenges in model-based data exchange and have not fully exploit the potential of the Cloud towards a loosely coupled integration (Afsari, Eastman and Shelden 2016). Lack of proper communication among disciplines as well as data and information losses between design stages makes it time-consuming and simultaneously results in a decreased design quality (Rasoulzadeh *et al.* 2022). Summarized, the data exchange of (free-formed) structural models has been a challenge, as the geometrical and construction information often lacks precision and completeness, leading to errors and inefficiencies in further structural analysis.

To address this issue, a novel approach for geometry export for structural analysis has been developed (Daleyev, Rasoulzadeh and Kovacic 2022). This paper highlights the application of this method on a realistic test case project emphasizing quick and efficient data exchange of (free-formed) geometry sketched within a developed 4D semantic, mixed reality application *MRSketch* (Kovács *et al.* 2022). Such an effective and precise data export gives an opportunity for defining the bearing structure in very early stages of planning. With the aid of multi-objective optimization (MOO), considering various design criteria, such as structural stability, constructability, costs and CO2-Footprint, the bearing structure can be optimized. The ultimate and serviceability limit state´s (ULS and SLS) criteria acc. to Eurocodes represent MOO-constraints.

The sketched and examined free-form geometry is similar to the BUGA-Pavilion (Universität Stuttgart and "Jan Knippers Ingenieure" 2019) and represents a free-form voluminous arc-like structure. Achieved results are examined and will be discussed. By highlighting the benefits of the described novel method, we aim to demonstrate the potential for improved data exchange and MOO of bearing structures in the very early stages of design of free-form structures. Additionally, a Life Cycle Assessment (LCA) analysis is made to obtain a comparison regarding CO2-footprint of different versions of the pavilion with three diverse materiality and bearing systems.

METHODOLOGY

In typical framework of numerical structural FE analysis and design, the preparation of models begins with defining the geometry, material properties, loads and boundary conditions of the system. The geometry may be (i) created using computer-aided design (CAD) software, (ii) be recreated by using point clouds, e.g. from 3D-scanned existing buildings (Barazzetti *et al.* 2015) or (iii) be obtained throw IFC BIM-data exchange (Lin and Scherer 2020; Ren and Zhang 2020). After the model is fully defined, it is usually meshed and then solved using numerical methods to obtain the deformations throughout the system. Based on the occurred deformation, distribution of inner forces and stresses, the structural analysis is performed in order to predict the behavior of the bearing parts.

Our approach to data export for structural analysis is based on capturing geometry directly from the design process. Such Framework enables a more efficient and streamlined process, as the geometry is easily accessible and transferable. With an aid of parametric modelling coupled to a multi-objective evolutionary algorithm, the creation of a significant number of model variants according to pre-defined requirements and theirs evaluation can be carried out (Reisinger *et al.* 2022b). The MOO process is executed with different goals depending on the chosen material and type of the structure (monolithic concrete shell, plywood timber panels and steel framework). The MOO-constraints are represented by ultimate and serviceability limit state´s (ULS and SLS) criteria. Such a framework of parametric optimization and decision support has proven to be efficient for studying different bearing structures (Reisinger *et al.* 2022a).

The following chapters describe the methodological framework of geometrical capture within 4D semantic sketching app *MRSketch*; the transition process of reconstructed meshed geometry to non-uniform rational B-spline (NURBs) patches; and final preparation, analysis, and optimization of structural finite element (FE) model. The process is depicted in Figure 1.

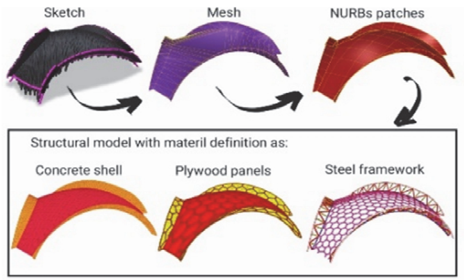


Figure 1
Framework of suggested pipeline

4D sketching interface

Within the developed 4D sketching app *MRSketch*, architectural design sketches may be created directly in 3D space using tablet with stylus function support. The sketched strokes are projected to so called canvases which represent a set of geometric primitives like plane, cube, sphere, cylinder, etc.). Additionally, the time record of the sketched elements and used canvases is captured during the process (4th dimension). The artist may apply different attributes and properties to the strokes that are to be drawn.

Once drawing is finished, the constituent strokes and their corresponding recorded information can be exported in a JSON file where it can be used in visualization and modelling software or to be further employed in a sketch analysis pipeline for design-intent interpretation.

For further information regarding the sketching interface of *MRSketch* see also (Kovács *et al.* 2022) and (Daleyev *et al.* 2022).

Geometry reconstruction

Observations of designers using MRSketch reveal that they inherently draw two types of strokes to communicate their design intent: *Shape* strokes, which mainly outline the boundaries, and *Scribble* strokes, which mark the enclosed areas with Shape strokes. These two sets of strokes are not perfect in a sense that Shape ones may have (partial) overlaps with themselves and may lack inter-stroke connectivity. Also, the Scribble ones may be (partially) overlapping as the designer might draw multiple Scribble ones on top of each other to fill the desired enclosed areas within the Shape ones.

Based on the aforementioned observations, coupled with MRSketch, a machine learning-based geometry reconstruction pipeline is researched and developed responsible for recovering curve networks from such 4D architectural design sketches capturing the design intent. The pipeline consists of three models: one classification model and two clustering models. The classification model distinguishes between Shape and Scribble strokes, while the two clustering models further group the strokes of each type into meaningful clusters employing the attributes recorded throughout the sketching. Subsequently, a surface mesh is reconstructed from the curve network derived from the recovered topology and its constituent cycles corresponding to the desired enclosing areas.

Panel layout

The geometry reconstruction pipeline coupled with *MRSketch* produces a surface S that has to be segmented into an initial set of panels. It is assumed that a parametrization of S is available. In the case of NURBS geometry a parametrization is readily available. If S is represented as a dense triangle mesh, a distortion minimizing parametrization is preferrable (Liu *et al;* Sorkine *et al.* 2002). As the showcase example is a height field, the projection of S onto the xy-plane is used.

Having established a parameterization, the boundary of S is sampled at regular intervals and the corresponding closed polyline is mapped to the parameter domain of S, resulting in a polygon P. Now the interior of S is sampled coarsely, at approximately the same rate as the boundary (see e.g. (Eldar *et al.* 1997)), and the obtained point cloud is mapped into the parameter domain of S. By construction, the mapped points belong to the interior of the polygon P. Subsequently a triangulation T of P is computed such that all mapped points become vertices (O´Rourke and Devadoss 2011). The panel layout is obtained as a polygonal mesh M combinatorial dual to T, i.e., vertices of M correspond to faces of T and two vertices of M are connected by an edge if the corresponding faces of T share an edge. In the example the vertices of M are the face barycenters of T. The faces of M are now used as trim curves to segment S into panels. See Figure 2 for the result of each step of the described process.

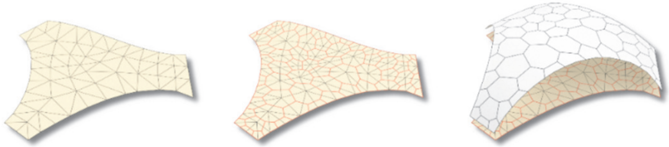


Figure 2
Panel layout process. Left: coarse triangulation T of the domain. Center: polygonal mesh M (red edges) combinatorial dual to the triangle mesh T. Right: lifting of the polygonal mesh back onto the target shape S.

Structural analysis and optimization

The computational framework of structural finite element analysis (FEA) and multi-objective-optimization (MOO) takes place within 3D modeling software *Rhinoceros3D* and its visual programming language *Grasshopper3D* (Robert McNeel & Associates). Due to its integrated programming functionality and parametric data input, a generative evolutionary process is implemented to the initial structural design and utilized in order to explore the design space and identify optimal solutions (Yetkin and Sorguç 2019 - 2019).

The tool employs the FEA method supported by Grasshopper3D´s plug-in *Karamba3D* (Preisinger and "Bollinger und Grohmann ZT GmbH") to simulate the behavior of the structure under permanent and variable loads, and their decisive combinations. The results of structural FEA can be used for structural design, whereby criteria of ultimate and serviceability limit states (ULS & SLS) represent the MOO-constraint during the optimization process.

The MOO methods powered by generative evolutionary solver *Octopus* (Vierlinger) are used to identify the Pareto front of optimal solutions, which allows the user to consider trade-offs between multiple objectives, such as minimization of used material and minimization of construction time effort. Summarized, the proposed pipeline allows users to optimize and improve the structural performance of their models sketched within *MRSketch*.

Life cycle Assessment

The aim of the life cycle assessment (LCA) is to measure, evaluate and minimize the environmental impacts from procurement of materials, through manufacturing, construction via dismantling, including the recycling/waste management process and the overall energy consumption for the life period of an object, a building, or a structure.

However, for complex systems such as a construction project, LCA analysis can verify significantly depending on the input parameters, boundaries, scenarios, which are set, and the calculations methods or software tools are used (Stavropoulos *et al.* 2016). Therefore, the proposed test case in this paper is used to identify and address problems, challenges, and possible solutions regarding the coherence between structural and LCA analysis and optimization.

To get a better understanding of the trail or else their repercussions, the LCA phases acc. to EN15978 (Austrian Standards 2012) and EN 15804 (Austrian Standards 2022) are highlighted in Table 1.

Table 1
MOO-variables, objectives, and constraints

Phase	*Description*
A1	Mining and supply of raw materials
A2	Transport to the factory
A3	Manufacturing
A4	Transport to the construction site
A5	Assembling on the construction site
C1	Deconstruction
C2	Transport (for disposal or treatment)
C3	Waste treatment
C4	Landfilling
D	Reuse potential

The method of adding up individual data from European Product Declarations (EPDs) and including all processes in the production part is applied for multi-layer structural elements. As a result, such an approach is sensitive to errors (Yang, Heijungs and Brandão 2017).

TEST CASE

As mentioned before, a test case was utilized within the scope of this paper. It focuses on examining a voluminous arc-like structure similar to the wooden BUGA-Pavilion (Universität Stuttgart and "Jan Knippers Ingenieure" 2019)

The geometry of the whole structure was sketched using *MRSketch*. This framework allowed to easily create an initial representation of the structure and its geometry (see also Figure 1). The mesh reconstructed from the 4D sketch was further converted into NURBs-patches as described before. The patches were used as geometrical topology of the structural FE model.

Geometrical model topology

Major focus lays on the geometry of the test case examined within the scope of this paper. Hereby, the voluminous arc-like structure is given with ratio of Length/Width/Height equal to approximately 33[m]/27[m]/6[m].

Material choice and structural integrity

Due to the significant impact of the material choice on the structural bearing system, it is crucial to consider different possibilities regarding the materiality and structural integrity already at the early stages of planning. Thus, structural flexibility linked to MOO-processes in early phases has proven to be efficient and deliver good results regarding sustainability of the structure. (Reisinger, Hollinsky and Kovacic 2021).

The optimization process in this test case was conducted with three different material scenarios which affect the bearing system: 1) Structure out of monolithic concrete shell; 2) Structure assembled with timber plywood panels (similar to original BUGA); 3) Steel framework structure with wielded beams.

To define different material and bearing system, the structure was separated into two parts: • *Cupola* and • *Edges*.

Support definition is located on the bottom edge lines and represents the hinged line support with rigid horizontal translation. For steel construction, the bottom lines of the edges are also defined with support definition.

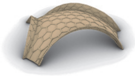
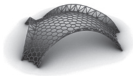
The structural analysis is performed with following loads: • Self-weight, • Deadloads (2.00 kN/m^2), • Roof loads of Category H. (1.00 kN/m^2).

MOO parameter

A thoughtful consideration of material choice and constraint´s criteria can ensure the longevity and safety of a structure.

Due to the unique structural topology of the models described in the previous chapter, no overall similar MOO-objectives can be defined. Thus, they vary depending on material choice and structural

Table 2
MOO-variables, objectives, and constraints for test case

Material choice:	*Concrete shell*	*Plywood panels*	*Steel Framework*
			
1^{st} variable	Concrete sort of cupola	Appr. size of plywood panels	Appr. size of steel segment
2^{nd} variable	Concrete sort of edges	Thickness of plywood panel of the cupola	Steel cross-section´s profile
3^{rd} variable	Thickness of cupola	Thickness of plywood panel of edges	-
4^{th} variable	Thickness of edges	-	-
1^{st} objective	Minimization of used concrete material mass	Minimization of used timber material mass	Minimization of used steel material mass
2^{nd} objective	Minimization of used reinforce steel mass	Minimization of number of panels (time effort)	Minimization of number of steel beams (time effort)
1^{st} constraint	SLS-criteria (deflection)	Initial ULS-criteria (structural integrity)	Cross section is optimized by Cros-Sec-Optimizer of Karamba3D (ULS)
2^{nd} constraint		Initial SLS-criteria (deflection)	SLS-criteria (deflection)
Elitisms 0.60. Mut. Probability: 0.273. Mutation Rate: 0.90. Crossover Rate: 0.80. Population size: 50. Max. Generations: 25			

part. MOO-Parameters and *Octopus´s* MOO-settings, the test case was conducted with, are represented in Table 2.

Results

This chapter presents the result of the test case with three different structural materiality. Regarding the solution finding and decision making, the MOO-results can be competitive (as in this case, see also Figure 3) and offer a range of optimal solutions, so called Pareto-front. Designers or investors can pick one solution based on their specific needs and wills out of this range of optimal solutions. The trade-off criteria are representative of the objectives of MOO.

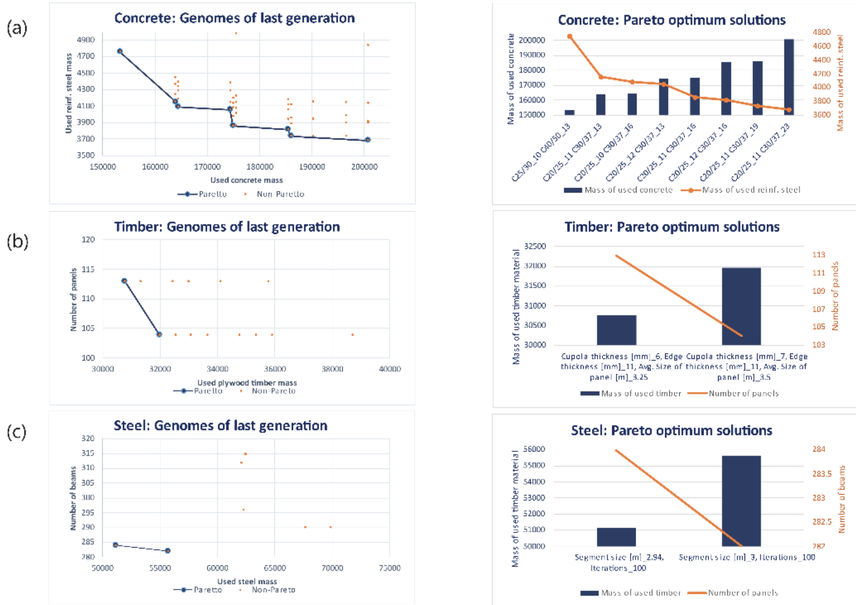
Test case results in the dependence on the material choice are listed below and depicted in Figure 3 3:

• *Concrete shell structure*: As awaited, the degradation of the concrete sort and minimization of the cupola´s and edges´ shell thickness leads to the greater needed mass of reinforced steel. Hereby, the trade-off is situated between the needed amount of concrete and steel. The Indication of the pareto solutions in Figure 3.a means "{Concrete sort of cupola}_{Thickness of cupola [cm]} {Concrete sort of edges}_{Thickness of edges [cm]}".

• *Plywood panels structure*: The examination of the structure out of plywood panels has shown that ULS-criteria took a significant role in MOO process. The genome´s diversity in the last generation turned out to be poor, what leaded to very small amount of Pareto-optimal solutions (Figure 3.b)

• *Steel framework structure*: Analog to the timber structure, the last generation provided poor genome diversity, which leads to a conclusion that an absolute optimum can be also found for steel structure (Figure 3.c).

Figure 3
Results of test case for: a) concrete shell; b) plywood panels; c) steel framework



Environmental consequences

Once the examined variants of the test case have been analyzed, they must be combined with the LCA phases A-D acc. to Table 1 and their possibilities, to achieve an optimum for the production, construction, and deconstruction process. The results are shown in Figure 4. It should be noticed, that B1-B7 (use phase) have no impact on this case study, therefore they are not included in this evaluation.

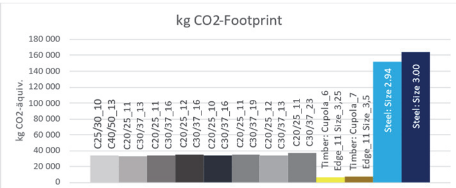


Figure 4
Environmental impact as CO2-footprint depending on the materiality and structural bearing systems of the test case geometry for the phases A1-A5 and C1-C4

As depicted, the wooden variants (indexed with {Cupola_Thickness [mm]} {Edge_Thickness [mm]} {Panel size [m]}) have smallest CO2-impacts with ~23t CO2.equiv., followed by concrete variants (indexed with {Concrete sort of cupola}_{Thickness of cupola [cm]} {Concrete sort of edges}_{Thickness of edges [cm]}". with ~35 t CO2.equiv. and 160 t CO2.equiv. for the steel framework.

CONCLUSION AND FUTURE OUTLOOK

The suggested framework of structural modeling, analysis, and optimization of bearing parts in free-formed arc-like Geometry reconstructed from 4D Sketches has proven to be highly effective and efficient in the area of structural design.

The implemented concept of MOO enabled a quick examination of a vast number of possible construction variants with different materiality. The Pareto-optimal solution may be used as basis for decision making support. Such design process has already proven to be beneficial regarding time and cost savings (Reisinger *et al.* 2022a).

Thus, the MOO-parameters and objectives can be extended in the future outlook of the suggested pipeline. The LCA-Analysis included directly into the optimization process, rather than as an additional calculation after the structural MOO-process, would further enhance the efficiency of the optimization, solution finding and decision making. The definition of variables, constraints and objectives can be customized to meet the specific needs of different scenarios. The structural FE analysis can be performed on a deeper level in order to provide more realistic and plausible results.

Summarized, the results of the examined test case have proven that the usage of advanced parametric modeling powered by genetic evolutionary solvers aided with novel MOO concept may be very helpful to find optimal solutions for engineering problems. Such framework may also be crucial not just for complex mega-structures like bridges, skyscrapers and luxury objects, but also for simpler building components and systems (Daleyev, Reisinger and Königsberger 2022). Thus, by leveraging the potential of parametric modeling, structural design aided by MOO and novel techniques for fast data exchange, designers and engineers can explore possible solution variants and tradeoff between the objectives. (Mueller and Ochsendorf 2015).

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Between System and Improvisation:

Aesthetic Performance in Donald Judd's 100 untitled works in mill aluminum

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In this paper, we intend to analyze Donald Judd's "100 untiled works in mill aluminum" to see whether they belong to a system, and, if so, what that system is and what delimits it. Our hypothesis is that there is a system driven by shape data, but the system is tempered by improvisational moments at multiple junctures in the project. We are interested in deciphering the systematic, but also the moments of artisticimprovisation. To that end, we will look at the roots of data-driven design in the "serial" artworks of the early 1960's documented in two Artforum essays by Bochner and Coplans, both citing Donald Judd. This period of artistic production is critical in the context of the development of shape grammars in computation which followed in the early 70's with Stiny and Gips's Shape Grammar essay. In 1983, Knight used shape grammar to describe the transformation of design languages. In the same period, Donald Judd, without the aid of computation or knowledge of shape grammar, developed a grammar towards the design of "100 untiled works in mill aluminum." We intend to explore Judd's 100 works as an example of the utilization of information and its analysis towards design and innovation, and to highlight the role of artistic improvisation in a systemic design process.

Keywords: *Donald Judd, Design System, Shape Grammar, Serial Art.*

INTRODUCTION

Design computation has its roots partially embedded in the shape grammar studies of the 1970's and 80's. These studies, in turn, have their roots in works of art that tended towards seriality, those by artists such as Georges Vantongerloo and Fritz Glarner about whose work Terry Knight developed her idea of transformation grammar (1989.) Our aim is to reconsider the systematicity of shape grammar in the context of aesthetic judgment as a critical examination of the process of design. We will explore serial works of art, and the most profound example of serially ordered work that has been tempered by artistic vision, what we have called improvisation, of Donald Judd: "100 untitled works in mill aluminum" (Figure 1). We propose Judd's 100 works as a model where aesthetic performance and technical performance have integrated.

SERIAL ORDER

Artists' artistry has traditionally been embedded in the particularity of their execution, in their brush-stroke, the way they frame reality, the plastic modeling of substance in sculptures, and so on. This understanding of artistry as related to execution had been the norm till the Nineteenth Century. Claude Monet and his seven views of *Gare Saint-Lazare* of 1877 put in motion a series of works that relied on a relational logic among works and less on

Figure 1
Donald Judd, 100 untitled works in mill aluminum, 1982-1986. Permanent collection, the Chinati Foundation, Marfa, Texas. Photo by Douglas Tuck, courtesy of the Chinati Foundation. Donald Judd Art © 2023 Judd Foundation / Artists Rights Society (ARS), New York.

the execution of individual works. Artists such as Monet, Duchamp, Stein, Albers, Reinhardt, Kelly, Warhol, and others developed serial works that highlighted the structure that governed the logic of repetition and variation instead of the execution. Serial works were produced with regularity between the late 1800's and the 1960's, however, the interest in serial works magnified in the decade leading up to Mel Bochner's *ARTFORUM* essay of December 1967, titled "The Serial attitude," followed by John Coplans' curated exhibition at the Pasadena Museum of Art of 1968, titled *Serial Imagery*. Together, they defined the parameters of what constituted serial works, almost ninety years after the first serial work was developed by Monet. We have analyzed both Bochner's and Coplans' essays elsewhere and have outlined what they share and where they differ. Here, we will briefly mention the three principles that are outlined by both and their differences:

1. Bochner and Coplans agree that "the derivation of the terms… of the work is by means of a… systematically predetermined process…" (Bochner 1967, 28), where a "macro-structure–-that which is apprehended in terms of relationalorder and of continuity..." governs the relationship among the individual works in the series (Coplans 1968, 11).
2. Bochner and Coplans also agree that "Serial Imagery is a type of repeated form or structure shared equally by each work in a group of related works made by one artist…"[2] where "order takes precedence over the execution." (Bochner 1967, 28).
3. In the third principle, Bochner and Coplans generally agree, but differ in one aspect. They

> agree that "There is no limit to the quantity of works in a series other than what is determined by the artist…" (Coplans 1968, 11), however, Coplans states there needs to be a minimum of two works to constitute a series, whereas Bochner accepts a single work as serial if its internal order meets principles one and two. Bochner also insists that series be self-exhausting, enumerating all the possibilities made available by the macro- structure.

Serial works of art serve as a bridge between analytical and generative systemic methods such as those used in computational shape grammars and the improvisational method of work by artists. The title of this paper points to this very simultaneity, between systemic thinking, methods that are prevalent in the computational environment, and the improvisational methods prevalent in the art world. Thus, in their best form, serial works of art present a critical practice, where systematicity and improvisation are constantly questioning one another. To explore this issue, we will look at the work of an artist, a Twentieth Century giant, Donald Judd, whose work appears to not only be driven by serial patterns, but also through improvisational moments, together and at once.

In the two essays by Bochner and Coplans, Judd is mentioned specifically. In Mel Bochner's 1967 *ARTFORUM* essay, titled "The Serial Attitude," he mentions Donald Judd's painted wall pieces as employing serial logic. In John Coplans' counter-essay, "Serial Imagery" published in 1968 in *ARTFORUM*, he does not mention Judd at all.[1] In fact, in the exhibition catalog of the same title that accompanied the exhibition that Coplans curated at the Pasadena Museum of Art, and included the essay as its main feature, he added a "history" section to the start of the catalog. In it, Coplans specifically noted: "Although the work of such sculptors as Donald Judd has been described as Serial, this is incorrect." (Coplans 1968, 9). The divergence of the two views caught our attention, because it pointed to an individual that did not fit easily into the "serial" label. This placed Judd at the intersection of the two methods, systemic and improvisational. We are exploring to see where his artistry comes into play and how it interacts with the systemic and serial methods in his work. In the early 1980's, Judd developed a design grammar towards the "100 untiled works in mill aluminum," permanently installed at the Chinati Foundation in Marfa, TX. We have analyzed and presented in other papers that Judd's 100 works fits the definition of serial works to a great degree, but not completely. We have argued that at decisive moments in the project, Judd has made decisions based on his artistic vision that are either outside of or completely defy the logic of the structure that governs most of the 100 objects. Our hypothesis, recorded elsewhere, is that there is a system in Judd's 100 works that is driven by shape data, but the system is tempered by improvisational moments at multiple junctures in the project. We have been deciphering the systemic, but also locating the moments of artistic improvisation.

Although Judd was practicing as a painter in the 1950's, he did not stake a claim in the art world till the 1960's when he moved away from painting and started producing three- dimensional objects. Judd's 1963 Green Gallery group exhibition brought him recognition and secured his inclusion in the 1966 "Primary Structures" group exhibition at The Jewish Museum in New York. He was also a prolific writer, having been writing art criticism for *Arts* (later renamed *Arts Magazine)* between 1959 and 1965, which also made him a known entity in the world of art. Another major break-through for Judd was the Whitney Museum solo exhibition of 1968. By this time, his "Specific Objects" essay of 1965 had also been recognized as an era-defining work that brought together and theorized the non-illusory three-dimensional work that was concerned with its own physical context and objecthood.

DONALD JUDD'S "100 UNTITLED WORKS IN MILL ALUMINUM"

By the time Judd began working in Marfa in the late 1970's and on the "100 untitled works in mill aluminum," in early 1980's, computational shape grammars had been outlined first by Stiny and Gips in 1971 as a generative tool to "use formal, generative techniques to produce good art objects" (1971, 125), and, later in 1983, by Knight as a transformation grammar to analyze art objects post-facto. In her case, the grammar was used in 1989 to describe "stylistic change in design" and to "analyze transformations of the De Stijl style of painting in the works of two artists." (1989, 51). The relationship between computational shape grammars and the arts is undeniable, given the direct connection that Stiny and Gips, and Knight make to the generation and analysis of art objects. Following in their foot- steps, we utilize shape grammar to analyze Judd's "100 untitled works in mill aluminum." We are not, however, interested in creating an all- encompassing grammar to include all objects and every decision, such as Benros et al's generic grammar (2014). We are just as interested in the improvisational moments that do not fit within the grammar as we are in the system of the grammar itself. In this light, we have written the tightest grammar possible to highlight the moments that do not fit within. We will approach this in separate categories of object chronology, object grammar, and object installation.

Object Chronology

Judd wrote in a short note in 1990: "Perhaps the point at which a piece of mine becomes good is when it opens toward many possibilities. One good piece naturally becomes a category of good pieces" (Judd 2016, 617). It is no surprise to see one of Judd's pieces re-made in different colors, materials, sizes, or finishes. In fact, this was one of the most common methods that Judd employed in his work. As early as 1964, he was using repetitive parts in the fabrication of single works of art. His progressions and stacks were perfect examples of this phenomenon. Starting in 1966, Judd started producing floor pieces in multiples, for example, his "Burnt Sienna Enamel on Cold- rolled Steel" that included four cubes, each 40"x40"x40", exhibited at The Jewish Museum in 1970. The number of pieces in a single work grew, but not beyond twenty. So, when the DIA Art Foundation commissioned him to make twenty- five pieces to go into the Wool and Mohair building in Marfa, Texas, it seemed within the range of his work at the time. Later this number increased to roughly 75 and eventually to 100 and with the increase, the location was also moved to the artillery sheds of the decommissioned Fort D.A. Russell Military Base on the Southwest edge of Marfa. The Wool and Mohair building was then dedicated to the installation of John Chamberlain works. The first 25 objects described in Judd's April 1980 sketches were all derived from configurations that he had tried previously, but not in the size and material of what we now know as the "100 untitled works in mill aluminum." The first twenty-five objects were from three separate sets brought together in the new size, finish, and material. Twelve of the objects were re- configurations of objects made for the 1973 exhibit, "18 Skulpturen" in Galerie Annemarie Verna in Zurich, Switzerland. The exhibit traveled to the Galerie Heiner Friedrich in Cologne, Germany, where two pieces were added to the eighteen and both served as foundations for reconfigured pieces for the 100 works. Three of the pieces from the 1978 "untitled, 16 plywood boxes," a part of the permanent collection of the Chinati Foundation, served as the source for ten reconfigurations and one of the pieces from the 1977 exhibit at the Heiner Friedrich Gallery of New York, "15 works," currently in the collection of the DIA Art Foundation, served as the source for the remaining piece. This practice confirms that, in Marfa, Judd was initially improvising methods familiar to his practice. The number of pieces commissioned by DIA Art Foundation, however, increased initially to 75, then to 85 and finally to 100. This increase necessitated a different method of production, which was more systemically engaged. In the first twenty-five, however, we believe that Judd was working more improvisationally. For example, of the eighteen pieces in the Galerie Annemarie Verna, he decided to not use six of the eighteen pieces. In hindsight, we can see that five of them would have made for difficult and sloppy detailing if made in ½” plate aluminum. The remaining one was a solid box, which apparently made sense in a small (23”x27”x4”) galvanized iron piece, but not in ½” plate aluminum. This decision was not part of a didactic method of reconfiguring pieces, rather an improvisational decision based on Judd’s vision and experience. We consider the first twenty-five objects to belong to the improvisational and not to the systemic. Their inclusion in the 100 works was entirely based on Judd’s judgment of how they would perform aesthetically in the new dimension, material, structure, and detailing.

Object Grammar

When the number of objects grew from twenty- five to one hundred, Judd became more didactic in the multiplication of configurations. Although Judd’s prior installations incorporating multiple objects had always had traces of systematicity in them, in this case, the sheer number of objects caused a more definitively didactic and systemic method for object configuration. We have documented our research about individual objects in detail elsewhere. Here, we will present a brief analysis of the systemic grammar and the improvisational moments.

Judd had made many box-like objects that had open tops, ends and sides. In each set, appearing together in a gallery, however, the objects were generally all open top, open end, or open side. In the 100 works, he decidedly mixed the three and used them as types, so he could create an equivalent object in, for example, open end and open side from an open top object (Figure 2).

Although the three types hold almost uniformly across the 100 works (except for four anomalies whose design language belongs to previous installations,) each type does not always have an equivalent in the other two. Most often, the logic is clear, but there are times when it is not clear why a certain equivalent was not fabricated. For example: Figure 3 maps two such objects which could have been made using the rulesets but were not made. Object #79 is made as a double of the source object #6 in the open top category. However, equivalent derivative doubles were not made of objects #28 and #35 in the open end and open side categories.

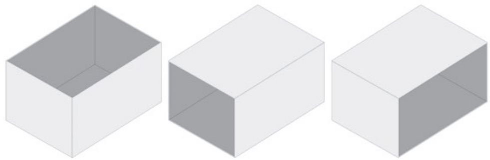

Figure 2
Diagrams of “Open Top,” “Open End,” and “Open Side” Objects number 1, 12, and 13. Diagrams by authors.

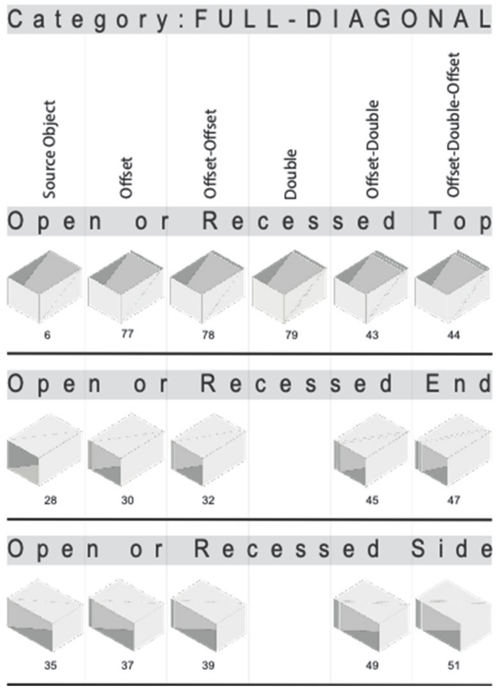

Figure 3
Diagram documenting categories of objects derived from rulesets applied to source objects, also identifying objects that were not made Diagram by authors.

There are altogether twenty-two objects that could have been made from the rulesets but were not made. They each present an improvisational moment in the object grammar, where Judd decided that a certain object would not perform its aesthetic function.

Besides the objects not made, Figure 3 also presents a set of rules that were utilized to produce new objects from a source object. The ruleset includes rules such as: "offset," "double," "bisect," and "close one end." These rules are also employed in combinations, for example, "offset- double," and "offset-double-offset," and so on (Figure 4). If followed didactically, the rulesets would have produced many more objects than one hundred. Once again, Judd introduced a layer of non-didactic decisions in the process. We could call it improvisational, or the artist's vision, or perhaps magic, alchemy, or artistry. He decided which of the resultant objects to make. He has said that he is not interested in didactically making all the variations, only the ones that are interesting. We interpret "interesting" as having the capacity to fulfill its aesthetic performance role (Jolles 2016, 9).

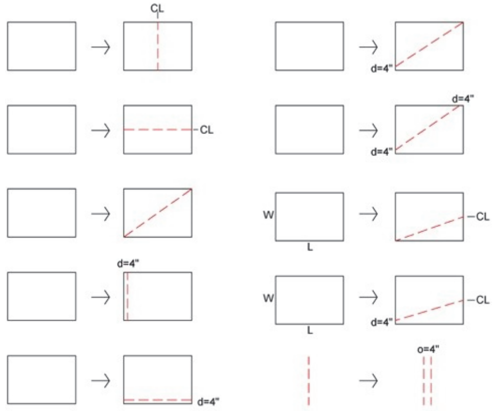

Figure 4
Rules of the grammar developed (by authors) to analyze Judd's design language.

Object Installation

Had this project been a purely systemic one, the design of the objects would have been based on the grammar, resulting in the sequencing of object fabrication. The placement/installation of the objects would have also been defined by the same sequence. The archival documents show that the design sequence and the placement/installation

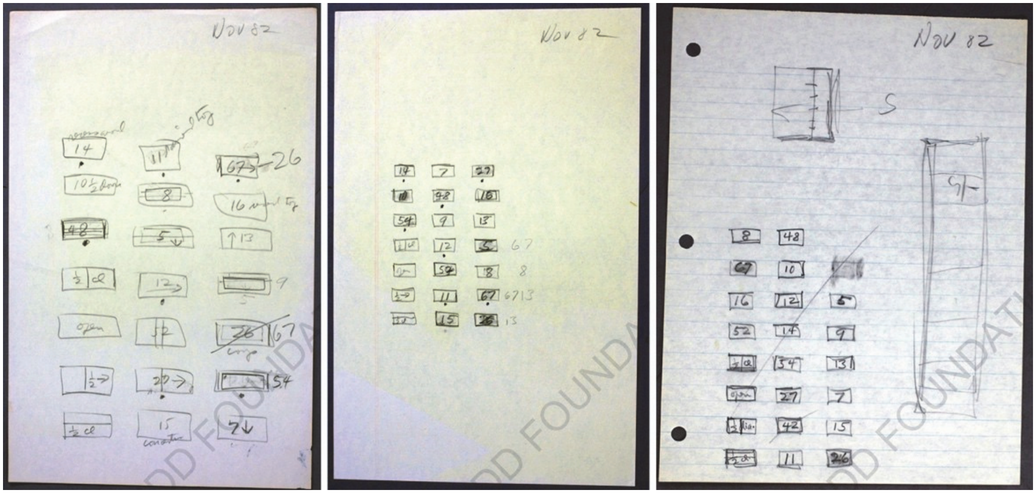

Figure 5
A, B, & C: Donald Judd, drawings for 100 untitled works in mill aluminum, pencil on paper, 8.5 x 11 inches each (21.59 x 27.94 cm), Nov. 1982. Judd Foundation. These drawings describe object placement strategies for the first twenty-one objects fabricated.

sequence were different. Although fifteen of the first twenty-five objects were fabricated in the first "batch," all were not. The first batch of twenty-one objects was commissioned to Lippincott Inc., the fabricators of the 100 works, on July 15, 1981. These objects were executed and shipped to Marfa on November 24, 1982. The first fifteen objects (objects 1-16, except #6) were fabricated in the first batch. But, the remaining six objects were all derivatives of the first twenty-five designed, but not the source objects. The Judd Foundation Archives holds three Donald Judd sketches from November 1982, the same time as the first batch was completed and shipped (Figure 5). These three sketches explore the placement of the first batch of objects and present slight changes of object placement. Except for objects one through four, the remaining seventeen objects were relocated several times until the final installation. In addition, the sketches show that Judd was placing and re-considering the placement of objects based on their relationship to one another.

We can see that Judd is marking closed surfaces and obliques with arrows pointing to the direction of the slope, relating each object to the neighboring ones. Although, as mentioned previously, these do not end up being the final locations for most of the objects, the sketches document that Judd was carefully considering the placement of objects in their relationship to one another. We have analyzed the patterns of objects carefully and have not been able to identify a definitive pattern that could govern object placement. There are, however, faint patterns that do emerge. For example, there are more open end objects placed in the East and West columns (files,) closest to the windows, than the center column, directing the view through the open end objects to the glass walls and the desert. In return, there are many more open side objects placed in the center column than the two East and West ones, directing the view through the object to the next object along the length of the artillery sheds. The open top objects are reasonably uniformly distributed in all three columns. We have also detected a desire for an object of any of the three categories (open top, end, or side) to be followed with a different category object. There are, however, instances where two, three, or four objects of the same category repeat, but this is only on five occasions that are reasonably consistent East to West. Other than these faint patterns, we believe that Judd was operating in the improvisational environment when it came to object placement. In other words, the aesthetic performance of the objects were the determining factors for their placements in the artillery sheds.

The archival material also shows that although by July of 1981, eighty-eight of the objects were designed and purchase orders were created to Lippincott Inc., the fabrication of the objects did not follow the numeric order of the objects designed. Instead, objects were selected to be fabricated based on their placement. For example, the entire group of objects fabricated in batch one was installed at the South end of the South artillery shed, in fact they were meant for the first seven rows. The first twenty-one objects were to occupy seven rows of three columns (or to follow the military language initially used on the placement sketches, seven ranks and three files.) However, one of the objects, #26, turned out to not have been made correctly and had to be re- made. Thus object 42 entered the 3x7 matrix, as witnessed in Figure 5. Other examples would include the sixth and final batch of sixteen objects which were all installed at the North end of the North shed. The installation progressed incrementally from South to North. We can conclude that Judd was selecting objects from among all one hundred to be fabricated in each batch, based on his vision of their placement, recorded in sketches that described shape and spatial relationships among objects, and not in a systemically defined selection process.

In Figure 6, we have mapped all the different placements of objects at each delivery. The numbers correspond to the 100 objects and the colors to Judd's placement sketches that date roughly to the delivery of each of the six batches. In

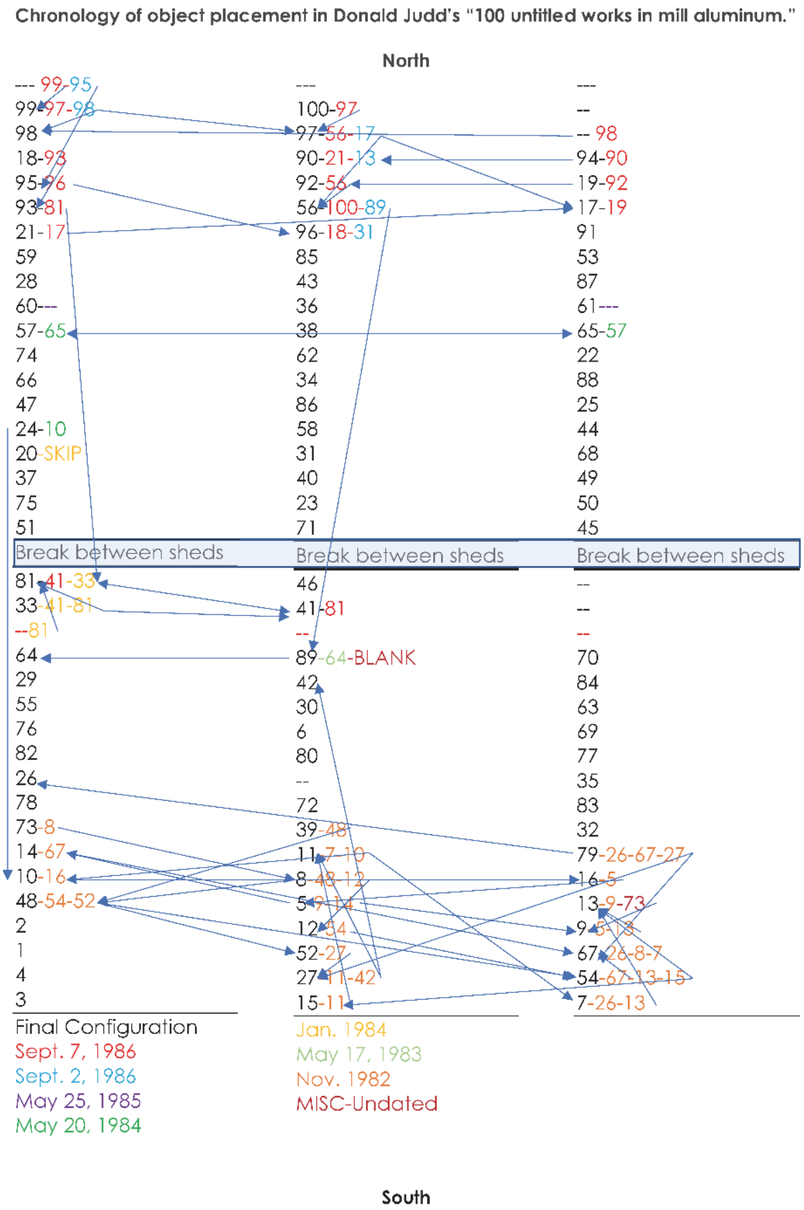

Figure 6
Object placement in the two artillery sheds with changes recorded chronologically. Diagram by authors.

other words, each time a new batch was delivered, it necessitated the rethinking of the placement plan. We can observe from the chart that most changes occurred with the first batch, the first seven rows of the South artillery shed. We also observe that the smaller enclosed spaces at the North end of both sheds necessitated the relocation of objects. In addition, the North end of the North shed also witnessed some relocation. Most of the placements in the core of both sheds remained stable throughout the four-year installation period. The chart suggests to us there was a period of adjustment at the very beginning with the first batch at the South end of the South shed. After that Judd's vision of object placement remained reasonably constant. Then, again, at the end of the installation, currently the starting point of visits due to its proximity to the visitors' center, Judd re-examined the placement plan for those objects. We have shown that there was not a didactic placement/installation plan for the 100 works, but one governed by Judd's aesthetic vision. We have also shown that the vision was re- engaged at each of the six object deliveries to enhance the aesthetic performance of the objects individually and as a group.

CONCLUSION

We set out to explore Donald Judd's "100 untitled works in mill aluminum" as a model for bringing together systemic methods and improvisational ones. This was to inform the development of computer aided architectural design so that it could address formal and aesthetic innovation through the simultaneity of systematicity and improvisation. We have described how Donald Judd used improvisational design methods to select among and limit the results of systemic and didactic design solutions towards aesthetic performance. Our larger interest in this paper is to provide a platform for re-introducing artistic/architectural aesthetic judgement at critical moments in a systemic design process. Our aim is to integrate two environments: those of systematicity and improvisations. Our interest in this analysis is to forward a process of work that utilizes systemic methods to collect and analyze data, yet, simultaneously, inject aesthetic intelligence into the process at precise moments. Our critique is no different than one we would mount of the divide between theory and practice, or the 2000-year-old divide among firmness, commodity, and delight, with delight always privileged, over the practical. With Judd and the 100 works, we put forth "aesthetic performance" as the alternative. Rather than design focused on purely formal possibilities, in the 100 works, it is focused on the achievement of aesthetic performance: in the selection of the aluminum alloy to produce the surface luminescence that allows the objects to transition from solid and opaque to ephemeral and translucent and finally to reflective and transparent; in the transition of colors from the dull dark gray of the aluminum in shadow to the shimmering silvery gray of the aluminum in light to the reflected reddish colors of the desert; in the transition from the luster of the oblique plane of one object to the opacity of the next; in the specific identity of one object and its transition to the identity of one of one hundred objects. We pose aesthetic performance as the antidote to pure formal innovation devoid of performance. In this, we de-hierarchize and integrate firmness, commodity, and delight.

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Thermal Engagement

A Method and Model for Analysing and Organising Thermal-Active Materials Close to the Human Body

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This study examines the performance and application of thermal-active materials by use of phase-change-composite structures close to the human body. The aim is to understand and model the thermal impact on a person in an office environment through 3 design test cases. In this process a design method is proposed to position PCM-wood based composites. Investigations are based on material studies by composite development and thermographic analysis, computational studies by generative design and thermal sensation modelling, and comparative studies from computational design and analysis processes by graphical mapping of results. The study finds that the PCM-wood composites have an impact on the thermal sensation within the cases studied, but only by the application of a large thermal-active surface close to the human.

Keywords: *Thermal Active Materials, Thermal Sensation, Generative, Simulation*

INTRODUCTION

Today, we spend 15% of our global electricity use on cooling buildings, and 20% of the global total CO_2 emission is based on air conditioning of buildings (Kiamili et al., 2020). Thermal conditioning plays a major role in the global energy use scheme as buildings are developed for an air-based setpoint temperature (Moe, 2014) suited for mechanical systems design (Battle, 2003) that unfortunately seem to only satisfy a small population group (van Hoof, 2008). Large ventilation and heating/cooling systems are installed for this purpose, which adds material use in direct system implementation, and indirectly through extending walls as floor heights that need to provide additional space that host ducts and system maintenance facilities.

Vernacular architectures have demonstrated passive approaches to construct and modify thermal environments without technical systems (Foged, 2019). Many of these are based on the organisation of thermal mass, positioning of shading geometries and colour schemes that reduce/increase solar absorption (Foged, 2017). A number of studies with advanced thermal-active materials have been conducted, focusing on phase-change-materials (PCMs), which are designed to change thermal capacity by altering the material phase condition from solid to liquid in as a reversible process. PCMs have been considered for textiles and clothing (Yang et al., 2022) and furniture (Barreneche et al., 2017), but predominantly as mixed into heavy, and fixed mineral based material structures, such as concrete and plaster boards (Pomianowski, 2013; Pomianowski et al., 2012; Wi et al., 2020).

This study investigates how thermal-active materials can be analysed, distributed, and evaluated through computational analysis and design processes. In addition, the study concentrates on reconfigurable elements, where the thermal-active elements can be moved by an occupant, enabling a human-influenced thermal adaptive process to take place. The objective is to understand, analyse and digitally model heat transfer processes from the dynamic material to an occupant, and analyse what specific resultant thermal sensations that are constructed, based on computed analysis and design simulations. Specifically, the study constructs three different design case conditions in an office setting, using three computed test geometries that represent different degrees of complexity in making and implementation. The computational test cases are based on a material investigation and registration by use of thermography measurements in a representative physical space, reproduced in the digital model, to examine and model the distribution of PCM (using Micronal, wax encapsulated paraffins with a 23 Celsius melting point). The PCM is embedded into a lightweight planar wood casing (poplar wood with low density/thermal capacity, 380 kg/m3) creating a light, movable, composite structure. The heat transfer from the composite to a human is digitally simulated by the surface radiant temperatures that impact the thermal sensation equations for thermal sensation, comfort, effective temperature, and radiation loss of an occupant exposed to the composite.

The paper presents the experimental material studies, computational analysis and design investigation, results and discussion. The results section elaborates on the dataset computed by the established computational model, before a discussion is provided to question results and outline conclusions.

METHODS

The investigation uses a mix-method approach, including material prototyping, thermography measurements, data analysis, computational thermal sensation modelling, material-form versioning and data mapping for comparative analysis.

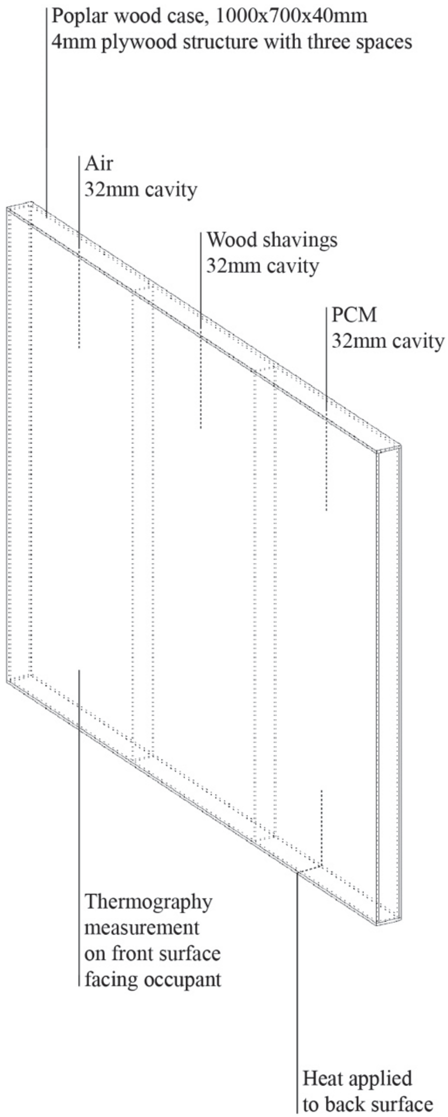
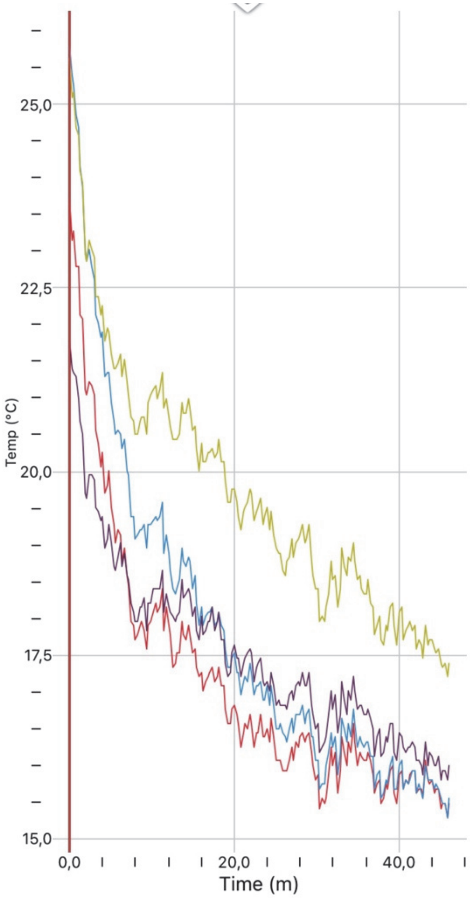


Figure 1
Material composites structure for thermographic measurements.

Figure 2
Measured surface temperatures from thermography registrations of the 3 composites and a reference surface. Green line = PCM, Blue line = Wood shavings, Red line = Air, Purple line = existing plaster wall.



Material Studies

Geometrical simple material composite samples are produced to enable thermographic analysis. The material composites consist of a poplar wood casing, 1000x700x40mm, constructed of 4mm plywood. The rectangle, figure 1, is structured with three internal compartments of identical dimensions. Each internal (enclosed) compartment contains a separate material; air, wood shavings and phase-change-material, respectively. The chamber with air is considered the reference composite of the assembly. The phase-change-material is a microencapsulated organic material (Micronal), with a designed phase change temperature of 23 degrees Celsius. To understand the heat transfer characteristics and the resulting surface temperature of the composites, the composites are positioned in an open office space for testing and measurements. The open office is chosen over an isolated lab space, to align the study closer to a real application environment than what would be the case in a climate chamber. The composites are exposed to a space heater with a planar front for 60 mins, elevating the temperature of the composites from the initial temperature defined by the air temperature. Following the heating of the composite, it is placed 1m behind an office desk, exposing the surfaces to the person at the desk, figure 3 (digital twin). The room is cooled to ~16 degrees Celsius, for then to conduct thermographic registrations of the surface temperatures of the 3 composites across 45 mins, figure 2, including also a reference temperature from the existing plaster wall surface next to the test composites. From these measurements, we construct a dataset of the composites surface temperatures facing a person over time in relation to the ~16 degrees air temperature.

Computational Studies

Based on the material-heat dataset, a bespoke computational analysis and design model is developed. From the integration of the dataset, three computation-based design investigations are conducted. These include (A) a 'digital twin' of the material experimental study, using a rectangular geometry position behind a person, sitting. And (B), a geometric wall surface area that is computed based on the exposed (view factor) surface area of the human sitting, which is hit by the wall normal vectors (view angles) of the surface, thereby identifying the areas of the human surface that are exposed to composite-based radiant temperatures, figure 3 and 4. In specific, the method/model compute the outline of the person and then project this onto walls that are within 1.5 meters of the subject. The projected geometry then becomes the digital surface for the phase-change-composite, which in turn sends heat energy to the person, based on the same dataset as case A. The entire simulation process then runs, and the person's spatial position, body posture and distance to walls, determine the reverse heat impact of the synthetic (digital) material samples, figure 3.The last test case (C) is based on a hemisphere geometry, which can be placed over and around the person. Based upon these geometric compositions, the analysis runs, across a sequence of 45-time steps, based on the 45 minutes thermographic dataset.

To evaluate the impact of the radiant surfaces on the human, for each case, Fanger's (Fanger, 1970) 6-factor heat balance model is used and implemented into the geometrical model studies through Rhino/Grasshopper/Ladybug Tools. Four of the six heat balance factors are considered static: Air velocity = 0.5 [m/s], Relative Humidity = 50 [%], Clothing rate, Icl = 1, Metabolic Rate, M = 1. Air temperature, Ta, is modelled for three values, Ta = 16, 19 and 22. One factor is dynamic, the Radiant Temperature, Tr = x, with the values of the surface temperature obtained from the material investigation. By use of a digital polysurface person, each surface segment of the total area of the digital person can be calculated based on the 6 factors, creating a detailed computed human surface mapping of the Predicted Mean Vote, PMV (thermal sensation), Predicted Percentage Dissatisfied, PPD (percentage dissatisfied), Standard Effective Temperature, SET (holistic effective temperature) and the Radiant Heat Loss (W/m2).

In a design process, each of the three cases presented can be developed into a versioning process of multiple design propositions. Case A uses a simple geometrical configuration, which can be readily mounted on a planar heating source and moved around as a generic heat surface. Case B presents a significantly more complex computational process, where the radiant surface is derived from the specific person geometry, in a specific body position. This method of constructing a geometry based on the human as a target geometry opens for the generative process of highly bespoke thermal-active material compositions, particularly if multiple people are present in the analysis space. Also, as the geometric outline and surface area is based on a dynamic entity, the human

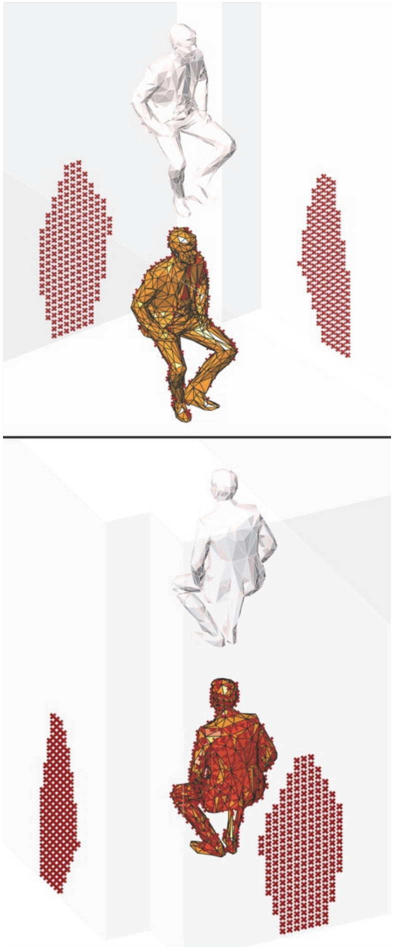


Figure 3
Computed relations between person surface profile and wall surface with thermal active material. Top person is in heat balance, with white colouring being in thermal neutrality. Bottom person with radiant heat mapping. Top image, person seen from front. Bottom, person seen from back with variance in surface temperature based on radiant wall surfaces.

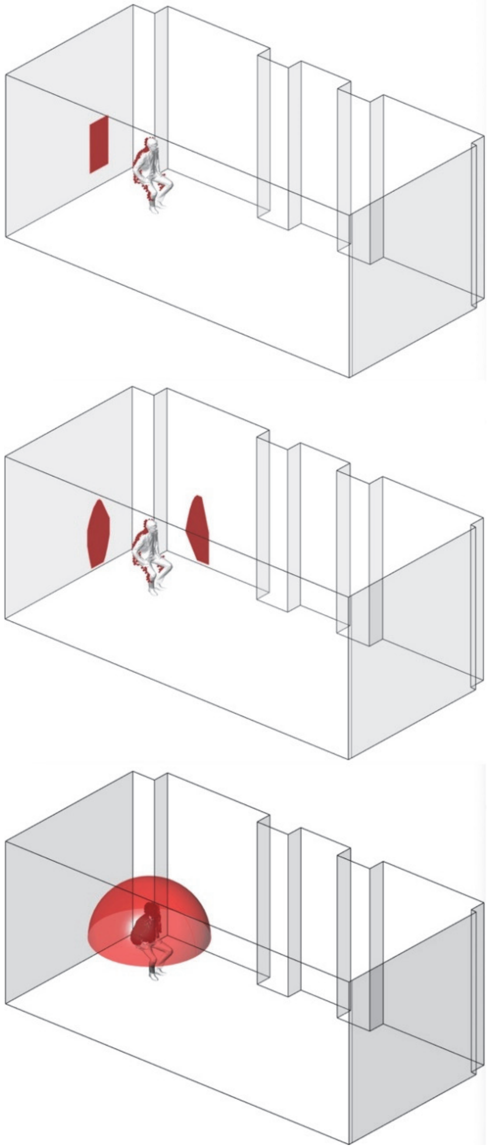


Figure 4
Computational design model, based on the space where thermographic/material testing were conducted, including the thermal space, radiant composite (PCM-Poplar structure) in A, B and C test cases, Rectangle, Profile, Envelope, respectively.

position, a generative feedback mechanism is constructed. Lastly, Case C is geometrically complex compared to A, and generic compared to B. Due to its spatial placement and potential for movement, not tied to a wall surface geometry, this case suggests an adaptive use, where the geometry, or a similar form, is placed according to highly personalised interests of heat sensation and privacy control.

Results are computed and mapped for the isolated radiant impact conditions and weighted radiant impact conditions. The weighted results are based on the 'arithmetic weighted mean', which relates the radiation influenced surfaces of the human body and the non-radiation influenced surfaces with the surface areas respectively, taking into account the relationship between surface temperature and surface impact to create a holistic assessment of the total body surface.

Comparative Studies

The computational design and analysis model generates a large dataset which is mapped and compared for material-thermal performances in relation to human thermal sensations, comfort assessment and heat loss from the subject to the test case environment focused on radiation transfer. Comparative analysis is done by direct comparison of the computed graphs to understand the absolute and relative thermal performances of the combined material and computational studies, figure 5 and 6.

RESULTS

When observing the surface temperature slope of the three material composites, figure 5, we see how the phase-change-material composite produces a higher surface temperature and a slower fall-off development across the 45 mins. Besides providing the basis for the computational design models and studies, this demonstrate that the tested thin poplar plywood structure with embedded PCM work as a fast thermal release structure, despite the poplar's low density and relative high insulating character, compared to mineral- and metal-based 'containers'.

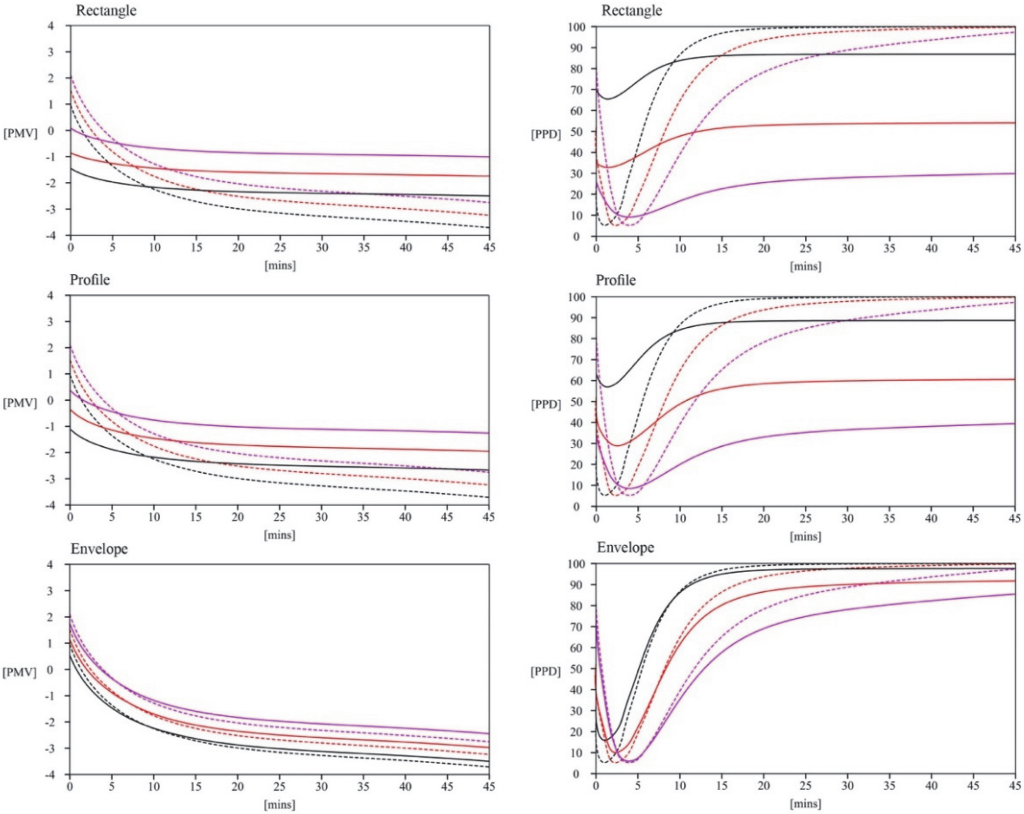


Figure 5
Simulated PMV and PPD results based on the Rectangle, Profile and Envelope design cases, with Ta = 22 (purple), Ta = 19 (red), Ta = 16 (black) degrees Celsius profiles.

From the computed test cases, with three different design implementations, Rectangle, Profile, Envelope, we can compare across the four aspects computed. The full graph line represents the weighted results of how the surface temperature influence the thermal heat balance, and the dashed lines represents the non-weighted results.

For PMV, predicted mean vote, a value of 0 is thermal neutral heat balance condition of the exposed subject. Purple lines represent air temperature, Ta = 22C, red lines, Ta = 19C and black lines, Ta = 16C. In all three design test cases, and in all three Ta segments, the PMV non-weighted initiates from between +1 to +2 (warm to very warm sensation) and crosses the neutral state (0 C) after between 2 and 7 minutes of exposure time, with a thermal sensation development aligning relatively close to the surface temperature of the PCM composite in the Rectangle and Profile cases. The non-weighted move further into -2 to -3 after 45 mins, being cold to very cold thermal sensation. The weighted simulations have much more conservative development in the Rectangle and Profile cases, initiating from 0 to -1.5, leading to -0.5 to -2. For the Envelope design test

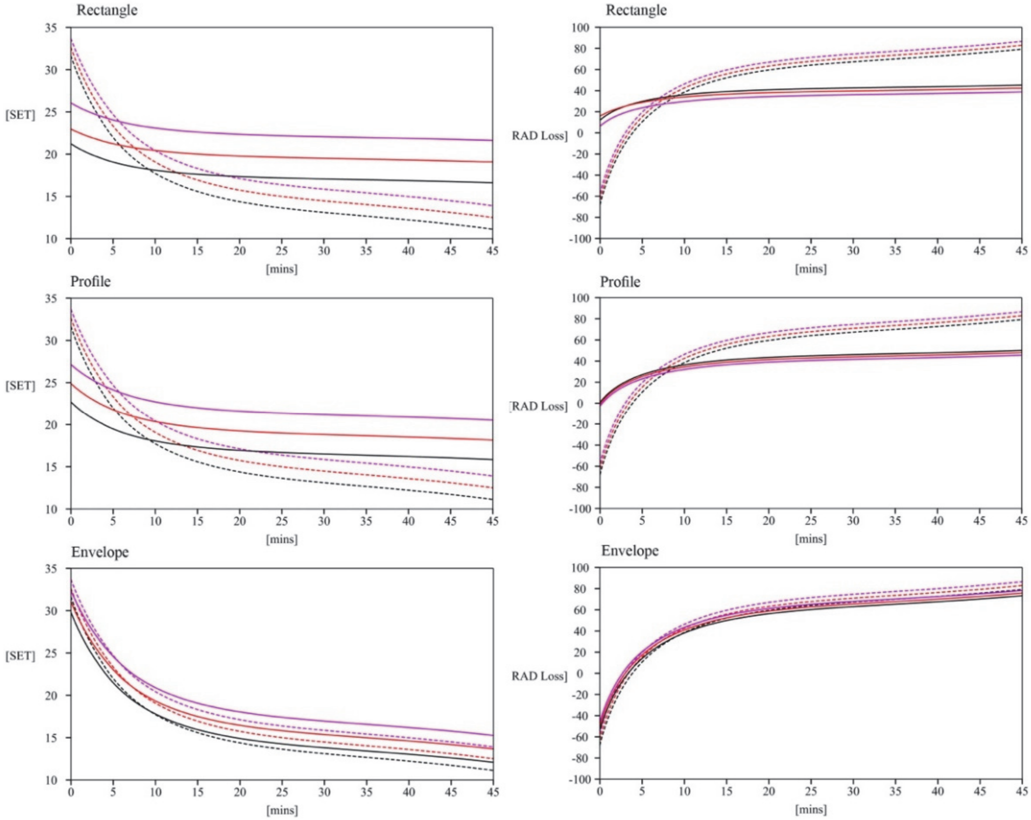


Figure 6
Simulated SET and Radiation Loss results based on the Rectangle, Profile and Envelope design cases, with Ta = 22 (purple), 19 (red), 16 (black) degrees Celsius profiles.

case, the subject is exposed to a much higher degree. We see this clearly in the results, with the weighted and non-weighted results following close throughout the 45 mins, leading from +0.5 to +2 at 0 mins. to -2 to -3.5 at 45 mins. From these results, the tapering profile and effect of the PCM composite works best in the 3 to 8 min exposure period, if thermal neutrality is desired. Also, the extra PCM composite surface of the Envelope test case, compared to the Rectangle and Profile test cases appear to have a significant higher impact.

For PPD, predicted percentage dissatisfied, the results are based on the PMV calculations, which is seen in the close connection between the Rectangle and Profile cases, with the Envelope case showing a different PPD development. In all three cases, the percentage is high for the first three minutes, with subjects being too warm, for then to move below heat balance at 8-10 mins. It is noticeable to observe the profile of the weighted simulations of the Rectangle and Profiles cases, with 22C maintaining a relatively flat and steady development, whereas from the Envelope case, all three Ta values move relative fast (5-10 mins) from dissatisfied, to satisfied to dissatisfied from a thermal comfort perspective. These results underline the results observed in the

PMV graphs, suggesting the importance of a significant PCM-composite surface exposure to construct altered thermal comfort conditions.

With the resulting PMV and PPD profiles, the SET, standard effective temperature, profiles of the weighted and non-weighted simulations have a similar slope behaviour and variance between the three Ta values and three computed design cases, figure 6. For the weighted results, this means a human of the Rectangle and Profile cases will initiate with a 26-27C condition, with Ta = 22C, converting to 22C after 45 mins. The Envelope case for weighted (and non-weighted) simulations initiate above 30C, for all Ta values, due to the high exposure degree of the large and warm PCM composite.

Applying the Tr profile from the material studies, the SET results in sub-Ta conditions, illustrating the consequences of thermal condition if the thermal-active material was able to initiate cooling impact on the exposed human. The latter effect is also identifiable in the Radiation Loss curves, figure 5. The negative numbers indicate that the human is receiving radiant energy from the environment, whereas positive numbers show when energy is lost to the environment through energy loss. It is evident how big an impact a large cooling envelope would have, as the energy transfer is reversed after just a few mins, whereas the weighted results from both the Rectangle and Profile test cases illustrate a significantly lesser energy loss, with the smaller surface areas of the thermal active material. These results highlight the impact of the combined material effect, exposed surface area between human surface and thermal active material surface and the speed of change, from negative to positive radiation loss between the human and the environment.

DISCUSSION

It was attempted in this study to construct a field condition setup for the initiating material study, which informed the computational design method, model and investigation. This approach is not without limitation as the composite developed is in active thermal transfer with the specific (messy office) environment during investigation. In a laboratory setting, such processes can be better controlled and influencing aspects minimised and understood. On the other hand, coupling the material investigation with the computational investigating through the same environmental setup, aligns the two studies and the findings transfer from one investigation to the next may have higher correlation, in the specific test case.

Another aspect of the study is the transfer of the PCM surface temperature curve to three simulated different air temperature environments. The material testing was done under ~16 degrees Celsius, which means that the direct correlation in the computational studies is the 16 degrees Celsius model only. The computational studies using 19 and 22 degrees Celsius for air temperature are theoretical and synthetic, assuming that the composite surface temperature can move below the air temperature. This is only possible with a cooling process, whereas the PCM would stagnate its dive and converge with the air temperature at 19 and 22, respectively. Nevertheless, the additional studies for 19 and 22C provides informative understandings for how surfaces with cooling capacity (below air temperature levels) impact the thermal sensation, comfort and heat transfer of the subject in each of the three computed test design cases.

Lastly, it should be noted that the energy embedded into the thermal-active composite is not for free. In this study, it is not a question of free energy, but a method and model to distribute thermal capacity in space and time in relation to a human subject.

CONCLUSION

It is noticeable how large a thermal-active surface that is needed to make a significant impact on the holistic thermal sensation of the person evaluated. The weighted results show that the effects in some ways are negligible. This is underlined by results of the black graph lines with the direct correlation between material studies and computational studies, showing only minor improvements to the PMV and PPD factors, if the aim is thermal comfort based on thermal neutrality.

However, the study also suggests that if surfaces are designed with sufficient and well-articulated relations, for instance based on the method presented here, thermal-active surface from PCM composites may play a part in material-driven passive thermal design systems to minimise technical, energy-demanding systems.

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Customer Configuration Systems as a Design Task

Architectural Education and Context-Driven Product Configurator Design

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This research deals with customer configuration systems for architecture and design products as a design task for students. The design of a product configurator accompanying the parametric design of a piece of furniture or an architectural element has been introduced in several courses over the last ten years at the HafenCity University Hamburg and at Hamburg University of Technology by the author. These studios are presented as case studies to discuss the didactic potential that lies in designing customer oriented product configuration systems with students of design and architecture.

Keywords: *Mass Customization, Configuration, Collaboration, Design Tasks*

INTRODUCTION

Customer configuration systems like online product configurators have emerged as a strategy of customer collaboration across diverse product lines as discussed early on by Pine (1993) later by Piller and Tseng (2010) and in the field of architecture for the development of furniture, building elements and even entire buildings (see e.g. Piller and Piroozfar 2013 as well as Naboni and Paoletti 2015).

Zuboff and Maxmin (2002) have pointed out the significant chance for a digitally enhanced customer/business relationship as part of a support economy, which doubtlessly is a positive potential goal for professional designers and architects who have learned to apply strategies of mass customization accordingly.

The design of product configurators (including graphic user interface and underlying solution space plus guiding rules and constraints) is decisive for the design quality of each instance that is established as a result of an asynchronous collaboration between designer, producer, seller and customer.

The widespread tendency to leave the layman with too much responsibility for the quality of outcome (also discussed in Kulcke 2019) can be countered as it is possible to raise awareness with students in the field of design and architecture for this problem and the chances that lie within an engagement in the field of designing configuration systems for customer use.

Configuration in Architecture

Since the afore mentioned 2010 publication by Piller and Zheng of a research handbook of mass customization and personalization, including among other product families furniture, and Pillers and Piroozfars publication on mass customization in architecture and construction in 2013 there has been an increasing interest in connecting consumer oriented mass customization with the field of computer aided design of the built environment.

Customer Configuration in Architectural Design Education

Dealing with this subject in a didactic context means building up on several research aspects and themes of digital strategies in architectural design, which have to be introduced to students when setting out to get them started on customer configuration as a design task.

Parametric Strategies

Parametric strategies are at the outset of developing designs for mass customization, therefor an introduction on these is the basis for all further steps toward designing products for customer configuration systems as well as those systems themselves. A crash course on Rhino/Grasshopper with a special focus on the specific design task of the studio is highly recommended.

Collaborative Customer Oriented Systems

Mass Customization is considered from a design oriented point of view, first and foremost about collaboration between system designers and users resp. customers. Students have to be enabled to get into a collaborative mindset that allows them to mentally envision the productive dialog with laymen.

Recommender Systems

End users of configuration systems like online product configurators are usually not design professionals. Felfernig et al. (2014) have pointed out the importance of differentiated recommender strategies as part of product configuration to address the subject of responsibility on part of the authors of customer configuration systems. To realize this responsibility students have to reflect on the subject of balance between professional guidance and customers' choices.

Analysis of Gestalt Quality in Architecture

To introduce recommendation and/or rules and constraints concerning Gestalt quality into a configuration system, digital tangibility regarding these qualities has to be reached and automated to a certain degree.

General attempts to reach an objectifying feasibility of Gestalt qualities have been made by Birkhoff (1933) and Bense (1971), who as well as von Cube (1965) have pointed towards the decisive aspect of complexity to define calculable aesthetic measures. As of yet there is no final description let alone a definitive set of digital tools to cover all aspects of Gestalt quality analysis in architecture. There are however promising first steps and prototypes that lead the way and the students should be made aware of existing approaches and ongoing discussion as they design their own systems to include some of these analyses (see e.g. Kulcke and Lorenz 2022).

TEST CASES

This chapter presents three approaches design studios supervised by the author have taken, each addressing a specific perspective in introducing design of customer configuration systems for architectural elements and furnishings as a didactic task (shelf systems have been chosen as examples for easier comparison).

1. customer configuration and parametric design,
2. customer configuration and designfunding,
3. customer configuration and production by SME.

Configuration and Parametric Design

This studio was part of the so-called digitorials which were at the time organized and funded by the students of the HafenCity University Hamburg to broaden the access to digital strategies. This happened during a time when the teaching of "applying proprietary software" in architectural processes was by some members of the institution not considered to be teaching on an adequate university level (this is sadly as of yet not an attitude which can be considered to be entirely of the past).

During the course a shelf system had to be parametrically designed and modelled in Rhino/Grasshopper including at least one aesthetic driven rule and/or constraints in preparation for setting up a configuration system. To achieve their goals students included scriptings in Python, C# and/or VB in their graphic macro programming to achieve instances that keep to certain aesthetic characteristics although defined by variable parameters to be chosen by customers (see figure 1).

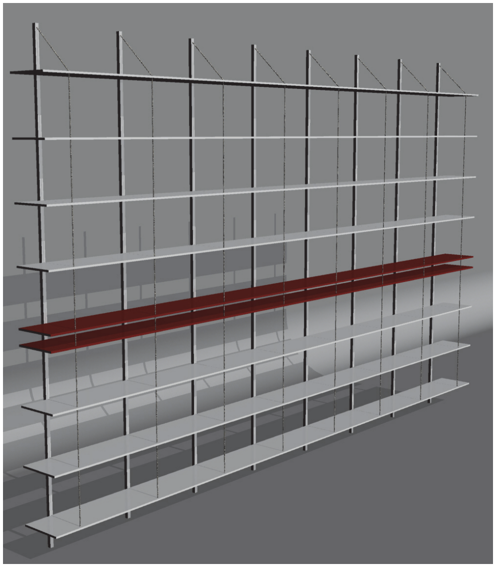

Figure 1
student work by Alexandre Fernandes 2015

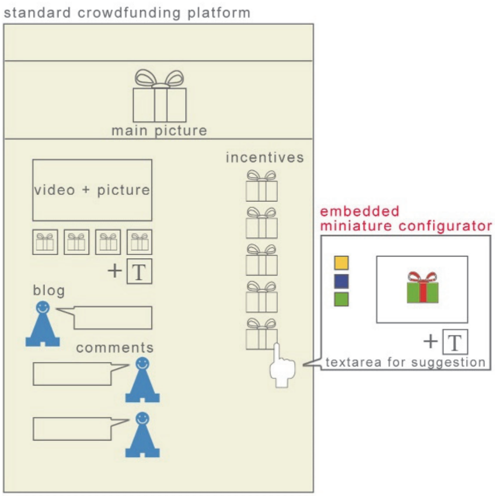

Figure 2
integrating configuration into a crowdfunding (Kulcke 2015)

Configuration and Designfunding

This studio took crowdfunding for design products, labeled as designfunding, as a starting point. Configuration was introduced to emphasize on the potential of a collaborative dialog with customers as early as the design phase. The participatory and grass-roots character of successful designfundings was taken as a vital source for shaping the design process and thus put a main priority on a democratization of designing products like furniture and architectural building parts.

As another aspect the task also called for student ideas on how to optimize existing crowdfunding platforms like kickstarter.com for designfundings including configuration strategies (see figure 2).

Configuration and SME-driven Production

There are certain needs and potentials on the part of SMEs, regarding product design and configuration (see Kulcke 2016). These where addressed in this studio which was characterized by a cooperation with regional production, i.e. craftsmen in the Hamburg area, designers and design-dealers. Here an emphasis was put on limiting designs to what may sensibly be produced by SMEs situated in a local perimeter, using online configurators in a joint effort with a real shop sales platform in the stilwerk Hamburg. The interaction with the craftsmen during the design phase of the products and the accompanying customer configurators fueled the development throughout the semester.

Within this experimental layout the central question of this studio was to design the product as well as the dialog with customers. Students had to present concise imagery illustrating how their product met the high demand put on design quality of each instance of the solution space as well as how the layout of their configurator would lead the user through every step of configuration.

All this served to help the students realize that product and configurator may be regarded as parts of one concept. Both parts influencing one another during the design process (see figure 3 and 4).

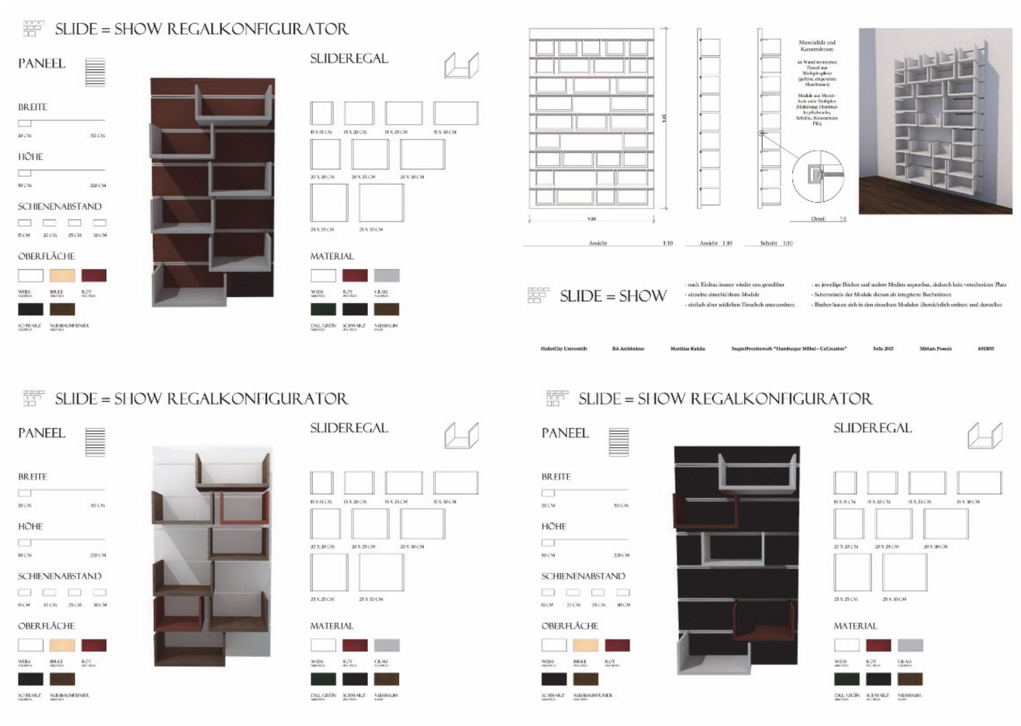

Figure 3
student work by
Miriam Posselt

ANALYSIS OF THE DIDACTIC APROACHES

There are besides a number of practical questions considering construction and production of the actual product some central points on aesthetics and ethics that needed to be addressed at some point during the design process in each of design studios; these were among others in essence:

- responsibilities on part of system designers,
- reliable quality of outcome,
- (individual) definitions regarding Gestalt quality.

It also became evident to the students that there is no ideal product configurator in the same way that there is no one ideal dwelling or shelf system.

Setting out to define a solution space the students overall took initially the following steps which were iterated and revisited in the ongoing process:

1. definition of a solution space by constructional boundaries and functionality,
2. definition of a solution space by material and surface,
3. definition of a solutions space by further Gestalt quality prioritization (e.g. restrictions on form, proportion or choice of color),

Arising mass customization specific questions (see e.g. Schwartz 2004) were addressed during the courses in an exemplary fashion and thus became a regular part of the groups' design vocabulary.

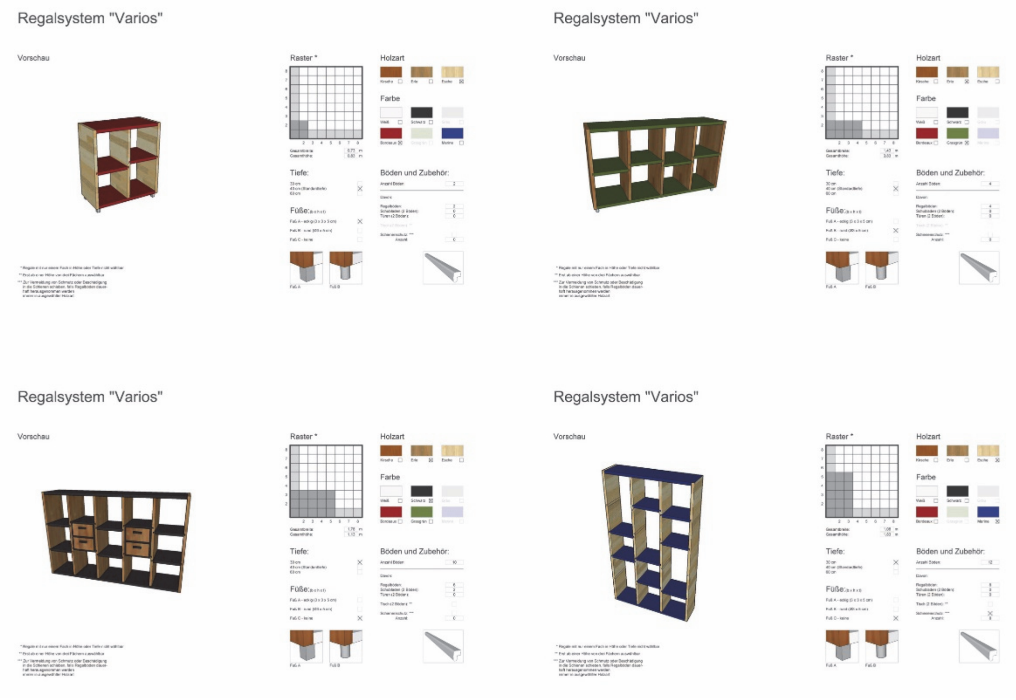

Figure 4
student work by
Denise Eudes

DISCUSSION AND OUTLOOK

Steinbusch and Walcher (2013) and recently Kolarevic and Duarte (2019) have branded mass customization as a significant path towards a democratization of architectural design. The more recent publication of the two shows that this potential of democratizing design has not yet been realized in practice and is still a desideratum. This is especially true for customer inclusion and among other aspects due to the fact that laymen are not fully equipped to create architecture and design-products, as they lack the necessary education.

To realize the democratic vision students in the field have to be equipped with knowledge about the discourse surrounding this path and the digital as well as conceptual techniques needed to pursue it as customer guides in a meaningful way; these skills include semi-automation of Gestalt analyses.

The latter is as vital for students as it is to become acquainted with the central terms being used in mass customization to consciously take the main areas of solution space development, robust process design and choice navigation into account while developing their products. The students have been inspired by the tasks' specific angles and the different approaches have produced a diversity of results, showing that task design details play an important role for customer configuration system development in the field of architecture.

Students were in most of cases able to tackle the complex problem of the solution space design while defining aesthetic-driven in addition to function-, construction- and production-driven rules and constraints. They were thus empowered through practice and group discussion to iteratively alternate product- and interface design aiming for a holistic aesthetic solution for context-driven product configurators to be used in a collaborative design process with laymen as customers.

Further development of packages of supporting design tools, easy to build (modular) configurators and even more diversified configurations of didactic processes are the areas of further research to be accompanied by further educational practice with a focus on responsible and Gestalt quality oriented design for mass customization.

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BIM and Teaching in Architecture

Current thinking and approaches

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Increasing use of BIM has represented a continuing shift in traditional assumptions on how we navigate the design process. BIM is affording the student the ability to gain a greater understanding of their design ideas via the exploration of scale, spatial organisation and structure, amongst many other design layers, in increasing levels of detail, at the same point in the design process. Architectural education is at a delayed tipping point where architectural students are increasingly looking towards BIM to streamline their design process drawn by the production of realistic visualisation, but with a lack of knowledge and skill in its application. With a lack of guidance and understanding around the application of BIM, the use of BIM in this manner overlooks the potential of BIM to construct and test virtual simulations of proposed schemes, to support design enquiry.
This study examines the design process of architectural students and the interaction between analogue and digital methods used in design. These primary modes of communication, offer the opportunity to query the roles and rules of traditional architectural conventions around 'problem finding' and 'problem solving', challenging the 'traditional' design process examined by pioneers like Bruner (1966) and Schon (1987). These approaches are distilled from the findings of the study and presented as guidance to those teaching in architectural academia to align pedagogic goals to methods of abstraction in this new era of design education reconsidering digital methods in design.

Keywords: *BIM, Pedagogy, Design Process, Architecture, Learning.*

INTRODUCTION

The ability to effectively navigate through an architectural design process is regarded as being the most important attribute for architecture student to possess and therefore one which is of historical interest particularly within architectural education. A concern for the pedagogy constructed around students' design process within an architectural design project is the application of methods and techniques adopted through the design process (Çakir and Uzun 2020; Daemei & Safari, 2018,). Dash (2021) highlights how these concerns become increasingly focused when CAD, "the process whereby computers and specialist software are used to produce virtual three-dimensional models and two-dimensional drawings".

Advances in recent decades have increased the production of renders and 3D models as a primary mode of communication, but also offered the opportunity to query the roles and rules of traditional architectural conventions around 'problem finding' and 'problem solving' (Zuo, 1998), greatly affecting the 'traditional' design process examined by pioneers like Bruner (1966) and Schön

(1987). The recognition of more digital processes and technologies being applied within the architectural design process saw the emergence of more digitally focused studies by Cross (1982), followed by other scholars such as Clayton (2010), Ambrose (2012), and more recently Abdelhameed (2018). However, although these studies considered the use of CAD/ BIM in terms of educational impact and benefits across the architectural design process, they did not consider the use of analogue (traditional) methods in parallel with CAD/ BIM and the combined effect of these on the design process.

To establish a clear understanding and foundation for this study, this study explores current literature relating to the design process in architectural education and explores the application of analogue and CAD/ BIM methods within the architectural design process separately. The study then explores the implementation of CAD/ BIM within architectural education before a summary of key findings is made. Specifically, the research is seeking answers for the following questions:

1. 'When' do students adopt analogue and BIM methods of design exploration and begin to actively move between them?
2. 'What' stages of design enquiry was BIM applied to and are there parallels to the student's design approach using analogue methods?
3. 'Why' were BIM and analogue methods applied and how were these activities connected across the design process?

METHODS

The primary intention of this study was to understand the effect of BIM within the design process of Architecture students, in parallel with analogue methods. The full design processes of 16 students were analysed and assessed for all activities (BIM and analogue) used during a 9-month design project. From these 16 students the patterns of BIM activities, in parallel within analogue activities, were mapped to create design process timelines for each individual student, indicating 'when' BIM and analogue activities took place on a month-by-month basis, and during 'what' stages of the design process. Associated interviews with each student undertaken throughout the design process were assessed using Nvivo to identify themes indicating 'why' methods were used. The resulting individual design process timelines and thematic analysis were then collated and assessed to gain unique and novel insight into the effect of BIM within the architectural design process of master architecture students. The study then presents a cross-analysis for 'what' analogue and BIM is used for. Figure 1 shows the design process stages.

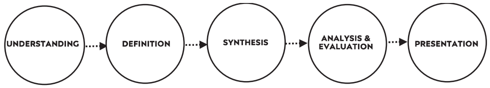


Figure 1
Stages of design process

As a result of the understanding gained through the analysis presented within this research, indicating the effect of BIM in parallel with analogue methods and its use within the architecture design process, the study is able to present findings to support the delivery of BIM within the architecture design studio within higher education.

In summary, the extant research on the use of BIM in the design process is focused on skills and activities within that are or have been augmented by the use of BIM/BIM. When considering the use of CAD/ BIM in the architectural design process the extant research is considerably smaller in scale and written by a limited number of researchers, some of which have been noted in this study. Therefore, this study will observe and map the entire design process of a randomly selected group of students, in order to understand how and where CAD/ BIM activities occurred and what are the effects of CAD/ BIM being exploited in these design processes.

RESULTS AND DISCUSSION

The study indicated that all students within the sample engaged with BIM at some point during the design process, with the majority of students using BIM by month 4 (the midpoint). Students were found to engage with BIM activities to gain a more intricate understanding of their design proposal. BIM allows for integrated and immersive opportunities in the design resolution, allowing students to 'experience' their design iteration rather than it be merely illustrated, providing a more efficient and informative approach for presenting and testing design solutions. The use of BIM would also reveal unexpected consequences, concepts or features of a design problem that otherwise may not have been achievable by analogue methods. However, students noted that considerable time and effort was required to move the analogue material into a BIM form but noted that this effort was a worthwhile time investment from the advantages BIM would later provide. In adopting BIM, students undertook a 'catch-up' phase as they transferred and therefore replicated existing material and understanding via previous analogue methods into BIM and explored any new insights that can be gained. It was established that those students who adopted BIM the earliest were found to me most confident in applying BIM, but also most confident in how BIM could benefit their design process. However, students who predominately focused on BIM activities did not, in the main, produce abstract material and lacked the 'conceptualising thought process' required to problem solve inhibiting their design process. Within those students who engaged with BIM the earliest, the majority did so to either undertake the 'understanding' stage of the design process, focusing on using BIM to improve the accuracy and co-ordination of their scheme, and on-site assessment and visualisation to support their design development, or as part of the 'synthesis' stage of the design process.

Furthermore, in adopting BIM it was established that the majority of students adopted a sequential process of synthesis > analysis & evaluation, > and presentation. While the latter stage of presentation utilised BIM for visualisation, specifically the production of final presentation material (accurate and realistic renders and visualisations of their scheme) for their design submissions, the stages of synthesis and analysis and evaluation were used to support conceptualisation and resolution of design ideas, moving between site and proposal in increasing levels of detail towards a final resolution of the scheme. With all students increasing their use of BIM as they approached the final months of their design process, with the potential to accurately predicting design solutions creating the capacity for richer learning, students who initially adopted BIM within this timeframe were found to be the most reluctant to use BIM due to skill level, and a feeling that BIM would restrict their design. However, their adoption of BIM stems from an acknowledgment that they couldn't resolve or refine some design issues using analogue methods, and as such were driven to use BIM to further develop and visualise their scheme. Throughout the design process students were most driven to use BIM to produce visualisations (outputs) of their scheme (building and the immediate context), and to gain benefits in the accuracy and coordination BIM offers over analogue methods. The ability to visualise a design problem to support conceptualisation and resolution of design ideas more rapidly and accurately appears to be the main prompt for the student's choosing BIM. The use of BIM for visualisation of their BIM was also an incentive for students who struggled with a lack of artistic ability. However, in exploring the application of BIM, there appears to be a lack of use for technical conceptualisation and resolution due to students running out of time to explore their design to this level of detail. However, those students who engaged with this use of BIM noted benefits of being able align the technical aspects of design resolution more closely to that of form finding, more accurately than with analogue methods. Similarly, there appears to be a lack of use of BIM for site analysis, driven by the existence of this knowledge from analogue activities. It is however of note that in exploring the relationship between 'why' BIM was used within 'what' stage of the design process, the analysis indicated BIM themes (individual and grouped) were often most dominant within one particular stage, and equally that theme was also the most dominant within that stage, signifying a strong relationship between why students used BIM within specific stages of the design process. The findings relating to the use of BIM within this study have been compiled in Table 1.

The use of analogue

The study indicated that all students undertook analogue methods from the start of the design process and the majority (12 out of 16) used analogue methods for all months of their design process, with one student focusing solely on BIM from month 2, and three further students who had resolved their design focusing solely on BIM for final presentation in month 9 (the last month of the design project). It was observed that the retaining of analogue activities throughout the majority design process, once BIM was adopted, helped the students to retain an abstract understanding of their proposed scheme. This was most noticeable in students who retained the use of conceptual

Part 1: 'when' and 'what'	**All students within the sample engaged with CAD at some point during the design process. With the majority (12 out of 16) of students engaging with CAD by month 4 (midway) in the 9-month design process.**
	Students who adopted CAD the earliest, did so to support their understanding stage of the design process
	Students who adopt CAD towards the end of the design process month 7+, did so largely for presentation, but in doing so, results indicate that to use CAD for presentation, there is a need for some initial CAD work (design stage) to take place
	The majority of students (13 out of 16) eventually used CAD for presentation.
	Students who adopted CAD later in the design process (4FB, 6KJ, 16JO and 7GP) were found to be the most reluctant to use CAD due to skill level, and a feeling that CAD would restrict their design. However, their adoption of CAD appears to stem from an acknowledgment that they couldn't resolve or refine some design issues using analogue methods.
	Beyond initial use, the majority of students (13 of the 16) in the study group all used CAD sequentially for synthesis, analysis & evaluation, and presentation stages of the design process
Part 2: 'why'	The primary reasons why students chose to use CAD was to produce visualisations (outputs) of their scheme (proposed building and the immediate context), and to gain benefits in the accuracy and coordination CAD offers over analogue methods.
	CAD was also used for conceptualisation and resolution of the students design throughout the design process.
	CAD for technical analysis was only undertaken by a limited number of students who had time to do so. However, there was a preference use digital methods over analogue when considering the constructional design and detailing of junctions between the building elements, as this was 'understood' to have the 'benefit' of aligning the technical aspects of design resolution more closely to that of form finding..
	CAD for site analysis may have ranked lower due to the dominance of this activity via analogue methods.

Table 1
Summary of findings of using BIM within specific stages of the design process

drawings and models to consider a design problem. In examining the design process stages when analogue was applied, it was established that the majority of the students undertook an analogue process of understanding, definition, synthesis, analysis and evaluation, and presentation, with analogue adopted in month 1 by the majority of students (all but one) to undertake the 'understanding' stage of the design process. Within the understanding stage students were focused on activities relating to site and brief analysis and the collation of existing material. In addition of this intense period of analysis activity in month 1 and 2 via analogue methods, throughout the majority of the design process students primarily used analogue methods to support scheme development via conceptualisation and resolution of their design ideas and testing of their design brief, by moving between and refining the problem and solution.

Within this period (typically months 3 – 5), it was noted while analogue activity was retained in some part, the intensity of its application would be replaced by BIM methods. However, in latter months of this 'production' phase (months 6 – 8), analogue methods were found to increase again as a way of problem-solving design ideas in parallel to BIM activities, with recognition that analogue methods were efficient in meeting this need, and also helping to compensate for lack of skill or efficiencies in BIM to conceptualise and resolve design ideas, and in doing so, to 're-cast' a design problem. However, these periods of analogue 'modes' were often very short or used as a method of quickly assessing an idea without formal 'commitment' to the BIM model. During the final stages of the design process dedicated towards the generation of visuals and final presentation material, analogue activity was minimal and dedicated towards final design ideas, changes and amendments, and less towards the presentation outputs. While the findings indicate a strong relationship between 'why' analogue methods were used within a particular design stage at a broader level, the exploration of individual analogue themes at a more focused level indicate a broader application. The findings relating to the use of analogue methods within this study have been compiled in Table 2.

The parallel use of BIM and analogue

In considering the use of BIM and analogue methods in parallel within the study, the findings indicated that all the students used both analogue and BIM activities at some point in their design process, with the majority of students undertaking a linear (on a month-by-month basis) BIM and analogue process in parallel for most of the design process. The findings also indicated that when BIM is adopted, the majority of the students adopted a similar BIM sequence of stages to their analogue sequence, indicating that as students' progress through their design stages, once BIM is adopted, they are applying both BIM and analogue methods in parallel to address the objectives of the design stage they are in. It was also established that within both analogue and BIM processes a common design process of Analysis > Scheme development through conceptualisation and resolution of design ideas > Final presentation, is evident. However, while BIM and analogue methods were often found to run in parallel, students would often give one more attention over the other, as they progressed through their project. In examining the design processes as a whole, it was common for the initial months 'the analysis' phase, or 'understanding' stage to be dominated by analogue approaches as students undertook site and brief analysis activities. During the 'scheme development' phase of the design process, during the definition, synthesis and analysis and evaluation stages, parallel BIM and analogue activities emerges to support the students design progression and scheme development through conceptualisation and resolution of design ideas (moving between site and proposal in increasing levels of detail).

However, within the initial stages of definition and synthesis (where they appear) students show

Part 1: 'when' and 'what'	**All students undertook analogue methods from month 1, with the majority (15 of the 16 students) using analogue for understanding.**
	With the majority of students (13 of the 16) undertaking a linear analogue process of understanding, definition, synthesis, analysis and evaluation, and presentation
Part 2: 'why'	The student's primary reasons for why analogue methods were applied within their design process was to support scheme development and analysis (site analysis and initial brief analysis).
Part 3: 'what' and 'why'	Analogue use was prevalent across all design stages, except for the presentation stage (typically the final stage of design process), with finding indicating a preference for using CAD within this stage.
	Grouped analogue themes, were often dominant within one design process stage indicating a strong relationship between 'why' analogue was used within a particular stage.
	Individual analogue often showed dominance across themes, indicating a broader use of analogue methods within the design process.
	Within the initial months findings indicate a preference to use analogue methods for brief and site analysis as part of the understanding stage.
Part 4: 'when', 'what' and 'why'	Analogue methods were retained when CAD was adopted. Increasing in later months as a way to conceptualise and resolve design ideas in parallel with CAD activities, with recognition that analogue methods were efficient in meeting this need.
Contextual observations	It was observed in the study that the retaining of analogue activities throughout the majority design process, once CAD was adopted, helped the students to retain an abstract understanding of their proposed scheme. This was most noticeable in students who retained the use of conceptual drawings and models to consider a design problem.

Table 2
Summary of findings of using BIM within specific stages of the design process

more of a utilisation of BIM processes, as students develop their digital models and gain benefits from an initial use of BIM. Following the creation of their BIM model, the finding indicated that in running BIM and analogue activities in parallel, this would help students to overcome any lack of intrinsic artistic ability, or BIM skills, thereby lessening the learning difficulties faced by students. It was also observed that the students would change activity type to remove their 'designers block'. This would establish a 'dialogue' for the student to test or amend design outcomes to problem solve. To re-cast a design problem allowed the student to visualise and explore the problem in a different way, allowing resolution of the problem visually. This movement between analogue and digital activities during the design process provided opportunities for the 'abstraction' of design decisions or iterations to occur, with students commenting that BIM methods allowed them to explore particularly difficult issues within their design that 'could not be explored by hand drawing' (analogue) methods. The use of BIM would also reveal unexpected consequences, concepts or features of a design problem that would otherwise may not have been achievable by analogue methods. In the later months of the design process, during the analysis and evaluation stage, parallel activity remains, but analogue methods increase to compensate for lack of skill or efficiencies in BIM to conceptualise and resolve design ideas, and in doing so, 're-cast' a design problem. However, these periods of analogue 'modes' were often very short or used as a method of quickly assessing an idea without formal 'commitment' to the BIM model. Similar 'short' periods of analogue use appear in the final months (during the presentation stage) for exploration of final design ideas, and adjustments to the BIM models, but this phase is dominated by BIM for generating final visualisations for schemes. Students within the study who were observed to efficiently use analogue and BIM activities once they had 'cast' their design, used increasing BIM activities to gain a more intricate understanding of their design proposal (Gentes, 2023). The findings relating to the use of BIM and analogue methods within this study have been compiled in Table 3.

Cross-analysis: design process timelines

We have independently examined 'when' BIM and analogue methods are used during 'what' stages of design process, from which subgroups indicating commonalities and outliers were identified and discussed. These findings are now brought together to examine any similarities between the analogue and BIM design processes and in doing so consider the design process as a whole. The outcome of this cross-analysis is shown in Figures 2 and 3. Figure 2 uses the previous analysis of 'what' stages of design

Table 3
Summary of the findings using BIM and analogue methods in parallel

Part 1: 'when' and 'what'	**All but one student progressed through monthly stages for both analogue and CAD in a linear fashion. With the majority of students (13 of the 16) undertaking a linear analogue process of understanding, definition, synthesis, analysis and evaluation, and presentation. Furthermore, 9 out of 16 of the sample were found to have a strong similarity to this common analogue process within their CAD design stages, with CAD stages either mirroring the analogue process or missing one stage.**
	When CAD is adopted, the majority of the students (12 out of 16) adopted a similar CAD sequence of stages, to their analogue sequence of stages, indicating that as students' progress through their design stages, once CAD is adopted, they are applying both CAD and analogue methods in parallel to address the objectives of the design stage they are in.
Part 3: 'what' and 'why'	Analogue use was prevalent across all design stages, except for the presentation stage (typically the final stage of design process), with finding indicating a preference for using CAD within this stage.
	A common process of Analysis > Scheme development through conceptualisation and resolution of design ideas > Final Presentation, is evident within both the CAD and analogue process.
	During the core months of the project, during the definition and synthesis stages, parallel CAD and analogue activities are undertaken for scheme development through conceptualisation and resolution of design ideas (moving between site and proposal in increasing levels of detail), with CAD taking initial dominance during the definition and synthesis stage while students gain benefits from an initial use of CAD,
	In the later months of the design process, during the analysis and evaluation stage, parallel activity remains, but analogue methods increase to compensate for lack of skill or efficiencies in CAD to conceptualise and resolve design ideas, and in doing so, 're-cast' a design problem. However, these periods of analogue 'modes' were often very short or used as a method of quickly assessing an idea without formal 'commitment' to the CAD model.

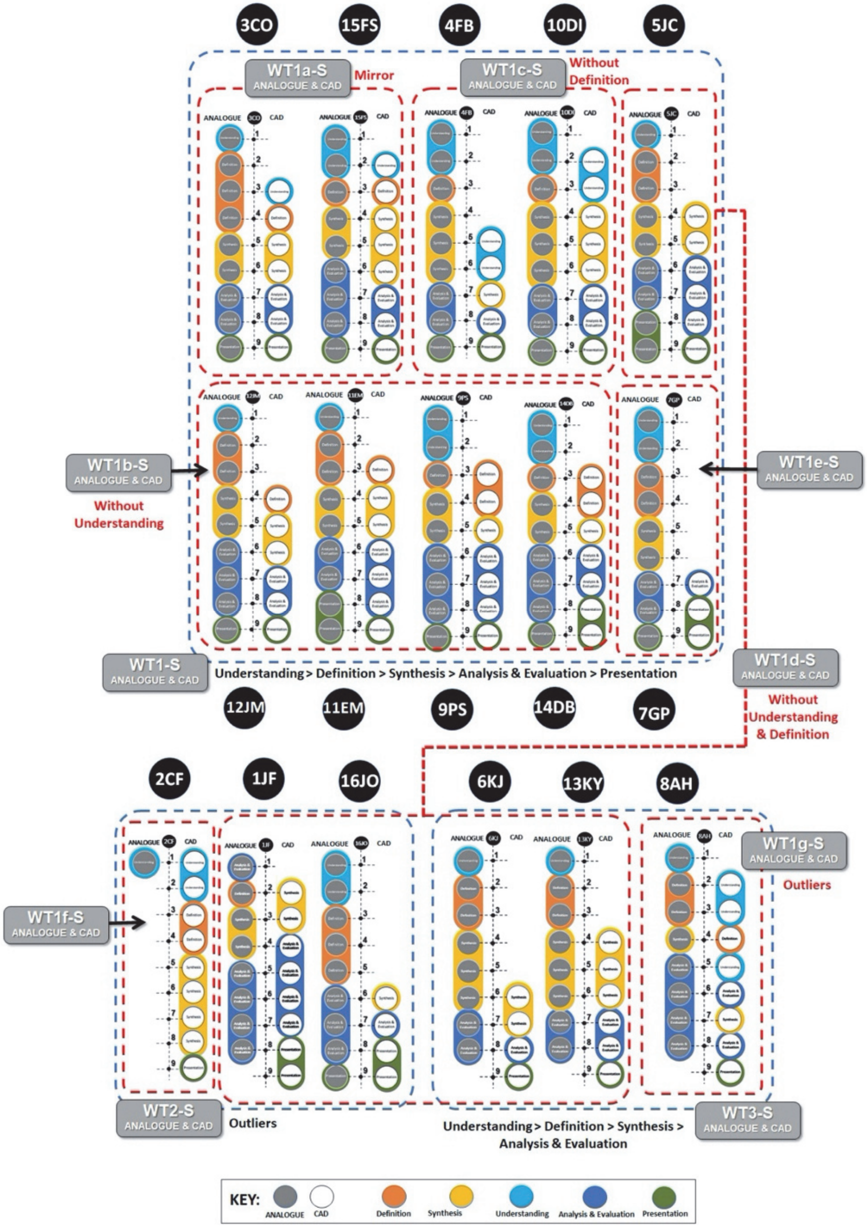
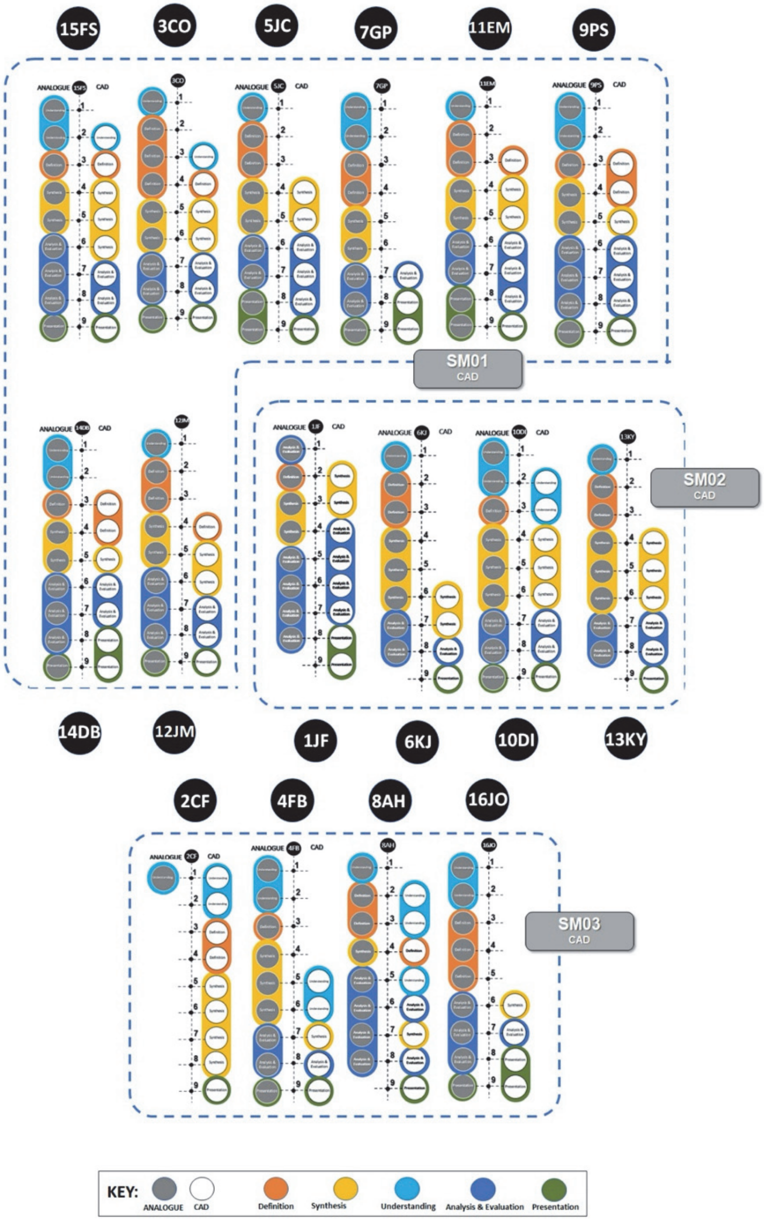


Figure 2
What analogue and BIM are used for

Figure 3
Similarities in the design process



process analogue methods are used as a base and identifies 7 subgroups (WT1a-S – WT1g-S) that indicate a range or similarities between the common analogue sequence of understanding, definition, synthesis and analysis and evaluation, and presentation, and the BIM design process stages. Figure 3, re-examines the timelines and identifies 2 subgroups (SM-1 and SM-2) that identify similarities between the sequence of BIM and analogue stages for each student, when BIM is initially adopted, with the remaining subgroup identifying outliers. These subgroups are now discussed collectively under the headings of 'what' Analogue and BIM is used for (Figure 2), and similarities in the design process when BIM is adopted (Figure 3).

'What' analogue and BIM are used for. In the analysis of the sequence of 'what' stages of the design process analogue methods were used for, it was established that the majority of students (10 of 16) undertook a linear process of understanding, definition, synthesis and analysis and evaluation, and presentation. When examining the BIM sequences of the 16 students it was established that 2 students (3CO and 15FS) mirrored this process (subgroup WT1a-S). Furthermore, it was established that an additional 7 students matched the common analogue sequence of stages, except for one stage. 2 students (subgroup WT1c-S) were without the definition stage, 4 students (subgroup WT1b-S) were without the understanding stage and 1 student (2CF) was without the analysis and evaluation stage within their BIM process. Of the remaining 7 students, 5 students were found to have BIM stages similar to the common analogue stages, but without understanding and definition (subgroup WT1d-S). Within this subgroup, 3 students (1JF, 6KJ and 13KY) choose not to use analogue methods for presentation. Instead focusing on solely BIM activities for presentation. Furthermore, 1JF first stage was analysis and evaluation, rather than understanding. The final groups contained 1 student each. Subgroup WT1e-S contained student 7GP who used BIM initially for analyse and evaluation before presentation. The final group, subgroup WT1g-S contains student 8AH, who was the only student in the sample to move back and forth between BIM stages as they progressed through the design process. The conclusion from this analysis is that when comparing the sequence of BIM design stages against the common analogue stages of understanding, definition, synthesis and analysis and evaluation, and presentation, 9 out of 16 of the sample were found to have a strong similarity to this approach within their BIM stages, either by mirroring the process or missing one stage. The remaining student either missing more than one stage or adopted a nonlinear process.

Similarities in the design process. In the final cross-analysis of 'when' BIM and analogue methods are used within 'what' stages of the design process, the timelines are re-examined to identify any similarities between the sequence of BIM and analogue stages for each student, when BIM is initially adopted. From this analysis 3 subgroups are established. Subgroup SM-1 identifies 8 students that share a similar approach to their sequence of BIM stages, as to their analogue process once BIM is adopted. It is noticeable that once BIM is adopted there is a "mirror" (+/- 1 month) between their BIM and analogue stages. A similar relationship is found in subgroup SM-2, where a "mirror" between the two sides of the design process is found, with the exception of one stage. Commonly, this subgroup contains students 1JF, 6KJ and 13KY, who choose not to use analogue methods for presentations, focusing solely on BIM. The remaining student in this subgroup, 10DI, undertook definition within their analogue process, but not their BIM process. The final, subgroup (SM-3), contains 4 students that were considered outliers in this analysis with little similarity between their BIM and analogue sequence of stages. For example, this group contains student 2CF who only used analogue methods in month 1, before focusing solely on BIM, and student 8AH, who didn't adopt a linear BIM approach. However, it can be surmised from this analysis that the majority of the students (12 out of 16) adopted a similar BIM sequence of stages, to their analogue sequence of stages. There is therefore an indication that generally as students within this sample progress through their design process and move through design stages, once BIM is adopted, they are applying both BIM and analogue methods in parallel.

CONCLUSIONS

In considering the application of analogue methods used across the design process, it was established that the majority of students progressed through these stages, from Understanding to Presentation. Findings also indicated that most students used both analogue and BIM activities in parallel for the majority of the design process, with findings further indicating that when BIM is adopted, students adopt a similar BIM sequence of stages to their analogue sequence, specifically the stages of Synthesis, Analysis & EvaluationPresentation.

During these stages, parallel BIM and analogue activities emerges to support the students design progression and scheme development through conceptualisation and resolution of design ideas (moving between site and proposal in increasing levels of detail). However, during this phase students would give more attention to one method over the other, as they progressed through the process to tackle specific problems or compensate for lack of skill or efficiencies in conceptualise and resolve design ideas, and in doing so, 're-cast' a design problem in an alternative method. It was established that only in the initial months during 'the analysis' phase, or 'understanding' stage, analogue approaches dominated, as students undertook site and brief analysis activities. Although existing literature doesn't provide the same detail between specific stage of design and the approach by students, research by Taraszkiewicz (2021) provides similar findings to those established, indicating architecture students typically start projects using freehand-drawing method due to its ability to quickly capture design ideas and its ease of communication with the tutor.

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INTERACTION, VIRTUAL REALITY, PHYSICAL-DIGITAL AND BIO-MATERIALS

Visualizing Dynamic and Highly Interactive Lighting

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As a defining factor in shaping people's experience in architectural spaces, lighting is realistically visualized via a plethora of rendering options in CAD and BIM solutions. However, their outputs are usually static or limited to basic changes. Thus, they may not satisfactorily visualize many dynamic and interactive lighting scenarios, such as energy-saving smart windows and lights, engaging street illumination, and entertainment setups. With the increasing automation of human-building interaction (HBI), visualizing such interactions empowers researchers and students who are interested in experimenting with customized lighting setups. Moving in this direction, this paper presents the lighting features of Tames, an open-source Unity toolkit developed by the author that visualizes dynamic and interactive elements in virtual environments without a need for programming. With Tames, the designers can navigate and interact with the design from the perspective of an occupant with the lighting and other elements in real-time manually or automatically. The workflow and capabilities of Tames are demonstrated by its application in the context of concert hall project designed by a student. This author argues that the availability and user-friendliness of this tool will contribute to architectural pedagogy and research. It allows students and researchers to visualize a wider variety of interactive designs and cases easier and, as an enabling tool, it may encourage them to explore and experiment with dynamic and interactive lighting.

Keywords: *Lighting, Interactive architecture, Unity, Human Building Interaction, 3D Visualization.*

INTRODUCTION

Many lights in the built environment are dynamic or interactive, sometimes with instantaneous changes. Historically, the visualization of such interactions was static, as 2D images or textual descriptions. More recently, with advancements in computer graphics, dynamic presentations of architecture have been possible by tools like Lumion and TwinMotion with realistic quality, but they may not capture a realistic interaction.

Despite differences between real and virtual experiences of lights in the environment, there has been considerable work in studying the latter (Bellazzi *et al.*, 2022; Gómez-Tone *et al.*, 2021). The research on the dynamism of lights in architectural visualization can be divided into two approaches: the dynamic or interactive visualization of architectural elements, in general, and the significance of differences in lighting. The former topic is occasionally encountered in literature with a focus on the research benefits of an interactive virtual environment (Heydarian *et al.*, 2015; Kumar *et al.*, 2011; Ugwitz *et al.*, 2021). The latter focus usually pertains to understanding the effects of different light settings on participants' virtual experience but with each scenario separately rendered (Ahmady and Kaluarachchi, 2021; Krupiński, 2020; Masullo *et al.*, 2023). Some studies feature a combination of the two approaches, with the light variation happening real-time. This variation might be external, triggered by the researcher or participant with controls not part of the design (e.g., an interface) (Gegana *et al.*, 2019; Natephra *et al.*, 2017) or internal with the triggering mechanism part of the design (e.g., a switch or virtual sensor). The findings of such studies are interesting, due to either their methodological or application merits. Cosma et al. (2016), for example, compared different lighting scenarios (static and dynamic) during an emergency and found that dynamic lighting and signs assisted evacuation better. Mahmoudzadeh et al. (2021) found that interactive lighting enhanced occupants' participation in environmentally conscious lighting. In both cases, the ability to visualize dynamism was crucial for conducting the studies.

In addition to its research usefulness, interactive visualization may also contribute to design pedagogy, although because of the general scarcity of research on interactive visualizations, this contribution is hypothetical. In general, immersive walkthroughs have learning potential for design students as they offer a relatively realistic experience of their design (Abu Alatta and Momani, 2021; Bashabsheh *et al.*, 2019; Valls *et al.*, 2017). As for lighting, Panyaa et al. (2019) argued that dynamic visualization can enhance students' experience and learning, as part of their study on interactive façades. At the minimum, an interactive visualization of lighting can let them experience the viewpoint of a hypothetical user, which is found useful for improving the design (Natephra *et al.*, 2017; Wong *et al.*, 2019).

However, in most mentioned studies, the visualization methods and tools were internal to their projects. Unless familiar with a project's specific programming environment, another researcher or student could not replicate it or conduct a similar study. This may hinder or discourage studying and experimenting with interactive visualization in general and of lighting, in particular.

In addition to academic approaches, there are multiple solutions in the industry, such as Enscape, Lumion and TwinMotion. These tools usually feature high-quality rendering; however, their dynamic and interactive capabilities may be limited. Lumion, for example, can add dynamic capabilities to lights or objects, but they are rarely interactive, and either are usable in a design-mode review or pre-recorded animations. Enscape allows a high degree of navigation but does not feature dynamism on its own. TwinMotion has the highest degree of interaction among the three, which may be due to its inherent connection with the video game's high interaction (i.e. developed by Epic Games). However, its customizability is somehow limited. For instance, it is not normally possible to create multicolour lighting changes (lights can only dim); triggers are usually binary (limited to distance-based presence) and non-associative (e.g., light does not change based on a door's position).

In reality, architectural elements may be connected and behave in coordination. They can also react to a wider range of people's behaviours. Higher customizability to address both change and its cause (interaction and association) for all assets (lights, materials and objects) was the main motivation behind the development of *Tames*, the toolkit reported in this paper.

Tames is an open-source experimental toolkit developed for Unity game engine to allow the mentioned dynamism and interaction without relying on scripting. The general features of this toolkit are introduced in the next section. The section after discusses some properties of light in the real world and how they are usually simulated in computer graphics (Unity, in particular). Then, the paper presents Tames' approach to creating dynamic lights. The final section discusses the implementation and future direction of this toolkit.

TAMES

Tames is a toolkit developed in Unity game engine that contains a wide range of code for automating interaction and dynamism of objects, materials, and lights in a project, without requiring programming skills. The latter feature makes it especially suitable for designers who usually do not possess the relevant scripting skills for graphical programming.

The idea of a visualization tool based on game engines has been approached before, but the earlier attempts were either not distributable (but only contextual to their developer's projects) (Kumar, 2013) or not extensive (Ugwitz *et al.*, 2021). Commercially, TwinMotion is a quality example of such a tool.

Tames is more extensive than its precedents but it has some downsides compared to the commercial solutions. It is only a library for dynamism and interactiveness and so, on its own, does not feature other desirable capabilities for an architectural workflow. The most important absent feature is seamless interoperability with BIM tools. Nevertheless, as a modular package, other tools or libraries (Huang *et al.*, 2017; May *et al.*, 2022) can be used with Tames for interoperability. Another shortcoming of Tames is that its rendering quality depends on the user's experience with realistic lighting in Unity, which would require significant practice.

Concept

The main concept and first principle of Tames is to abstract changes of architectural elements into 'linear' or 1D numerical progress values. Even if the change is a movement in a three-dimensional space (e.g., a door's rotation), it is usually constrained to a predefined curved or linear path. Thus, the change can still be represented the 1D progress on that path, with 0.0 marking its beginning and 1.0 (100%) its end. The main exceptions are people or other 3D entities whose activity or position matters for interaction. In such cases, their interaction is usually abstracted to a direction factor and applied to the linear progress. For example, for an automatic door, the position of a person only matters in the sense of its opening or closing (i.e., positive or negative progress).

Each progress has a few other properties that control its continuity, speed, and direction. For example, the progress value of a revolving door keeps changing in a cyclical mode. The speed or duration of progress tells Tames how fast the element can change from 0.0 to 1.0 in its progress. Finally, the direction is a ternary multiplicative factor (-1,0 or +1) on the speed.

The linearity of the progress facilitates the association of elements with each other. This associative linking is an essential concept in Tames that makes it different from many available tools. Although the association is not as flexible as a full parametric environment (e.g., Grasshopper) it still provides a relatively high degree of customizability for the timing and control of real-time changes. Furthermore, Tames features various progress triggers that allow full scheduling of changes in elements with multiple steps.

The second distinguishing concept of Tames is the diversity in modes of interaction. A person can interact with their surroundings by their presence (e.g., as distance in TwinMotion), manually (by grabbing a handle or pressing a switch), or remotely (e.g., remote controls). Tames provides different variants for each mode while being able to convert them to the aforementioned associative control. For example, regarding distance, a light can change colour proportional to it, only activate within certain distance ranges, or like in TwinMotion based on proximity to a point (though unlike the latter, the distance control is not local; i.e., one can walk into one room but a light turns off in another).

As for lighting, a third distinguishing feature of Tames is its multistep changing. It is possible with Tames to change a light colour or other properties between an unlimited number of custom steps and with different intervals. A combination of all features can provide a near complete customization of elements, including lights. For example, in figure 1, the colour of Light D is changed linearly as time passes and so each colour step takes the same duration. In contrast, Light C is updated by the progress of Object B, which in turn spatially tracks Object A on its irregular path. Because the juxtaposition of A on B's path depends on the path's angle, C's colours take a different time each.

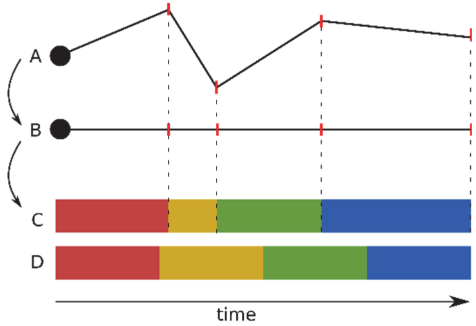

Figure 1. A linear (D) and non-linear (C) timing for changing light colours.

Tames' Initiation

To use Tames, it should be first downloaded from its GitHub page (https://github.com/Tames-temp/Tames-base). Once the project is opened, the user can import their models and other files in Unity Editor. Unity can work with several common 3D file formats (e.g., FBX, .blend, .max, .3dm, etc.) however, it cannot open native BIM files directly. Therefore, a BIM file should be exported to FBX first. This means Unity (and Tames) are not synchronized with the BIM model without using additional packages in Unity.

At this point, Tames is ready to work with (users can refer to a PDF manual in the Manual folder in the above link). Considering the associative and parametric nature of Tames, the user needs to plan the assignment and adjustment of the components in advance. They need also to pay attention to the loss of components after major changes to the models (Unity recognizes objects by name and hierarchy; once changed, it cannot reassign components to them).

LIGHTS IN REAL WORLD AND UNITY

Real-world lights have numerous properties that are simulated via different methods in computer graphics. In this section, first, some of the real-world properties of lights are discussed and then common ways of rendering them in Unity are highlighted which will be the basis for Tames' lighting dynamism in the section after.

Light in the real world

Discussing properties of light in real life requires an in-length explanation of the physical and optical characteristics of its emission, transmission, absorption, etc. which transcends this paper's scope and the author's expertise. Instead, a simplified introduction is provided here in a way more familiar to and applied by architects. Hence, the discussed properties are the light's *source*, *photometric* properties, *device*.

A light source is the electrical element (filament, LED, etc.) that emits the light. It has a specific geometry, profile and basic photometric properties. The first two are usually constant in the real world. However, its photometric properties are often changeable. They include its intensity and wavelength (or spectrum).

A light device encapsulates the light source. For example, while a torch's LED component is the light source, the torch's body, switch and front lens comprise the light device. In this sense, a light device is mostly made of solid mechanical objects, possibly with movable parts that control the light's direction or focus.

Light in Unity

Considering the discussed dynamic properties of lights in the real world, Unity has a variety of approaches to address them. For small light sources with a simple shape (e.g. circle), Unity uses *Light* components. However, for irregular shapes (e.g., a twisted neon tube) or mediated through objects (e.g. translucent objects), a combination of emissive materials and lights may be used and strategically placed to simulate the light effect. The photometric properties of light are directly set by the Light component's properties (colour, temperature, or intensity). The angle of a spotlight is also set here, all of which are easily changeable in real-time. The Light component is always attached to a 3D object whose movement will also move the light, accordingly, functioning as its device.

DYNAMIC LIGHTS IN TAMES

To demonstrate relevant features of Tames to lighting, they are applied in the context of a student design submitted for and awarded the Inspireli Archicad Prize in 2021. It was a floating Concert Hall (figure 2) on Vltava River (Prague, Czechia) designed by Alžběta Bílková, then a student at FSV ČVUT (the background in the subsequent figures is only for illustration and does not reflect the real context). Tames can create a variety of dynamic and interactive scenarios, but only examples are introduced here that used the three distinctive features of Tames (association, multi-step scheduling and interaction areas) to highlight its usefulness.

Figure 2. The Concert Hall on Vltava river ("Inspireli Award", n.d.)

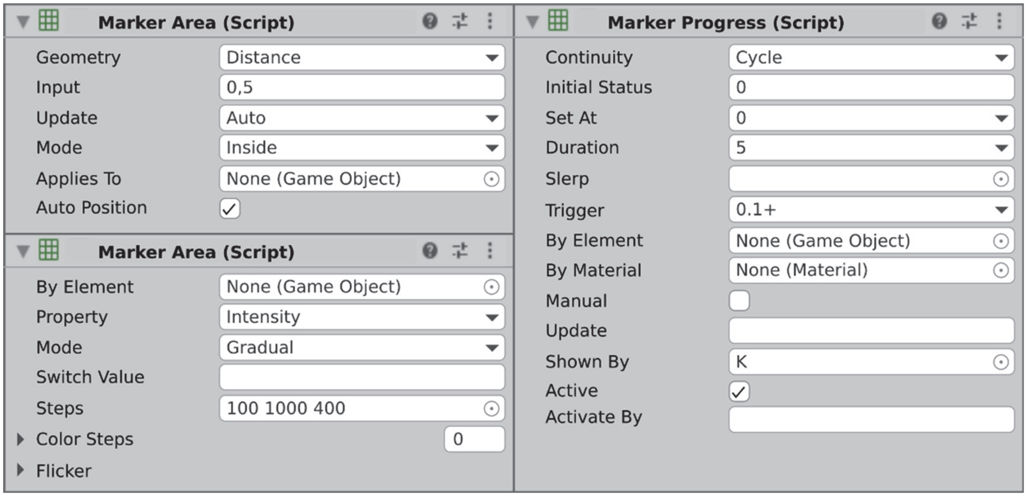

Figure 3. Three most useful components in the context of lighting.

Tames and lighting

As mentioned in the previous section, Unity imitates real lighting with properties of both emissive materials and lights. In addition, real-world lights as light components in Unity are attached to devices with possible mechanical movements. Therefore, when creating dynamic lights in Tames, all three types of visual elements (objects, materials and lights) may be used to address different features of lighting.

Features in Tames are defined by components. Components in Unity are C# classes that are attached to objects to provide additional control or properties for them. Tames uses 27 different components with names usually starting with *Marker*. Some are more relevant to lighting and materials (shown in figure 3).

For lights and materials, all changes in their properties are defined by *Changer* classes represented by *Marker Changer* components. A Changer has three basic fields *property*, *mode,* and *steps*. The property sets the light or material property which should change (e.g., intensity, colour, texture UV, etc.). The mode sets the way it would change (gradually or abruptly), and the steps include the changing steps.

The timing and most controlling logic for these changes are set in another component, *Marker Progress*. There, we define the duration, trigger scheduling, cycles, association with other elements, manual control and so on. Finally, the human factor is simulated by either certain tags in the 3D models or *Marker Area* components. These markers allow various forms of interactions as discussed in the Concept subsection.

Examples

As an entertainment facility, a concert hall may demand certain lighting scenarios that correspond with its hosted performance. This section demonstrates how Tames can be useful in creating interactive visualizations of lighting and related scenarios that make sense in the context of the selected design project.

A common lighting feature in an entertainment setting is the spotlights following actors on the stage, especially, focusing on them when necessary. This can be done by setting the light object to track a person on the stage while assigning the light's focus when this tracking is active (figure 4). The tracking is automatic but is activated remotely (represented by an input device shortcut) which also activates the light's focusing. Using the same control again will change the lighting back to the default (wide angle and fixed).

Playing with colours, especially by interacting with passers-by, is an interesting feature for an art-related facility. Here, a part of the circumferential ramp is covered by LED stripes between the floor tiles whose individual colour depends on the distance of the closest person to each (figure 5). This is made available by auto-positioning area markers that convert distance directly to a progress value for an automatically created custom parameter. This parameter in turn would affect the progress value of the material on each tile.

Lights and signs are frequently used in architecture to communicate changes or possibilities in design elements or behaviours. The most obvious example is the traffic lights. In a building, lights can guide people in potentially unsafe situations. This concert hall features a significant amount of glass, especially on all its doors and most walls, it makes sense to use lights to prevent bumping into them. An emissive texture for the doors is created whose U offset would change depending on the status of their opposite leg (using progress triggers which react when a door is more than 90% open). If one leg is open, a green arrow would appear on the other leg pointing to the opened space (figure 6).

Altering the light colour and intensity are common mechanisms to change the mood of a theatre or concert. In the real world, this can be automated by a program or done manually by a digital or mechanical control. Of course, this is possible in the design mode (using the BIM or CAD gizmos to change lights in a preview mode), but this doesn't have the same spatial experience of doing it while present in the space.

In this paper's case, a sliding handle is positioned behind the stage with which the scene manager can manually change the hue of the lights (figure 7). This is made possible by first assigning a grip area to the slider's handle, and then by associating its progress to the lights' colour property (via Changers). Alternatively, if we wanted to see the hue change from the perspective of a spectator, we could have associated the light colours with a shortcut button or have a multiuser session with one user assuming the role of the scene manager.

The provided four examples demonstrate how Tames can visualise a high level of customisation and

Figure 4.
Spotlights tracking the actor on the stage.

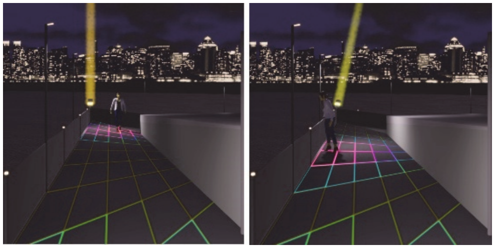

Figure 5.
Floor tiles change colour proportional to their distance to the closest person.

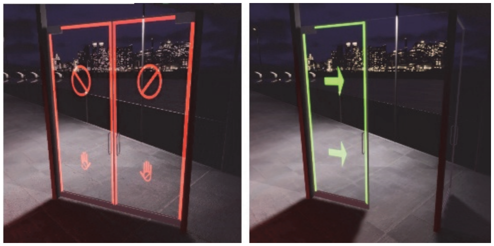

Figure 6.
The door's holographic signs changed depending on their state.

Figure 7. The user changes the light hue by moving the slider attached to the wall behind the stage (right).

interaction for different types of lighting scenarios. While some available tools can create a presentation that visualises such interactions by adjusting the timing of changes, they may not be able to create a real-time immersive interaction.

Comparison with TwinMotion

TwinMotion is a well-curated proprietary tool and excels in a wide range of important features where a comparison between it and an experimental toolkit like Tames does not make sense. In particular, the former's BIM interoperability, rendering and ease of use are phenomenal. However, Tames' *raison d'etre* is to provide a platform for interaction and dynamism, especially for research purposes. Hence, a comparison between the two can be made on this ground. Table 1 illustrates such a comparison and shows how Tames can extend the visualization of human-building interaction (HBI). In summary, Tames allows more control over the timing of changes and their trigger, as well as more ways of interaction with a virtual user (or object). While Tames falls short in creating a *realistic visual* of HBI, it has the potential in creating a visual of *realistic HBI*. In addition, an important feature of Tames is its recording of the behaviour and geographical information of the users (in a spreadsheet format) for analytical purposes.

DISCUSSION

This paper has presented Tames, a toolkit for facilitating the visualization of dynamic and interactive lights. The general aim of the toolkit was to enable students and researchers to create highly interactive and customizable visualization of their projects, comparable to video games. In this paper the lighting features of this toolkit were introduced.

Tames is not meant to replace common interactive visualization tools, especially commercial ones with exuberant visual realism, as they are proficient in addressing common needs of architectural visualizations. However, existing possibilities in HBI are already extensive and more will emerge. Less common, novel or context-specific interactive scenarios eventually evolve within design projects that cannot readily be modelled, experienced or studied with common tools. This is where Tames' relevance mostly lies. It provides a relatively easy setup for experimentation and visualization that does not require any expertise

Dynamic property	Features	Tames	TwinMotion
Timing	Passage	Linear, non-linear	Linear
	Speed	Variable (associative)	Fixed
	Scheduling	Immediate; Delayed; Fully scheduled; Random;	Immediate; Delayed
Trigger	Presence	Local or global point or area; Binary, multiple or proportional distance ranges	Local point; Binary distance
	Manual	Handle grip; Remote control; In-situ switch	Handle grip
	Position Following	Yes	No
	Associative	Multiple sequences	No

Table 1. Comparison between features of Tames and TwinMotion

outside what most architectural students or scholars already possess. This usefulness is not without caveat: lighting with Unity is more complex than in tools tailored for the architectural community. This shortcoming, however, is easier to overcome and less debilitating than the complexities of coding that would otherwise be inevitable.

Using Tames on the studied case revealed some inherent difficulty working with ArchiCAD files. When developing Tames, the author had only tested it with Blender and Revit exports, which featured readable naming of objects. In our case, ArchiCAD exported objects by coded names. This made it time-consuming to identify and work with objects and their properties.

The future of Tames toolkit will head in three directions, namely, improving its device compatibility, its usefulness and linking with common packages. Currently, Tames is tested with Windows PCs, Valve Index VR headsets, Xbox style game controller, and with no raytracing by GPU. To make it more usable, it will be tested on other devices (VR and MR headsets, different input devices, raytracing, etc.).

The usefulness and user-friendliness of this toolkit are only understood within the author's institution by people who already have an interest in the topic or some appreciation of Unity. Research is being conducted to understand the opinion of and usage by other students (which may also contribute to the first direction).

As a game engine, Unity is inherently friendly to modular programming. Considering there are dozens of Unity packages and projects that exist for architectural research and BIM operability (e.g., agent-based navigation, IoT connections, etc.), a seamless concurrent implementation with them will create new opportunities for research and experimentation on joint topics.

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Echoes of Union Depot

A virtual reality educational game for historic preservation and public awareness

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This paper presents the design, development, and potential impact of Echoes of Union Depot, a virtual reality (VR) game aimed at promoting historic preservation and raising public awareness about El Paso's Union Depot, a building listed on the National Register of Historic Places Inventory. The game leverages the immersive capabilities of VR technology and 360° images to engage players in exploring the site's rich history and architectural evolution. Players assume the role of a time-traveling detective, guiding lost spirits to resolve their past and move on. The paper outlines the development process, highlighting the use of 360° panoramic images and 3D Vista Virtual Tour Pro software to create an accessible and user-friendly experience that fosters historic preservation awareness and cultural appreciation. The study also discusses limitations and areas for future research, including expanding the scope to include other heritage sites, working with historians and cultural consultants for accurate representations, and evaluating the game's effectiveness in promoting awareness and fostering a sense of community pride.

Keywords: *Historic Preservation, Educational Games, Registered Historic Buildings, Virtual Reality (VR), Cultural Heritage, Public Awareness.*

INTRODUCTION

According to the National Park Service, historic preservation is how humans communicate with their past concerning their future. Historic preservation enables individuals to identify significant aspects of history and elements that can be conserved for future generations. This method effectively conveys the current generation's comprehension of the past to those who come afterward. Historic preservation can embrace various factors, such as individuals, events, concepts, locations, and moments (NPS, 2023a). Considering historic buildings, they hold various values for individuals, including existence, choice, altruism, community identity, and recreation (Counts, 2003). These values render such buildings essential for present and future generations, as they enhance the quality of life and lifestyle. As a finite resource, preserving and restoring historic buildings is crucial. One of the most notable preservation initiatives in the United States is the inclusion of properties in the National Register of Historic Places. Established under the 1966 National Historic Preservation Act, the National Park Service administers this national initiative, which aims to unite and bolster both public and private endeavors in recognizing, assessing, and safeguarding the United States' historical and archaeological treasures. It means the National Register of Historic Places serves as the authoritative catalog of the country's historically significant sites deserving of conservation (NPS, 2023b). Generally, any historic or prehistoric district, site, structure, building, or object and any related remaining recording, material, and artifact to these properties or resources which fits in the category of historic properties or historic resources are already included in or qualified for inclusion in the National Register list (ACHP, n.d.). The National Register of Historic Places also documents cultural heritage for interpretation and educational purposes (Risk, 1994). According to De Guichen and d'Ieteren (2009), preserving cultural heritage largely relies on public awareness and informed decision-making by governing bodies. Hence, even though these historic structures are registered for the sake of preservation, the general public may still lack awareness of their significance.

As an emerging media form, gaming can foster awareness and submerge participants in virtual worlds. The concept of gamification has gained traction in various domains, including education and practice, as gaming becomes more widespread in everyday life. Not only do games hold educational value, but they can also impart cultural heritage and deliver detailed information to players via in-game interactions (Huang and Soman, 2013). Mortara et al. (2014) maintain that games' virtual environments grant extensive access to cultural heritage for diverse audiences. Notably, games have a transient nature, enabling them to traverse different cultures, exemplify cultural globalization, and promote intercultural exchange (Šisler et al., 2017). Since 2002, educational games, also known as serious games, have risen in popularity for purposes beyond mere leisure (Alvarez and Djaouti, 2011; Anderson et al., 2009; Becker, 2007; De Freitas and Liarokapis, 2011). Educational games have the potential to instruct players about a specific subject matter or improve a particular ability by providing practice in different fields, including cultural heritage (Örnek and Seçkin, 2016; Sharafi Rohani and Kim, 2022). De Freitas and Liarokapis (2011) assert that the educational success of games can be ascribed to their audiovisual components, which facilitate memory retention.

The main objective of this paper is to increase public awareness about the significance of preserving Union Depot, a nationally registered historical building located in El Paso. The study has developed a virtual reality (VR) game using 360° panoramic images of the building to educate users about the structure's importance and history. The game is created using 3DVista Virtual TourPRO software and aims to encourage users to visit the building and engage with the relevant content, both virtually and in situ. Hence, the study eventually aims to answer how a virtual reality game can effectively raise public awareness about the importance of preserving historic buildings, particularly those listed on the National Register of Historic Places. What critical design elements and features should be incorporated into the game to ensure a successful and engaging educational experience for players?

LITERATURE REVIEW

Educational games have become a popular tool for engaging the public in historic preservation and fostering an appreciation for cultural heritage. In recent years, numerous studies have explored the development and assessment of games specifically designed for this purpose. For instance, Mortara et al. (2014) presented a comprehensive review of serious games aimed at enhancing the understanding and experience of cultural heritage, highlighting their potential for engaging users in innovative ways. Also, the authors investigated the evolution of virtual landscapes in educational games and their impact on the educational content conveyed previously, addressing a gap in the literature (Afshar et al., 2022). In addition, the study aimed to understand the relationship between virtual landscape transformation, VR technology, and game content delivery.

Several recent examples of games for historic preservation include the *Cultural Memory Game* (Chatzopoulos et al., 2020), which uses augmented reality to engage players with historical content and foster collaboration; *TimeMesh* (Di Tore et al., 2018), a location-based mobile game designed to enhance the learning experience of visitors to historical sites; and *EcoCity: The Lost World* (Ozcinar et al., 2021), a serious game that aims to raise awareness about the preservation of ancient cities by immersing players in a realistic 3D environment. Another example is *The Time Traveler* (Schrier, 2020), an alternate reality game that teaches players about the history of a specific location through interactive storytelling and challenges. In *Heritage Quest* (Karaman et al., 2020), a virtual reality game, players explore cultural heritage sites and solve puzzles, promoting engagement with historical content. *Ghosts of a Chance* (Klopfer et al., 2018) is an educational game that utilizes a museum's collection to create a narrative-driven, interactive experience, engaging players in the process of historic preservation. Lastly, as a series of continuous research endeavors focused on the preservation of both tangible and intangible heritage, specifically concerning the Silk Roads and their associated caravanserais, the authors developed three educational games named the *Sericum Via* (Eshaghi et al., 2021), the *Anatolian Journey* (Vaez Afshar et al., 2021), and the *Khan Game* (Varinlioğlu et al., 2022). Throughout this series, the researchers have tried to develop serious games that leverage GIS data. With each successive study, the series demonstrates an evolution in game development and the incorporation of game elements, reflecting an ongoing commitment to refining these educational tools for historic preservation.

METHODOLOGY

Setting

As discussed, the primary purpose of this research is to raise public awareness for the sake of historic preservation. Therefore, as the game's development setting, the study selected the Union Depot, a registered historic building in El Paso. This historical building was registered nationally in 1975 as El Paso Union Passenger Station (NRHP, n.d.). According to the National Register of Historic Places Inventory - Nomination Form (1975), the Union Passenger Station was constructed in 1905, showcasing a Neo-Classical design on the intersection of Coldwell and San Francisco Streets at the western boundary of downtown El Paso. As the first union station created explicitly for managing international traffic in the United States, it holds a prominent place in the country's railroad history, highlighting the city's significance as a transportation center. Designed by the Chicago-based architecture firm Daniel H. Burnham & Company, the station boasts a six-story bell tower at its northeast corner.

Game Design and Story

This paper presents *Echoes of Union Depot*, a virtual reality (VR) game aimed at promoting historic preservation and raising public awareness about El Paso's Union Depot, a building listed on the National Register of Historic Places Inventory. Since it is suggested that innovative media formats like 360° videos be utilized for digital storytelling in order to create immersive experiences through the use of VR technology (Sylaiou et al., 2018), hence, by leveraging the immersive capabilities of VR technology and 360-degree images of the Neo-Classical architecture, players assume the role of a time-traveling detective, guiding lost spirits to resolve their past and move on. The game fosters a deeper appreciation for the significance of preserving heritage sites through engaging explorations of the Union Depot's history, architectural evolution, and cultural impact. The VR experience showcases the station's significance as the first union station built explicitly for handling international traffic in the United States and its role in connecting people and cultures. Additionally, A scoring system is incorporated to enhance player engagement and foster a sense of accomplishment.

Echoes of Union Depot is set in contemporary times and weaves urban legends surrounding Union Depot into its narrative. Players are assigned by a mysterious figure, The Stationmaster, to travel through time and assist trapped spirits in finding closure by uncovering their stories and the history of the station. As players progress through the game, they earn points for solving puzzles and making key decisions, enhancing engagement and fostering a sense of accomplishment. The immersive VR experience of the game allows players to explore the

Union Depot across different eras and witness key moments in American railroad history. The narrative unfolds through interactions with diverse characters, puzzle-solving, and decision-making, culminating in restoring the Union Depot and liberating the trapped spirits.

The following diagram (Figure 1) visually represents the game flow and method for *Echoes of Union Depot*. This flowchart illustrates the key steps and interactions that players will experience throughout the game. The diagram serves as an overview of the game's structure, providing a comprehensive understanding of the narrative progression, exploration, and decision-making elements that contribute to the immersive VR experience and the promotion of historic preservation awareness. The scoring system adds an extra layer of engagement to the game, motivating players to interact with the game's various elements and compete with others for high scores. The scoring logic can also be used to gather insights into players' interaction with the game, enabling developers to identify areas for optimization and improvement.

The target group for *Echoes of Union Depot* consists of history enthusiasts, students, educators, local community members, and casual gamers interested in immersive storytelling and puzzle-solving experiences. The game is designed to engage this diverse audience through a captivating narrative, historical exploration, and interactive gameplay elements.

Therefore, the recommended age range for *Echoes of Union Depot* would be 12 years and older. This age range is appropriate as the game focuses on historical exploration, immersive storytelling, and puzzle-solving, which requires a certain level of cognitive ability and comprehension skills. While *Echoes of Union Depot* offers an engaging and educational experience, it faces certain limitations when competing with commercially successful games. These limitations, however, do not detract from the game's primary focus on promoting historic preservation and education.

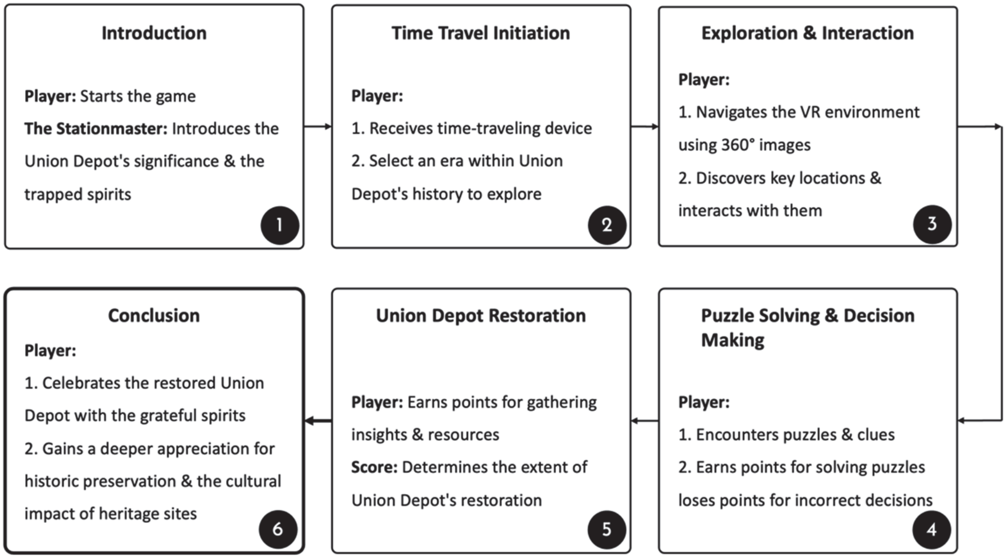


Figure 1
Game's key steps and interaction flowchart

Visual Material and Game Development

Based on the conversations thus far, the research chose to employ 360° panoramic images as the visual content for the game creation process. As a result, 360° panoramic field photography was used in the investigation. In this regard, due to the literature, a 360° camera and an action camera can function as affordable, rapid, effective, lightweight, and high-resolution instruments (Prittinen, 2021). The GoPro Max camera is one of the top 360° action cameras on the market. However, a more cost-effective option is desirable due to budget limitations and the goal of utilizing existing devices inventively. Consequently, the research emphasized enabling 360° photography using smartphones.

Among available applications, the Panorama 360 & Virtual Tours (2023) application, which is compatible with iOS devices, appears to be the most efficient and appropriate choice (Figure 2). Utilizing the app's free trial, 360° perspectives of the target building were obtained. While this approach offers several benefits, the resulting images do not include sky and ground views, which can be captured using a GoPro Max for a comprehensive 360° experience. Nevertheless, as smartphone photography does not necessitate a tripod stand like the GoPro, the produced images can be used directly without the need for post-production editing to remove the tripod's presence in the final image.

The development process of *Echoes of Union Depot* is facilitated by the 3D Vista Virtual Tour Pro software, capitalizing on its e-learning and gamification features to create engaging virtual tours with 360° panoramic images and interactive multimedia elements, enabling developers to construct detailed and engaging spaces for players to explore efficiently. Moreover, the software's user-friendly interface and various pre-built features, such as hotspots, navigation tools, and multimedia support, significantly reduce the learning curve and development time. This allows creators to focus on crafting compelling narratives, designing intriguing puzzles, and enhancing the overall player experience (Figure 3).

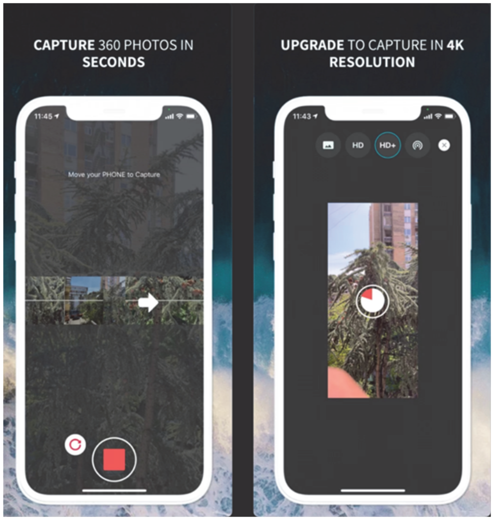


Figure 2
Panorama 360 & Virtual Tours application

Vishwanath et al. (2017) state that, at present, users can opt for affordable smartphones, cost-effective VR headsets, and VR applications, which enable them to access VR-compatible games, 360° videos, and panoramas more efficiently than ever before, in addition to using Head-Mounted Displays for immersive experiences with 360° media (Argyriou et al., 2020). Therefore, the software's user-friendly interface, compatibility with various platforms and devices, and its support for both VR and web-based experiences further contribute to the game's ease of development. Furthermore, this adaptability ensures that the game remains accessible to a wide range of players, regardless of their device or system capabilities.

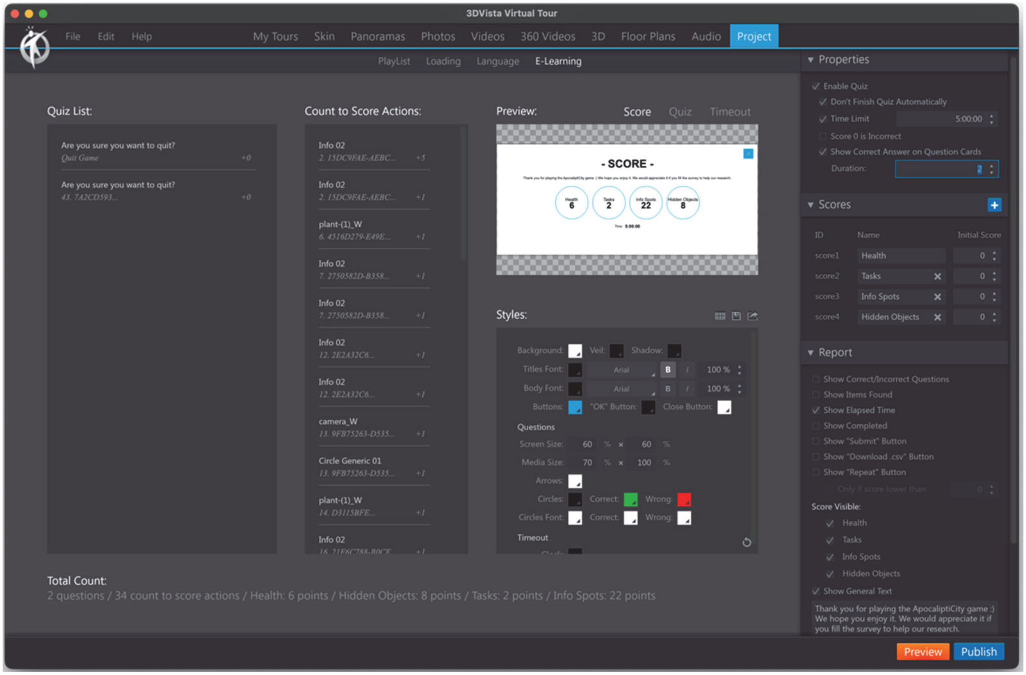


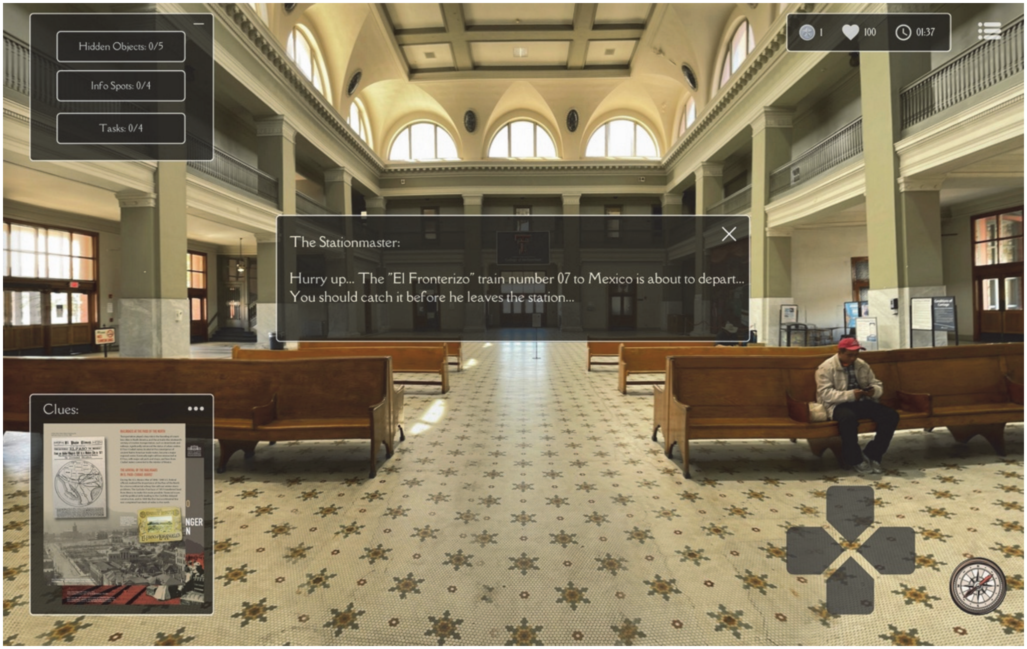
Figure 3
Game Development Process

The 3D Vista Virtual Tour Pro software offers the possibility to integrate scoring systems within the game, enabling players to earn points as they progress through *Echoes of Union Depot*. This feature can be woven into the narrative, as players are encouraged to help the trapped spirits by solving puzzles, uncovering historical information, and making key decisions. As players accumulate points, they not only contribute to the resolution of each spirit's story but also gain a tangible sense of accomplishment and engagement in the game. Hence, by integrating quizzes, challenges, and interactive components, the study developed an interactive game experience that fosters historic preservation awareness, engages players in exploring heritage sites, and provides an enjoyable learning experience (Figure 4).

Overall, the *Echoes of Union Depot* game benefits from a streamlined development process, enabled by the 3D Vista Virtual Tour Pro software, which simplifies the creation of rich, immersive environments and interactive elements, resulting in an engaging experience that promotes historic preservation awareness and cultural appreciation.

Finally, integrating Google Analytics and a custom script in the game can enable recording player interactions, such as clicks, location, and browser information, while the script captures individual scores from various in-game challenges. This valuable data allows developers to identify less-visited areas of the virtual environment and pinpoint more challenging puzzles, providing insights for further optimization and enhancing user engagement in the game.

Figure 4
Echoes of Union Depot Game Screen



CONCLUSION AND DISCUSSION

Echoes of Union Depot emphasizes the importance of preserving sites and buildings listed on the National Register of Historic Places Inventory by engaging players in the rich history and cultural impact of the Union Depot. By harnessing the power of VR technology and 3D Vista Virtual Tour Pro, the game encourages a deeper understanding of the significance of historic preservation and fosters community pride and involvement in protecting local heritage. This innovative approach serves as a model for future efforts to raise awareness and promote the preservation of other historically significant sites.

In conclusion, the *Echoes of Union Depot* game offers an accessible and user-friendly experience due to its web-based nature, incorporating the possibility of VR mode using a headset, eliminating the need for high-configuration systems, and its streamlined development process, making it a valuable tool for promoting historic preservation awareness and engaging diverse audiences in the appreciation of cultural heritage.

While *Echoes of Union Depot* has demonstrated the potential of utilizing virtual reality and interactive storytelling to promote historic preservation and public awareness, the study has limitations and areas for future research to address. Considering the scope, this game focuses primarily on Union Depot and its history. Expanding the scope to include other heritage sites listed on the National Register of Historic Places Inventory could increase the game's educational and preservation impact. Additionally, regarding cultural sensitivity, the developed game incorporates historical events and characters but may only partially capture the complexity and nuance of some cultural contexts. Future iterations could consider working closely with historians and cultural consultants to ensure accurate and respectful representations. As for future work, the study needs to focus on the evaluation of impact. Assessing the game's effectiveness in promoting historic preservation awareness and fostering a sense of community pride requires systematic evaluation. Future studies could involve pre- and post-game surveys, interviews, or focus groups to gauge players' attitudes and knowledge changes. In this regard, comparing VR and web-based experiences via analyzing the differences in player engagement and learning outcomes between the VR mode using a headset and the web-based game accessible on any device or browser could provide valuable insights into optimizing the game design for various platforms. As mentioned, incorporating Google Analytics in the game link, which tracks the players' interactions and performance, can provide valuable insights for optimizing the game experience and enhancing user engagement. Finally, with the new update of the 3D Vista Virtual Tour Pro software, which allows the use of 3D models in addition to 360° photos, future research could explore how the integration of 3D models can enhance the overall immersion and interactivity within the game. This could lead to more engaging and realistic virtual environments, improving the player experience and educational outcomes.

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Treading Lightly on Architectural Heritage

An experiment on wheel designs of mobile robots

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Mobile robots have become increasingly popular in recent years, with a wide range of applications in engineering and architecture. They are used for many purposes, for example, material supply in remote construction sites. Existing studies primarily focus on the development of the robot itself and its ability to adapt to different functions. Its movement and control are especially challenging on sensitive surfaces such as historical buildings' floors. Robots navigating a surface can damage it due to the pressure from the carried load or the shape characteristics of the wheel. How robots interact with the environment should be revisited to cope with this problem. This paper examines wheel designs for mobile robots against the surface slope and the stability of movement during load bearing. The aim is to minimize damage to the surface while ensuring a stable and smooth motion. A set of experiments are conducted with an Arduino-based mobile robot to perform environmental monitoring and inspection tasks. The robot consists of a main body and four motors turning the wheels. Each experiment uses the same main body and actuating mechanisms to test the effect of different wheels on the surface. The robot's performance is evaluated based on observations in terms of its load-carrying capacity, any resulting damage on the surface, and the sustained stability in movement. The results show that small wheels with a low profile and soft materials provide a better balance ensure stability, smooth motion, and minimal damage. A weight distribution and control strategy are proposed to minimize the impact on sensitive surfaces. The findings contribute to the design of mobile robots operating in historical buildings, delicate or damaged surfaces, and remote construction sites.

Keywords: *Mobile Robots, Wheel Design, Environmental Monitoring, Inspection, Robotics and Automation in Architecture.*

INTRODUCTION

Today, mobile robots have many significant applications in architecture, especially in construction. For example, they can move materials and tools around the construction site, excavate, and level the ground, and assemble prefabricated components. Also, they can be used to inspect and monitor buildings and other structures for maintenance purposes. They can inspect roofs, facades, and other hard-to-reach areas to detect damage or defects in the building. Mobile robots can also be used for maintenance tasks such as cleaning, painting, and repairing. They can clean windows, paint walls, and repair or replace damaged components. In addition, these robots can be used for security purposes, such as patrolling the perimeter of a building or monitoring the interior for suspicious activity. They can improve accessibility in buildings for people with disabilities. For example, they can transport people in wheelchairs or assist people with mobility impairments. Using mobile robots in architecture can improve efficiency, safety, and accessibility while reducing costs and increasing sustainability. As technology evolves, we can expect to see even more innovative applications of mobile robots in architecture.

According to DeSouza & Kak (2002), we can expect advancements in mobile robots that are tailored to specific tasks and environments, and robots that have already been tested in patient care, building security, and hazardous-site inspection will likely be equipped with vision capabilities, allowing for smarter navigation and interaction with objects and people in the environment. The usage of mobile robots in cultural heritage is open to discussions and research because these robots may have important impacts on preserving and promoting cultural heritage, as exemplified below.

- Documentation: Mobile robots can document cultural heritage sites, artifacts, and collections. They can take high-resolution images, create 3D models, and collect other data that can be used for research, conservation, and education purposes (Cigola, 2012, Krátký et al, 2021).
- Preservation: Mobile robots can also preserve cultural heritage sites and artifacts by monitoring the condition of objects, controlling temperature and humidity levels, and detecting and preventing damage from pests or other threats (Montalvo et al, 2017).
- Restoration: Mobile robots can assist with restoration and conservation efforts. They can be used to clean and repair objects, apply protective coatings, and perform other tasks that require precision and delicacy (Ceccarelli et al, 2017).
- Education and outreach: Mobile robots can promote cultural heritage by providing immersive and interactive experiences for visitors. For example, they can create virtual tours of cultural heritage sites, offer augmented reality experiences, and provide educational content in museums and other cultural institutions (Germak et al, 2015).

The scenarios above present the significance of using mobile robots in cultural heritage. The success of applications is only possible if the movements of these robots are provided properly. However, the movement of mobile robots becomes crucial on sensitive surfaces like historical buildings' floors. Robots can damage the surface while navigating due to the pressure from the carried load and the wheel design.

In damaged buildings, the structures may be unstable and fragile, and the artifacts within may be delicate and easily damaged (Halder & Afsari, 2023). Mobile robots with appropriate wheel design can move through the environment smoothly and safely, avoiding collisions and impacts that could cause further damage to the building or its contents. It is necessary to revisit how robots interact with their environment to achieve smooth navigation and prevent any damage that may occur while they are in use. There is a need for caution and proper planning when using mobile robots in sensitive environments. Therefore, this paper questions the wheel design principles for mobile robots regarding the wheel's type, material, form, load-carrying ability, and surface (ground) slope. It aims to minimize damage to the surface while ensuring a stable and smooth motion.

BACKGROUND

Mobile robots can move in different ways:

- Main bodies attached to each other like modular roombots (Hauser et al, 2020)
- Leg-like structures, such as robot Bill-e (Jenett & Cheung, 2017)
- Wheels, as in the Swarmanoid project (Dorigo et al, 2013)

The wheel is the most important locomotion system for traversing even terrain, and wheeled mobile robots are commonly used due to their simplicity, relatively low design cost, and lower energy consumption than other locomotion systems (Siciliano et al, 2008). Taheri & Zhao (2020) review different wheel mechanisms and navigation approaches in terms of speed, payload capacity, motion stabilization, uncertainty, vibration, and slippage. They guide designers and researchers in selecting appropriate mechanisms and control approaches to meet their requirements but for only omnidirectional wheels.

The omnidirectional wheel is a wheel that can freely roll in more than one direction and can turn and move in 360 degrees. They do not swivel, nor do they turn. Among the omnidirectional wheeled robots, robots with mecanum wheels are significant in gaining maneuverability (Adăscăliței et al, 2011) and, therefore, speed because these wheels change robots' direction without changing the body orientation.

In maintaining maneuverability, tracked tank robots can also be useful in addition to omnidirectional wheels. Tracked tank robots are highly mobile and can move over rough and uneven terrain, climb inclines and stairs, and navigate obstacles with which other robots might struggle (Budiharto et al, 2022). The tracks on tank robots provide stability and balance, making them ideal for working in harsh environments, such as construction sites, mines, and disaster zones.

Load-bearing capacity is another important consideration in wheel selection and design. For instance, the Termes project (Werfel et al, 2011), the wheeled mobile robots inspired by ants' ability to carry loads, allows robot agents to climb without falling or sweeping due to wheel design. However, this kind of wheel can harm sensitive surfaces because the area of the wheel in contact with the ground surface is narrowed. Still, the wheel design is promising for staying upright while carrying loads.

Existing studies cited above primarily focus on the development of the robot itself and its ability to adapt to different functions because robots' movement and control scenarios are challenging. This study has a unique aspect in the application field and the experiment setup compared to the relevant studies. It uses the standard wheels in the experiments yet within the scope of architectural heritage.

METHODOLOGY

Experiments are created based on case studies with Arduino-based mobile robots to perform environmental monitoring tasks. The robot used in the experiments consists of a main body and four motors turning the wheels. Each experiment uses the same main body and actuating mechanisms, as indicated in Figure 1. Accordingly, robots are equipped with ESP32 powered by two batteries because ESP32 is a low-cost and low-power microcontroller system with Bluetooth and Wi-Fi capability. This way, the main server can communicate with the robot even in remote areas. In the experiment, ESP32 is powered by a power bank.

The body that suits the wheels is shown in Figure 1. Four motors power the robot, whose layout is illustrated in Figure 1, and the same robot is used in each experiment set by changing its wheels. The hardware equipment in the experiment is listed below.

- Two Vtc6 18650 3.7v 3000Mah Li-ion rechargeable batteries
- Four 5V geared DC motor
- L298N motor driver
- ESP32-WROOM-32U Wi-Fi Bluetooth Development Module
- Prototyping plate
- Power bank 10000 mAh, input: DC5V/2.0A, output: DC5V/1A/2.1A

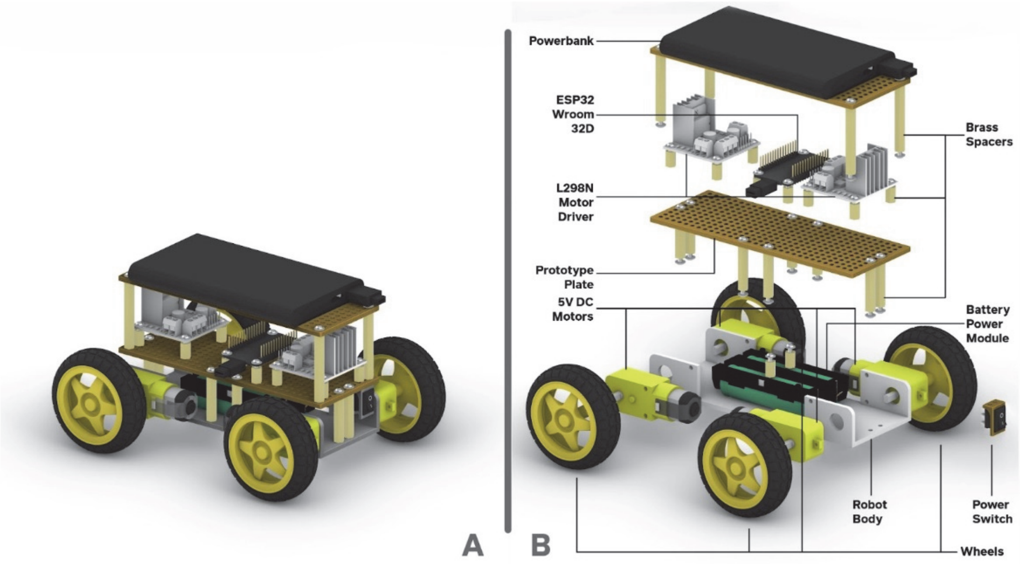


Figure 1
A: The robot used in the experiment sets, B: The robot’s components

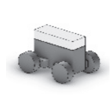
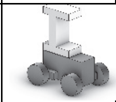
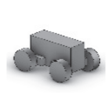
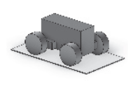
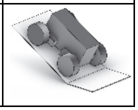
Wheel					Load			Terrain	
ready-made				developed	with load		without load	flat	inclined
standard	tracked	mecanum	Termes	flexible	uniform	uneven			
									

Table 1
Variables in the experiment set related to wheel, load, and terrain

Each experiment tests distinct wheel types to understand their effect on soft wooden surfaces. These sets test three factors, namely 1) the tracked tank, 2) the direction of motion - mecanum wheels, and 3) the sharpness of the wheel's claws. Therefore, the wheel types used in the experiment are standard, tracked tank, mecanum, and TERMES-like. In addition to these ready-made wheels in the existing literature and physical applications, the wheel named flexible, shown in Table 1, is developed by the authors based on the observations from the experiment. It depends on the TERMES-like wheels but contains more branches. Note that TERMES-like and flexible wheel types are printed in Ender3 with 1.75 mm PLA.

In the experiment, cardboard and foam are used as ground materials to provide a reasonable approximation for experimental purposes because they are inexpensive and accessible. The robot's carried load and the terrain's slope also affect the damage on the surface due to the robot's navigation, so these factors are also considered. Table 1 briefly illustrates the variables in the experiments and their sub-categories. Uniform refers to the carried load with a symmetrical geometry whose center of gravity is in the exact center of the shape. On the other hand, uneven load indicates a geometry whose center of gravity is in the upper or below part of the shape.

The used robots are manually controlled via a mobile app called Dabble (STEMpedia, n.d.) to turn right and left and move forward. The robot's performance is evaluated based on observations over case studies in terms of obstacle climbing ability, load-carrying capacity, resulting damage on the surface, and sustaining stability in movement. Also, the challenges that occurred in the experiment, the reason for the cause, and its effect are discussed together with the wheels' advantages.

FINDINGS FROM THE EXPERIMENT

The observations from the experiments are discussed under two titles: advantages and disadvantages of the wheels in terms of surface damage risks for architectural heritage. Figure 2 shows the experiment setup.

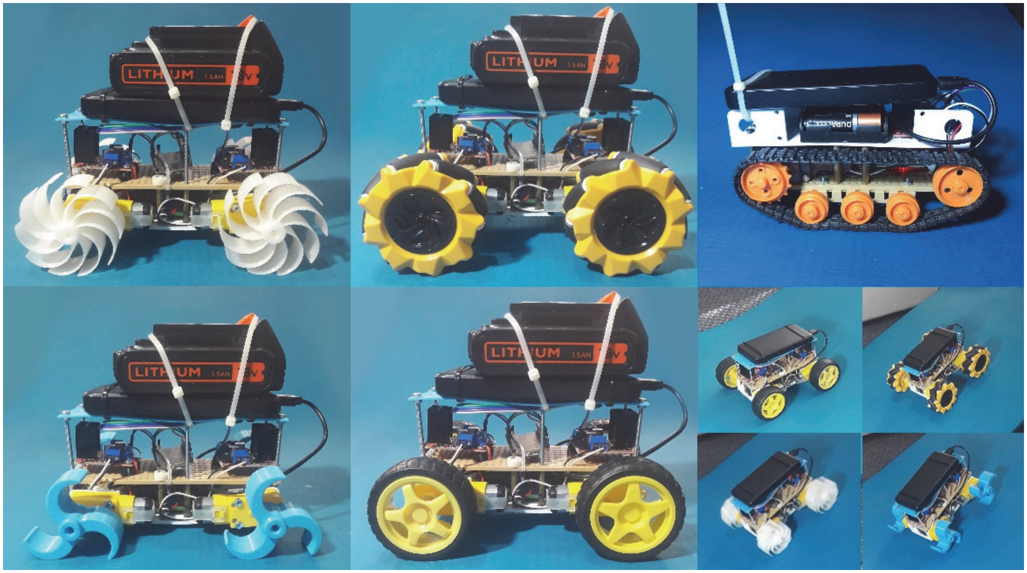
Advantages of the wheels

The three factors tested in the experiments are 1) the tracked tank, 2) the direction of motion - mecanum wheels, and 3) the sharpness of the wheel's claws, have advantages regarding mobility, movements, and operation.

Tracked tank robots have been used in the field of cultural heritage preservation for their ability to move on various types of terrain and their non-invasive design. The advantages of using tracked tank robots for architectural heritage are listed below.

- High mobility: They can move on various types of terrain, including uneven and rough surfaces, making them useful for inspections and maintenance work on historical buildings with complex architectural features.
- Non-invasive: They have a low profile and can move without causing damage to the building or surrounding environment, making them ideal for conducting inspections without causing damage.
- Precise movements: They have a high degree of precision in their movements, which can be useful for delicate operations, such as cleaning or restoration work.

Figure 2
The experiment



- Remote operation: They can be operated remotely, allowing inspectors and maintenance personnel to access difficult-to-reach areas without endangering themselves or the building.

In terms of the direction of movement, mecanum wheels are typically constructed of high-quality polymers that are completely resistant to rust and corrosion, unlike metals. At the same time, polymers can withstand extreme force without sustaining physical damage. Mecanum wheels offer load stability and are designed to provide a static load center relative to their base. Other types of wheels may or may not provide this level of load stability. Swivel-mount wheels, for instance, typically do not provide stability for a stabilized load in which the weight is evenly distributed.

In architectural heritage, the robots with sharp wheel claws, like in the TERMES project, could present advantages that need to be considered for their use in this field of operation. These advantages include the following points.

- Improved mobility: The wheel design allows for moving over uneven and rough terrain, which could be particularly useful for working on historical buildings with complex architectural features and uneven surfaces.
- Non-invasive: The wheel design is less invasive than other types of locomotion systems, such as tracks or legs. This feature means they may be used for inspection and maintenance work without causing damage to the building or its surroundings.
- Autonomous operation: Robots can operate autonomously, which could be particularly useful for architectural heritage in remote or hard-to-reach areas. The robots could be programmed to perform inspection and maintenance tasks without human intervention, reducing the need for humans to climb on the building and potentially cause damage.

The robots with sharp wheels could be advantageous for working on architectural heritage, particularly for inspection and maintenance work in remote or hard-to-reach areas. However, their limitations should also be considered, and a careful assessment should be made to determine if they are the most suitable option for a particular project.

In the experiment, the abilities sought in the wheels are 1) obstacle climbing, 2) load carrying, and 3) stability in the movement are evaluated, as stated in Table 2. The first ability concerns two types of obstacles regarding the position of the top level of obstacles relative to the bottom level of the robot body. The second ability encapsulates the carried objects' geometries' center of gravity. The third ability is the robot's stability during navigation in inclined and flat terrains with and without loads.

Table 2 labels these three abilities of the wheel types as limited, low, or high levels. Limited indicates situations where the wheel abilities are limited and have difficulty representing the required behavior. Low points out that the wheel exhibits the related behavior but does not fully reach the desired state. Lastly, high refers to the wheel showing expected behavior.

Disadvantages of the wheels

The wheels have advantages but represent distinct challenges, especially in speed, maneuverability, and movement stability. Accordingly, the wheel types' disadvantages are explained in this regard.

Tracked tank robots have advantages in their high mobility, non-invasive design, precise movements, and remote operation, making them useful tools in cultural heritage preservation. However, their limitations in speed, maneuverability, maintenance requirements, and environmental restrictions should also be considered in the decision-making process for a specific project. The disadvantages of tracked tank robots inferred from the experiment are listed as follows (on the next page).

Table 2
Observations during the experiment

abilities		standard	tracked	mecanum	Termes	flexible
obstacle climbing ability	obstacle below the body level	Limited	High	High	High	High
	obstacle above the body level	Limited	High	Low	High	High
load carrying ability	uniform object	High	High	High	Limited	High
	uneven object	High	High	Low	Limited	High
stability in movement	inclined terrain with load	Limited	Low	Limited	Limited	Limited
	inclined terrain without load	High	High	Limited	Low	High
	flat terrain with load	High	High	High	Low	High
	flat terrain without load	high	High	High	Low	High

- Limited speed: They move slower than other robots, which could disadvantage them in time-sensitive situations.
- Limited maneuverability: They struggle to navigate tight spaces or move around obstacles, which could be a disadvantage when working on architectural heritage with narrow corridors or complex architectural features.
- Maintenance requirements: The tracks and joints may require more maintenance than other robot types. This need could be a disadvantage in architectural heritage where minimizing impact is critical.
- Environmental limitations: Tracked tank robots have difficulty moving over soft or muddy terrain, limiting their use in some architectural heritage located in areas with difficult terrain.

In addition to the tracked tank robots, mecanum wheels are challenging in cost and complexity (easier to fail than a standard wheel), require an additional design to operate properly, and are limited on the surface it can drive on (need to be a smooth surface, could not move the robot effectively through rough terrain). Less surface contact means less friction, which results in possible surface slipping. The disadvantages of this wheel type are briefly explained as listed below.

- Limited load capacity: It may have a limited load capacity, which could be a disadvantage when heavy equipment or tools are required.
- Limited speed: It is slower than other robots in moving straight, which could be a disadvantage in time-sensitive situations. However, it moves faster in turns.
- Maintenance requirements: Mecanum wheels have more moving parts than other robots, which could increase maintenance requirements and costs.
- Power limitations: It has limitations in battery life and power, which could restrict the duration of their use in the field.

The robot with mecanum wheels has advantages in its high maneuverability, non-invasive design, precise movements, and versatility, making it useful for cultural heritage preservation. However, their limitations in load-carrying capacity, speed, maintenance requirements, and power restrictions should also be considered in the decision-making process for a specific project.

Lastly, the disadvantages of sharp wheel types like TERMES-like wheels are listed as described below.

- Limited maneuverability: While the sharp wheels would allow them to move over uneven terrain, they may struggle to navigate tight spaces or move around obstacles, which could be a disadvantage when working on architectural heritage with narrow corridors or complex architectural features.

	Wheels	Pros	Cons	Cause	Potential solution
The ready-made wheels	standard	It moves straight in a stable way.	It has difficulty climbing an obstacle and carrying weight on the slope.	It cannot hold onto the ground and slides under the weight. The reason why it cannot climb an obstacle is that it cannot hold onto the surface.	By changing the wheel material, the friction effect on the ground surface can increase while the robot moves. The number of wheels can also be increased.
	tracked	It can climb an obstacle while navigating.	Front and back wheels do not turn with the same speed.	Front and back wheels are connected to the same track.	Using encoder or powering front and back wheels from the same input.
	mecanum	It moves fast with a minimum range of space in turns. Since the wheels have a curvilinear volume, the trace is left on the surface remain smooth.	It is slower than a standard wheel when going straight. It has too much friction with the wheel body and less stability than standard wheels.	The wheel itself consists of moving parts. However, this feature also allows it to navigate in multi-directions.	Increasing the number of wheels and reducing the wheel size. Modifying the connection between the wheel and the motor by adding a coupling with a shock absorber to reduce the vibrations from movement.
	Termes	It can climb an obstacle while navigating.	The movement is fragmented and the robot has difficulty carrying a balanced load.	The wheels' center of motion changes during navigation.	Increasing the number of wheels' branches. Ex: flexible.
The developed wheel	flexible	It can climb an obstacle while navigating. It moves more stable than TERMES-like wheels.	It is a fragile wheel.	Branches can be stuck in terrain and break.	Choosing the wheel material that is durable and soft.

Table 3
Pros and cons of the wheel types concerning damage to the surface

- Limited speed: The wheel design may limit their speed, which could be a disadvantage when time is of the essence, such as emergency repairs or assessments.
- Environmental limitations: The sharp wheels may not suit all terrain or environments. For example, they struggle to move over soft or muddy terrain, which could limit their use in some architectural heritage located in areas with difficult terrain.
- Maintenance requirements: The sharp wheels may require more maintenance than other locomotion systems, which could be a disadvantage in architectural heritage where minimizing the impact on the building and its surroundings is of utmost importance.

As a result, the pros, cons, causes of challenges, and potential solution(s) of existing wheel types are briefly discussed in Table 3 based on the above-stated advantages and disadvantages. Concerning these discussions, a wheel named flexible is developed by the authors. The flexible wheel performs better than the TERMES-like wheel in movement stability and climbing ability.

CONCLUSION

The experiment results show that small wheels with a low profile and made of soft materials provide a better balance, ensuring stability, smooth motion, and minimal damage. A weight distribution and control strategy are proposed to minimize the impact on sensitive surfaces.

Mobile robots equipped with sensors and imaging systems can detect and map the building interior, identifying any unsafe areas that need further reinforcement before humans can enter. This ability helps to ensure the safety of those working to restore and preserve the building and its cultural value. The wheel design of mobile robots plays a crucial role in preserving cultural heritage by allowing safe and efficient access to delicate or damaged buildings while minimizing the risk of further damage to the artifacts within. By using robots to survey and assess the damage to a building, architects and conservationists can better understand the extent of the damage and plan restoration work accordingly. This usage can minimize the risk to workers and provide accurate mapping and imaging data for architects and conservationists to inform their decision-making in restoration projects. The findings of this paper can contribute to the design of mobile robots operating in historical buildings, remote construction sites, and hazardous places to guide designers in selecting typical wheel types and designing new ones concerning requirements in load-bearing capacity, navigation on inclined surfaces, and conservation needs for architectural heritage. The robot used in the experiment can work in different project sites with a change of wheels according to the needs of a specific task.

The experiment has limitations in terms of the used materials. Using cardboard in the experiment, intended to stand in for traditional building materials such as wood, has limitations in obtaining increased accuracy. It was an accessible and affordable material to conduct a preliminary experiment regarding the wheel design effects on surfaces. Other limitations drive from the scale of and the carried weight on the robot, the ground slope, and the wheel types. Using four 5V DC motors with plastic reducers and the direct connection of the wheels to the motor reduced the maximum weight the robot could carry. A torque problem arose because the load was transferred directly to the motors.

The experiment setup can be expanded regarding the wheels, the distinct features of the terrain, and robot tasks. Future works will focus on the following concerns.

- Number of wheels as a variable in the experiments,
- Distinct wheel types,
- Distinct terrain surfaces to test brittleness, dust, crush, and homogeneity,

- The maneuvering capability of the robot in narrow spaces,
- Distinct tasks, such as picking and placing materials.

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Physicalizing Digital Design Methodology

Material-linked digital making

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Architectural design process, heir to craftsmanship traditions, formulates making as its vehicle of analysis. This curious pedigree directs high-level thought process through the restraint of material limitations; a methodology based in respect for materials whose properties and tendencies are capable of driving outcome. In this tradition of making, design as an intellectual act is dependent on engaging active, spatiomaterial media. Additionally, contemporary literature suggests physical materiality as an interface is uniquely suited to human intelligence, at once corporeal and intellectual. Therefore, if digital is understood as an extension of our intellectual thought process, its evolution should intertwine with the physical.
This paper reports on research examining the role of physicality as a component of digital design method. The research constructs hybrid models and physicalizations, physical makings parametrically linked to inform digital design; thereby testing the integration of physical and digital as a material-based digital making methodology.
The proposed next digital turn is a return to materiality as conduit transporting the full range of human intelligence (sensorial, intuitive, and intellectual) within digital making. Key to this methodology is designing with live, spatiomaterial media capable of reacting and providing feedback during making. The supposition contained turning towards physical-digital integrated methodology is that the wicked problems we face are best served by a design methodology accessing the full arsenal of our intelligence with media that is connected to the same multiplexity of context it seeks to remedy.

Keywords: *materiality, modeling, digital modeling, hybrid modeling, micro sensor, analogue-digital, digital craftsmanship, corporeal intelligence, spatiomaterial, physicalization.*

INTRODUCTION

Physicalizing Digital Methodology seeks to integrate physical making into digital modeling. What we want is a methodology for creating digital design objects informed by that object's material reactions to site conditions (gravity, natural light, etc.) based on its material nature (soft and pliable, rigid, reflective, etc.). Additionally we want those conditions consistently present while we are working with the model so that these factors influence the design outcome.

This paper will look at two studies which explore directly connecting digital modeling to physical making: Hybrid Modeling and Physicalizations. Before presenting these two studies and their results we will contextualize the aim of the research and the reasons, as architects, we wish to directly connect physical and digital modalities.

MOTIVATION

The technique of attaching architectural modeling to the realities of physical (modeling) materials and spatial forces is inspired by Frei Otto and Antoni Gaudí. In their methodology physical modeling acts as formal computation connected to dynamic variables of real material and spatial properties. Resulting in a design object that is inescapably a product of both, therefore site and material specific. Their example is considered a forbearer exemplifying what we wish to achieve with digital architectural modeling.

Contemporary digital design remains largely self-contained and isolated in digital space. While techniques like digital fabrication do incorporate physicality in the design process, the modalities of digital and physical remain separate, i.e., they occur sequentially rather than simultaneously. This means that the information in each modality is influencing the design object at different moments rather than the same moment in which design decisions are taken. Further, in contemporary digital modeling, digital materiality is treated as neutral, without agency, passive, and within the control of the designer.

Physicalizing Digital Design Methodology addresses the isolation and neutrality of digital design using two aspects found in Gaudí and Otto's modeling methodology:

Object-Site, Spatiomateriality

In digital design, we want models/ design objects that are 'live', consistantly connected to their material natures responding to spatial conditions of their site. This creates a design process connected to unpredictable and often uncontrollable interactions between material properties and site conditions as dynamic variables. The inherent interactions between material and spatial properties which provide design objects (or design media) with agency to critique (resist or facilitate) design intent is referred to as spatiomaterial (Iverson-Radtke, 2022, viii). Spatiomateriality denotes an active media composed of bonded states of spatial and material properties. Writ large, spatiomateriality connects object and space at the level of their internal properties. This is a view of the stable world of objects as actively involved in the internal fluctuations of physical space. Object as system connected to, rather than separate from, context.

In Physicalizing Digital Design Methodology, our intention in connecting material irregularity and unpredictability within pristinely rational digital environments, seeks to remove distance between design considered digitally and its solution as a physical object, i.e., design in close proximity to subject.

Sensory Intelligence, Craftsmanship

In digital design, as a modeling engagement we want design object feedback communicated non-verbally during making as the material design object responds to its tooling in context of physical forces. This is a methodology recognizing physical engagement with material object as aligning with our human ability to understand, learn, and explore as a sensory act.

Central to the engagement of objects as an analytic exercise is the ability of these objects to provide feedback during making to drive outcome, as Schön states:

"…designers develop a design proposal "in conversation" with the situation…" (Paans, 2022, p. 5)

Both aspects: sensory engagement and materials connected and responding to spatial forces (spatiomateriality), recall architectures ancestry as craftsmanship training towards material mastery. Architectural design process, inheritor of traditions of material making, routinely examines ideas as objects. Design process therefore constitutes analytic thought conducted through material (physical and digital) mastery. This is

"…object(s) formed through the imposition of mental realities upon material ones" (Ingold, 2007, p.5)

All design is media-driven solution. Further, by specifying that media engaged in design is spatiomaterial, animated and formed by the bonding of material and spatial properties, ensures a design object capable of feedback as well as connected to context. Physicalizing Digital Design Methodology seeks to create awareness, knowledge, and demand, in contemporary design communities of digital natives, for a design media as sparring partner capable of providing resistance and feedback.

So that is what we are trying to do, to connect digital modeling methodology directly to physical making. Thereby achieve spatiomaterial design objects providing feedback during digital design and to have some kind of sensory access to this digital making. This is Physicalizing Digital Design Methodology, and this paper reviews two different studies in which it was pursued: a doctoral research using Hybrid Analogue-Digital Modeling and a workshop using Physicalizations. Before describing these studies it is incumbent to locate our research aim within State of the Art (SoTA) design and hybrid design research.

SOTA

In contemporary SoTA analogue-digital design practice we locate our research among four key markers: architectural design process, Data Physicalization (Jansen, 2015), Hybrid Analog-Digital Modeling (Iverson-Radtke, 2022), and simulations. Hybrid Analogue-Digital Modeling will be reviewed later as one of the studies of Physicalizing Digital Design Methodology. Though this area of of research includes many others who have and continue to make significant innovations in this area[1], these four reference points relate specifically as an analogue-digital modeling practice.

Architectural Design Process

Physicalizing Digital Methodology specifically targets digital architectural modeling; seeking to alter its image as high-tech and automated to a process necessitating direct connection with physical making. Design process, including analogue and digital modeing, is a pillar of architectural practice and thought process. Attaching material and spatial interactions and limitations to digital design process targets its transformation and thereby all subsequent design phases, including the constructed environment.

Data Physicalization

'Physicalizing' Digital Design Methodology references its namesake, 'Data Physicalization[2]' (Jansen, 2015). The mirrored terminology: 'Data Physicalization' and 'Physicalizing Digital' indicates a critical change in directionality. The latter, our research, seeks to move information from the physical into the digital. Thus rather than *"Materiality increasingly…enriched with digital characteristics"* (Gramazio, Kohler, 2008, p. 2) this research strives to establish a digitalization increasingly enriched with material characteristics.

Simulations

Environmental studies such as natural lighting (the subject of the workshop discussed below) often achieve far better results with physical simulation like a heliodon device and camera recordings then with digital simulations. This underscores the complexity of physical systems which remain out of reach through purely computational means. Further, as sensory intelligent beings, we are better able to comprehend information that is physically rather than an entirely digitally produced.. Here again, there are echoes in terms of modeling techniques connecting to real world conditions, that recall the well-known lineage of Gaudí and Otto, their scaled models attached to real-world phenomenon.

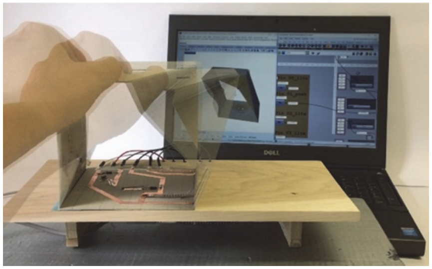


Figure 1
Hybrid Analogue-Digital Model

METHODOLOGY: DOCTORAL RESEARCH + WORKSHOP

The premise of Physicalizing Digital Design Methodology, connecting physical makings to digital models, was explored in two separate but related studies. First as doctoral research in Hybrid Analogue-Digital Modeling (Iverson-Radtke, 2022) and second in a workshop 'Topographies of Light' (Gandia, Iverson-Radtke, 2023). Examples of these studies, their results and significance are reviewed next.

Doctoral Research/ Hybrid Modeling

The Hybrid Analogue-Digital Modeling[3] developed in the doctoral research uses physical models embedded with micro sensors hardwired to microprocessors. These 'Sensor Models' are used as interface with digital modeling, replacing mouse and keyboard, see Fig. 1. The research has produced significant insights into what is required to connect analogue-digital modalities into a single modeling method and the effects of this hybrid modeling on digital design. Two findings of this methodology are described here as potentially transformational to the future of digital making.

These findings are reviewed using one of the experiments of the doctoral research. The experiment reviewed also describes the use of hybrid modeling to transfer physical making and real-world aspects into digital modeling.

Case Study 4 (CSo4) 'Rubber Vase'

In this hybrid modeling technique each modality, analogue and digital, consists of a partial construction that together form a single hybrid model. In this experiment:

1. A Sensor Model (analogue) is constructed to hold a pliable rubber strip at an angle to gravity. The rubber strip has pressure sensors with wire mesh tabs (to hold the form in bending) attached at intervals, see Fig. 2a and 3a.
2. This Sensor Model is mirrored digitally by placing a digital mesh strip of the same dimensions, placed at the same angle, in virtual gravity. The mesh strip, see Fig. 2b, has assigned points of inflection corresponding to the position of the sensors, see Fig. 2c .

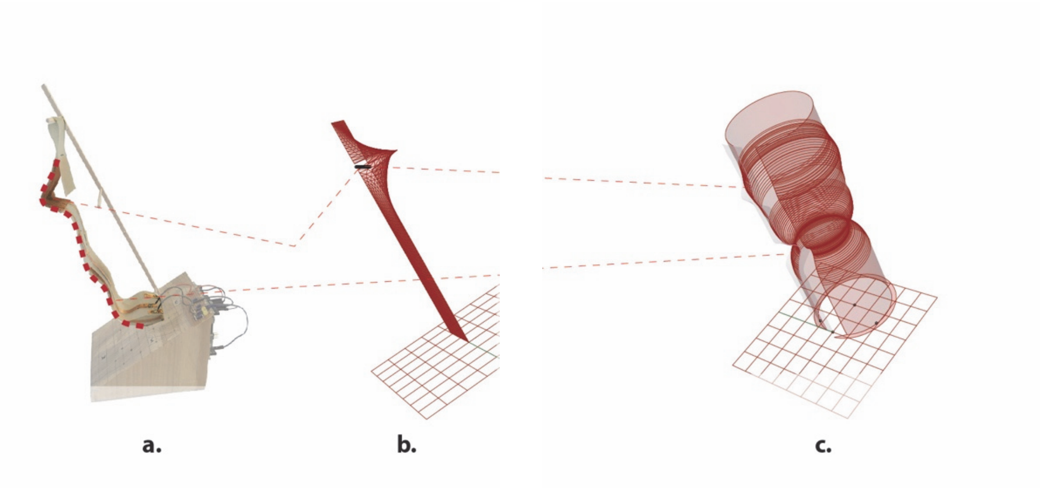


Figure 2
Case Study CSo4
Hybrid Modeling

3. The aim is to manually shape the rubber strip by bending at the sensors/ inflection points. Then sensor data is transmitted to the digital mesh strip via a parametric script to bend the digital mesh as a factor of pressure intensity.
4. The shape of this strip is then revolved 360 degrees to form the Rubber Vase, see Fig. 2c.

In terms of an architectural design solution, the result is a design object (Rubber Vase) whose form is a product of its material properties (floppy), site conditions (angled thus pulled in gravity), and design intent (manual manipulations). Eureka! This is the digital modeling sought, informed by physical making, constraints and affordances of material and site conditions!

Results/ Significance

Two findings of this hybrid modeling technique are seen as transformative to future digital architectural modeling:

Alignment.

Creating a unified, singular hybrid modeling engagement requires reciprocal response across physical-digital modalities. This means modeling using hybrid methodology demands focus on careful alignment of material behaviors. Such alignments often require digital materials to be altered to respond and behave in ways similar to physical. For example digital materials must be scripted to remain dimensionally stable rather than stretch infinitely when subjected to virtual force. In the case of the Rubber Vase, the digital material (mesh) required altering its parametric definition to bend in smooth curves, similar to rubber material, rather than the default bending in sharp angles, see Fig. 3.

These small inconsistencies in themselves are perhaps not significant. However, in architectural modeling there are countless such moments of spatiomaterial formal negotiations, see Fig. 4.

Hybrid modeling necessitating analogue-digital alignments, begins to align digital modeling to our intuitive sense of material nature and thereby effect an understanding between designer an object that is basic, fundamental, and corresponds to our lived experience and understanding of space and objects.

Digital Material Properties

A second significant contribution of hybrid modeling is to further evidence the existence of

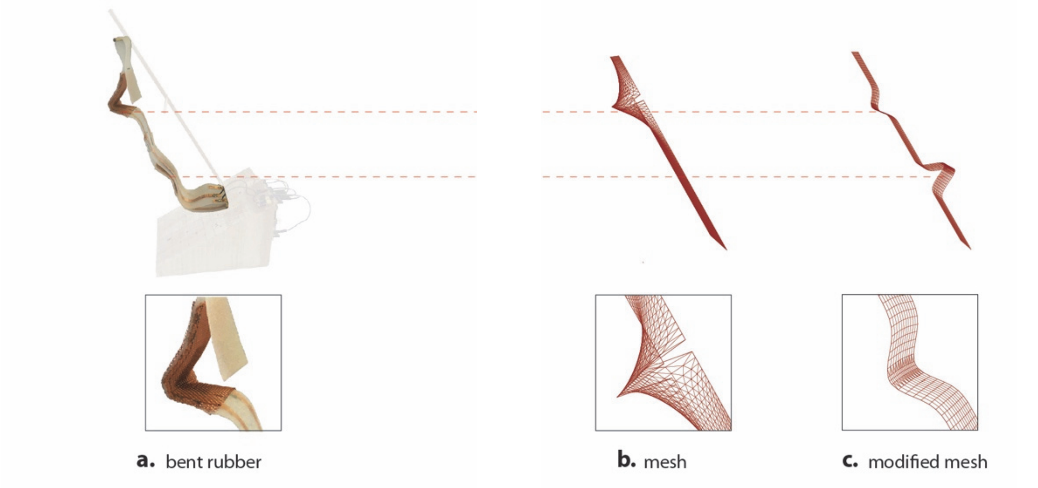


Figure 3
Alignment in
Hybrid Modeling

digital material properties. This means that digital meshes, surfaces, BREPs, etc. have specific behaviors related to their internal structure, see Fig. 5.

This finding supports other research revealing a change in our understanding of digital materials:

"...computational objects are typically thought of as neutral...(yet) meshes can have agency beyond that which is expected from predetermined representations because they can embody traces of generative behaviors." (Jahn, Morgan, & Roudavski, 2014, p. 135, 143)

To understand why digital materials, essentially immaterial, exhibit 'material properties', it is useful to recognize that digital design space is colonized by human thought process shaped by lived experiences. We create technology in the image of that which we experience and inhabit, as Simondon puts it:

"We can create technical beings because we have within us a play of relations and a matter-form relation that is highly analogous to the one we constitute in the technical object (Simondon, 2017, p. 62)" (Paans, 2022, p.6)

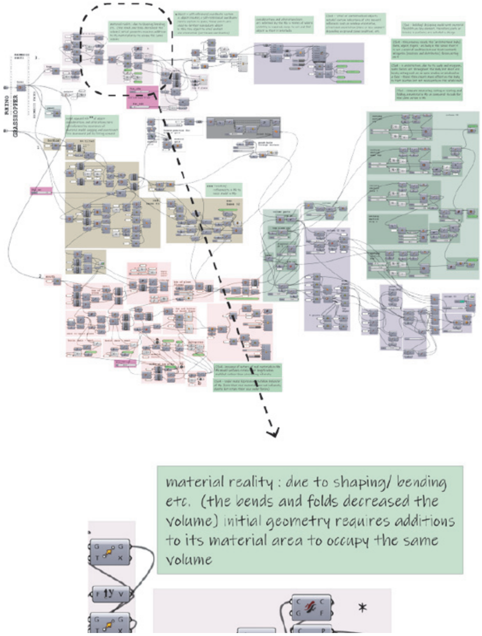


Figure 4
Running Dialogue during modeling notated in the green text box

With these two findings: the existence of digital material properties and granular alignment across modalities, practice with hybrid modeling gradually shifts the focus of digital modeling from geometry to the internal properties of digital materials, and represents a potential paradigm shift in digital making. The revolution is made by changing digital design objects from self-contained and isolated in digital space to objects-as-systems inherently products of, and connected to, their context.

The significance of the doctoral research recommends further development and study in material-linked digital making. This is being undertaken in workshops, the first of which is reviewed next.

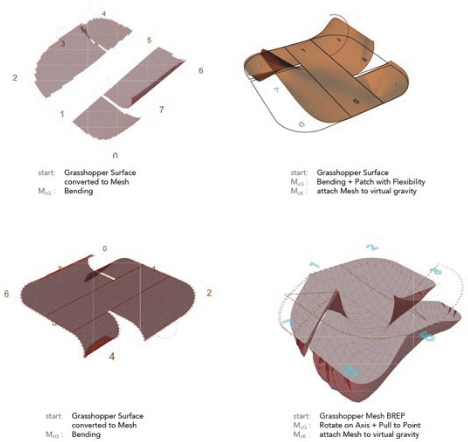
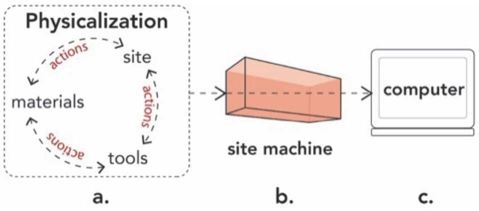


Figure 5
Digital Material Properties (behaviors as factors of internal structures)

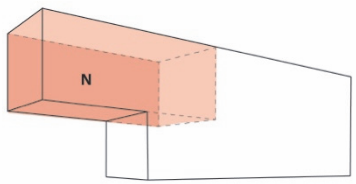
Figure 6
Physicalization
Diagram



workshop[4]/ Physicalizations

The next study, a workshop entitled 'Topographies of Light' (Gandia, Iverson-Radtke, 2023) uses 'physicalizations' rather than Sensor Models as a way to introduce greater physicality into digital design process. Physicalizations are defined as discrete sets of physical making that can be inserted or attached to digital design process. Physicalizations contain materials, tools, and spatial context. Also included are actions, the designer's engagement with physical making in manipulating/ tooling materials, and spatiomaterial resistance and affordances encountered, see Fig. 6a.

Figure 7
House, project site
shown in red



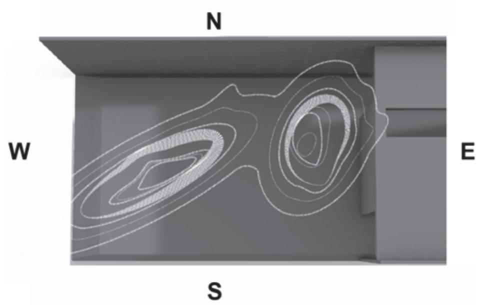
The workshop design problem is an examination of the potential for prefabricated composite panels to integrate artificial lighting within the architectural envelope. The project site is a single room in a two-story house composed of prefabricated composite panels. The room is located on the second floor, west facing, and cantilevered above grade, see Fig. 7. Student projects focused on proposals for the north wall of the room.

The conceptual framework of the workshop instructs students to envision natural light as a dynamic topography and dominant spatial attribute of the cantilevered room, see Fig. 8. Students were asked to design the north wall panel to interfere, shape, and augment—thereby conceptually creating temporal 'hills and valleys' in the room's dynamic light topography .

Additionally, to facilitate student's projects, a 'site machine' was constructed consisting of a 3D printed scaled model of the room embedded with an array of ambient light sensors, see Fig. 9c & 6b.. These sensors are electronically and parametrically connected to control a digital model counterpart, see Fig. 9a. A robotic arm , see Fig. 9b, holding a flashlight and programmed to move in an arc over the site machine, see Fig. 9d, was used as a makeshift simulation of natural light path.
This design problem framework was used to test Physicalizing Digital Design Methodology, as material-linked digital making directing students to create physicalizations driven by material engagements with natural light.

The project site model/ site machine allowed students to insert their physicalization into the project site (room) and see the changes in the light topography as a digital model, see Fig. 9a & 6c. Fluctuations in the light sensor readings indicated changes to the light quality in the room. Therefore the site machine acts as conduit translating physical to digital modeling.

Figure 8
natural light as
dynamic
topography



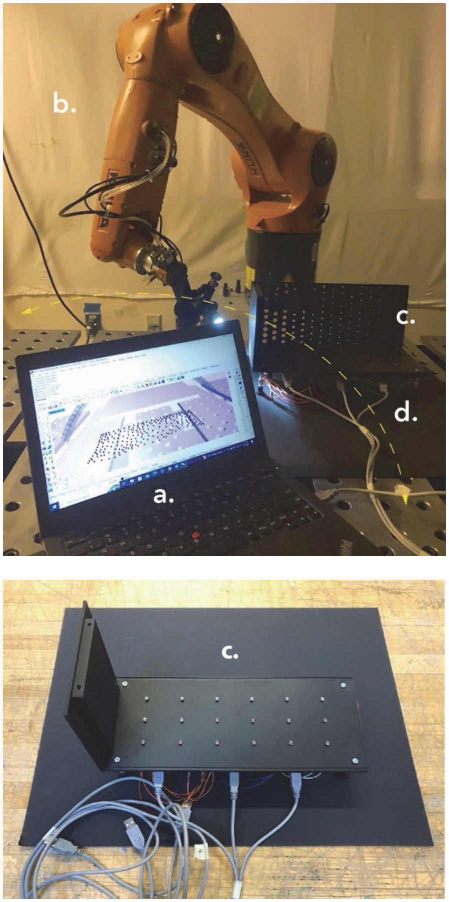


Figure 9
workshop site machine (bottom left) with robot arm (top left)

Student Physicalizations[5]

Student physicalizations varied based on the diverse expertise and skillset of their experience and background. Two student physicalizations are reviewed here and demonstrate this diversity:

Student 1

Stephen is a highly skilled woodworker practiced in working with material and tool affordances and limitations as driving factors of fabrication and assembly. In Stephen's project plexiglass was selected as the material of investigation for its ability to engage with and alter the quality of natural light and its accessibility to mechanical tooling. Both Plexiglas and natural light have refractory qualities that presented complexities not easily anticipated.

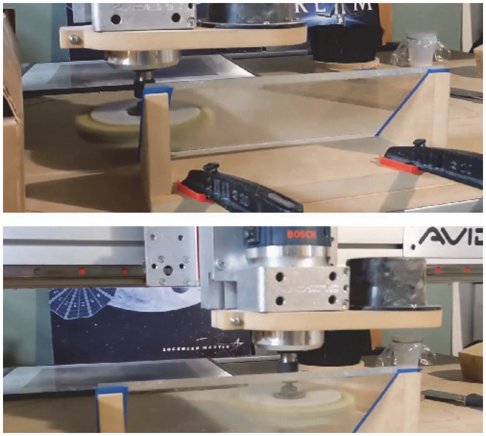


Figure 10
Tool Path, Plexiglas held at an angle to machine tooling.

As a result, Stephen's physicalizations embraced what could be controlled: the tool path (see Fig. 10) generating the altered Plexiglas, while allowing the lighting design to be the result of this designed the tooling method, see Fig. 11.

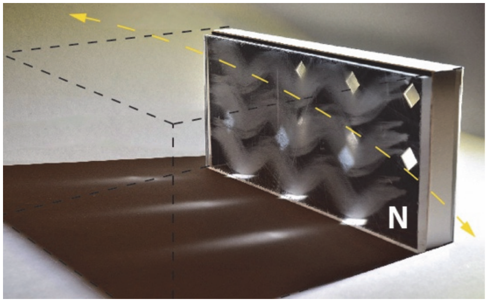


Figure 11
Plexiglass with patterns from tooling – lighting affects

Student 2

Enrico brings his expertise in video animation to orchestrate the dynamics of sunlight entering the room with wall openings whose locations are determined in response to natural light levels, see Fig. 12. Enrico further links his panel design to the site machine's ambient light sensor data. Connecting to light level data attempts to integrate the automation of artificial light whereby low light level readings activate LEDs in the panel, see Fig. 13.

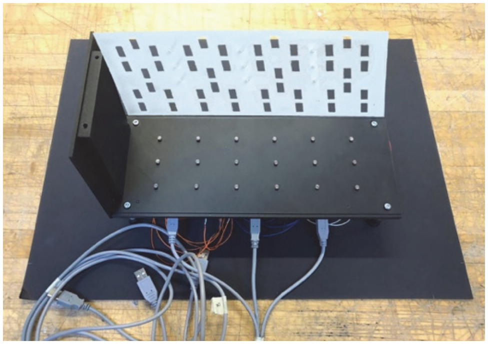


Figure 12
Physicalization, white paper model (left)

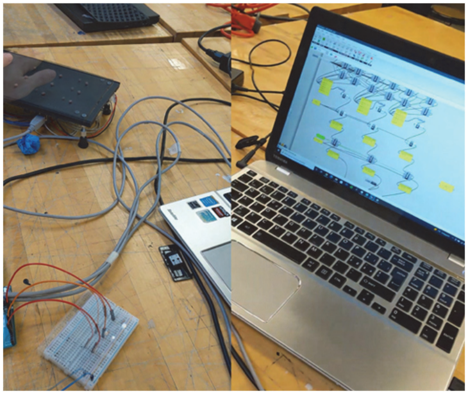


Figure 13
Testing Light Sensors with LEDs (right)

As Physicalizing Digital Design Methodology the choreography is: physicalization (physical model)—inserted into site machine (digital)—adding sensor data (digital)—to activate LEDs (physical).

Summary

Physicalizations as experience in this workshop connect the joy, frustrations, and discovery of material-led interactions as parameters of digital modeling. The restrictions, limitations, and problematic realities of physicalizations help students negotiate their approach in digital design.

Through physicalizations students create live design interactions as dynamic engagement with materials and tool path (Stephen) and responsive electronic design object (Enrico). Using the site machine light sensors students transfer physicalizations into digital visualization of changes provoked in light topology qualities of the room. These physicalizations initiate an iterative process towards fine tuning integration of lighting (natural and artificial) into architectural design.

Importantly, physicalization engagements facilitated greater awareness of the effects of analogue and digital modalities and their sequencing on design outcome and thought process.

CONCLUSION AND OUTLOOK

Both Hybrid Modeling and Physicalizing Digital Design Methodology studies use electronics (microsensors) to bridge between physical and digital modalities. The conceit here is that material-linked digital making using smart technologies to attach to the irregular and unforeseeable proclivities of the natural world, support digital design methodologies with greater proximity to their subject.

Additionally such engagements teach valuation for accessing live spatiomaterial design objects capable of critiquing design intent (through resistance, affordance, etc.), during the design process when such inputs my still affect outcome. This timing and sequencing of analogue-digital modalities and interactions are critical since

"…problems and solutions coevolve (Dorst 2003). In one gesture, the relation between a problem and a response (is) redefined as a process of mutual definition and dynamic demarcation." (Paans, 2022, p.4)

The workshop (Physicalizations) and doctoral research (Hybrid Analogue-Digital Modeling) are the beginning of what we hope is a new taxonomy in digital making—digital architectural modeling tethered to physical making by smart technology electronics. Findings such as those supporting the existence of digital material properties provide a basis for establishing digital architectural modeling generating from the internal structure of its materials. This is material-linked making reflecting traditions of craftsmanship in architectural making. Such findings also signal a potential reciprocity between analogue-digital making that could become conduits for fully integrating these modalities. While this is yet out of reach, emerging research and writings are beginning to herald a not insignificant call for this new hybrid digital design:

"… (one) that acknowledges and builds on material engagement…and embraces the critical role of resistance and sensuous reasoning in the design process that material provides." (Bardt, 2022, p.8)

The goal of this paper and the research behind it is to bring material-linked digital making into wider discourse and thereby encourage continued development towards viability. We hope to have peaked interest and happily add our voice to the call to advance and encourage more research in this area. Envisioned is a near-future technology of haptic access to spatiomaterial digital media in dialogue with context. This direction of inquiry will surely occupy the author of this paper for some time, and she looks forward to discovering this world of material-linked digital making with others.

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[1] Although MIT Media Lab and Firefly Projects are examples of significant analogue-digital design research and innovation, at the time of this writing no research was found using embedding smart technologies into architectural models as an interface to digital architectural modeling.

[2] Epitomized in the work of MIT Tangible Media Group (Ishii).

[3] The Hybrid Analogue-Digital Modeling produced in the research is beta stage and requires further technological development as a viable tool.

[4] My thanks to Dr. Augusto Gandia (MIT) for the opportunity to collaborate in this workshop.

[5] My thanks to Stephen Thrasher and Enrico Milanese for referencing their work for this paper.

Bric(k)Colage, CMU Spolia Composites

3D Scanning and Printed Clay for the Recapture of CFD Masonry Waste

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This research investigates the use of LIDAR scanning, physics computational simulations, and ceramic 3D printing to streamline a process for generating a structural masonry bond-work from a given set of discarded pre-fabrication concrete parts. The research capitalizes on an initial set of large scale mockups developed using intuition based stacking of CMU Block detritus, which were in turn LIDAR scanned to produce a series of custom robotically 3d printed ceramic figural bricks to infill the gaps in a mortar based assembly. Following the proof of concept, the researchers explored computational means for simulating various configurations of aggregates using individually scanned broken blocks placed within a physics simulation. The outer boundaries are rigidly defined along with placeholders for desired apertures, and then the scanned detritus is dropped to inform a tight packed bond-work. The final digital aggregate is then run through a grasshopper simulation to derive the linework and print files for a robot to print the negative infill. This paper will discuss the ability for the designer to work within a computational process to produce structural envelope based construction with spoliated detritus towards new varied organizations embraces an aesthetic of visual reuse.

Keywords: *3D-Printed Clay, 3D-Scanning, CFD Waste, Spolia, 3D-Collage*

INTRODUCTION

The 2016 US Environmental Protection Agency reported that 23.1 million tons of broken pieces of concrete waste are annually discarded from new construction sites (2016. p.3) . This alarming statistic, which is merely a demonstration of construction waste in the United States alone, speaks towards a global issue in how we construct buildings, and simultaneously to the intrinsic value that our culture places on new perfect parts over the broken and old - a culture which has been built on the economic efficiencies of reaching for the new rather expending time, energy, and labor on re-using the old. While most of concrete waste either ends up in landfills or as aggregate which can be re-injected into the asphalt and civil engineering projects, relatively little investigation has occurred in how this material could reappear in the architectural project, as a viable alternative to new and clean element, that might honor its intrinsic broken quality as a part of its materiality within a life-cycle of continual usage. While recent scholarship such as Clifford and Mcgee's Cyclopean Cannibalism, (2018) has focused on how new technology may recapture site-cast concrete demolition waste, no examinations of how the architectural discipline may devise a paradigm to re-inject the broken and defective masonry waste extracted from our construction and landfill sites back into the project, short of their granular breakdown into asphalt.

PRE-CAST CONCRETE WASTE

Several researchers have only focused on the idea of what happens in post demolition waste. This research showcases what happens not only during the post demolition process but the construction process as well. An investigation by the Connecticut Department of Energy (2014 , was conducted for its state, where it was determined that only 6.6% of C&D concrete is recycled; the rest is thrown out in landfills as it is labeled “contaminated or too hard to process on a large scale." Very little is recycled because asphalt, brick, and concrete (ABC) can only be recycled at a small number of Volume Reduction Facilities (VRF), which essentially grind the recycled material down to be later sold as aggregate. The facilities’ role is to sort waste and only a limited number of these locations have this capacity, leading to much of the masonry waste being relocated to landfill. Notably, in 2013 Connecticut collected 93,748 tons of Asphalt, Brick and Concrete (ABC) materials that year which is 9% of all waste gathered, of which only 6.6% or 6,267 tons were recycled. The economics for this relocation are also staggering, wherein the overall disposal cost for CT VRFs with existing rail infrastructure to transport and dispose of waste via rail is approximately $50-$60/ton. The largest and most widely used landfills for ABC waste are located in the northeast corner of Ohio. These landfills are charging approximately $15-$25/ton for disposal at their facilities. Meaning that in 2013 the state of Connecticut spent an average of $6,561,075 dollars to dispose of ABC materials alone. A typical process for recycling ABC material, sees the gathered refuse grinded into a gravel base substance, generating a variety of aggregates sizes. A recent document produced for the Chinese Government by T. Li Wang (2022) document states “Recycled ABC materials are generally marketed as a gravel sub-base, which is a substitute for virgin aggregates. While this speaks about the costs to the state, perhaps more significantly the mass transportation of waste to be relocated into facilities for recycling or to ‘acceptable’ landfill locations creates a significant carbon footprint. We might ask, if there is another paradigm that would not require the discarding of this material in the first place.

THE CULTURE AND ECONOMICS OF SPOLIA

This sample vignette above reflects on a culture which does not create a value for the discarded, but notably Architectural history demonstrates an interest in determining other ways to recapture waste within the physical building project. The Roman late republic between the years 123 - 23 BCE, showcases a period where scavenging for building materials was a thriving business. Examples from this time particularly those for adaptive re-use, where a building itself is expanded upon, often use Spolia, or stolen (recycled) bits of buildings as a construction material in a primary sense. Historian Hans-Rudolf Meier (2011, p. 225) points our attention to the idea that “In material-poor pre-modern eras, the reuse of building elements was more the rule than the exception.” Economics would not be the only reasoning in historical examinations, where modern scholar of Spolia, Dale Kinney (1997, p.122), discussed how “Virtuvius claimed that ‘the strongest burnt brick walls are those which are constructed out of old roofing tiles,’ because reused tiles were weather-tested.” At a time in history where societies and empires were being sacked, causing the wreckage of much of the building, whole cities were like material warehouses, replete with construction resources, for the next project. Herein, the concept of Spolia inherently requires sustainable reuse, within the locality the building material is found, as our aging buildings in cities reach the point of demolition it could be understood that this stock is itself the marketplace for future construction.

It is also of note that the deployment of Spolia within history was not only for the reasons of economic efficiency - in some cases it was used for displaying the power of specific heritage as symbolized through architectural ornament and in others a mere tie to the memory of recent past.

Historian Arnold Esch (2011, p.17) points our attention to the need for Ancient Rome's "assembled from rough, half-finished, and fully finished architectural elements from various eras and places, which had been set aside in marble warehouses for public use. The already finished ornaments came from building projects that were never carried to completion, or they had been salvaged from ruined buildings and stored." The use of marble as inlaid in a larger brick wall, obviously draws attention to itself, and therein finds itself in the role of ornament. Esch goes on to discuss this through the reuse of the "Architectural elements were not only reused in structural contexts, but also as isolated decorative pieces. The capital was not only reused analogously, as a capital, but also, hollowed out, as a baptismal font or stoup, as a reliquary, or as a fountain. Hollowed out, the column shaft became a saint's tomb or a bishops' throne." Culturally this speaks towards a society which was accustomed to seeing the old incorporated in the new and utilized for new fashion, not as defect but reinterpreted. Perhaps we might understand that a culture which wishes to address the climate and carbon impact of C+D waste may need to re-address its primary aesthetics and ability to incorporate the old in more literal ways.

A DIGITAL SPOLIA

Several recent changes in the paradigms surrounding digital technology have prompted the possibility of looking at C+D waste and spoliation as part of the building envelope more seriously. Mario Carpo's recent work, *The Second Digital Turn : Design Beyond Intelligence* (2017) discusses the past thirty years of architectural technology in terms of two micro-epochs known as turns, each of which play a role in the digital spolia project. The first turn which unfolded during the last decade of the twentieth century, describes digital fabrication procedures writ large, wherein making processes could result from third dimensional digital investigations from within a computational environment. These processes have included computer numeric controlled multiple axes machines that can register the digital coordinates from a computer for the purposes of manipulating a tool for the extraction geometry from solids or adding geometry through processes such as 3d printing. Throughout the first two decades of the twenty first century, many such as Matthew Trislbeck (2019, p.148) have noted that additive manufacturing was relegated to plastics towards the production of small models and "Despite the relative accessibility of clay, its low cost and reputation as a robust and sustainable building material, clay three-dimensional printing remains an under-utilized digital fabrication technique in the production of architectural artifacts." More recently through the injection of commercial paste extruders into the architectural marketplace, we have seen the ability to produce larger architectural components emerge from the production of these paste extrusion additive manufacturing machines.

Carpo maintains that the second digital turn, in which we currently reside, has switched our focus away from explorations concerning the output of digitally generated output, to our newfound ability to input elements of the environment into our digital existence (2019 p.200). Carpo elaborates that the fundamental shift exists in the shift in how our sensors recapture the environment as points rather than measured lines and orthographic drawings. LIDAR scanning or Light Detection and Range based scanners are the critical technological advance that provides new access to this modality. Nic Clear describes this process in his 2019 exhibition (2019, p.6) manifesto *Synthetic Spaces,* where LIDAR laser scanning has introduced a point cloud system which allows for the creation of synthetic spaces that "offers greater accuracy than most conventional approaches… [and a space where] the virtual and the actual are combined" in order for more accurate measurements. This technology has been used successfully in archaeological object excavation where Ahmed, Carter, and Ferris explain how "Laser pulse/radar technologies operate much like radar and sonar, relying on a 'bounce back' and the calculated time taken to return a sample to the scanning sensor." This modality has already been

Figure 1
Researcher's using physical drop process to create material for collage matter.

explored in recent design project scholarship by architects such as Matter Design Studio, who's "Cyclopean Cannibalism," has leveraged digital scanning, stacking, and carving techniques to achieve geometric intricate interlocking between salvaged site-cast concrete. This project utilizes 3D scanning as a means of obtaining accurate measurements, which can then inform the development of finely-tuned cuts and patterns. The Concrete Masonry cluster research in a similar but different vein utilizes the scanning process to register the intricacy of masonry block parts, and rather than exploring cutting, then utilizes paste extrusion as a means of providing an infill bondwork to create a structural envelope solution.

PROOF OF CONCEPT

The above background served as the basis for an examination in the context of a design research studio at the principal investigators architecture education institution. Herein, the group of researchers developed a working methodology towards a proof of concept using a combination of intuition based physical modeling approaches, LIDAR scanning and clay 3d printing. The researchers chose to work with a common CMU Block typical to north american construction, measuring 8″x8″x12″, or nominally 7-⅝″x7-⅝″x11-⅝″. The team surveyed several commercial construction sites in their immediate vicinity to observe the types of CMU Block waste found in these locations. Following this, the team began a process of simulating a cache of precast concrete waste, as might be found on a typical construction or post demolition site, through the process of dropping, within a local construction lot as shown in figure 1.

Each piece was in turn numbered and categorized, based on its size, figural shape, geometry, mass and density. The group then utilized a FARO quantum max Scan Arm, to develop a laser scanned digital model of each piece of detritus, inclusive of its concave and inner boundaries as shown in figure 2.

The resulting spolia 3D point-cloud model based on this point cloud, which in turn was triangulated

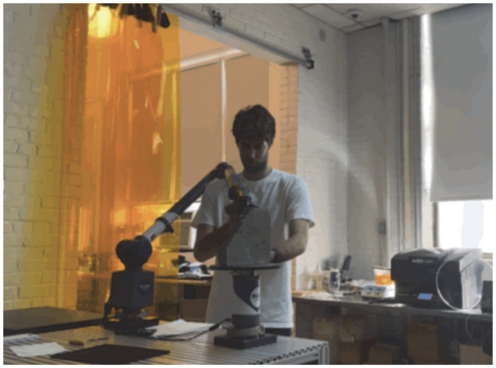
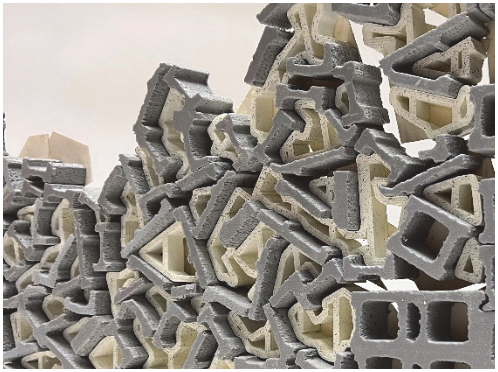


Figure 2
Researcher's using Faro Scanning arm to input Masonry Block.

into a 3D mesh model water-tight model that was initially scanned with 40,000-50,000 polygons. Following scanning, these complex meshes were reduced to 120,000-15,000 polygons, which resembled geometry within a 1mm tolerance.



Figures 3 + 4
Physical model with PLA and foam elements.

The mesh models were used to create a physical replica of each piece printed at 1:10 inch scale using PLA plastic for the purpose of model experimentation. A physical jig frame of 6 cm in width by 12 cm tall and 2 cm in depth was constructed to support the aggregation of the plastic replicas within in ways that would allow the design team to study the figure and ground pattern as shown in figures 3 + 4.

These figural infill blocks were then prototyped at full scale as individually extracted from XPS foam utilizing a 3 axis CNC router. The original cataloged CMU block detritus along with these brick inserts were then stacked to test whether the geometric bond-work aggregate would perform at full-scale. Following the success of this test, the foam blocks were made into 3d printed files for a 3mm nozzle clay paste extruder. Each infill block geometry in the digitally modeling environment was contoured in third dimension with a 2mm separation between contours to allow for interlayer adhesion. Vertical bars are again added at 5mm spacing to strengthen the rings along the vertical axis of compression, which are then unioned with the outer ring. The pieces were printed utilizing Stoneware Amaco 38 clay, on a 3d potter paste extruder mounted to a 6 axis IRB 2600, and then fired to cone 04 as bisqueware.

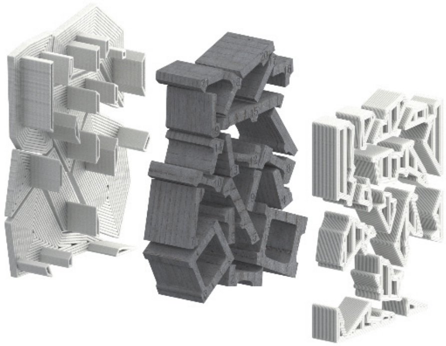


Figure 4
The 3 layers show the 3d printed infill on the left, the middle the spoliated masonry and a possible interior finish.

The final pieces were assembled with type S mortar mix, which for its high strength capacity and high density mixture to infill between the textural nature of the 3d-printed infill, see example in figure 5.

DIGITAL DROP COLLAGE PROCEDURAL REFINEMENT

Based on this proof of concept model the research team examined means of reproducing the intuitive stack based physics produced in real world models utilizing simulated physics engines to determine the structural possibilities of a complex bondwork. A digital process of simulating the natural resting position of the found detritus objects are proposed using the digital tool Rhino 7, parametric design tool Grasshopper, and rigid body simulation native to the Unreal Engine 5.1. The design team constructed a digital scene, into which the desired broken masonry pieces could be inserted as mesh objects, and then dropped into a constraining bounding box made of rigid bodies. The bounding box is constrained on the X and Y axis, with a plan of 60x22 cm. A floor of the bounding box is also provided as a rigid body, and no other constraint is offered in the Z- Axis. The simulation assumes that the resting state of equilibrium predicted by a series of objects dropped within the constrained boundary produces a state

Figure 5
Proof of concept model, provided with salvaged and infill panels 3d printed bricks as brought together by a mortar process.

that would mimic a structurally rigid bond-work framework.

The mass of each piece of salvaged masonry is determined through a calculation of the volume of the mesh, as multiplied by the density of conventional concrete masonry units, *2.4x10^3 kg m^-3.* The mesh objects of the desired salvaged masonry are arranged in a cartesian grid above the

boundary of dropping simulation, and the scene is exported for processing in Unreal Engine. Once imported into UE5, a collision box of 20-100 vertices is given to each mesh object for balance between accuracy and efficiency. This simplified bounding box provides the necessary resolution for the object's boundaries while avoiding jitter due to excessive collision of detailed models, see Figure 6.
A physics simulation is enabled, wherein each mesh object is provided with a load along the Z-axis akin to gravity. In the first trial, the mesh objects are contained from rotating, during fall, along the XZ plane as well as rotation on the Y axis, in order to study the resting aggregate of the mesh elements in a 2D scenario. In the second trial, similar constraints are offered, with the addition of a rectilinear rigid body placeholder, pre-added into the constrained bounding box. In this condition, the rectilinear place-holder demonstrates a desired placement of an aperture or potential window within the final aggregate. This placeholder does not have the load associated with it along the Z-axis and thereby the mesh objects react and fall around this object during transit. In a third trial, the constraints are removed to allow the mesh objects to tumble in all axes while dropping. Various drop configurations were tested for each of the three trials described above, including dropping the blocks in order from largest first to smallest last, smallest first to largest last, based on descending and ascending mass and volume, and from most complex surface area to least complex surface area. Simulation results are recorded in drawings when the physics simulation reaches equilibrium and each trial is run several

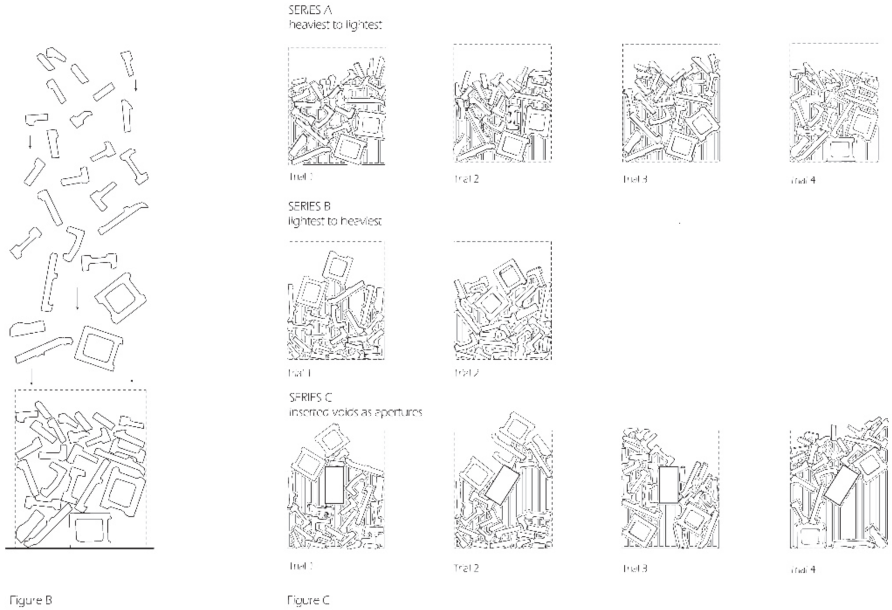


Figure 6
Matrix of various drop trials as shown at point of equilibrium.

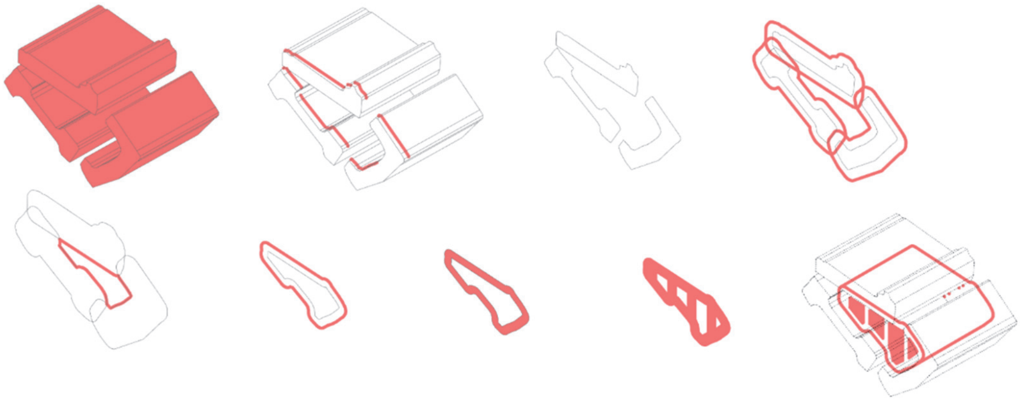


Figure 7
The 3d printed infill blocks and their 3d print files for the figure-ground pattern with spoliated masonry bond-work was programmed for auto-generation in grasshopper 3d.

times to explore the amount of variation that comes from incidental bounces and collisions. The resultant bond work is then exported back to rhino as a mesh model for the generation of the infill blocks.

Once returning to the modeling program of rhino and grasshopper an XZ plane is inserted that intersects through the network of the mesh objects generating a contour of each of the ground spaces within the figure -ground network. Each contour is then offset by 5 mm to provide a thickness and then this 5 mm outline shape is extruded along the y axis to form solid 5mm rings in the figural voids. 2.5 mm vertical bars are again added at 5mm spacing to strengthen the rings along the vertical axis of compression, which are then unioned with the outer ring. Finally, the algorithm generates a contour suitable for 3d printing from this solid geometry, with 4mm vertical spacing suitable for a 3mm paste extruder nozzle as shown in Figure 7.

CONCLUSION

This process that utilizes simulated physics for modeling different bond-work patterns of found material refuse demonstrates its facility for adapting to many configurations. The assembled concrete masonry clusters have the potential for deployment in many situations in terms of both new and old construction, both creating capacity to lower our intake of new materials in local conditions but also to suggest the life-cycle of material waste can be a continuous form of new aesthetic matter in envelope construction.

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Mycelium in Architectural Education

Digital Fabrication Reconsidered

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With supply chain issues and rising price of construction materials, mycelium can potentially provide reliable, eco-friendly and sustainable alternatives to traditional construction materials as substrates used for growing mycelium can contain almost any recycled cellulose: sawdust, used coffee grounds or paper. Characteristics of the final product are determined by substrate, mushroom species, the time of growth and further treatment of mycelium (e.g. high pressure forming). In this paper we describe semestral work of both students and tutors of an Experimental studio, focused on additive manufacturing together with rather novel sustainable materials. Students' semestral task was to find use cases for mycelium as a building element. As a part of the assessment they were tasked to come up with use cases, designs, manufacturing methods and finally build a mock-up model in 1:5 scale. Students intuitively started with the combination of digital modelling plus digital fabrication. In the end they finished with manufacturing the physical model traditionally, where they had to react to the change of the visual outcome of the model. Firstly, we present the students' solution for the mycelium material used in their model, next, we describe our observation of the whole process of letting students go through "learning by doing" research, Finally, we present lessons learned in this experiment.

Keywords: *Architectural Education, Digital Design Reconsidered, Mycelium.*

INTRODUCTION

This paper describes semestral work of students and tutors in an experimental studio focused on new manufacturing techniques together with sustainable materials (Jones et al., 2020). The overall aim of the studio is to introduce students to innovative materials, to encourage them to experiment and to explore possibilities of a material they have not worked with beforehand. Important part is also final mock-up construction, at which students test their conjectures in the practice. A task for the aforementioned semester was to design a tiny house built mostly out of mycelium as a new experimental and sustainable material.

Mycelium as a sustainable material in architecture

Nowadays, when there is an increased emphasis on the use of materials that are renewable and their production leaves a low carbon footprint, the use of mycelium-based materials (MBM) represents a very promising way forward. MBM combines many properties in one material that are interesting in terms of use as a building and decorative material in architecture and interior design. Its production is less energy-intensive than other building materials like rock wool for example. Sources for production are lignocellulosic substrates from agriculture and forestry, and secondary raw materials can also be used to produce upcycled materials based on mycelium. MBM can be easily shaped by moulding, as tested by Jones et al. (2018) it burns more slowly than other polymers, can be used as a heat insulator as describe Shao et al. (2016) and according to Pelletier et al. (2013) it can act as a sound absorber. We must not forget one property that can cause some problems, which is its water absorption as described by Appels et al.(2019).

The above-mentioned properties predestine this material for use in construction and interior design. MBM appears to be a suitable material for the production of interior acoustic panels. Commercial products are offered, for example, by the company Mogu. The properties of this material can be used architecturally not only as a substitute for commonly used building materials and solutions but can also influence the actual design of buildings. In the recent past, several experimental buildings have been constructed using composite materials by Almpani-Lekka et al.(2021) or by Ghazvinian & Gursoy(2022). Due to the softening of the mycelium in higher humidity environment described by Appels et al.(2019), all these buildings use some form of skeleton, be it the internal iron Hy-fi Tower by David Benjamin with Ecovative and ARUP as you can be seen in an Clark, Saporta (2014), the external wooden frame The Growing Pavilion by Pascal Lebouq and Erik Klarenbeek as seen on the pavilion webpage About the growing pavilion (2022), or the internal wooden structure of El Monolito Micelio by Dessi-Olive (2022).

Studio and goals

The topic for the semester was to design a tiny house or a shelter-like structure with long-term living qualities out of mycelium. The design was required to be transportable on a truck, therefore its size or size of its parts had to meet the dimensions 2,3x6 m.

To kickstart the designing process and to set up a sufficient knowledge base tutors organised lectures from experts, giving detailed presentations on MBM characteristics, its potential use cases and how it has to be treated while forming, growing and drying. The students were then asked to do a state of the art presentation and share their knowledge with the studio colleagues to understand and discuss existing projects and to see what has been done so far. After the presentation of the references, the students came up with their own concepts and solutions for the topic. The consultations were done collectively so the students could react to the design of others and shared problems and outcomes of one's solution. One month was dedicated to experimental fabrication. In order to engage students in experiments, the manufacturing method of the final design was not specified, but the students were encouraged to explore multiple possibilities and to find what they thought was the best technology for their design. With obtained knowledge students voted which one design they will manufacture in 1:5 scale out of the mycelium.

MATERIAL AND MANUFACTURING

Most of the students turned to 3D printing as their fabrication method of choice, which we observed as an interesting phenomenon. At first glance they probably didn't realise the caveats of 3D printing and they hoped 3D printing would save their effort of coming up with a more complex manufacturing method.

In order to learn about the material behavior, students were encouraged to try 3D printing mycelium with a standard desktop delta printer and custom-built piston extruder (Figure 1).

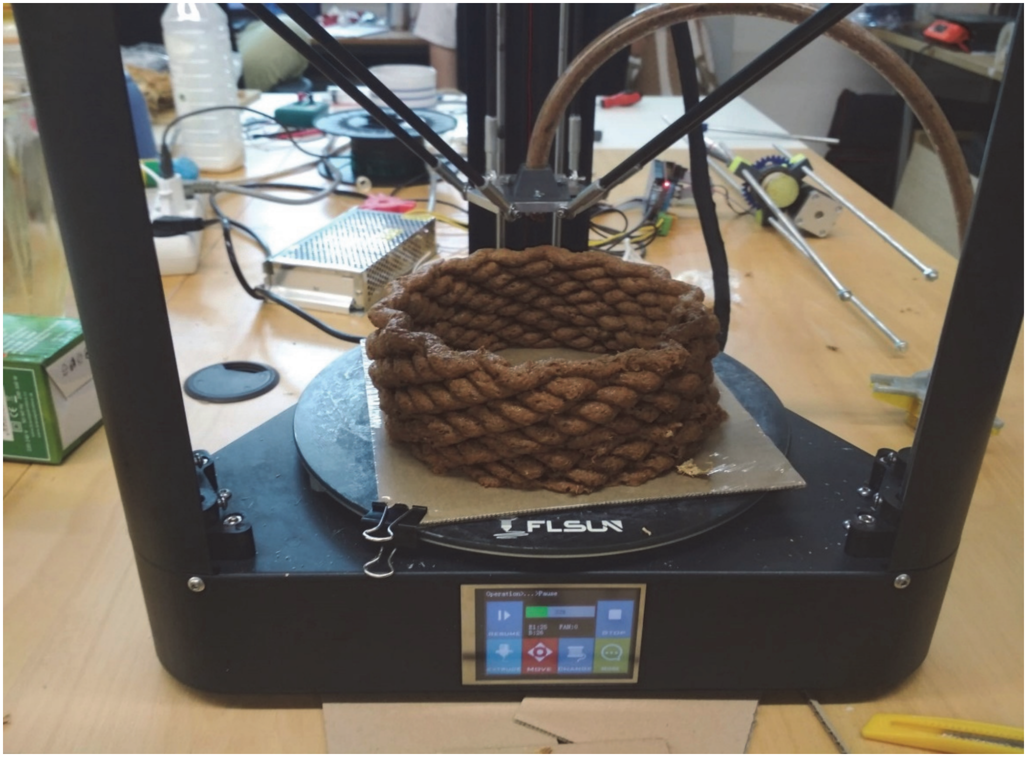

Figure 1
Mycelium printing test on standard delta printer setup

Layer height was set to 4 mm with 7 mm thick nozzle, final layer thickness was measured to be 8 mm. Material used for printing was a mixture based on the recipe by Bhardwaj et al. (2020), consisting of wet sawdust and wood flakes already grown through with mycelium. 5 kilo of this mixture of was then mixed and sieved to remove big particles. 200 grams of flour and 200 grams of psyllium was added to introduce more food sources into the mixture. An additional 2 litres of water and 400 grams of xanthan were added to improve the material printability. Without a sufficient amount of xanthan, material got stuck inside the tank.

During the initial testing, it was observed that this material has a poor buildability. Experimental shape - cylinders of diameter of 15 centimetres - started collapsing at approximately 8 cm height. After assessing usability and advantages of mycelium-based materials, students came up with a different manufacturing method, where the final model was divided into small blocks with lower than maximum printable height. Those would be left to grow for 1 week on their own. After this growing period, bricks with mycelium still alive would be assembled together. By letting them grow further, still single elements would grow into a monolith, serving as a mortarless construction.

Students anticipated that this approach would give them design freedom. However, while growing, some bricks were infected by mould. If such bricks were assembled, mould would spread and grow onto all of them. Discretization and manufacturing of redundant bricks would solve this issue, but it would also prolong the designing, printing, and assembling process by weeks due to the inoculation and growth cycle - described by Jones et al. (2020). This and the fact that measured shrinkage after drying was over 30% led students to develop a different fabrication method than 3D printing.

After 3D printing was proven to be ineffective, students had to redesign their projects. It was remarkable how they rationalised and simplified their designs, taking into account different manufacturing methods, like e.g., moulding.

Reevaluation resulted in the new approved design together with fabrication method. Students implemented an idea of making planar panels moulded into triangular frames, made of 2mm thick cardboard, which were expected to become structural formwork (Figure 2).

As a material for production of the panels, the mycelium of the Ganoderma lucidum strain M9726 obtained from Mycelia NV was used. Beech sawdust 31%, 4% wheat seeds and 65% H_2O were used as substrate. The substrate was then sterilised in an autoclave for 2 h at 121°C and 15PSI. The sterilised substrate was inoculated and cultivated at 21°C for one month. The fully colonised substrate was then ground and filled into prepared forms. These filled moulds were further cultured for one week at room temperature. Subsequently, they were dried for 1 h at 80°C to inactivate the mycelia.

The theory of mycelium inhabiting cellulose rich formwork showed up as successful and mycelium grew into it during the growing period. Together with the application of cardboard frame the shrinkage of the mycelium was reduced to minimum.

An experimental model for a full scale 1:1 scenario where wood was used for the form was set up as well, but it failed due to extensive and quick growth of mould. We suspect, due to the location of the appearance of the mould, that it could have been caused by insufficient treatment of the wood and leftover mould spores.

Figure 2
Students filling forms with inoculated substrate

One of the students also experimented with another approach of forming mycelium. The idea was to achieve three-dimensional shaping by laying mycelium over fabric that was suspended on strings and stretched into desired 1x1 meter shape using gravity (Figure 3).

Figure 3
Forming of the mycelium on gravity-shaped fabric form

DISCUSSION

After the end of semester, students were asked for feedback and from their replies it turned out that they mainly enrolled for the studio because they were excited to work with new eco-friendly material. Students described working with mycelium as a completely new experience. Some of them were surprised by the fact how many different ways it can be used – as load-bearing material or as heat or sound insulation. But in the beginning of the semester they didn't realise how much work was needed to first test and understand the new material. Since we as teachers also don't have experience with the use of this material in architecture, the whole studio had to conduct research by experiment approach. That was a bit overwhelming and time demanding for students and later during the semester they felt they can't submit in time. Time management of the studio had to be taken into account. Students usually finish their models as the last part of the studio submission at the last minute. When working with mycelium, they had to be ready with the model 3 weeks before the deadline (Figure 4). Plus manufacturing conditions were not typical - all work had to be done in a special lab. This was a lesson students learned.

Figure 4
Final delivery of the students – 1:5 mycelium model and their initial designs (1:50, PLA)

The students also expressed hopes that there will be developed a solution for water protection in the future that would allow mycelium composites to be exposed on the exterior. During the design stage we noticed that susceptibility of mycelium to moisture was a crux of many students' designs and that some were having trouble working around those limitations and changing their approach. The common element of those designs was an effort to use mycelium similarly to béton brut (raw concrete) and showcase it as a design element.

At the beginning of the semester, we observed too much attention focused on 3D printing and too high expectations of students from this manufacturing method. This was probably due to their belief that 3D printing can easily manufacture any shape without much thinking about the construction process. If students were introduced to the issues of mycelium 3D printing earlier, it is possible that they could have concentrated on coming up with a more detailed manufacturing plan, possibly other than 3D printing. We value the decision of students to change the approach and manufacturing method during the process. This decision was based on their newly gained experience in working with mycelium and it led to a successful fabrication of the 1:5 model.

Regarding 3D printing of bricks, we still see a great potential in such an approach, but a better mixture has to be developed. It should probably be mixed into a more homogenous mixture containing less water and less xanthan. On the other hand, moulding into paper forms proved to be a viable option and it should be tested on a real scale.

At the end of the semester each student managed to deliver a viable design showing a potential way of using mycelium as a building material.

CONCLUSION AND FUTURE WORK

Our goal of the next experimental studio is to continue with mycelium research, where we implement the knowledge of the material (time of growing, lab conditions) and focus on digital manufacturing technology. In incremental steps, each semester students will be following the findings of the previous era with the aim to improve buildability of 3D printed mycelium. The goal is to fabricate a 1:1 scale model, where we can measure material resistance to weather and quality of an interior environment.

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REFLECTIONS ON THE RIS 2023 SYMPOSIUM

Closing the Gap Between Research and Practice for Sustainable Urban Densification

Experiences and Findings from the RIS2023 Workshop

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More than the half of world population live in urban areas, and there will be an important need to densify cities. Urban densification will lead to cities with higher level of obstruction due to new surrounding buildings compromising daylight, energy consumption, view out, solar access among others sustainability aspects, which are often in conflict during renovation and early design stages of urban areas. There are novel fast design workflows based on prediction formulas that do not rely on the traditional and time-consuming approach based on daylight/thermal modelling-simulation. The main aim of this 7-hours workshop celebrated within the RIS23 international conference is to teach young designers how to use a novel urban densification method based on prediction formulas implemented as Grasshopper plug-ins in Rhinoceros. This paper describes the motivations of this workshop, a brief explanation of the design workflow taught and the different densification strategies proposed by each participant, highlighting their pros and cons as well as feedback of the design workflow itself.

Keywords: *Education, Workshop, Future Cities, Human Comfort, Daylight, Building Massing, Urban Planning*

INTRODUCTION

The 80% of the world population will live in cities by 2030 (Sanaieian et al., 2014). Cities will need to be densified, increasing the level of obstruction of facades: urban planners and designers can face several challenges related to sustainability aspects. One of the main sustainability aspects is to reach a balance between indoor and outdoor thermal comfort (De Luca et al., 2021). Daylight provision and solar access (SA) are two key factors of human health in buildings (Lockley, 2009), as they influence on circadian cycles and human's psychological and physical well-being (Batool et al., 2021). Thus, a sustainable urban densification could be a real challenge, even for experience practitioners if a suitable design workflow is not applied.

Human-centric design techniques

In practice, the functions that could be in conflict in a specific design depend on the building use(s) (Table 1). For instance, residential spaces should have enough daylight provision, view out, solar access, and overheating protection. However, for office spaces, solar access might not be such critical as the glare protection or overheating protection. Commercial indoor spaces might only need glare protection and overheating protection, since the contact with the outside can distract costumers from their attention to products. In educational buildings the solar access might not be needed as could provoke discomfort glare in students while attending lectures whereas in computer labs or conventional auditoriums.

The concept of the solar envelope (SE) is not new, and it has been used for decades to propose building massing without compromising the solar access rights of the existing buildings (Knowles, 1980). Indeed, SE as its evolution, the novel Reverse Solar Envelope (RSE) have been included in several design workflows in order to consider SA during the design process including single plots buildings (Sepúlveda & De Luca, 2020), residential clusters on multiple subplots (Sepúlveda & De Luca, 2022b), trade-offs between energy consumption and solar access (De Luca & Sepúlveda, 2023; Sepúlveda & De Luca, 2022a), facade optimization to balance daylight and overheating protection using machine learning (Sepúlveda, Eslamirad, Salehi, et al., 2023), rules of thumb (Sepúlveda, Salehi, et al., 2023) or solely prediction formulas (Sepúlveda, Eslamirad, & De Luca, 2023). In summary, the use of performance-driven design is being more common nowadays when simulation-tools are more developed/validated, documented, affordable, and accessible than in the past.

Aim and novelty of this investigation

The main novelty of the RIS2023 workshop was the teaching of a fast and flexible design workflow based on prediction formulas to densify urban areas (Sepúlveda, Eslamirad, & De Luca, 2023). Within the context of the RIS2023 workshop, this investigation aims to answer the following research questions:

- How useful would be the multi-performance design method for future cities?
- How compatible is the design workflow with the designer's creation process?
- Is it possible to teach this urban densification method in a 7-hours workshop and meaningful design proposals from it?

METHODOLOGY

Target group and workshop structure and

Six participants attended the workshop (Figure 1) using their own laptops. All participants have a background in architectural/engineering-related field. They were one PhD student, one MsC architect, two Master students, and one bachelor student. The tutor developed Grasshopper plug-ins for Rhinoceros and shared it with the participants. The installation of the plug-ins was done within the first 30 min of the workshop. The effective duration of the workshop was 7 hours. Two coffee breaks of 15 min each and a lunch break of 1.25 h.

Figure 1
Workshop´s participants working on the urban massing stage.

Design workflow

The design workflow is part of the performance-driven densification method recently proposed by the author (Figure 2). It consists of 6 steps.

- Step 1: The generation of the trimmed reverse solar envelope (tRSE) (Sepúlveda & De Luca, 2022b) within the urban block plot;

- Step 2: The designer should define different massing proposals according to different subjective design criteria;

- Step 3: SA and obstruction analyses needed by the prediction formulas (Sepúlveda et al., 2022);

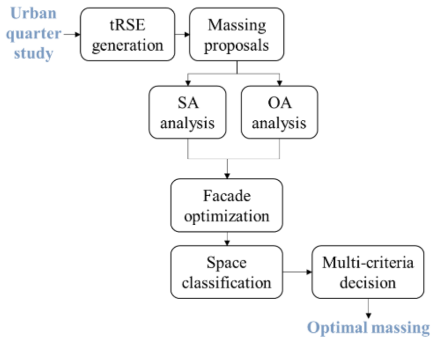

Figure 2
Workflow followed by the participants. tRSE=trimmed Reverse Solar Envelope, SA= Solar access, OA= Obstruction angle.

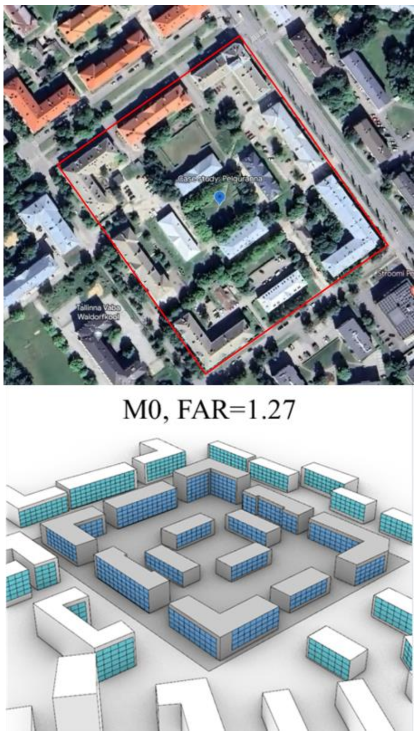

Figure 3
Top view of the urban quarter study (upper figure) and existing building massing distribution (M0). FAR=Floor area ratio.

- Step 4: Facade optimization consisting on the definition of the optimal glazing properties (g-value and visible transmittance (Tvis)) for each potential room in order to maximize the indoor space with enough daylight provision according to the designer's criterion;

- Step 5: Indoor space classification per building use (residential, office, and auxiliary/retail) depending on the room depth and SA level.

-Step 6: Selection of the building massing strategy whose overall performance (OP value) is based on FAR related to different building uses when different design criteria (e.g. 50%Residential-50%Office, 100%Residential, 100%Raw volume, 33%Residential-33%Office-33%Commercial, etc).

CASE STUDY

Our case study is an existing urban block located in Pelguranna neighbourhood located in north-west part of the capital of Estonia, Tallinn. The urban block has 12 residential buildings (Figure 3) of height ranging from 13 to 24 m. (Lat. 59.451◦ N, Lon. 24.693◦ E). Tallinn has a warm summer humid continental climate (Dfb) according to Köppen-Geiger classification (Climate onebuilding, 2022). The average annual temperature is +6.4°C and the average temperature during the warm season is +16.2°C (Estonian Weather Service, 2021). The existing FAR of the urban quarter (M0) was 1.27.

RESULTS

Participants´ performance

From the initial 6 participants who registered the workshop, the bachelor student quit because she thought the scope of the workshop was more related to parametric aesthetic design in architecture.

The PhD student had problems to follow the design process from the beginning due to a lack of experience with Grasshopper and Rhinoceros, which was essential to could follow the workshop. One of the Master students did not share the massing proposal and the other three sent their massing proposals (all of them respect the solar access rights of the surrounding buildings) and explained their massing strategy (Figure 4):

- M1 (MsC architect): It was inspired in the typical urban distribution in rectangular quarters with courtyards (e.g. Barcelona city). The densification (FAR=2.28) comes with a high increase of the level of obstruction with respect M0.
- M2 (Architecture master student): It was inspired by local Estonian rules of thumb based on minimum distance between buildings. The distribution of the building volumes was set to linear and the dependent height with the tRSE. The densification (FAR=2.58) comes with an increase of the level of obstruction with respect M0.
- M3 (Engineering master student): It was based on creative footprints and massive volumes located where the tRSE allows maximum buildable height. The densification achieves a FAR of 2.5 and the level of obstruction is higher than in M0 due mainly to the proximity of the volumes with the surrounding buildings, themselves as well as the inner courtyard of the hexagonal-base volume.
- M4 (Tutor): It is based on the maximization of the length of 20 m-width and 28 m-height linear buildings contained in the tRSE. In addition, secondary criterion where the maximization of the distance between buildings in order to not have parts of the facade with mean obstruction angles higher than 35°. The target FAR is this case was 2, thus a small linear building was added in the NW corner to not decrease SA of the rest of proposed buildings of the plot to reach this FAR value.

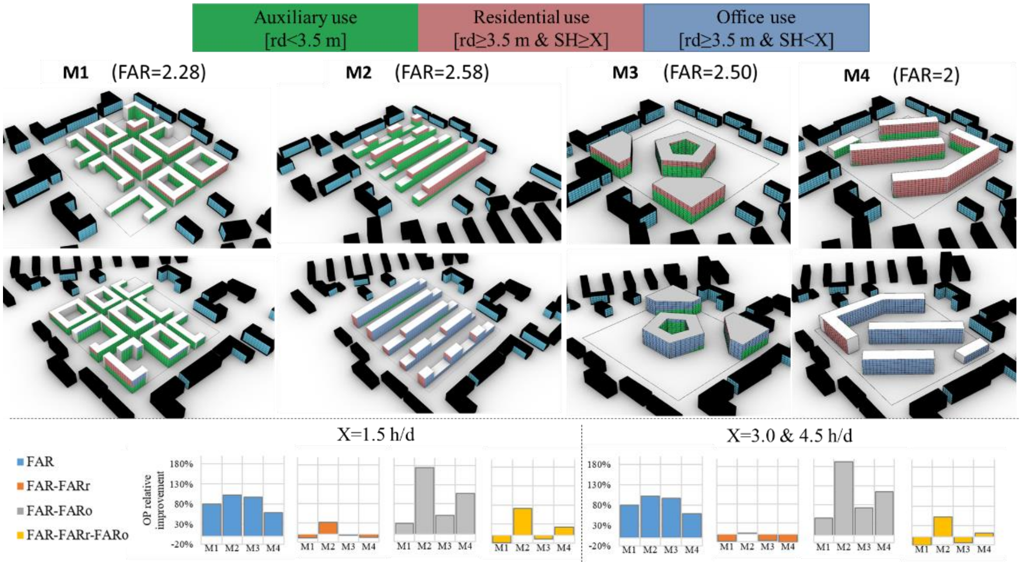

Figure 4
Densification strategies proposed by participants (M1, M2, M3) and the lecturer (M4). South-oriented side is shown in first row. SH= number of daily sun hours, rd= room depth, FARr= FAR related potential residential spaces, FARo= FAR related to potential office spaces.

Design proposals comparison

Considering a design criterion based on raw volume (FAR) (Figure 4), M1, M2, M3, and M4 can increase relatively the existing OP by 80%, 103%, 97%, and 59%, respectively. The best design proposal in this case is M2 and M4 the worst one.

Considering a design criterion based on a trade-off between volume and potential office use (FAR-FARo), M1, M2, M3, and M4 can increase relatively the existing by 28-45%, 174-194%, 49-71%, and 107-114%, respectively. According to this design criterion, the best and worst design proposal are M2 and M1, respectively.

Considering a design criterion based on a trade-off between volume and potential residential use (FAR-FARr), the improvement of OP is much lower than for previous cases and dependent on the target solar access level (X). For X=1.5 h/d only M2 improve the OP by 31%. However, this OP improvement is just 3% when X=3h/d or 4.5h/d. The other design proposals reduce the OP related to M0 by up to 22%. According to this design criterion, the best and worst design proposal are M2 and M4, respectively.

Considering a design criterion based on a trade-off between volume, potential residential-office use (FAR-FARr-FARo), there is only OP improvement for M2 and M4: for X=1.5 h/d M2 and M4 improve the OP 71% and 22%, respectively, whereas for X=3.5-4 h/d, the OP improvement is 51% and 10%, respectively. The consideration of M1 or M3 would decrease the OP by 9-21%. According to this design criterion, the best and worst design proposal are M2 and M1, respectively.

In summary, it can be said that M1 is not a good strategy for target uses different than commercial/auxiliary. M2 has proved to be a good massing strategy in terms of volume, residential use, and mixed-use urban quarters. M3 and M4 result can be acceptable designs depending on the distribution of the residential and office spaces within the urban quarter. As can be seen in Figure 2, office spaces tend to be located in parts of the facade with low solar access level and not too obstructed (at least a room depth of 3.5 with enough daylight level).

CONCLUSIONS

From the workshop final design solutions and learning experience of the participants, the following conclusions can be drawn:

- Multi-performance design methods are key for future cities where different comfort domains will be in conflict, depending always on the building use distribution of new and renovated urban areas.
- The creative process during design early stages was supported by the taught design workflow. The participants felt in control with their design decisions during the densification exercise proposed in the workshop. Exercise and felt guided through the challenging process of evaluating their massing strategies.
- The parallel learning and application process of the design workflow by participants was crucial to find optimal building massing strategies depending on the target building use of the urban quarter in less than 7 hours of effective design time.

Future steps

In future investigations it would be beneficial to teach the design workflow to a greater number of participants with different background and professional experience. The design workflow used in this workshop will be available as open-source plug-ins for Grasshopper. In this way, practitioners and designers could conduct faster urban densification plans in existing and new urban zones. In addition, the content of this workshop will be included in the course “Human-centric methods for urban densification” designed by the tutor/author as part of the courses offered for Architecture master students by the lab "Architecture and Intelligent Living" in Karlsruhe Institute of Technology (KIT), Germany.

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Algorithm Morphogenesis by Solar Parameters and Model Fabrication of a Temporary Architecture

Workshop Educational Experience

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The study reports on the results of a one-day workshop held during the RIS23 conference. The proposed exercise concerns the design and construction process of a temporary architecture optimized on solar parameters for the climatic adaptation of urbanized and natural open spaces. The morphogenesis is obtained on the data of solar vectors in relation to climatic comfort and the shadow optimization. Rhino / Grasshopper / Ladybug are the adopted software. The process results in 1/30 scale cardboard models customized on the climatic data of three locations. Shade analysis of the models by Heliodon concludes the workshop.

Keywords: *Workshop, Climate Change, Temporary Architecture, Algorithmic Design, Shadow Analysis, Heliodon.*

INTRODUCTION

Climate change (EEA, 2017) significantly affects urbanized spaces (Kumar, 2021) (de Sherbinin, Schiller, & Pulsipher, 2007). Design models based on morphogenesis by environmental parameters have valuable potential in the development of architectures that counteract the negative effects of climate discomfort (Elnabawi, Hamza, & Dudek, 2015) (Emmanuel, 1993) (Naboni, et al., 2023) (De Luca, 2019).

In this study, we report on the experience of a training workshop where a temporary architecture composition, modeled in algorithmic design (Oxman & R., 2014) using solar parameters, is constructed in 1/30 scale physical models. These models were then subjected to a shadow study using a Heliodon (Rogers, Day, & Balcomb, 1983) (Figure 6). The workshop is part of the organization of the RIS23 conference held at Taltech, Tallinn University of Technology. Participants included researchers from various countries and some local students.

AIM

The aim is to develop and disseminate useful strategies for climate adaptation temporary architecture in urbanized and natural open spaces by algorithmic design. The didactic proposal is functional for the dissemination of these topics and at the same time is a good opportunity to test the validity of the process with experienced researchers and young students.

METHODOLOGY

The proposed methodology refers to actions carried out during a single-day 6-hour workshop. The topics are proposed and experimented during the workshop to convey a method of experimentation and verification. The experimentation by participants with experience and training is intended to enrich the course and

help discover the flaws and potentialities of the process itself.
The working time is divided into 4 parts of equal length:

- algorithm project;
- customization of the project;
- model fabrication;
- shadow analysis;

The labor is calibrated for the short time frame of the workshop. Some steps in the design and construction phases are simplified to achieve useful results in the time available. Despite these simplifications, each participant fully experiences the customization, model building and shadow analysis phases.

Algorithm project

The algorithm project is developed at a stage prior to the workshop. It is part of a larger research work, which aims to create a temporary architecture for optimizing the conform of outdoor seating The software employed are Rhino Grasshopper and Ladybug (R. McNeel & Associates, n.d.).

The climate data in the preliminary design are for the coordinates and climatic conditions of the city of Parma, Italy. The reference climate data is the UTCI index (Bröde, Jendritzky, Fiala, & Havenith, 2010). Based on this datum set as a reference, the periods of the year and the day that do not meet the predetermined comfort level emerge. These periods of the year and day are translated into a geometric model of the sun path, and the vectors of the sun's rays matched to them are the generating parameters of the project surface.

The morphogenic result is a circular plan architecture, with diameter ranges from 5m to 10m and height from 3.5m to 6m. The surface is larger on the east to west sides than at the top. The west side surface is wider than the east side one. The single surface rotates on itself and is stopped at the edges of a circular base, where the arc-shaped seats are placed. For the construction of the model, this single surface is discretized into bands of varying width. Each band works structurally as a single arch; this proposal is valid for the 1/30 scale cardboard model. For full-scale construction, consolidation should be created for the discretized bands to ensure proper stability.

The parts of the algorithm are described step by step in the first part of the workshop. Participants have various levels of knowledge of Rhino Grasshopper Ladybug software, some are experienced, some have a beginning level, and some have no previous experience with algorithmic generative software. They are helped to achieve an understanding of the project; group work is proposed so that skills are balanced to achieve the objective.

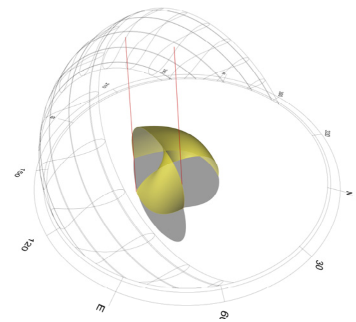


Figure 1
Digital graphic of algorithmic project. In yellow the optimized surface. In red the sun vectors. In gray the shadow.

Project customization

The design algorithm has some fixed and some customizable parameters.
The fixed parameters are:

- the circular base;
- the surface wrapped around itself;
- the discretization of the surface in bands;
- the arched benches on the east and west sides;

The customizable parameters are:

- the geographical coordinates;
- the range reference data for climatic comfort;
- the dimensions of the base circumference and height of the structure;
- the number of bands (linked to the width)

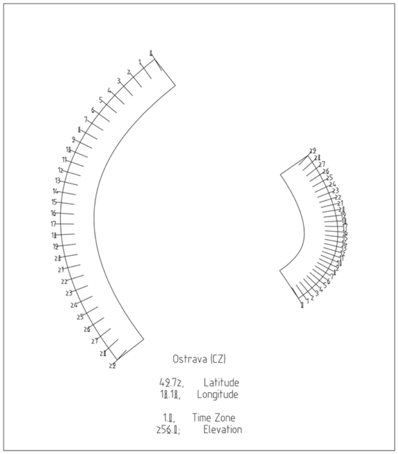


Figure 2
Base of the project for Ostrava (CZ). Printable file.

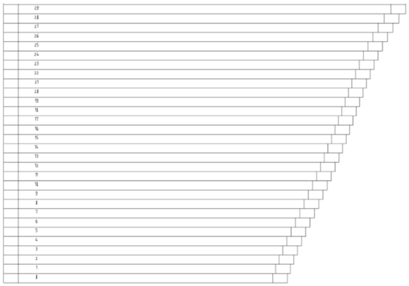


Figure 3
Strips of the project for Ostrava (CZ). Printable file.

The choice of coordinates makes the project suitable for a specific location. This is an important aspect of the experimentation because the solar path has great variations between latitudes, and the experiments during the workshop help to understand the behavior of the design in various cases, including borderline cases. Depending on the geographical location, the climate data also change, and so do the generating parameters.

Changing the dimensions and proportions between parts helps to make considerations about the architectural composition and the relationship with any other built elements. The number and size of the bands into which the surface is discretized is closely linked to the construction of the work. In the 1/30 scale model to be realized in cardboard, the variations can still be quite arbitrary and even contemplate extreme solutions with a few very wide strips or many narrow strips. This is a good exercise to understand the limits of the design, but for an actual full-scale realization a special study is required, considering the characteristics of the material.

The project emerges from the selected parameters with a morphogenesis approach. From a common genotype project arise as many phenotypes as the participants' project proposals.

Model fabrication

Model fabrication is optimized in relation to the time and tools of the workshop. The dedicated time is approximately 90 minutes. The tools available are an inkjet printer for sheets of size ISO A3 (29.7x42cm), tools for manual cutting. The material available is cardboard of size ISO A3 and grammage 200 g.

In connection with these tools, the three-dimensional design is organized to be developed into two-dimensional drawings. These drawings comprise the boundary base (Figure 2) and the strips (Figure 3) that make up the discretized surface. The 1/30 scale proposed for the models was previously calculated as the most suitable in relation to the dimensions of the ISO A3 cardboard sheets available. Participants print the two-dimensional drawings relating to their project on cardboard and proceed to manually cut (Figure 4) the elements, then complete by assembly the parts (Figure 5) to create the 1/30 scale model. The use of an inkjet printer guarantees the precision of the creation with manual cutting. The same cutting operation can be carried out by a laser cutter. The assembly of the parts helps to understand any defects in the project and helps to focus attention on the construction phases, which should not be underestimated.

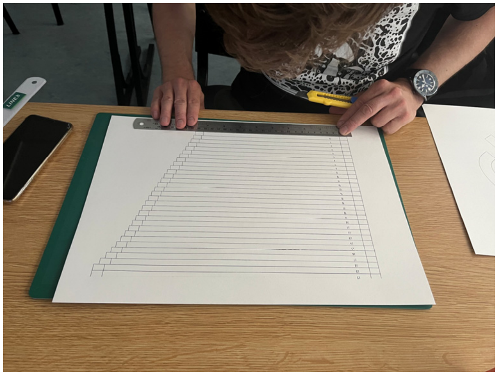


Figure 4
Manual cutting of cardboard model

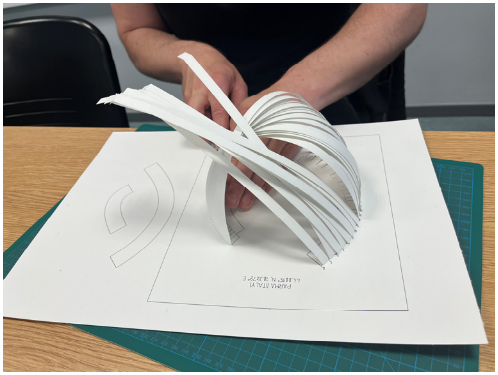


Figure 5
Manual assembly of cardboard model

Shadow analysis

The models created are subjected to a shadow analysis with the Heliodon of Tallinn University of Technology (Figure 6). This instrument is manually programmed for different geographic latitudes and period of the year and times of day. For the analyzes in question, the summer solstice (21 June) was chosen with the hours from 10.00 to 17.00.

RESULTS

The workshop participants organized in groups created three projects and related 1/30 scale models. The projects were developed in relation to three locations, with coordinates different enough from each other to create appropriate diversification. The locations are:

- Tallinn (Estonia) 59.4370° N, 24.7536° E
- Ostrava (Czech Republic) 49.8209° N, 18.2625° E
- Parma (Italy) 44.8015° N, 10.3279° E

The dimensions of the architectures, the number and thickness of the bands into which the generative surface is divided, and the reference UTCI (Bröde, Jendritzky, Fiala, & Havenith, 2010) (Matzarakis, Muthers, & Rutz, 2014) comfort parameters were chosen by the participants. These data, combined with the geometric data of the solar path and of the solar vectors corresponding to the solar rays, generated the three projects through a morphogenesis process. Analyses of the shadows relating to the three models were conducted with the Heliodon (Figure 6) (Rogers, Day, & Balcomb, 1983) in the period of the summer solstice (21 June) from 10.00 to 17.00. Photos (Figure 7, 8, 9) and video are taken to collect the shadow results.

Figure 6
Heliodon. Tallinn University of Technology

Figure 7
Project for Tallinn (EE). Shadow analysis on 21 June – h 10:00 - 17:00

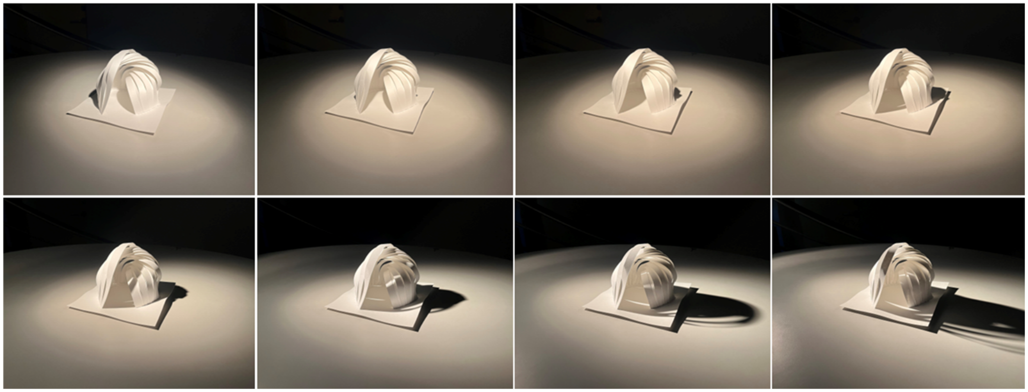


Figure 8
Project for Ostrava (CZ) Shadow analysis on 21 June – h 10:00 - 17:00

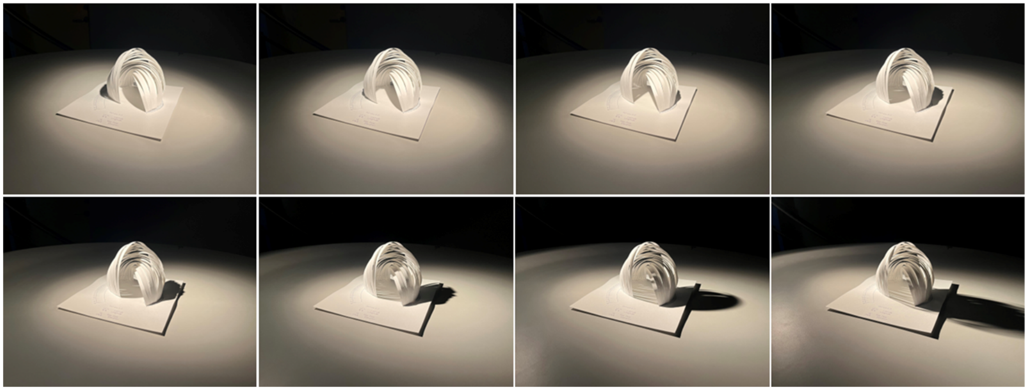
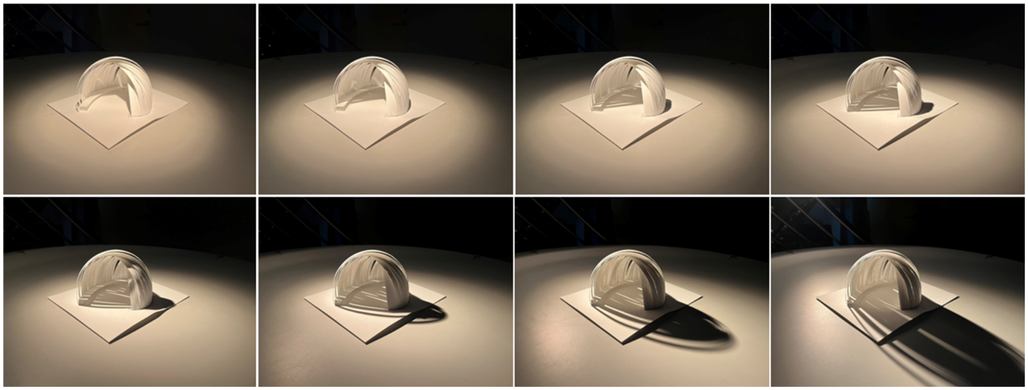


Figure 9
Project for Parma (I) Shadow analysis on 21 June – h 10:00 -17:00



DISCUSSION AND CONCLUSION

The educational experiment demonstrated that a simplified process of morphogenesis on environmental parameters can be addressed and understood by participants with different levels of knowledge of the topic. The creation of phenotypic variants of the genotype project revealed some observations.

Work with the possible variables of the algorithmic genotype design led to appropriate examples at different latitudes. In all cases examined, the predominance of the vertical surface on the east and west sides favoured the optimisation of shadow spaces.

The construction phase (Figure 3) of the scale model highlighted the need to define the assembly order of the bands that make up the surface. The most appropriate order is from longest band to shortest. This observation will be very useful in the assembly phase of the full-scale work.

The use of Heliodon (Figure 6) for shadow analysis (Figure 7, 8, 9) has very positive results in the teaching phase. In fact, nowadays there is a very widespread use of digital tools, which simplify and speed up the various phases of the work. Shadow analysis can be conducted with various CAD software and also, within the Rhino / Grasshopper software, the LadyBug plugin is widely used.

Combining digital tools with physical machinery such as the Heliodon can be an excellent support in learning phase. Physically moving and manoeuvring the solar path, the lamp representing the sun, setting the latitude and the time of year: all these actions have a greater impact on the understanding and memory of the processes linked to shading. The lower precision of physical instruments is compensated by the greater understanding of the phenomenon.

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Challenges and Ways Forward for Performance-driven and Simulation-based Computational Design for Sustainable Cities and Communities

Reflections on the RIS 2023 Theme

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Cities are among the main responsible of the environmental crisis and the quality of urban life is endangered by climate change and the increasing urbanization. Architects needs efficient design tools and methods to improve the climate adaptation, healthiness and resource efficiency of the built environment. Performance-driven and simulation-based computational design can support them in this task. This short paper discusses the challenges and ways forward in the use of simulation, computation and analysis methods and tools for the realization of sustainable cities and communities.

Keywords: *Computational Design, Performance-driven, Simulations, Urban Design.*

INTRODUCTION

Cities and the built environment are directly responsible of global crises such as climate change and global warming (IPCC, 2023). Cities produce more than 50% of the world's greenhouse gases and utilize 75% of the energy produced on a global scale (UN-Habitat, 2023). These numbers are expected to increase with the increasing of the urban population from today's 55% to 68% in 2050 (United Nations, 2018). Human health in cities is undermined also by phenomena such as the urban heat island effect and air pollution. The quality of life is influenced by social liveliness and economic activity of districts and accessibility of public areas.

To solve the global crises and improve social justice, human health and guarantee a better future for all, several international initiatives have been launched. The United Nations proposed 17 Sustainable Development Goals some of which are related to cities urging the adoption of strategies for implementing solutions for inclusion, safety, resource efficiency, resilience, mitigation, and climate change adaptation, the main of which being Goal 11 Sustainable Cities and Communities (United Nations, 2015). The European Green Deal and the New European Bauhaus are programs with the objective of a carbon neutral society by 2050 and of inclusive and sustainable cities. At the same time countries adopted detailed building regulations, private initiatives created comprehensive sustainable building rating systems and researchers developed environmental key performance indicators and metrics, simulation software, computational and environmental design tools.

Although the global efforts by institutions, undertakings and the scientific community to create frameworks, guidelines and tools several challenges still exist. These are related to the complexity of finding design solutions in consideration of factors such as building structures and materials, variable climatic conditions, indoor and outdoor spaces use, human preferences, energy demand and supply. To tackle the challenges, current research efforts are developing methods and workflows to help designers and planners to realize healthier buildings and climate neutral cities.

In the following sections, the challenges and the opportunities related to performance-driven and simulation-based computational design for sustainable cities and communities are presented and briefly discussed.

CHALLENGES

Through the integration of climatic, environmental, energy and comfort simulations in consideration of urban geometries, building use and materiality to assess performances related to human well-being, carbon emissions, energy use and generation, the potential of computational design is to enable the development of workflows that take into account the built environment, humans, and natural systems. However, several challenges exist.

Holistic approaches

There is a growing body of research work that evidence that to improve sustainability of the built environment we have to shift from investigating solutions with the only objective to improve the energy efficiency of buildings to considering comprehensive principles of indoor environmental quality (Altomonte *et al.*, 2020). These take into account all the factors influencing wellbeing and human health in buildings such as thermal comfort, daylight provision, glare risks, visual contact to the outside, and acoustics. The challenge here is to realize computational workflows that include different type of simulations and assess the results on the basis of different metrics to investigate design solutions that fulfill all the environmental key performance indicators (KPI) used as design goals.

Indoor/Outdoor

The urban environment characterized by parameters as building distances, heights and orientations has a significant influence on building performances and occupant wellbeing, also in relation to the latitude and climate. It determines the quantity of solar irradiation received by building interiors that influence visual comfort, energy use for heating and cooling, and by roofs and facades that can be exploited for renewable energy generation (Formolli, Kleiven and Lobaccaro, 2022). Outdoor thermal comfort that is strongly influenced by the urban fabric allowing or blocking solar irradiation and urban winds during different seasons, and by materials and green elements, is a key factor for the accessibility and inclusivity of public areas. The challenge is to develop co-simulation workflows to investigate urban design solutions that balance indoor and outdoor environmental requirements.

Urban scale

The realization of sustainable cities and communities or the conversion of existing ones is not possible through the analysis of performance simulations using a building-by-building approach. The buildings of entire neighborhoods or districts must be analyzed simultaneously. This is due to the necessity to balance energy use and on-site generation to eliminate operational carbon emissions, that is possible only taking advantage of the synergies allowed by different energy use and generation profiles of several buildings of different type and function (Ang, Berzolla and Reinhart, 2020). The challenges here are the consideration of the complex interactions between buildings form, building component thermal properties, urban density parameters, climatic factors and microclimatic conditions, and the uncertainty of buildings use profile, construction type and layout.

Competing objectives

The main challenge for the performance-driven and simulation-based design of sustainable cities is that the environmental KPIs can be competing, i.e., one design solution can fulfil one or few KPIs while having a negative effect on others. At the building scale, increasing fenestration size have the positive effect of improving daylight availability and the negative of increasing energy need for cooling during the warm season. At the urban scale varying the layout and distances of buildings influences synergistically or inversely outdoor thermal comfort and indoor solar gains that can reduce heating and increase cooling energy use depending on surrounding fabric, location and season (De Luca, 2019). Thus, the scope of the designer is to find balanced solutions for all KPIs in consideration of several design parameters, simulations, indoor and outdoor domains, integrating different scales.

WAYS FORWARD

To tackle the challenges, researchers are developing computational workflows and methods taking advantage of the potential of the parametric design environment to integrate: building and urban form generation procedures; climatic factors; building systems, occupant use and material thermal properties; environmental simulations; different domains and scales; optimization and design exploration procedures. The scope is to find optimal or trade-off design solutions (De Luca, 2023).

Co-simulation workflows

To investigate several building and urban performances different computational workflows are used depending on the simulation objectives and types (e.g., solar irradiation, daylight, energy use, microclimate), domains and scales. The sequential workflow uses the results of one or more simulations to select design solutions to investigate further with other simulations. The iterative workflow uses one or few simulations of non-competing objectives to adapt design solutions until one with the desired performance is found. Although fast to perform, these methods investigate a limited number of design variations. The parallel workflow, on the contrary, runs all the possible simulations and calculations simultaneously for each design variations and analyzes the results to find the optimal or best balanced design solutions (De Luca, 2017).

Multi-domain

A large body of research is successfully investigating computational workflows that integrate simulations and assessments related to the interior, envelope and exterior building domains to improve comfort and livability of all the environments, also through passive design measures, and to minimize resource use. Assessments of daylight availability and energy use influenced by window-to-wall ratio and urban density, of energy generation through building integrated photovoltaic systems on roof and façades influenced by building heights, distances and orientations, and outdoor thermal comfort influenced by local microclimate, urban surface materials and green features are performed through integrated multi-domain co-simulation workflows (Natanian and Auer, 2020).

Multi-scale

The analysis of performances at the urban scale requires scalable approaches to shift from the building to the neighborhood and district scale while guaranteeing adequate simulations reliability. In this regard advancements in energy and microclimatic modeling are providing multi-scale methods and tools. The uncertainties of the cadastral and use data of groups of numerous buildings, existing or during the early planning stages, are solved using archetypes and schematic floor plans, that significantly help designing positive energy districts. Representative thermal zones obtained by clustering multitudes of building facades and simplified metrics considerably shorten simulation times. Progressing and accuracy adaptive modeling approaches demonstrated to be a viable solution for outdoor thermal comfort analysis at the urban scale (Mokhtar and Reinhart, 2023).

Design exploration

To find balanced urban design solutions in consideration of several KPIs, researchers are developing computational workflows integrating parametric models and multi-objective optimization and design exploration analysis methods. multi-objective optimization tests the performances of solutions through combinations of design variables finding the non-dominated solutions that are the best trade-offs for the analyzed performances. Among several algorithms the model-based is particularly efficient in architectural performance optimization (Wortmann, 2017). Capitalizing on automation processes to generate large quantities of design variations through parametric design, design spaces are created using variables and performance results to find building and urban design solutions fulfilling all the KPIs and to analyze the influence of the parameters on the performances (Natanian, Aleksandrowicz and Auer, 2019).

CONCLUSION

This short paper discusses the challenges that architects and planners are facing in the application of performance-driven and simulation-based computational design and the opportunities provided by the research in the field. Designers and researchers are continuously demanding for efficient simulations and computational workflows to find optimal design solutions or trade-offs exploring design spaces, and to investigate the relation between design parameters and performances. In this way they can contribute to improving the climate adaptation and resilience, healthiness and resource efficiency, thus the sustainability of cities and communities.

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Data-Driven Planning and Design for Spatial Justice

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To harness the potential of data-driven planning, it is imperative to conscientiously account for the unintended consequences inherent in the web of urban systems. A paramount issue revolves around the burgeoning societal disparities stemming from these complexities. When employing digital tools, data, and methods, it is crucial to uphold the principles of spatial justice. This pertains to the use of sophisticated participatory platforms but also extends to the tools utilized for land-use allocation, planning, and the analytical and simulation processes that underpin them. Furthermore, it is vital to recognize the significance of activism and self-organization as integral components in the introduction of novel urban ontologies.

Keywords: *Data Driven Planning, Technology-mediated Cities, Spatial Justice, Complexity.*

URBAN COMPLEXITY

By the late 1990s, it was realized in urban studies and planning that late modern cities had become extremely complex, dynamic, networked systems. Traditional planning tools were unsuitable to guide them, as they still predominantly adhered to the rational-comprehensive planning paradigm, despite improvements resulting from, for example, the communicative shift. The inherent unpredictability and uncertainty of cities forced planners and urban scholars to seek a better understanding of the transient dynamics of self-organizing urban processes, resulting in the emergence of surprising patterns from dissipated decision making of actors, and the absence of equilibrium. (Castells 1996, Shane 2011, Portugali et al. 2012). Larger-scale unintentional consequences affected not only economic life but also societal issues. These emergent effects often appeared negatively and severely in phenomena such as ethnic-linguistic segregation, downward spirals of neighborhood reputation, land prices, and the clustering of socioeconomic disparities. However, the longer-term socio-spatial impacts may be overlooked in discussions surrounding 'data-drivenness' in planning and design, as it often emphasizes methodology and tools. (Graham & Marvin 2001, Soja 2013).

Consequently, the increased interest and understanding of spatiality in urban studies took place in the shift of the 2000s. Academics began to recognize the circular interdependence of urban, socio-economic processes and flows of people and goods, and the resulting spatial configurations that both attract and direct these flows. In the wake of this spatialization of urban science, the concept of spatial justice, focusing on the spatiality of social justice, was introduced (Ascher 2004, Batty 2012).

Spatial justice refers to unintended, often unpredictable, and sometimes larger-scale consequences appearing as social inequity. In planning, it implies addressing the unfair spatial outcomes resulting from emergent urban processes, as well as those influenced by biased or misinformed decision-making or discriminatory structures. The term was introduced to build a new, redefined, overarching approach that could bridge the separate movements sometimes with colliding interests for inclusive urbanity. Rooted in the 1970s, exemplified by Henry Lefebvre's advocacy for the 'Right to the city' and the social construction of space, this concept experienced a revival in the 2000s thanks to scholars like Susan Feinstein and Edward Soja (Harvey 1973, Lefebvre 1996, Feinstein 2009, Soja 2013).

In the complex, self-organizing city accommodating myriads of uncertainties and emergent phenomena makes strict control and long-term forecasting impossible (Portugali et al. 1012, Batty 2012). The primary challenge in pursuing spatial justice in urban planning is to better understand urban processes and the relationships of factors influencing their behavior. The increasing availability of diverse, comprehensive data, and appropriate digital methods, holds promise for addressing societal urban issues (Nunes Silva 2022).

DIGITALIZING URBANITY

In recent decades, digitalization has added yet another layer to urban complexity in the form of a system of sensors intertwined with the physical city, and the technology we use to structure our daily routines. The impacts on spatial justice is redefined by the emerging new logics of technology-mediated cities, often developed with the interests of the higher middle class in mind (Batty 2016, Ridell 2019). Currently, digital tools and applications through which we interact with the city, such as phones, applications, computers, bonus cards, IoT, networks, and more, generate vast amounts of unstructured data every millisecond. A key challenge in urban planning pertains to the classification and organization of this data. However, this data offers opportunities for a profound understanding of the emerging new logics of digitalizing cities central to data-driven planning.

Another promising approach for planning complex, technology-mediated cities is necessary, namely, the wide range of digital planning and design tools. These tools have the potential to make significant contributions to data collection and organization, and also to advanced processing and analysis, thus enhancing our understanding of the emerging new urban spatio-virtual landscape. However, it is essential to comprehend their characteristics and limitations in the context of urban planning and design.

CLASSIFICATION OF DIGITAL TOOLS

Digital planning and design tools can be categorized into two types (Figure 1): Approaches stressing representation in the decision making, and those emphasizing spatial resource allocation.

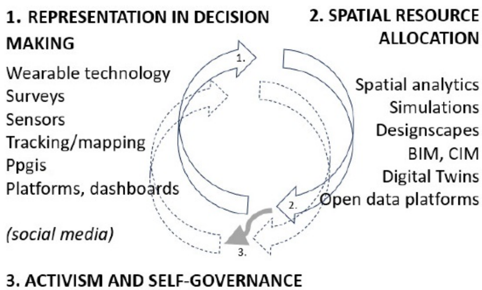

Figure 1
Classification of digital tools

Approaches prioritizing representation in decision making often focus on who is involved in the decision-making process. These approaches delve into procedural steps in decision-making and spatial representation within it. This may involve studying territorial identity or the experiences of minorities to unveil hidden discrimination. The corresponding digital tools may include those enabling many forms of data collection through online and onsite participatory tools, public and private sector platforms and dashboards, voluntary tracking, mapping, sensor data, wearable technology, or smartphones. The collected data, both quantitative and qualitative, may include spatial data of our preferences or daily routines, or even bodily functions and welfare in relation to daily activities.

Digital tools and methods involved more directly in spatial resource allocation contribute to the land-use and spatio-functional configurations of the city. They encompass the design of street system design, green infrastructure, service networks, and public transportation, among other aspects. The data gathered can be used for advanced spatial analyses to recognize mobility and land-use patterns, spatial and temporal correlations, urban diversities, vitality, and developmental needs of service networks. Based on these analyses, (agent-based) microsimulations can be built to study scenarios resulting from planning decisions. The data produced can be stored in building and city information models (BIM, CIM) and Digital Twins, also increasingly used for participatory processes. The outcomes - and the data overall - can be used in other, more dynamic design environments like algorithmic and procedural design programs and shared via open data platforms with the layman planners and invite them to co-create the city.

Additionally, a third category of approaches can be identified, which may significantly contribute to the recognition of novel phenomena and the empowerment of people. These approaches involve activism and self-governance on various online and offline platforms - social media, internet sites, campaigns, and mailing lists, but also in physical meetings, and social spaces. While they fall under the category of participatory or representational tools, they exhibit certain distinct features. Importantly, the processes for gathering and classifying data, along with the data libraries and algorithm structures, are often ontologically predefined. For example, they might pertain to certain traditional mobility modes, land use categories, professions, services, or household types, which are in transition. Furthermore, the data about vulnerable, marginalized groups is often limited and access restricted due to data sensitivity. Activism can also be powerful in gathering people with common interests, enabling the critical assessment of urbanity, and self-organization of information about new, unrecognized phenomena and challenges in the city (Brenner and Elden 2009). It is noteworthy though that digital activism is powerful in good and in bad: social platforms are notorious for their capacity for spreading mis- and disinformation (Aïmeur et al 2023), and even impact democratic elections and global public relations, which undermines their potential presented here.

DISCUSSION

Data-driven planning and design have become increasingly important, often considered a key solution to address the challenges of digitalizing urban environments. This thinking is however not new: good city planning has always relied on meticulous multi-scalar analyses and a thorough understanding of the specific conditions of the target area. This, in turn, demands a wealth of information – data - to be successfully executed. Given the intricate complexities of today's technology-mediated cities, exemplified by the avalanche of available data, data-drivenness has evolved from being desirable to becoming a necessity. Comprehensive city planning hinges on a profound understanding of urban processes. To achieve such an understanding, one must recognize the emergent nature of urban dynamics. Without this understanding, it becomes impossible to address often unintended, sometimes undesired higher-level consequences, such as unjust spatial configurations. Digital tools can then be employed to harness and leverage data for more informed urban planning and design. Moreover, in the quest to identify new phenomena in the city, informal planning and activism should be acknowledged as sources for the ontological reclassification of urban features.

Throughout the entire planning process, from data collection to analysis and design, it is essential to keep the principles of spatial justice in mind. While sophisticated tools and strategies aim to enhance public involvement, participation alone cannot be a panacea, as there will always be segments of the population who either do not wish to, cannot, or will not participate, even when their very interests are at stake. To some extent, this challenge could be mitigated by new methods such as tracking or sensors, but not entirely. Public planners, in particular, should consider the needs and perspectives of marginalized and vulnerable groups when shaping a more equitable urban environment.

It's important to recognize the limits of what urban planning and design, even the most data-driven approaches, can achieve for a city. Planning is inherently political, and planning decisions reflect the political agendas of the governing regime. Furthermore, non-spatial decisions can have unjust consequences, as seen in scenarios where a low minimum wage and limited part-time job opportunities for low-paying work compel the urban poor to divide their time among multiple jobs across the region unfairly. Even the most efficient public transport system can only partially alleviate this issue. As a result, I invite my fellow urban scholars engaged in data-driven initiatives to scrutinize the new political agendas from the perspective of their impact on spatial justice. Today's technology-mediated cities offer the data and methods for in-depth analyses, simulations, and design, enabling the creation of high-quality, just urban environments.

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Reflections on Practice at RIS 2023

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The practice panel of the RIS 2023 aimed to illuminate how the knowledge generated by a community such as eCAADe is applied in the realms of architecture, planning, and policy in the Estonian context. Touching upon different aspects of practice, the presentations highlighted three main directions towards regenerative design: facilitating participatory processes, augmenting creativity by incorporating performance simulations into the early design stages and harnessing digital technologies to manage complex problems. Besides its value as a case study of the Estonian context, the practice panel can serve as an inspiration for a more complex – and messy – understanding of performance.

Keywords: *Practice, Regenerative Design, Performance, Participatory Processes, Digital Twin, Wicked Problems, Transdisciplinarity.*

INTRODUCTION

The goal of the practice panel of RIS 2023 was to transcend the optics of academia and get some insight into possible needs, challenges and synergies that arise when the knowledge produced by a community like eCAADe is used for design, planning, or policy purposes. During discussions with eCAADe at the early stages of the conference organization, it became clear that the viewpoint of practice has been an underrepresented topic. This does not imply a scarcity of previous editions featuring original research on practices (see Penttilä, 2006; Szalapaj and Rafailaki, 2005); rather, it underscores the insufficient representation of practitioners themselves compared to researchers. This discussion provided the motivation to give the panel as much importance as to the contributions from research. Furthermore, this input from practice provided an opportunity to contextualize the conversation, linking all discussions to Estonia in various ways. Consequently, the panel also served as a tool to highlight the regional nature of the symposium. The speakers were selected to encompass a wide variety of practice sectors and scales.

THE PRESENTATIONS

Helen Sooväli-Sepping introduced the potentials and the challenges of the sustainability transition of TalTech and extended an invitation for new ideas and collaborations in support of this difficult shift. She spoke both about steps already taken (such as the CO_2 inventory of the university and the mapping of its biodiversity) and about the main challenges that lie ahead (such as changes in mobility, the integration of green skills into education programs and fostering university-wide collaboration). Her presentation was appropriately titled "*Strive* towards climate neutral university" (emphasis added), since the key takeaway was the truly sociotechnical nature of the change: the investigation, design and implementation of technical solutions cannot be separated from negotiating, understanding practices, communicating, and eventually persevering. The message towards the community was therefore twofold: firstly, to continue thinking of ways that research can help in such highly complex problems, and secondly to continue believing in and advocating for change.

Jaan Kuusemets explored the possibilities of what he called *augmented creativity* in architecture by reflecting on his own architectural practice (DAGOpen). He examined two potential avenues for enhanced creativity: the first involves employing generative artificial intelligence tools for ideation, while the second centers around the early use of analysis and simulation tools to shape performance-informed concepts. In his experience through practice, he found that while generative AI is a fast way of producing alternatives, it has multiple disadvantages: it can be superficial, non-contextual, and hindering the designer's creativity and ability to learn. More importantly, he finds that AI produces images without an underlying meaning or performance; these images are visual but not functional approximations of things. This shortcoming was also illustrated in Jenni Partanen's keynote with the use of the biology metaphor of *phenotype* versus *genotype* (see also Taylor and Lewontin 2021). Given these challenges, Kuusemets argues that the second approach is more useful for architectural design. He sees the incorporation of analysis and simulation in the conceptual design phase as a different kind of augmented creativity, one that supplements intuition with evidence. Besides making the conceptual phase more robust, he argues that an evidence-supported process can also help with moving forward confidently and getting consensus from different stakeholders.

Viktorija Prilenska presented the results of GreenTwins, a project that simulates and visualizes the temporal and seasonal variations in urban vegetation while actively engaging citizens in the design of green spaces within the city. She outlined the three main contributions of the project: adding a layer of greenery to the Urban Digital Twin (UDT) of Tallinn, providing two new digital tools (Virtual Green Planner and Urban Tempo), and finally hosting them under a common roof in a physical space in the heart of Tallinn (AvaLinn). Prilenska emphasized the uniqueness of GreenTwins in several aspects. Firstly, it provides a dynamic model of urban vegetation that captures temporal and seasonal change. Secondly, it keeps the Virtual Green Planner open source to be tailorable to the needs of the user community and it supports an *active shutter* (stereoscopic projection) 3d system that allows multiple stakeholders to interact with the same 3d mode. Finally, GreenTwins created AvaLinn, the first physical space in Tallinn for digitally aided participation and collaboration, thus connecting the digital tools more directly with the citizens and providing a platform for future participatory discussions about the city (as we will see below).

Expanding on the theme of digital twins beyond Prilenska's discussion, Esther Linask presented the broader GIS ecosystem being developed by the city of Tallinn. She views the digital twin of Tallinn as a foundational structure that can incorporate various data sources and tools, aligning with the city's long-term strategy. Linask provided a roadmap for the digital twin, setting the target year as 2035, with the GreenTwins project discussed earlier being an initial step in this extensive process. Future steps involve creating LOD3 and BIM models for all city buildings, implementing mobile data capture, conducting solar energy analyses, and piloting a city VR/AR model. Linask highlighted a significant challenge—the presence of multiple parallel databases for Estonian GIS data (building registry, land board, and planning registry)—which the digital twin aims to unify into a single interface. She concluded by outlining several strategic objectives for the digital twin, including supporting participatory processes, enhancing city real estate management, conducting life cycle analyses, promoting universal design, and ultimately contributing to a better living environment in Tallinn.

DISCUSSION

The four talks were not treated as a focus group in the strict methodological sense (Wilkinson, 1998), mainly because of the small number of presenters and the limited amount of time for an appropriately in-depth conversation following the talks. Therefore, we cannot claim that the following reflections represent the only or the most important underlying common threads of all represented practice domains. However, we do see some common emerging themes which are consistent with key directions that sustainable and regenerative design literature dictates: participatory processes (Stauskis, 2014), performance at the center of design and not as an add-on (Østergård et al., 2016), and the digital transition at the service of the sustainability transition (Fouquet and Hippe, 2022). Perhaps more interestingly, we would like to suggest that learning from this practice panel also underscores the need for a *synthesis* of multiple such directions. A transdisciplinary approach to research, that breaks down the silos of different disciplines but also is open to tacit knowledge from practice, has been long considered instrumental in tackling real-world complex problems (Lawrence et al., 2022; Polk, 2014; Westberg and Polk, 2016; Wickson et al., 2006) such as the ones our presenters introduced: steering a transition, adapting multi-performative architecture to different contexts, or supporting the strategic objectives of a whole city. Therefore, it would be interesting to see eCAADe research that investigates the potentials and challenges of combining multiple strategies, multiple disciplines and/or multiple tools at the service of messy, complex, and situated (or why not also *wicked*) problems. Besides this value of such multi-performative investigations for real-world problem solving, we also see the potential for a more philosophical contribution. What architecture *does* (as opposed to what it *is*) has been a pivotal question in recent discussions of contemporary architectural theory (Gorny, 2018; Thomsen, 2008). This emphasis on *doing* has been strongly connected with a wider understanding of performance, one that includes all ways in which architecture has the capacity (and agency) to influence social, cultural, and ecological contexts (Hensel, 2010; Smitheram, 2011). The tradition and experience of investigating performance among eCAADe scholars could provide a robust foundation for expanding the discourse to include the analysis of multiple, intertwined, and sometimes conflicting and contested performances, thereby allowing the eCAADe community to engage more closely with fundamental discussions about the nature of the discipline of architecture.

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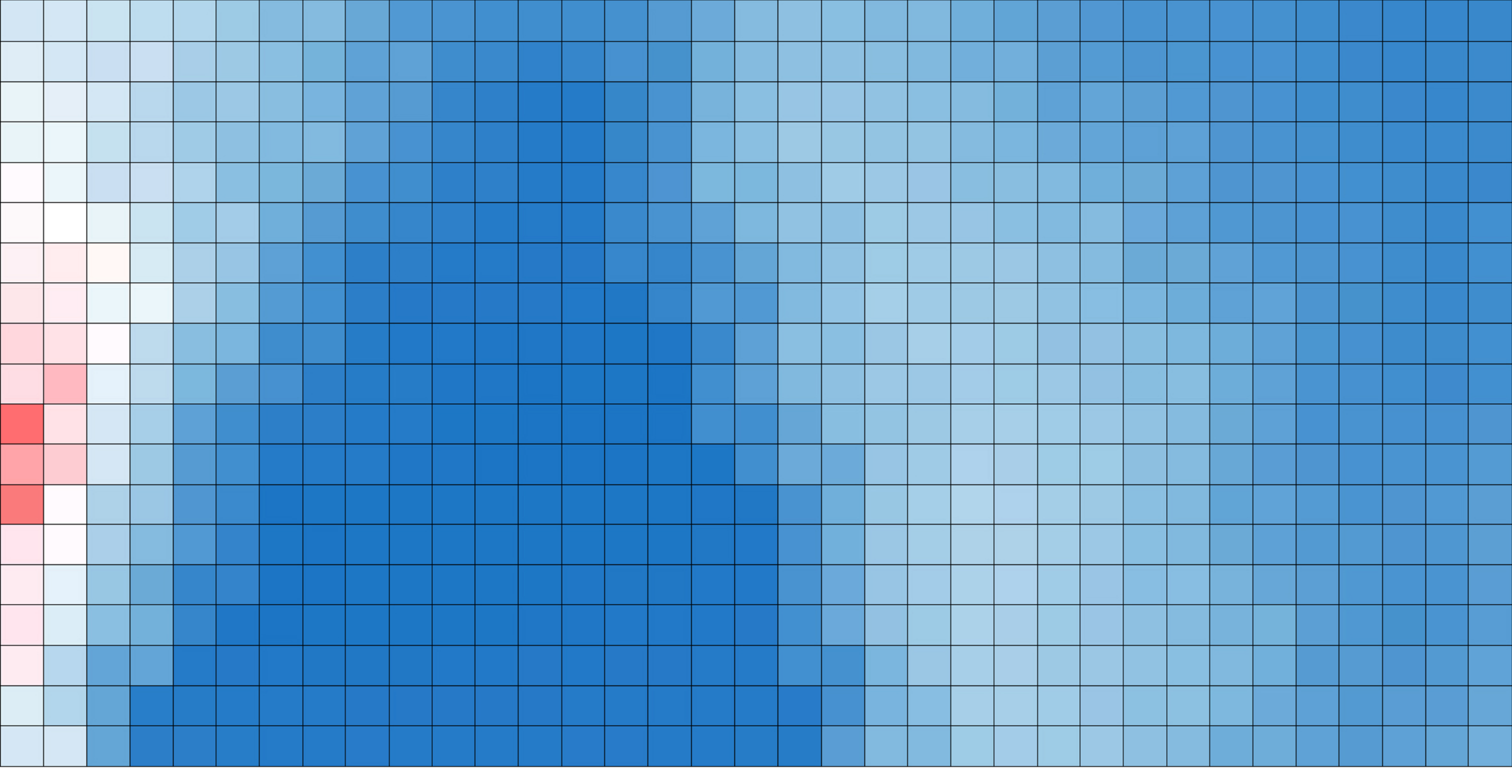

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