eCAADe 2024

DATA-DRIVEN INTELLIGENCE

9-13 SEPTEMBER 2024
NICOSIA, CYPRUS

EDITED BY:
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MARIOS C. PHOCAS

EDUCATION AND RESEARCH IN COMPUTER AIDED ARCHITECTURAL DESIGN IN EUROPE

University of Cyprus

BOOK OF ABSTRACTS

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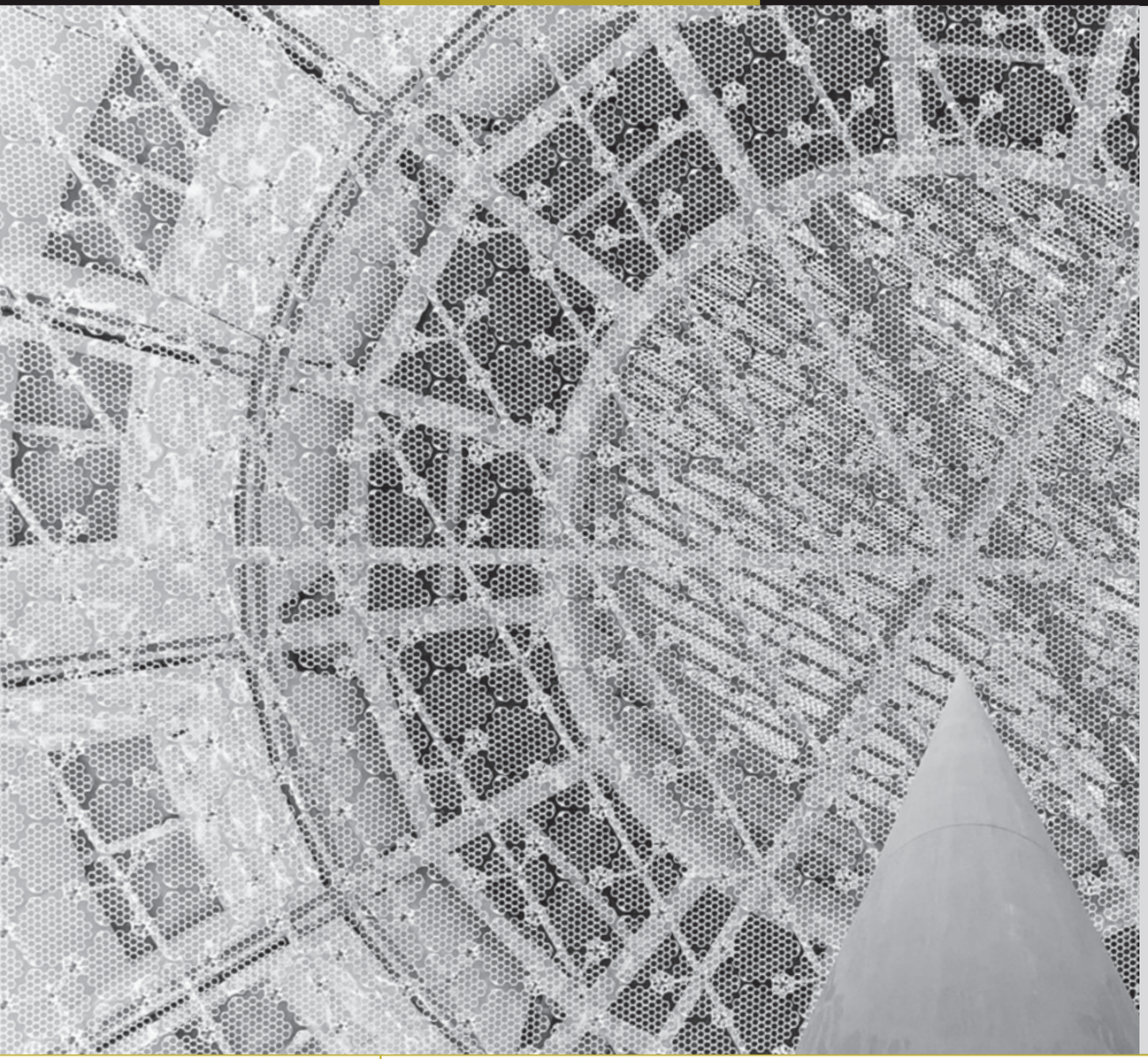

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eCAADe 2024 EDITORIAL

During the 2020s and beyond, the field of computational design and fabrication will face a number of new challenges and opportunities offered by Artificial Intelligence (AI) and Machine Learning (ML). These technologies represent a new era of data-driven intelligence, which is steadily gaining increasing influence in other fields, but as yet has had little impact in architecture. At the core of this new technological shift, data will be collected, processed, shared, and used as a decision-making tool to resolve a multitude of social, economic, and environmental issues.

In the near future, the dynamic and adaptable changes occurring in the built environment which are influenced by climatic and environmental phenomena will be leveraged and used. This includes the effects of occupancy behaviour, the building's structural behaviour, fabrication and material characteristics, in combination with the effective harvesting, harnessing, processing and use of large amounts of data. This process will in turn offer new opportunities in design decision-making, as well as in the implementation of new ideas for achieving the best performance, but also for considering contradictory objective criteria.

In view of this paradigm shift, the conference attempts to provide the ground for presenting and discussing possibilities offered by data-driven intelligence across a range of thematic areas. These diverse themes might in turn influence and provide the ground for reconsidering architectural knowledge and practice in the future. Characteristic examples might include the recording of environmental and behavioural conditions in the built environment. For example, the recording of lighting and temperature through the Internet of Things (IoT), as well as examining their integration with AI, and therefore allowing for greater customisation of spaces by the users. Moreover, cases where future advancements in computer capacity, combined with AI and ML, will offer the prospect of more powerful immersive environments coming to the fore. In addition, the conference aims to showcase examples where Virtual and Augmented Reality (VR and AR) experiences can be leveraged by datasets in the form of point clouds. This could, for instance, be through 3D Scanning, allowing for greater interaction between the physical and digital worlds, and simultaneously, through the introduction of concepts such as Digital Twins (DT) in various aspects of architectural design and construction. Furthermore, the conference attempts to discuss cases where a large number of fabrication datasets and workflows might be evolved, in combination with the plethora of digital tools currently available. The aim here would be to present how the collection and processing of constantly added data might extend fabrication intelligence, providing a number of advantages, as well as new challenges. More specifically, the conference aims to demonstrate cases where numerical control mechanisms, including robotic technologies applied in several fabrication tasks, such as Additive Manufacturing (AM) and 3D Printing, might be more adaptive in structural and material behaviour conditions. This adaptability allows for superior fabrication intelligence to emerge.

In parallel, the conference attempts to critically reflect upon, discuss and question the

future of applying data-driven intelligence in architectural knowledge and practice. What are the risks posed by the use of data-driven intelligence in architecture? In this new era, what will the role of architects be? Does this mark the beginning of a reconsideration of the way architects participate in the creation of knowledge and practice, or will it bring about their marginalisation? What will the social, economic, and environmental impact of data-driven intelligence be?

The conference endeavours to address the theme of data-driven intelligence in architectural knowledge and practice spherically. It also looks to explore the advantages and disadvantages that this can bring to the discipline, but also the possibilities that it might offer, with particular emphasis on computational design and fabrication. In view of this perspective, the conference includes, but is not limited to, the following topics:

- Artificial Intelligence, Machine Learning and Deep Learning for Design and Built Environment
- Building Information Modelling, Parametric and Generative Design
- Collaborative and Participative Design
- Data Acquisition, Big Data and Digital Twins in Architecture
- Design Concepts, Strategies and Experimentation
- Design Tools Development and Application
- Digital Design and Construction for Sustainable Built Environment
- Education in Computational Design and Digital Fabrication
- Human-Computer Interaction in Design
- Information Technology and Digital Heritage
- Internet of Things for Built Environment
- Numerical Control and Robotic Fabrication
- Shape, Form, Geometry and Material Studies
- Smart and Responsive Design and Optimization of Structures
- Smart Cities, Simulation, Prediction and Evaluation
- Theory and Practice in Computational Design and Digital Fabrication
- Virtual Reality, Augmented Reality and Mixed Reality in Architecture

Dr. Odysseas Kontovourkis
Associate Professor, University of Cyprus

Dr. Marios C. Phocas
Professor, University of Cyprus

Conference Chairs eCAADe2024

eCAADe 2024 ACKNOWLEDGEMENTS

We would like to sincerely thank those who have helped and contributed to the successful organization of the 42nd eCAADe Conference in Nicosia, Cyprus.

We would like to express our gratitude to the members of the eCAADe Council for providing the opportunity to organize the eCAADe annual conference 2024 in Nicosia. Especially, we would like to thank the President Aulikki Herneoja, the Vice President (Elect) Anetta Kępczyńska-Walczak and the Vice President (Emeritus) Rudi Stouffs for their trust and continuous support. Also, we want to thank Bob Martens for his tireless support, especially during the reviewing and selection process of papers, Gabriel Wurzer for putting together the layout and final production of the proceedings, and Martin Winchester for running and operating the OpenConf system.

We also want to express our gratitude to our keynote speakers Branko Kolarevic (New Jersey Institute of Technology), Georg Vrachliotis (TU Delft) and Achim Menges (University of Stuttgart) for accepting our invitation to be the keynote speakers of the conference and for providing their valuable insights to the conference.

Moreover, we would like to thank the Scientific Review Committee for their help during the two-stages double-blind peer review process. Their remarks were significant for the selection of the papers that are presented in the conference and in the present proceedings. Also, we want to thank all the authors of the 146 papers included in the present proceedings, the chairs of the sessions and roundtable discussion, the participants of the pre-conference workshops and their workshop leaders, as well as the participants and the organizer of the Ph.D. workshop. Without their participation, support and valuable contribution, the organization of the conference would not have been possible.

Finally, we want to give thanks to the Deputy Ministry of Tourism of Cyprus and to Bentley Systems for their generous support. Also, thanks go to the whole Conference Team at the Department of Architecture of the University of Cyprus and the EasyConferences Team for taking care of the conference website and registration procedure, for designing the conference booklet, the logo, the banners etc. and for the smooth operation of all conference and social activities during the conference.

Last but not least, we would like to express our gratitude to the Department of Architecture and the University of Cyprus for their support and help. Also, for providing all necessary premises in the University of Cyprus for the smooth operation of the conference. Their contribution and help were crucial in the successful organization of the 42nd eCAADe conference in Nicosia, Cyprus.

Odyssseas Kontovourkis and Marios C. Phocas

Conference Chairs

August 2024

eCAADe

eCAADe (Education and research in Computer Aided Architectural Design in Europe) is a non-profit association of institutions and individuals with a common interest in promoting good practice and sharing information in relation to the use of computers in research and education in architecture and related professions. eCAADe was founded in 1983.

The purpose of eCAADe is to promote the sharing of ideas and collaboration in matters relating to CAAD eduction and research. The eCAADe region covers Europe, Middle East, North Africa and Western Asia. eCAADe works in collaboration with its sister organisations: ACADIA in NorthAmerica - acadia.org CAADRIA in Asia &Australia - caadria.org SIGRADI in SouthAmerica - sigradi.org More information about the association: www.ecaade.org The annual conference is a major source of information in this field and members have access to digital proceedings in the CUMINCAD database. More information on “cumincad.scix.net”. Participation in the annual confernce automatically includes eCAADe membership with its consequent benefits.

eCAADe 2024 ORGANIZATION

CONFERENCE CHAIRS

Odysseas Kontovourkis
Marios C. Phocas

CONFERENCE TEAM

Stefanos Gkatzogiannis
Panayiotis N. Panayiotou
Savvas Dimitriou
Christos Georgiou
Pantelis Hadjigeorgiou

Department of Architecture,
University of Cyprus

CONFERENCE CONTACT EMAIL

ecaade2024@ucy.ac.cy

CONFERENCE WEBSITE

https://cyprusconferences.org/ecaade2024/

WORKSHOPS VENUE

University Of Cyprus
Department of Architecture (Old Campus)
Kallipoleos 75, 1678, Nicosia

CONFERENCE VENUE

University Of Cyprus (New Campus)
Panepistimiou 1,2109, Nicosia

ECAADE 2024 CONFERENCE PROGRAM

- WEDNESDAY 11.09.2024
  Registration 08:00
  Conference Program
- THURSDAY 12.09.2024
  Registration 08:00
  Conference Program
- FRIDAY 13.09.2024
  Registration 08:00
  Conference Program

CONFERENCE DAY 01 WEDNESDAY 11.09.2024

Registration	08:00
Opening	09:00
KEYNOTE 1: BRANKO KOLAREVIC	**09:30**
Coffee Break	10:30
SESSIONS 1.1,1.2,1.3	**11:00**
Lunch	12:30
SESSIONS 2.1,2.2,2.3	**14:00**
Coffee Break	15:30
SESSIONS 3.1,3.2,3.3	**16:00**
Reception	19:00

CONFERENCE DAY 02 THURSDAY 12.09.2024

Registration	08:00
KEYNOTE 1: GEORG VRACHLIOTIS	**09:00**
Coffee Break	10:00
SESSIONS 4.1,4.2,4.3	**10:30**
Lunch	12:00
SESSIONS 5.1,5.2,5.3	**13:30**
Coffee Break	15:00
SESSIONS 6.1,6.2,6.3	**15:30**
Coffee Break	17:00
SESSIONS 7.1,7.2,7.3	**17:30**
Conference Dinner	20:30

CONFERENCE DAY 03 FRIDAY 13.09.2024

Registration	08:00
KEYNOTE 3: ACHIM MENGES	**09:00**
Coffee Break	10:00
SESSIONS 8.1,8.2,8.3	**10:30**
Lunch	12:00
SESSIONS 9.1,9.2	**13:30**
Coffee Break	15:00
ROUND TABLE SESSION	**15:30**
AGM, AWARDS & ANNOUNCEMENTS	**17:00**
Final Closing Event	20:30

CONFERENCE SCHEDULE

CONFERENCE DAY 01 WEDNESDAY 11.09.2024			
REGISTRATION			08:00
OPENING			09:00
KEYNOTE 1: BRANKO KOLAREVIC LOCATION: B108			**09:30**
Coffee Break			10:30
SESSION 1.1 **DIGITAL FABRICATION I** LOCATION: LRC012	SESSION 1.2 **AI IN DESIGN I** LOCATION: LRC 014	SESSION 1.3 **DESIGN TOOLS AND DEVELOPMENT I** LOCATION: LRC019	**11:00**
Lunch			12:30
SESSION 2.1 **AUTOMATED FABRICATION I** LOCATION: LRC012	SESSION 2.2 **DATA IN DESIGN** LOCATION: LRC014	SESSION 2.3 **COLLABORATIVE DESIGN** LOCATION: LRC019	**14:00**
Coffee Break			15:30
SESSION 3.1 **CONSTRUCTION** LOCATION: LRC012	SESSION 3.2 **BIM I** LOCATION: LRC014	SESSION 3.3 **DIGITAL DEVELOPMENTS I** (ONLINE) LOCATION: LRC019	**16:00**
CONFERENCE RECEPTION			19:00

CONFERENCE SCHEDULE

CONFERENCE DAY 02 THURSDAY 12.09.2024			
REGISTRATION			08:00
KEYNOTE 2: GEORG VRACHLIOTIS LOCATION: B108			**09:00**
Coffee Break			10:00
SESSION 4.1 **DIGITAL FABRICATION II** LOCATION: LRC012	SESSION 4.2 **SMART CITIES** LOCATION: LRC014	SESSION 1.3 **DESIGN TOOLS AND DEVELOPMENT II** LOCATION: LRC019	**10:30**
Lunch			12:00
SESSION 5.1 **MATERIALS AND FORM I** LOCATION: LRC012	SESSION 5.2 **BIM II** LOCATION: LRC014	SESSION 5.3 **EXPERIMENTATION I** LOCATION: LRC019	**13:30**
Coffee Break			15:00
SESSION 6.1 **MATERIALS AND FORM II** LOCATION: LRC012	SESSION 6.2 **VR-AR** LOCATION: LRC014	SESSION 6.3 **EXPERIMENTATION II** LOCATION: LRC019	**15:30**
Coffee Break			17:00
SESSION 7.1 **DIGITAL DEVELOPMENTS II** LOCATION: LRC012	SESSION 7.2 **IT IN HERITAGE** LOCATION: LRC014	SESSION 7.3 **EDUCATION I** LOCATION: LRC019	**17:30**
CONFERENCE DINNER			20:30

CONFERENCE SCHEDULE

CONFERENCE DAY 03 FRIDAY 13.09.2024			
REGISTRATION			08:00
KEYNOTE 3: ACHIM MENGES **LOCATION: B108**			**09:00**
Coffee Break			10:00
SESSION 8.1 **AUTOMATED FABRICATION II** **LOCATION: LRC 012**	SESSION 8.2 **AI IN DESIGN II** **LOCATION: LRC 014**	SESSION 8.3 **EDUCATION II** **LOCATION: LRC019**	**10:30**
Lunch			12:00
SESSION 9.1 **STRUCTURES** **LOCATION: LRC 012**	SESSION 9.2 **DESIGN TOOLS AND DEVELOPMENT III** **LOCATION: LRC014**		**13:30**
Coffee Break			15:00
ROUND TABLE SESSION **BRANKO KOLAREVIC, GEORG VRACHLIOTIS, ACHIM MENGES** **LOCATION: B108**			**15:30**
AGM, AWARDS & ANNOUNCEMENTS **LOCATION: B108**			**17:00**
CLOSING EVENT			20:30

KEYNOTE SPEAKERS

BRANKO KOLAREVIC

Branko Kolarevic is a professor and former dean of the Hillier College of Architecture and Design at the New Jersey Institute of Technology in Newark. He has taught architecture at several universities in North America and Asia and has lectured worldwide on the use of digital technologies in design and production. He has authored, edited or co-edited several books, including “Mass Customization and Design Democratization” with José Pinto Duarte. He was elected and served as president of several organizations: Association of Collegiate Schools of Architecture (ACSA), Canadian Architectural Certification Board (CACB), and Association for Computer Aided Design in Architecture (ACADIA). He is a recipient of the ACADIA Award for Innovative Research in 2007 and ACADIA Society Award of Excellence in 2015. He holds doctoral and master’s degrees in design from Harvard University and a diploma engineer in architecture degree from the University of Belgrade.

CONFERENCE DAY 1: WEDNESDAY, SEPT 11th 2024 – 09:30

GEORG VRACHLIOTIS

Georg Vrachliotis is a Full Professor and the Head of the Design, Data, and Society Group at TU Delft’s Faculty of Architecture and the Built Environment. He leads “The New Open,” a flagship project focusing on open data for design and societal change. Holding a Ph.D. from ETH Zurich, Georg previously served as the Dean of Architecture at the Karlsruhe Institute of Technology (KIT), where he was also a full professor specializing in architectural theory with an emphasis on digital culture. Georg’s career includes curating notable architecture exhibitions such as “Fritz Haller: Architect and Researcher” in Basel (2014), “Sleeping Beauty: Reinventing Frei Otto’s Multihalle” at the Venice Biennale (2018), and “Models, Media, and Methods: Frei Otto’s Architectural Research” at Yale University (2020). An accomplished author, he wrote “The New Technological Condition: Architecture and Design in the Age of Cybernetics,” (2022) among others. Georg is a member of the advisory board for the ARCH+ journal and serves as an external examiner at the Bartlett School of Architecture, UCL London.

CONFERENCE DAY 02: THURSDAY, SEPT 12th 2024 – 09:00

ACHIM MENGES

Achim Menges is a registered architect in Frankfurt and full professor at the University of Stuttgart, where he is the founding director of the Institute for Computational Design and Construction (ICD) and the director of the Cluster of Excellence Integrative Computational Design and Construction for Architecture (IntCDC). In addition, he has been Visiting Professor in Architecture at Harvard University’s Graduate School of Design and held multiple other visiting professorships in Europe and the United States. He graduated with honours from the Architectural Association, AA School of Architecture in London, where he subsequently taught as Studio Master and Unit Master in the AA Graduate School and the AA Diploma School. Achim Menges’ practice and research focus on integrative computational design methods, robotic fabrication and construction processes, as well as advanced material and building systems for future-proof architecture. His work is based on an interdisciplinary approach in collaboration with structural engineering, systems and production engineering, computer science, material science, as well as the humanities and social science.

CONFERENCE DAY 03: FRIDAY, SEPT 13th 2024 – 09:00

MAPS

V.1
Kallipoleos 75, Aglantzia

First Floor

Room: 107
Workshops

Ground Floor

Room: 013
Workshops

V.2
MAIN CONFERENCE VENUE
Panepistimiou 1, Aglantzia

V.2.1
Anastasios G. Leventis building

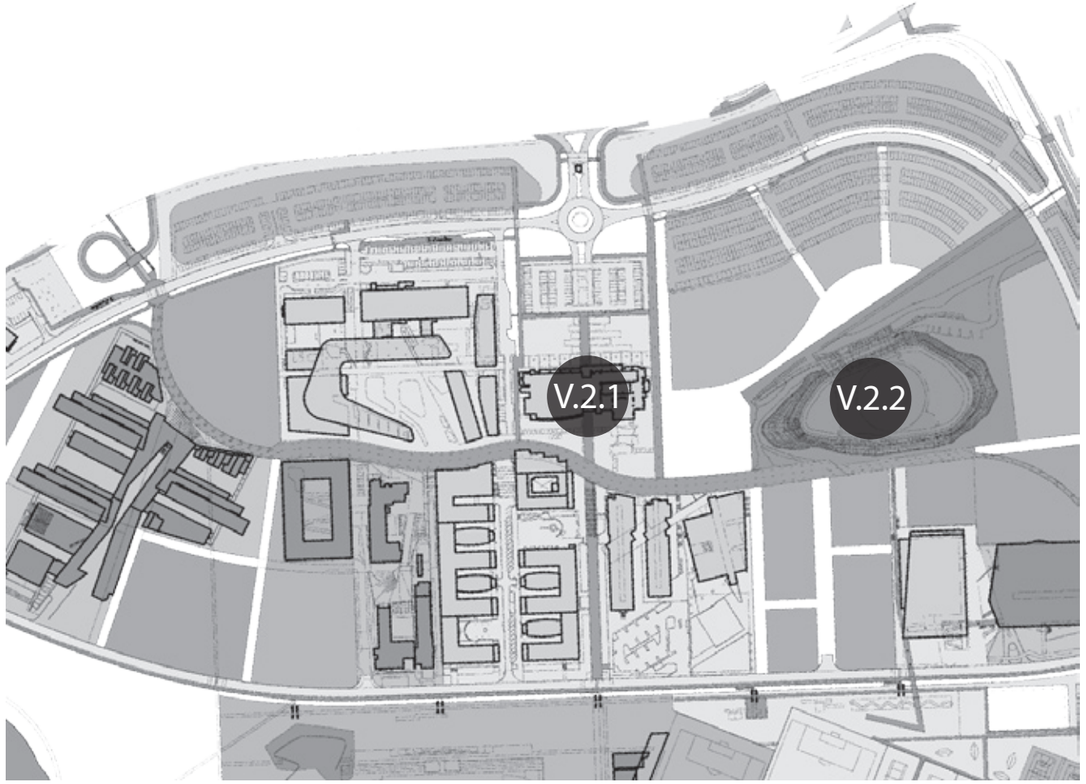
Basement

Room: B108
Keynotes

V2.2
Stelios Ioannous Learning Resource Centre

Ground Floor

Rooms: LRC012, LRC014, LRC019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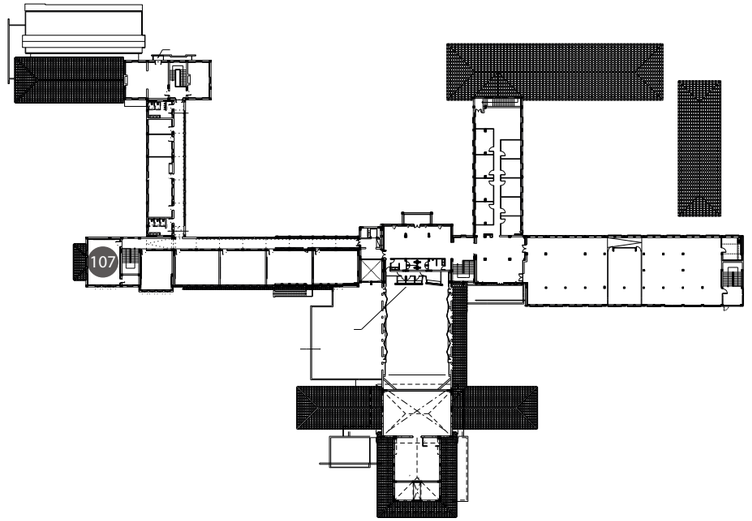
V.2.2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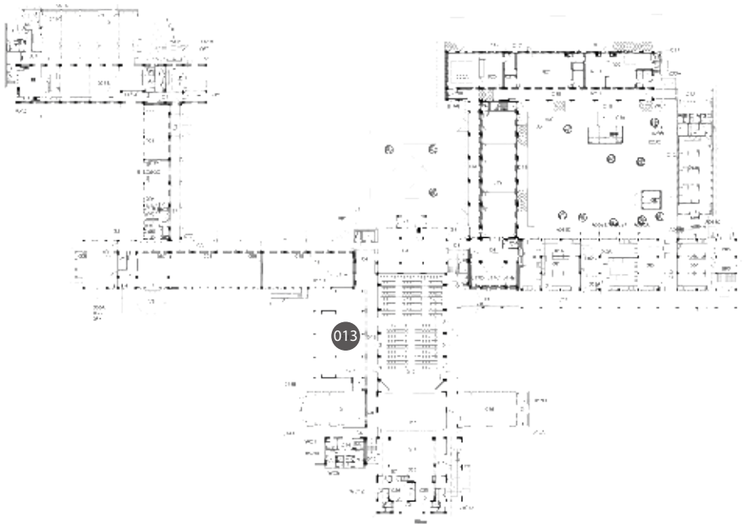
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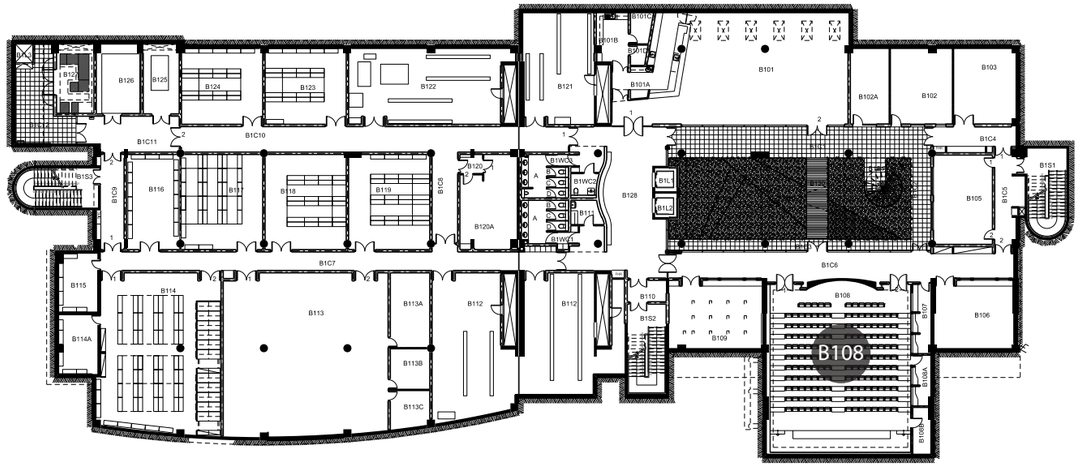
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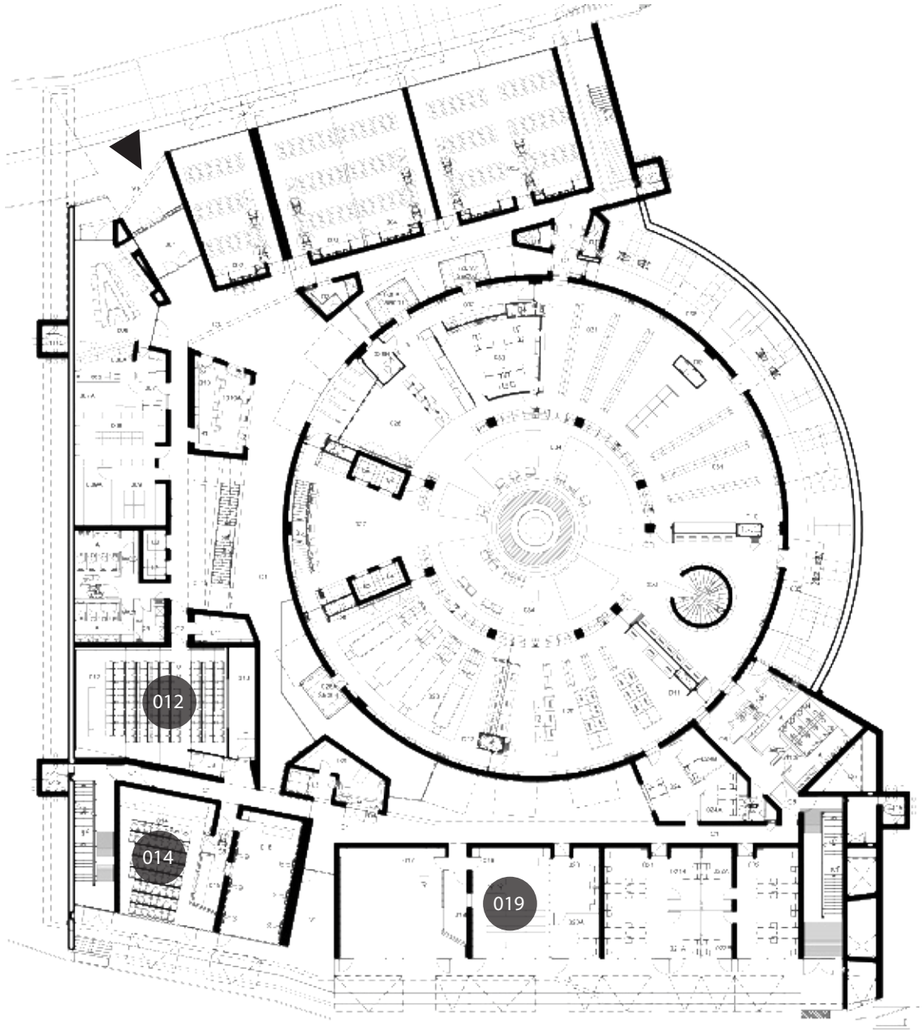
012
014
019

SESSIONS SCHEDULE DAY 1

1.1 SESSION 1.1

DIGITAL FABRICATION I

WEDNESDAY 11.09.2024 • 11:00-12:30

ROOM: LRC012

Session Chair: ***JOSE PEDRO SOUSA***

359	**Strengthened Shells. Possibilities of conformal printing on curved surfaces in large scale 3D printing**	*Ondřej Cigáník, Daniel Sviták, Kateřina Sýsová, Shota Tsikoliya, Imrich Vaško*
102	**Robotic Sand Shaping for Reusable Formworks. From toolpath design to emergent shapes and patterns in cast form**	*Kieron Cook, Özguc Bertuğ Çapunaman, Benay Gürsoy*
230	**Fabrication with Residual wood through Scanning Optimization and Robotic Milling**	*Hugo Fekar, Jan Novak, Jakub Míča, Viktoria Žigmundová, Diana Suleimanová, Shota Tsikoliya, Imro Vaško*
137	**Transforming Earths. Designing 3D printable materials for robotic earth architecture**	*Ofer Asaf, Pavel Larianovsky, Arnon Bentur, Aaron Sprecher*
361	**Bioreceptive Parameters for Additive Manufacturing of Clay based Composites**	*Petra Sochůrková, Svetlana Devyatkina, Sára Kordová, Imrich Vaško, Shota Tsikoliya*
413	**The Computational Clay Column. Computational ceramic systems with additive manufacturing**	*Cristina Nan*

1.2 SESSION 1.2

WEDNESDAY 11.09.2024 • 11:00-12:30

ROOM: LRC014

Session Chair: ***ADAM SEBESTYEN***

AI IN DESIGN I

302	**Sequencing the Architectural Design Process for Artificial Intelligence. A design-theory-based framework for machine learning approaches**	*Jessica Bielski, Ozan Karaali, Viktor Eisenstadt, Christoph Langenhan, Frank Petzold*
262	**Impact of the Training Set Consistency on Architectural Plan Generation Effect Based on Pix2pixHD Algorithm**	*Yu Guo, Zhe Cui*
117	**Text to Terminal. A framework for generating airport terminal layout with large-scale language-image models**	*Xinyu Su, Jianhe Luo, Zidong Liu, Gaoliang Yan*
234	**Using Generative Adversarial Networks to Create 3D Building Geometries. 3DBuildingGAN**	*Lisa-Marie Mueller, Charalampos Andriotis, Michela Turrin*
310	**Data-driven Reduced-Order Models for Multidisciplinary Design Optimization Process**	*Caterina Mosca, Federico D'Amico*
029	**Towards a Robust Evaluation Framework for Generative Urban Design**	*Haya Brama, Agata Dalach, Tal Grinshpoun, Jonathan Dortheimer*

1.3 SESSION 1.3

WEDNESDAY 11.09.2024 • 11:00-12:30

ROOM: LRC019

Session Chair: ***UWE RUPPEL***

DESIGN TOOLS AND DEVELOPMENT I

257	**Formulating the Generative. History, logic, and status of computing designs in a latent space**	*Alexandros Haridis*
395	**Kaleidoscopic Pragmatism. Generative illumination of an historical Athens office building**	*Eftihis Efthimiou, Alexandros Vaitsos*
354	**Polysemantic Entity Extension of Project Models. A theoretical overview to power computable representations.**	*Armando Trento, Antonio Fioravanti, Paolo Fiamma*
199	**Building-Agent. A 3D generation agent framework integrating large language models and graphbased 3 D generation model**	*Ximing Zhong, Jiadong Liang, Yingkai Li*
408	**Integrating Surrogate Modeling and Design Analytics for Data-informed Exploration in the Early Phases of Building Design**	*Esmaeil Mottaghi, Halil Erhan, Ahmed M. Abuzuraiq, Victor Okhoya, Spyridon Ampanavos, Marcelo Bernal, Cheney Chen and Yehia Madkour*
291	**Spatiotemporal Modeling Vertically Integrated Project. A VIP on human-centered metrics for architecture**	*Paula Gomez Z., Matthew Swarts, Gonzalo Vegas*

SESSION 1
Session Chair: ***JOSE PEDRO SOUSA***

1.1

359

Strengthened Shells. Possibilities of conformal printing on curved surfaces in large scale 3D printing

Ondřej Cigánik, Daniel Sviták, Kateřina Sýsová, Shota Tsikoliya, Imrich Vaško

This paper investigates the potential impact of conformal filament layering on various 3D printed structures with the aim of enhancing or altering their properties. Currently, large scale 3D printed objects predominantly utilize vase-mode style prints, occasionally featuring more intricate internal structures resembling FDM infill patterns, yet typically produced in a single continuous extrusion, resulting in a single perimeter wall thickness. This research seeks to explore the advantages of layering additional material onto the outer perimeter of a print, leveraging the capabilities of 6-axis robots and conformal printing techniques. To empirically assess the efficacy of this technique, an experiment is designed involving the fabrication of a consistent one-layer domed shell on a supportive form, onto which additional layers, oriented differently and featuring various patterns, are subsequently applied. The resultant samples are subjected to tests measuring both their strength and visual attributes, generating data for further analysis and application.

102

Robotic Sand Shaping for Reusable Formworks. From toolpath design to emergent shapes and patterns in cast form

Kieron Cook, Özguc Bertuğ Çapunaman, Benay Gürsoy

This paper introduces a research project that involves using a 6-axis robotic arm to shape kinetic sand. The goal is to create reusable and reconfigurable sand formworks with intricate patterns and textures for casting concrete. When kinetic sand is compacted, it creates emergent "material shapes" on the sand surface due to material spring-back. The research aims to identify the causal relationships between the robot's toolpath design, material and fabrication parameters, and emergent material formations. This will allow for a fine level of control over the design process of sand formworks for casting concrete panels without any formwork waste. The paper also reviews existing literature on reconfigurable formworks, presents the workflows for robotic sand shaping, and provides examples of concrete panels cast on sand formworks generated using these workflows.

230

Fabrication with Residual wood through Scanning Optimization and Robotic Milling

Hugo Fekar, Jan Novak, Jakub Míča, Viktoria Žigmundová, Diana Suleimanová, Shota Tsikoliya, Imro Vaško

The project deals with the use of residual wood of tree stumps and roots through scanning, optimization and robotic milling. Wood logging residue makes up to 50 percent of the trees harvested biomass. Among prevailing strategies is leaving residue on site, and recovering residue for bioenergy. The project explores the third strategy, using parts of the logging residue for fabrication, which may reduce the overall amount of wood logging volume. Furthermore, the approach aims for applying residue in its natural form and taking advantage of specific local characteristics of wood. The project applies the strategy of working with stump and roots of an oak tree. Due to considerations of scale, available milling techniques and available resources, the chosen goal of the approach is to create a functioning chair prototype. Among the problems of the approach is the complex shape of the residue, uneven quality of wood, varying humidity and contamination with soil. After cleaning and drying, the stump is scanned and a 3D model is created. The 3D model of a stump is confronted with a 3D modelled limits of the goal typology (height, width, length, sitting surface area and overall volume of a chair) and topological optimization algorithm is used to iteratively reach the desired geometry. Unlike the established topological optimization process, which aims for a minimal volume, the project attempts to achieve required qualities by removing a minimal amount of wood. Due to geometric complexity of both stump and goal object, milling with a 6 axis industrial robotic arm and a rotary table was chosen as a fabrication method. The object was clamped to the board (then connected to a rotary table) in order to provide precise location and orientation in 3D space. The milling of the object was divided in two parts, with the seating area milled in higher detail. Overall process of working with a residual wood that has potential to be both effective and present aesthetic quality based on individual characteristics of wood. Further development can integrate a generative tool which would streamline the design and fabrication process further.

137

Transforming Earths. Designing 3D printable materials for robotic earth architecture

Ofer Asaf, Pavel Larianovsky, Arnon Bentur, Aaron Sprecher

This paper explores the potential of using different local earthen materials in robotic additive manufacturing workflow despite challenges arising from soil variability. We propose a method to design materials based on locally sourced soils for 3D printing, focusing on the physical and mineralogical characteristics of the soil and the rheological properties of the mixture. By tailoring mixtures for both extrusion and stability and correlating straightforward tests with laboratory data, we advance the adaptability of earth-based materials for 3D printing. Experiments with robotic 3D printing across five soils validate our approach, suggesting pathways for furthering earthen material use in digital fabrication and underscoring the importance of material design.

361

Bioreceptive Parameters for Additive Manufacturing of Clay based Composites

Petra Sochůrková, Svetlana Devyatkina, Sára Kordová, Imrich Vaško, Shota Tsikoliya

Due to climate change and the problematic amount of waste and CO2 emissions in the construction industry, non-human organisms and sustainable solutions are key motivators of the study. This paper focuses on developing a bioreceptive (Guillitte, 1995) composite suitable for additive manufacturing, composed to support growth of various organisms. It investigates key properties which have shown to be beneficial for promoting biological growth, such as water absorption, water permeability, humidity, and surface texture. The study evaluates the effect of two groups of clay-based waste additives, wooden sawdust (Arslan, et al., 2021) and sediment material sourced from local tunnel excavation in Prague. Simultaneously the need for intelligent reintegration and waste use is prevalent. Additive fabrication offers the ability to test a variety of composites and (re-)integrate them into the manufacturing processes. Current approach explores how to design artificial environments/skins for greenery and small life with the potential to improve both diversity and survivability while maintaining a better climate in its immediate surroundings. Bioreceptive design has the potential to improve the quality of the urban environment and bring new aesthetic influences into it (Cruz and Beckett 2016, p. 51-64).

413

The Computational Clay Column. Computational ceramic systems with additive manufacturing

Cristina Nan

This paper presents a different conceptual approach and robotic fabrication strategy for ceramic additive manufacturing showcased through a fundamental architectural element, the column. The Computational Clay Column is treated as double system made out of core and skin, both fabricated with 3D clay printing. The underlying principle is the spatial self-interlocking of the two subsystems, core and skin, thus eliminating the need for a substructure or fastening. A particular emphasis is placed on the infill beyond its stabilizing function. Expressive and ornamental value is not only assigned to the skin but also translated to the infill. Based on a conceptual strategy of unwinding, the infill is punctually exposed, showcasing it to the viewer and amplifying the ornamental aesthetic and digital materiality of the computational design strategy and robotic fabrication logic. By exposing the core with its ceramic self-interlocking system, the tectonic expressiveness of the column as an architectural archetype is amplified. The research discusses the computational workflows, material experimentation, the interlocking and assembly logic, fabrication strategy as well as the concepts of digital craft and digital materiality. The applied methodology is based on research-through-design. No prioritization is given to form over material and process of production. The knowledge derived from analog and robotic material experimentation as well as clay's specific material behavior relating to drying, shrinkage and warping are used to inform the design, production sequence and fabrication logic.

SESSION 1

Session Chair: ***ADAM SEBESTYEN***

1.2

302

Sequencing the Architectural Design Process for Artificial Intelligence. A design-theory-based framework for machine learning approaches

Jessica Bielski, Ozan Karaali, Viktor Eisenstadt, Christoph Langenhan, Frank Petzold

Similar process models of the architectural design process of the early design stages have been formalised. However, recognition by machine learning (ML) based approaches fails due to the individuality and vagueness of the inherent method of sketching. Nevertheless, contemporary ML approaches have the potential to support the architectural design process through auto-completion-based suggestions. In order to provide data for MLbased suggestion generation, we propose a customisable framework with according steps. Drawing from design theory, it is establishes the design process as sequences of three levels of detail and their respective linking. These literature-based sequences serve to label sketch protocol studies. Finally, the framework is validated through Recurrent Neural Networks (RNNs) with Long-Short-Term-Memory (LSTM) architecture trained in isolation on sequences of different level of detail, for prediction purposes.

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Impact of the Training Set Consistency on Architectural Plan Generation Effect Based on Pix2pixHD Algorithm

Yu Guo, Zhe Cui

In research on machine learning-assisted architectural plan generation, the sample composition of the training set is one of the most important factors influencing the model's performance and outcomes. In most previous research, architectural plans in the training set exhibited a lack of consistency in design principles, which hindered generation effectiveness. In this study, we have developed an 'architecture-like plan' dataset that adheres to a set of unified principles. We carried out a training-testing experiment based on the pix2pixHD algorithm with architecture-like plans and quantitatively evaluated the similarity between the predictions and ground truths by the pixelmatch algorithm. The similarity was high, up to 92.26%, and the predictions were high quality, suggesting that the algorithm has learned the design principle. The result significantly outperforms similar studies, suggesting that the training set consistency positively affects the generation effect. Next, we validate this on the open-source residential plan dataset (RPLAN) through another training-testing experiment. We filtered a subset with uniform criteria, containing design principles and label accuracy, as the experimental group, and the original unfiltered dataset as the control group. The results showed that the similarity of the experimental group achieved 72.03%, compared to the control group's (55.13%), and the experimental group's predictions were significantly superior to those of the control group. Both experiments show that the higher the training set consistency, the more likely it is to obtain a generative model with excellent results, and that the training set consistency significantly affects the generation of architectural plans.

117

Text to Terminal. A framework for generating airport terminal layout with large-scale language-image models

Xinyu Su, Jianhe Luo, Zidong Liu, Gaoliang Yan

Large-scale language-image (LLI) models present novel opportunities for architectural design by facilitating its multimodal process via text-image interactions. However, the inherent two-dimensionality of their outputs restricts their utility in architectural practice. Airport terminals, characterized by their flexibility and patterned forms, with most of the design operations occurring at the level of master plan, indicating a promising application area for LLI models. We propose a workflow that, in the early design phase, employs a fine-tuned Stable Diffusion model to generate terminal design solutions from textual descriptions and a site image, followed by a quantitative evaluation from an architectural expert's viewpoint. We created our dataset by collecting satellite images of 295 airport terminals worldwide and annotating them in terms of size and form. Using Terminal 2 of Zhengzhou Xinzheng International Airport as a case study, we scored the original and generated solutions on three airside evaluation metrics, verifying the validity of the proposed method. Our study bridges image generation and expert architectural design assessments, providing valuable insights into the practical application of LLI models in architectural practice and introducing a new method for the intelligent design of large-scale public buildings.

234

Using Generative Adversarial Networks to Create 3D Building Geometries. 3DBuildingGAN

Lisa-Marie Mueller, Charalampos Andriotis, Michela Turrin

Generative Artificial Intelligence (AI) promises to make a vast impact across disciplines, including transforming the architectural design process by autonomously generating full building geometries. One form of generative deep learning that has been used to

create 2D and 3D representations of objects is Generative Adversarial Networks (GANs). Existing literature, however, has limited applications that utilize 3D data for building geometry generation, with previous studies focused on low-scale 3D geometries suitable for objects such as chairs or cars. This paper develops a new GAN architecture to produce high-resolution feasible building geometry. The training dataset used is a selection of 3D models of single-family homes from an existing database, pre-processed for the specific application. State-of-the-art GAN models are initially tested to establish baseline performance and applicability potential. Then, a systematic study is performed to identify the structure and hyperparameters necessary to successfully fit a GAN to this design task. The successful architecture, named 3DBuildingGAN, uses a combination of Wasserstein loss with gradient penalty, leaky rectified linear units for neuron activation in the generator and the critic, and the root mean squared propagation optimizer with a fixed learning rate. The proposed model generates outputs similar in size, shape, and proportion to the training data with minimal noise in the output. Evaluation of memorization properties indicates open research directions, such as incorporating memorization rejection and training on larger data sets. Finally, the study reflects on how AI algorithms can reshape creativity through data-driven design solutions.

310

Data-driven Reduced-Order Models for Multidisciplinary Design Optimization Process

Caterina Mosca, Federico D'Amico

Multidisciplinary Design Optimization (MDO) is a model-based simulation and optimization process that integrates multiple disciplines with conflicting objectives and design constraints to allow a more affordable design. In the Architecture, Engineering and Construction (AEC) sector this method still in the research and testing phase compared to the automotive and aerospace industries. However, the ability of MDO to extend the number of solutions examined through automation requires significant computational resources. In this context, the following paper explores the advantages of reducing simulation times using the AI-based reduced-order models (ROM). This datadriven method combines Artificial Intelligence and system modelling techniques to reduce computational complexity as Digital Twin ("As Designed") and it can be used to speed up system design and optimization analyses. This paper presents a test application that explores how AI-based ROM can support the MDO process, which has already been applied to an AEC retrofit project. The case study is a classroom of an existing building where fluid dynamics, thermal and comfort performances have been optimized to support decisions in the conceptual design phase. Although the simulations were successful, a high computational complexity emerged, making it difficult to extend the simulations to the entire building and to more disciplines. The digital experiment carried out in this paper is about speeding up the process and making simulations easier compared to the legacy approach based on high computational simulations. The digital experiment carried out in this paper is about physics phenomena in buildings, which are only a part of the architecture performance and quality. This is an early example of demonstrating how AI-based ROMs can accelerate MDO simulations to make it scalable up the entire AEC design process in the future.

029

Towards a Robust Evaluation Framework for Generative Urban Design

Haya Brama, Agata Dalach, Tal Grinshpoun, Jonathan Dortheimer

This paper critically reviews the evaluation methods employed in the Generative Urban Design (GUD) literature. The review reveals various evaluation methods, including human-based, performance-based, and statistical evaluation. An analysis of the evaluation methods shows that each approach has limitations, and none fully addresses the unique challenges of evaluating GUD. The paper concludes that more robust and comprehensive evaluation methods are needed for GUD. The findings of this study have implications for GUD researchers, providing them with a critical understanding of the strengths and limitations of current evaluation methods and suggesting directions for future research.

SESSION 1

Session Chair: ***UWE RUPPEL***

1.3

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Formulating the Generative. History, logic, and status of computing designs in a latent space

Alexandros Haridis

This paper separates out and finds relations between individuals and the historical contexts in which they operated who formulated conceptual and computational interpretations of the term generative. It synthesizes literature published from the 1500s to the 1950s, beginning with the Art of Combinations (1500s—) and the pursuit of universal generative languages, leading to the information-processing systems view and heuristic programming (1950s—), the first long-term research program in AI and cognitive science. The present data-driven formulation of the generative enabled by engineering achievements in AI technology has not fundamentally changed a longstanding vision: design or creation as computation remains a kind of mechanized search of design options in a 'latent space of possibilities.' Understanding the generative in this way will enable researchers and educators in design, art and science to resolve various controversies that rage today—between cognitivist and connectionist approaches to creativity, between "rules" and "data."

395

Kaleidoscopic Pragmatism. Generative illumination of an historical Athens office building

Eftihis Efthimiou, Alexandros Vaitsos

This paper explores the dynamic interplay between computational design, digital simulation and physical modeling in the creation of an innovative architectural intervention within a historical office building in Athens. Spanning several decades of construction (1930s-1980s), the building's illumination waned amidst the encroachment of contemporary structures. Our solution involves a meticulously designed 2.60*2.60m light well, carving through the building's core and housing a nine-storey generative sculpture. This colossal kaleidoscopic prism, working in tandem with a heliostat, serves both as a striking aesthetic statement and an efficient lighting apparatus, ensuring stable natural lighting conditions in the surrounding office space. During the form-finding phase, rigorous computational processes guided the placement of reflective and refractive triangles within the sculpture, achieving specific degrees of porosity and performativity. Simultaneously addressing a demanding architectural program while enhancing spatial qualities, the apparatus showcases its multifaceted nature. Physical modeling played a pivotal role, with a precise model constructed from true-to-scale materials. Employing photometry, we validated lighting performance, bridging the gap between computational simulations and real-world applicability. The confluence of computational design and physical computation not only shapes the aesthetic and functional aspects of the generative sculpture but also fortifies the credibility of its lighting performance. As the work undergoes construction in Athens, this paper offers a comprehensive exploration of the innovative synergy between computational and physical methodologies, providing valuable insights into the seamless integration of cutting-edge technologies with traditional architectural practices. Within the paper, we present the intricacies of the computational apparatus, showcasing conceptual and user-friendly implementations for accessibility by non-specialist end users. We delve into digital simulation steps, integrating their findings and cross-referencing them with their physical computation counterparts, offering a holistic understanding of the project, from the standpoint of the computational designer.

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Polysemantic Entity Extension of Project Models. A theoretical overview to power computable representations

Armando Trento, Antonio Fioravanti, Paolo Fiamma

This research domain fits in the systemic decomposition/classification of the building organism, specifically focusing on the topic of ‘design entity’ computation models. Entities discussed are those regarding architectural spaces, building components and design process procedures for an AECO project. The paper looks at the progress achieved by the academia and industry in the digital representations of CAAD entities, both tangible and intangible, by reviewing their limits and potentials starting from the second half of the last century on. In order to contribute to the enhancement of existing building modelling standards in this field, we discuss the potentialities offered by multiinheritance formalism, overcoming the limits of traditional static object-oriented representation, like the IFC standard. Certain object-oriented programming languages allow for multiple inheritance, which consents an object or class to inherit characteristics from many ’parent’ classes or superclasses. It is not the same as single inheritance, in which a class or an entity can only inherit from one specific class or entity at a time. That is, a design entity can take on different meanings depending on the context and domain of the actor using it, or it could have multifunctional uses. Recent most advanced research proposed the ’polysemantic’ entity that could have multiple superclasses at the same time. By analysing in deep computable project models, we schematize a theoretical framework where a new knowledge-based system synergically work with the basic commercial models – IFC-based – by means of ontologies and graphic systems, to enable semantic reasoning. As a result we aim at providing some helps for designers, software developers and academicians to power the CAAD entity representations of the tools they use.

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Building-Agent. A 3D generation agent framework integrating large language models and graphbased 3D generation model

Ximing Zhong, Jiadong Liang, Yingkai Li

Large language models (LLMs) possess powerful intelligence, demonstrating unprecedented potential in AI-driven architectural design. While LLMs can understand design tasks, they lack the reasoning capability from language to three-dimensional (3D) architectural models. This paper proposes a novel 3D building generative agent framework, Building-Agent, which combines LLMs' decision-making capabilities with Graph Neural Networks (GNNs) generative abilities. Experiments utilize real design briefs and site constraints to test the building agent's task-processing capabilities. The results demonstrate that the Building-Agent can accurately predict different site layout outcomes and achieve high task completion rates. Furthermore, it enables interactive 3D building layout iteration through multi-step natural language instructions. The BuildingAgent's ability to comprehend and reason about 3D spatial layouts, based on the graph representations of 3D models in the modeling engine and the requirements of natural language inputs, showcases its potential to accomplish tasks with initial proficiency. Compared to previous 3D generative models that rely on human decision-making for inputting spatial constraints, the Building-Agent paves the way for AI to comprehend and complete 3D design tasks autonomously, promising a transformative impact on AI and architectural design.

408

Integrating Surrogate Modeling and Design Analytics for Data-informed Exploration in the Early Phases of Building Design

Esmaeil Mottaghi, Halil Erhan, Ahmed M. Abuzuraiq, Victor Okhoya, Spyridon Ampanavos, Marcelo Bernal, Cheney Chen and Yehia Madkour

Building design workflows have been influenced by incorporating data-driven decisions, algorithmic content generation, and performance analysis support offered by machine learning methods. The challenge lies in bringing these seemingly isolated but highly related design tasks together in an engaging design environment that can maintain designers' creative decision-making flow while reducing system interferences' complexity. This paper presents D-Predict.v2 as an experimental prototype we developed following a design study methodology to tackle this challenge. As a contribution, we propose a design workflow and a system that can be adapted to support building performance prediction using surrogate models in direct or parametric design modelling driven by interactive data visualizations. Our initial findings demonstrated that expert designers welcomed the proposed workflow with caution and recommendations. Our future work will focus on conducting ecologically valid case studies and rebuilding the system by addressing the concerns raised by the expert designers.

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Spatiotemporal Modeling Vertically Integrated Project. A VIP on human-centered metrics for architecture

Paula Gomez Z., Matthew Swarts, Gonzalo Vegas

Spatiotemporal Modeling towards human-centered metrics for architecture refers to the integration of a set of parametric models, including: 3D models, building type and functions, schedules, Agent-based simulations (ABS) of human activities, and Computational-Fluid Dynamics (CFD) models of airflows. The meta-goal is to develop human-centric metrics for improving humans’ quality of life. This work specifically focuses on virus spread modeling, thus we added a fifth model: The virus characteristics model, which includes the virus survival time and transmissibility through Direct, Airborne, and Fomite pathways. The objectives are to integrate the models to determine the impact of specific parameters on human-centric metrics, in this case the “risk of exposure” in certain scenarios. We developed ABS and CFD simulations in Anylogic and Eddy3D platforms, respectively. The integration of all models was implemented in Grasshopper. This paper presents three pilot studies, in the context of the Vertically Integrated Project (VIP) program, using a K-12 school project provided by Perkins&Will architecture firm. We explain the structure of the VIP, interdisciplinary research-based class, emphasizing the sub-projects, research designs, and preliminary results. The technical integration of the aforementioned models into one spatiotemporal model aims to communicate the probability of risk under specific scenarios. Examples of pilot studies under this framework include: What is the best high school schedule to reduce the probability of contagion, in a regular weekday, with/out the implementation of policies such as socialdistancing?; What is the impact of a door handle on reducing contamination?; What are the safest chairs in which to sit in a classroom in relation to the HVAC system configuration? among others. The analyses for specific scenarios helps propose general solutions for spaces, behaviors, and protocols, to increase human safety inside buildings.

2.1 SESSION 2.1

WEDNESDAY 11.09.2024 • 14:00-15:30

ROOM: LRC012

Session Chair: ***WASSIM JABI***

AUTOMATED FABRICATION I

306	**Research on Autonomous Recognition and Gripping Method for Robotic Fabrication of Heterogeneous Masonry Based on Computer Vision**	*Sijia Gu, Philip F. Yuan*
077	**Multi-Robotic Maypole Braiding**	*Pengfei Zhang, Selin Sevim, Samuel Leder, Mathias Maierhofer, Tobias Schwinn, Achim Menges*
193	**Robotic Assembly of Timber Plate Structures. Design and assembly strategies towards autonomous assembly**	*Juan Gracia, Balu Anil, Cephas Bhaskar, Guillem Perutxet Olesti, Jingyuan Meng, Pradeep Devadass*
155	**Mortise and Tenon Beam-to-Beam Joints Solver for Discrete Timber Structures. A structural performance-driven tool based on finite element analysis**	*Xincheng Jiang, Tianyi Gao, Chi Zhang, Philip F. Yuan*
282	**Non-planar 3D Printing of Clay Columns**	*Jiri Vele, Simon Prokop, Ondrej Ciganik, Lukas Kurilla, Henri Achten, Katerina Sysova*
019	**Enhancing 3D Concrete Printing Buildability with Non-Planar Layering. A case study**	*Jiri Vele, Oto Melter, Ales Hvizdal, Henri Achten, David Citek*

2.2 SESSION 2.2

WEDNESDAY 11.09.2024 • 14:00-15:30

ROOM: LRC014

Session Chair: ***SIMON PROKOP***

DATA IN DESIGN

016	**Implicit Inequality. Urban inequality mapping and boundary detection through big data analysis and machine learning**	*Zhanlin Yan, Han Tu, Rudi Stouffs*
424	**Neural Network-Driven 3D Generation of Urban Trees. Advancing Carbon Mitigation Simulation through Detailed Tree Modeling from Point Cloud Data**	*Chaowen Yao, Pia Fricker*
235	**Data and Parameterization Requirements for 3D Generative Deep Learning Models**	*Lisa-Marie Mueller, Charalampos Andriotis, Michela Turrin*
198	**Building-VGAE. Generating 3D detailing and layered building models from simple geometry**	*Jiadong Liang, Ximing Zhong, Immanuel Koh*
169	**Theatre4all Spatial Inclusivity to the Visually Impaired. An indoor positioning research approach for Michael Cacoyannis Foundation's theatre**	*Mattheos Papavasiliou, Konstantinos Gounaridis, Charalampos Marantos, Michail Vakis, Sotirios Kokosis*

2.3

SESSION 2.3

WEDNESDAY 11.09.2024 • 14:00-15:30

ROOM: LRC019

Session Chair: ***THEODOROS DOUNAS***

COLLABORATIVE DESIGN

363	**Collaborative Design with Generative AI and Collage. Enhancing creativity and participation in education**	*Christina Doumpioti, Jeffrey Huang*
060	**How Augment Reality Support Public Participation in the Urban Design Decision-Making. A ten - year literature review**	*Zijun Wan, Shuaibing Sun, Fanjing Meng, Yu Yan*
284	**Situating Digital Participation. Incorporating material, contextual, and performative learnings into digital toolkits**	*Matti Drechsel, Nick Förster, Gerhard Schubert, Frank Petzold*
399	**Data-Informed Design Democratization. Engaging design stakeholders for creating livable built environments**	*Md Zishaan Khan, Halil Erhan, Elif Sezen Yagmur Kilimci*
040	**Phygital Recycling. Development of a gamified interactive XR structure to enhance the participation of recycling**	*Tian Tian Sky Lo, Hanzhe Bao*
348	**Towards a Decentralized Physical Infrastructure for Additive Manufacturing in Architecture. A proof of concept for a tamper proof, secure connection between designs, blockchains and 3d printers**	*Theodoros Dounas, Yorgos Berdos, Jiri Vele*

SESSION 2

Session Chair: ***WASSIM JABI***

2.1

306

Research on Autonomous Recognition and Gripping Method for Robotic Fabrication of Heterogeneous Masonry Based on Computer Vision

Sijia Gu, Philip F. Yuan

The emphasis on material diversity in robotic fabrication processes enhances the freedom of design in form and function, enabling the possibility of masonry working as functionally graded materials. However, in the robotic fabrication process based on offline programming, the lack of autonomous judgment of brick materials restricts the fabrication of multi-material masonry, resulting in additional labor and equipment costs. In this context, improving the autonomous judgment ability of construction robots on materials becomes an important breakthrough point, for which computer vision is a possible solution. However, current research on brick materials based on object detection mainly focuses on crack inspection and cannot distinguish multiple types of bricks in the same fabrication process. Therefore, the research aims to establish a methodology for an automatic multi-material brick grasping process based on the plane. The method consists of three parts: target detection, data conversion, and robot grasping. In this process, the research aims to innovate in four aspects: targets of object detection, derivation of dataset structure, introduction of design models, and real-world physical validation. Based on the proposal, a full-stage validation experiment was conducted. The experimental results validate the feasibility of the proposed method, hoping to bring new insights to robotic fabrication and parametric masonry design.

077

Multi-Robotic Maypole Braiding

Pengfei Zhang, Selin Sevim, Samuel Leder, Mathias Maierhofer, Tobias Schwinn, Achim Menges

Although braided structures are considered highly versatile, resilient, and scalable, there is a lack of suitable tools for designing them in architecture. This research explores a bottom-up behavioral strategy to investigate the design and simultaneous fabrication of braided structures using a multi-robot system. To achieve this a cyber-physical workflow, inspired by the traditional maypole dance where a group of dancers maneuvers ribbons into a braided spatial network, was developed using agent-based modeling and simulation (ABMS). Similar to the maypole dancers' choreography, each agent in the model, which represents a mobile robot in the real world, takes the positions of neighboring agents as input to decide how to act. These simple actions or behaviors allow complex braided geometries to emerge over time. To verify the model in the real world, the proposed approach was tested on a swarm of autonomous two-wheel mobile robots called RADr. A braided structure with a size surpassing each individual robot was built as a demonstrator. This research provides a case study for the automation of braided structures using behavioral strategies, allowing for the design of the braids to emerge as they are built.

193

Robotic Assembly of Timber Plate Structures. Design and assembly strategies towards autonomous assembly

Juan Gracia, Balu Anil, Cephas Bhaskar, Guillem Perutxet Olesti, Jingyuan Meng, Pradeep Devadass

This research paper introduces design and assembly strategies for autonomous construction of timber plate structures. Current state-of-the-art research shows robotic assembly of Integrally Attached Timber Plate Structures (IATPS) is feasible, yet achieving precise, fully automated assembly encounters challenges such as setup inaccuracies, spring back forces, material warping, and a lack of strategies for design optimization tailored to autonomous assembly. The research comprises three main areas: designing timber plate structures with an emphasis on optimizing joinery design for autonomous assembly, establishing a multi-robotic path planning that considers assembly sequence and direction of assembly, and implementing feedback-based assembly using real-time positional tracking system for accuracy and efficiency. The research investigates the constraints of design by constructing two prototypes: a folded timber plate structure and a trivalent polyhedral timber plate structure. The folded timber plate prototype serves to explore and analyze three different types of joinery. Through this experimentation, effective joinery assembly strategies are identified, which are subsequently applied in the final prototype of the trivalent polyhedral timber plate structure. This research paves the way for future exploration in the field, indicating vast potential for further innovations in design strategies for automated assembly.

155

Mortise and Tenon Beam-to-Beam Joints Solver for Discrete Timber Structures. A structural performance-driven tool based on finite element analysis

Xincheng Jiang, Tianyi Gao, Chi Zhang, Philip F. Yuan

Timber, as a building material with carbon sequestration ability, has significant potential in promoting sustainable development goals. Advancements in parametric design and robotic fabrication are revitalizing traditional timber craftsmanship, leading to a new era of non-standardized design a mass customization. Modern timber structure construction faces key challenges, including analyzing traditional mortise and tenon joints' structural performance and seamlessly integrating parametric designs into robotic workflows. Achieving effective modeling for these joints requires a specialized, intelligent toolkit that spans the entire design-to-fabrication process, tailored for robotic fabrication. The study focuses on the "Mortise and Tenon Beam-to-Beam" technique, combining traditional methods with advanced technology through the FUROBOT-based "Mortise and Tenon Beam-to-Beam Joints Solver." This innovative toolkit, applied in designing and constructing a timber pavilion, enables largescale, flexible customization in timber structures. The research begins with a detailed description of the generation of parametric joints. Following this, to enhance joint performance, finite element analysis is conducted in Abaqus, focusing on the anisotropic nature of wood joints. This analysis feedback is used in conjunction with the solver to compare multiple solutions and obtain the best highperformance joint solution. Subsequently, robot tool path generation and trajectory optimization are undertaken, considering the constructability of the wood. In the practical application phase, a timber pavilion spanning 682 square meters and standing 6 meters tall, constructed from 603 glued wood components, was erected. The empirical demonstration of the "Mortise and Tenon Beam-to-Beam Joints Solver" process verified its effectiveness and efficiency in enabling architects to design high-performance joints and implement robotic fabrication workflows. The total processing time for the 603 glued timber components was 30 days, marking a 1/3 reduction in time compared to traditional timber structure workflows. This achievement underscores the toolkit's role as a driving force in advancing non-standardized design and promoting large-scale, flexible customization in timber structure construction.

282

Non-planar 3D Printing of Clay Columns

Jiri Vele, Simon Prokop, Ondrej Ciganik, Lukas Kurilla, Henri Achten, Katerina Sysova

The contemporary landscape of construction 3D printing of materials like clay or concrete mainly relies on planar slicing, which, regrettably, impose constraints on the realization of overhangs and cantilevered structures, thereby limiting architectural design flexibility and posing issues in fabricating intricate structures. In response to this challenge, we investigate the integration of non-planar slicing in the construction printing of structures featuring substantial overhangs. We present a novel approach to crafting print paths strategically, fragmenting the global overhang into discrete local segments. Additionally, we introduce self-balancing control to help the buildability within segments of the print path, elevating the stability of the freshly deposited concrete during the printing process. Our methodology redistributes a portion of the bending forces into tension forces oriented along the print path, thereby augmenting the structural integrity and buildability of intricate structures with overhangs and vaults. The efficacy of our method is demonstrated through a computational parametric model and a physical prototype. A comprehensive comparative analysis is conducted against conventional planar printing methods, encompassing metrics such as geometric accuracy, buildability, material efficiency, and print time.

019

Enhancing 3D Concrete Printing Buildability with Non-Planar Layering. A case study

Jiri Vele, Oto Melter, Ales Hvizdal, Henri Achten, David Citek

This paper explores improvements in 3D Concrete Printing (3DCP) buildability using non-planar layering. Our proof-of-concept experiment validates the assumption that nonplanar layering enhances the buildability of overhangs and vaults. To test this, we designed an object comprising two columns with a Gothic arch and overhangs on the upper part, resulting in a continuous wall at the top. The object measures approximately 1.5 meters in length, 400 mm in width, and 700 mm in height. The design was executed to maintain the centre of mass in the centres of the columns across all print layers, mitigating unwanted deformation. The overhang angle ranged continuously from 0 to 70 degrees. The object was modelled in Rhinoceros software, and G-code for both planar and non-planar printing was generated in Grasshopper. Both samples were designed to use the same amount of material, print length, and print time. We printed these using a cementitious mixture with plastic fibres and an additional accelerant mixed in the nozzle on a gantry printer. Throughout the printing process, we conducted careful observation and monitoring to detect any instances of buckling or collapse. Post-print measurements were carried out to evaluate the deformation of the printed objects, revealing a reduction in deformation with non-planar printing. This paper discusses the analysis of results and proposes a workflow for future data preparation for non-planar slicing.

SESSION 2

2.2

Session Chair: ***SIMON PROKOP***

016

Implicit Inequality. Urban inequality mapping and boundary detection through big data analysis and machine learning

Zhanlin Yan, Han Tu, Rudi Stouffs

To understand and interpret the multi-dimensional nature of the implicit inequalities, we premise “inequality” as a neutral word and map the physical distribution of different elements related to everyone's daily life by utilizing the strength of big data technology and machine learning. Using geo-located street view images and GIS data of points of interest, we analyse the “inequality” condition in multiple dimensions for one specific region in Singapore. We propose a new methodology to detect and analyse “inequality boundaries” in Singapore, revealed in the form of linear elements such as edges and pathways. The methodology functions by developing a scoring system of cells in a regular grid, that belongs to a uniform fishnet covering the whole Singapore region. The cell scores relating to contrasting measures are considered as the foundation for boundary detection. This research successfully identifies boundary locations where areas of opposing measures lay side by side and determines the specific “inequality boundary” as linear elements within the boundary locations.

424

Neural Network-Driven 3D Generation of Urban Trees. Advancing Carbon Mitigation Simulation through Detailed Tree Modeling from Point Cloud Data

Chaowen Yao, Pia Fricker

Urban digital twins are essential for climate-responsive urban planning but often fail to accurately represent trees, relying instead on oversimplified models that inadequately capture their environmental impact. Traditional methods for tree modeling, notably skeletonization, are both iterative and labor-intensive, leading to inefficiencies in environmental simulation accuracy. Addressing this gap, our study introduces a novel approach using a PointNet-based Convolutional Neural Network to generate precise 3D tree models from mobile laser-scanned point clouds, significantly enhancing simulations for carbon mitigation efforts. Our method, tested in Helsinki's Jätkäsaari area, leverages pre-defined skeleton data to train the neural network, streamlining the extraction of movement direction and distance, thus bypassing traditional skeletonization's iterative nature. We further refine our model's accuracy and robustness by incorporating point clouds of varying densities and tailoring our approach to account for the morphological diversity of specific tree species. This specificity enables our models to more closely mirror real-world trees, making them invaluable for dynamic environmental modeling within urban digital twins. Moreover, our models support integration with the L-system, a prominent plant growth simulation algorithm, showcasing the potential of advanced neural networks to revolutionize computational architecture and foster precise, sustainable urban environmental simulations.

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Data and Parameterization Requirements for 3D Generative Deep Learning Models

Lisa-Marie Mueller, Charalampos Andriotis, Michela Turrin

It is now within reach to use generative artificial intelligence (AI) to autonomously generate full building geometries. However, existing literature utilizing 3D data has focused to a limited degree on architecture and engineering disciplines. A critical first step to expanding the use of generative deep learning models in generative design research is making training data available. This study investigates 3D building model data characteristics that make it suitable for generative AI applications. Key data set attributes are identified through a systematic review of the object-containing datasets currently used to train state-of-the-art 3D GANs. These requirements are then compared to attributes of existing available building datasets. This comparison shows that publicly available data sets of 3D building models lack essential characteristics for generative deep learning. Features that make these building models inadequate for the task include but are not limited to, their mesh formats, low resolution and levels of detail, and inclusion of irrelevant geometry. To achieve the desired properties in this work, necessary transformations of the data are incorporated into a tailored preprocessing pipeline. The pipeline is applied to an existing dataset that contains 3D models of single-family homes. The transformed dataset is tested within state-of-the-art GAN models to assess training performance and document future data requirements for applying deep generative design to buildings. Our experiments show promise for the impact that architectural datasets can make on deep learning applications within the discipline. It also highlights the need for additional 3D building model data to increase the diversity and robustness of new designs.

198

Building-VGAE. Generating 3D detailing and layered building models from simple geometry

Jiadong Liang, Ximing Zhong, Immanuel Koh

In the current field of AI-assisted architectural design, deep learning models primarily focus on simulating the highly detailed final models designed by human architects. However, in practical design tasks, the final model demands a high level of detail and clear layered classification information for building components. This presents a more significant challenge. We propose a three-dimensional(3D) building generation framework—Building-VGAE, based on Variational Graph Autoencoder (VGAE). Building-VGAE can generate 3D models with detailed building components and layered structure information from end to end, according to design constraints and building volumes. Building-VGAE’s experiment involves transforming 27,965 Housegan data into 3D data represented as graph-structured. The VGAE model then learns the data features and predicts the building component categories to which nodes and edges belong in the experiment. The results demonstrate that the framework can precisely reconstruct and predict building layouts that comply with design constraints and enable unified editing of building components of the same category. Building-VGAE contributes to its ability to learn the generative relationship from design constraints and building volumes to complex high-detail models compared to existing AI generative models. It also possesses prediction and editing capabilities based on the layered classification information of building components. This framework has the potential to position AI as a design partner for human architects, offering end-to-end 3D generative intelligence.

169

Theatre4all Spatial Inclusivity to the Visually Impaired. An indoor positioning research approach for Michael Cacoyannis Foundation's theatre

Mattheos Papavasiliou, Konstantinos Gounaridis, Charalampos Marantos, Michail Vakis, Sotirios Kokosis

The objective of the research is forward to the inclusion as an act of a fundamental right to culture, leveraging the relationship between technology and cultural heritage. A prototype system for the indoor navigation of visually impaired users is implemented, specifying the diversification of the given needs. The scope is to provide the experience of cultural performance, using architecture and technology, by means of human-oriented procedures according to the specific condition. The project consists of three principal aspects forward to its execution: a mobile application that provides voice directions to the user accessing their ability to navigate, which is based on the survey of the building's circulation space and a sensor system (Bluetooth AoA Angle of Arrival) capable of calculating the exact position of the user. Architecture computational design tools are used to inform the application for the spatial characteristics and geometry of the building's circulation space. Regarding the sensor system, the capabilities of a simple solution, based on the signal strength of Bluetooth beacons (small devices that continuously emit Bluetooth signals), were initially tested. Then, a second approach based on Bluetooth AoA (Angle of Arrival) is presented. Bluetooth AoA allows measuring the angle from which a signal is received, and therefore increases accuracy, reduces signal interference and achieves wide coverage. The calculated position is continuously given in the mobile application, the design of which is presented in a detailed manner. The paper presents the results of a study through interdisciplinary procedures, engaging social and spatial conditions of architecture, using computational design and new technologies (IoT, software/hardware), towards the adoption and further enlargement of Inclusive Design. A series of experiments on how Bluetooth technology works for indoor positioning are presented and the design of the user navigation application is described. Conclusions, challenges, as well as next steps are discussed.

SESSION 2

Session Chair: ***THEODOROS DOUNAS***

2.3

363

Collaborative Design with Generative AI and Collage. Enhancing creativity and participation in education

Christina Doumpioti, Jeffrey Huang

This study explores the integration of visual generative artificial intelligence (VGI) tools in the early stages of urban design and communication within a UX design course. Students developed urban design concepts from initial ideas to visual prototypes, promoting creativity and collaboration. The research investigates the role of VGI in the ideation process and its potential as a participatory tool for urban regeneration. Collage, reappropriated as a collaborative technique, works alongside generative AI to aid in creating and refining ideas. Additionally, the study presents a method for creating beforeand-after images, providing a dynamic way to visualise urban evolution. Through an analysis of student feedback and project outcomes, the study identifies both the benefits and limitations of using generative AI in design education, aiming to improve AI interfaces and their application in collaborative design contexts. The findings suggest that VGI can impact design thinking and practice, serving as both a creative tool and a means to facilitate inclusive and insightful decision-making processes.

060

How Augment Reality Support Public Participation in the Urban Design Decision-Making. A ten - year literature review

Zijun Wan, Shuaibing Sun, Fanjing Meng, Yu Yan

Emerging applications of AR have demonstrated its powerful visualization capabilities, which is a potential solution to enhance public participation in the urban design process. However, there is still a lack of complete understanding of how AR gets involved in this decision-making process. Therefore, this paper reviews 33 empirical studies relating to the topic through the four steps of "PRISMA". The results indicate that the quantity and quality of research is increasing yearly. As AR technology progresses, the techniques and research methods used in those studies show a trend toward diversification and customization; this has also led to a shift in the scale of urban design from large and abstract to small and concrete. In terms of content, the topics have gradually changed from "people group" to "technology", and then to "environment". Notably, a small number of cases in tangible interaction and multi-user collaboration have emerged from 2020 — areas showing great promise. In terms of user assessments, most studies give positive feedback, but there are currently concerns about problems in poor AR visualizations, privacy risks, and the social inequality caused by technical affordance.

284

Situating Digital Participation. Incorporating material, contextual, and performative learnings into digital toolkits

Matti Drechsel, Nick Förster, Gerhard Schubert, Frank Petzold

Complex planning problems like the mobility transformation require the inclusion of stakeholders and situated knowledge. Generic map-viewers, surveys, or visualisations often fail to incorporate situated, complex, and contingent aspects of participatory negotiations – aspects which are more central to artistic, performative and analogue formats. In the context of a New European Bauhaus project, we discuss a participatory process through which mobility-related interventions, so-called NEBourhood-hubs, are located, configured, and designed. We propose a hybrid approach to combine the potential of digital participation methods with contextual and situated perspectives. Firstly, we developed several experimental analogue formats, highlighting bodily, spatial, and interactive dimensions of participatory involvement. Building upon these learnings, we explore how these aspects can be incorporated into the design of digital tools. We tested this approach in a design studio with students of architecture and urbanism, who explored the analogue participation formats and translated these contextual learnings into an array of digital tools. Through an analysis of these prototypes, we critically reflect on the underlying approach and its potential contribution to the collaborative planning of the mobility transformation.

399

Data-Informed Design Democratization. Engaging design stakeholders for creating livable built environments

Md Zishaan Khan, Halil Erhan, Elif Sezen Yagmur Kilimci

Fostering an inclusive and democratic decision-making process is essential to developing liveable, socially acceptable, and environmentally conscious built environments. For informed decision-making in this process, stakeholders' understanding of design data plays an important role, as do the other disciplines embracing data-informed discourses and cultures. However, more work is needed to develop novel platforms for supporting data-informed decision-making in built environment design. Public engagement and town hall meetings are common methods to engage the public. They are often restricted by time, space, and participation scope. The online tools for data democratization in various fields offer opportunities to promote a democratic

discourse; although their purpose varies, their characteristics can guide the search for novel approaches adopting a new class of tools for building design. We propose a conceptual framework for evaluating and designing tools supporting data-informed [built environment] design democratization through inclusive discourses called Di-Dem. As a contribution, we demonstrated the application of the framework in evaluating ten platforms offered for similar purposes.

040

Phygital Recycling. Development of a gamified interactive XR structure to enhance the participation of recycling

Tian Tian Sky Lo, Hanzhe Bao

The issue of plastic waste recycling transcends national boundaries, presenting a formidable challenge on a global scale. In Hong Kong, the endeavour to recycle plastic waste commenced in the 1980s and has undergone nearly four decades of evolution and transformation. The initial landfill-centric approach has given way to a more multifaceted and integrated waste management model. Recent years have witnessed certain communities adopting innovative joint recycling systems, which are propelled by incentive-driven mechanisms. These systems have shown initial success, yet they grapple with the challenges of low participation rates and limited reach within the populace. To amplify user engagement, gamification strategies have been incorporated into the recycling infrastructure, yielding notable efficacy in specific locales. Nevertheless, the prevailing systems predominantly rely on two-dimensional, planar interactive devices, which are beset by a paucity of informational resources and suboptimal interactivity. Immersive technologies emerge as a promising avenue to enhance the efficiency of graphical information exchange and to elevate the level of information visualization. Historical precedents indicate that immersive techniques can significantly augment user experience and bolster the propensity for repeated engagement. This study endeavours to forge an avant-garde recycling paradigm that marries the incentivizing allure of gamified reward systems with the interactive prowess of immersive technologies. It champions the adoption of a 'Phygital' system, which seamlessly melds physical and digital elements within contextually relevant environments to achieve superior outcomes. The article highlights a design framework that utilizes immersive technology to gamify recycling engagement. This framework incorporates mixed reality (MR) devices and sensors to enhance the overall experience for participants.

348

Towards a Decentralized Physical Infrastructure for Additive Manufacturing in Architecture. A proof of concept for a tamper proof, secure connection between designs, blockchains and 3d printers

Theodoros Dounas, Yorgos Berdos, Jiri Vele

We introduce a promising proof of concept: a blockchain to additive manufacturing pilot prototype. In this paper we focus on developing the functional cyberphysical prototype of the smart contracts running on a blockchain, orchestrating the workflow of additive manufacturing in architecture. We have used design science research and rapid prototyping as methods to create our cyberphysical system. Our prototype allows for the discretisation of a design in components, which are then placed for bidding for production. The components are indexed, with a Non-Fungible Token is produced for each component, recorded on the smart contracts of our platform. The original designers are recorded and then rewarded if the component is ever re-used. A set of additive manufacturing shops then cost and bid for the production of the components, recording their bid on-chain. Component fabrication quality is then validated against the tamperproof blockchain storage system. Our pilot project establishes viability and a direct link between a blockchain network and 3D printers, facilitated by microcontrollers interfaces acting as blockchain “Oracles”. The significance of this paper lies in its potential to reshape the architectural manufacturing and fabrication landscape. By integrating blockchain with 3D printing, we address critical issues such as efficiency, in challenging locations with labour shortages or logistical constraints.

3.1

SESSION 3.1

CONSTRUCTION

WEDNESDAY 11.09.2024 • 16:00-17:30

ROOM: LRC012

Session Chair: ***JACOB GROBMAN***

243	**Rearticulated Architectural Glass. A computational method and model for the organisation of reused glass**	*Isak Worre Foged, Maria Sparre-Petersen, Vasiliki Fragkia*
264	**Opportunities for a sustainable future. Testing the biocompatibility of new materials for large scale additive manufacturing**	*Joost Meyer, Federico Garrido, Ana Martarello, Christina Hömberg*
331	**Towards New Materiality and Structures. Generating 3D topological interlocking assemblies from 2D Penrose tiling using interactive geometric software**	*Mengdi Mao, Marjan Colletti, Guan Lee*
168	**Thermal and structural performance of cork-cement composite for Additive Manufacturing (AM)**	*Ohad Yaacov Meyuhas, Pavel Larianovsky, Jonathan Natanian, Aaron Sprecher*
286	**Preliminary Energy Simulations of Smart Materials on Building Façade. A hypothetical case study to determined energy performance of smart materials**	*Stefanie Aylien Jonatan, Miktha Farid Alkadri*
349	**Maximizing Solar Energy Harvesting of the Kinetic Photovoltaic System**	*Karolina Dąbrowska-Żółtak, Krystian Kwieciński, Jakub Oszczyk*

3.2 SESSION 3.2

WEDNESDAY 11.09.2024 • 16:00-17:30

ROOM: LRC014

Session Chair: ***BOB MARTENS***

BIM I

066	**Graph Neural Networks for Node Classification and Attribute Allocation in Architectural BIM**	*Wassim Jabi, Yang Li*
297	**Building Information Model Analysis Through Large Language Models and Knowledge Graphs**	*Angelo Massafra, Ugo Maria Coraglia, Giorgia Predari, Riccardo Gulli*
201	**A Surface Modeling Method for Indoor Spaces from 3D Point Cloud Reconstructed by 3D Gaussian Splatting**	*Keiji Hashizume, Tomohiro Fukuda, Nobuyoshi Yabuki*
223	**Development of Structure-Specific Architectural BIM Object Automatic Generation Technology for Reverse Design Based on Deep Learning**	*Taehoon Kim, Geunjae Kim, Soon Min Hong, Seungyeon Choo*
232	**A Holistic Documentation and Analysis of Timber Roof Structures in Heritage Buildings Using Scan to HBIM Approaches**	*Panayiotis N. Panayiotou, Odysseas Kontovourkis*

3.3 SESSION 3.3

WEDNESDAY 11.09.2024 • 16:00-17:30

ROOM: LRC019

Session Chair: ***GABRIEL WURZER***

DIGITAL DEVELOPMENTS I (ONLINE)

322	**Mindscape. Research of high-information density street environments based on electroencephalogram recording and virtual reality head-mounted simulation**	*Yijiang Liu, Xiangyu Guan, Lun Liu, Hui Wang*
101	**Application of Artificial Neural Network for Predicting UValues of Building Envelopes in Temperate Zone**	*Jiaqi Yu, Kening Guo, Zishen Bai, Zitong Wen*
061	**Multi-Objective Optimization of Iranian Windcatchers Based on Building Energy Consumption and Indoor Thermal Comfort**	*Haojun Wang, Yulin Chen, Hainan Yan*
005	**Exploring Virtual Reality's Role in Assessing Public Spaces for Children: An embodied design approach**	*Yuchen Zheng, Lingchuan Chen, Xiangduo Meng, Tian Tian Lo*
406	**From Past to Present. A study of AI-driven gamification in heritage education**	*Sepehr Vaez Afshar, Sarvin Eshaghi, Mahyar Hadighi, Guzden Varinlioglu*
105	**A Data-Driven Model for Sustainable Performance Prediction of Residential Block Layout Design Using Graph Neural Network**	*Zhaoji Wu, Mingkai Li, Wenli Liu, Zhe Wang, Jack C.P. Cheng, Helen H.L. Kwok*

SESSION 3
Session Chair: ***JACOB GROBMAN***

3.1

243

Rearticulated Architectural Glass. A computational method and model for the organisation of reused glass

Isak Worre Foged, Maria Sparre-Petersen, Vasiliki Fragkia

This research project investigates how glass from existing buildings can be extracted, redesigned and re-used through computational design and fabrication methods. Glass is a fundamental building component in the built environment, and at the same time the material with the highest environmental footprint per kg. With the current trend of a high glass-to-opaque building façade ratio, glass remains a central, important and problematic material for architecture. The studies are focused on experimental methods through material studies, computational studies and the making and observation of a fullscale demonstrator structure from harvested building glass. The method (water jet technology) proposed extracts around 90% of the glass, with the articulation method (sandblasting) providing significant transformation capabilities by re-designing the light, thermal and reflection properties with minimal removal of the material by computational models.

264

Opportunities for a sustainable future. Testing the biocompatibility of new materials for large scale additive manufacturing

Joost Meyer, Federico Garrido, Ana Martarello, Christina Hömberg

This paper is about recycling, reuse, composting and degradation of natural 3D-printing materials based on waste from the wood industry. Wood is an abundant organic material used in the construction industry that generates significant waste during its manufacturing process. Liquid Deposition Modelling (LDM) offers a flexible and energyefficient additive manufacturing method for paste-like materials made from these same waste materials. Due to the inherent properties of its components, the resulting material is sustainable and complies with the principles of the circular economy. The potential impact of this emerging and scarcely investigated technological opportunity on the construction industry could be immense. The sustainable properties can lead to a turning point in the carbon-conscious design in architecture. For this reason, a young team of researchers, supported by architectural students in their Masters, designed experimental set-ups, methods and evaluation criteria focusing on aspects of ecology.

331

Towards New Materiality and Structures. Generating 3D topological interlocking assemblies from 2D Penrose tiling using interactive geometric software

Mengdi Mao, Marjan Colletti, Guan Lee

The term Topological Interlocking Assembly (TIA), proposed by A.V. Dyskin et al., refers to an assembly system whose internal elements are both translationally and rotationally locked. Such systems allow masonry construction to form stable assemblies more sustainably, relying not on mortar or special connectors but by the geometric arrangement of bespoke blocks. Prior studies in TIA focused mainly on platonic geometries, and a few have considered curved structures, derived primarily from regular 2D tessellations. In contrast to existing methods, this paper explored nonplatonic mortarless vaults with TIA generated from aperiodic Penrose tiling for both structural function and aperiodic aesthetic in architecture. The patterns formed by Penrose tiles, invented by Sir Roger Penrose in the 1970s, are aperiodic, i.e. they do not repeat regularly. This research used Rhino Grasshopper to enable real-time control and visualization of design parameters and variations in 2D tiles and 3D aggregation methods. Using geometric software as an interface enables architectural form-finding through material behavior and structural principles. The TIA approach considered is shown to offer ample design space for nonplatonic geometries and breaks masonry architecture's dependence on conventional construction methods. This computer-aided design outcome allows us to formulate new understandings of materiality and structures.

168

Thermal and structural performance of cork-cement composite for Additive Manufacturing (AM)

Ohad Yaacov Meyuhas, Pavel Larianovsky, Jonathan Natanian, Aaron Sprecher

This study explores the potential of cork-cement composites for structural and thermal performance in architecture through additive manufacturing (AM) technology. By optimizing the composite for 3D printing, the research demonstrates the unique applicability of this composite for large-scale architectural projects, particularly for building envelope elements. Employing a robotic 3D printing process, masonry blocks were manufactured and evaluated for structural performance and thermal efficiency. The results of this study demonstrate the practicality of using cement-cork composite in AM architectural envelopes. In addition, the results show that 3D-printed cork-cement composite elements outperform traditional masonry blocks. Ultimately, this study paves the way for future 3D printing of architectural elements with functionally graded structural and thermal performance.

286

Preliminary Energy Simulations of Smart Materials on Building Façade. A hypothetical case study to determined energy performance of smart materials

Stefanie Aylien Jonatan, Miktha Farid Alkadri

As the earth's surface temperature rises, maintaining comfortable indoor temperatures without increasing the energy consumption of cooling systems is necessary. One climate change mitigation that may provide great relevance to this issue is to use adaptive facades as they can provide flexible energy flows in response to dynamic external conditions. Among adaptive facades strategies, smart materials show great potential to respond intelligently to the surrounding environment through changes in material properties. In this regard, smart materials require little to no additional active system because of changes made internally by the material. This paper aims to investigate potential applications of smart materials in building facades by first analyzing the energy performance of 9 smart materials (i.e., low-e glass, nePCM, PCM filled, paraffin MG29, PV Vacuum glazing, semitransparent PV A, semitransparent PV B, insulated DSSC-R, DSSC-G) found in adaptive facades. This study then specifically calculates EUI (energy use intensity), cooling load, and average solar heat gain for existing buildings located in Jakarta. Lastly, two smart materials (i.e., PV and PCM) are selected to compare building façade construction proposals based on their transmissivity, maximum solar heat gain, and conductivity. Despite the potential application of smart materials, this study found that PV and PCM provide lower performance values due to energy demand functions that predominantly focus on

generation rather than contributing to heating and cooling aspects. This study can further benefit architects when dealing with façade construction materials, especially in tropical countries. It needs to be aligned with the energy performance produced by the façade, the surrounding environment, and the local context.

349

Maximizing Solar Energy Harvesting of the Kinetic Photovoltaic System

Karolina Dąbrowska-Żółtak, Krystian Kwieciński, Jakub Oszczyk

This study presents a method for analyzing the energy efficiency of photovoltaic (PV) panels in various configurations, including static, single-axis, and dual-axis tracking systems, specifically applied to canopies. Focusing on a selected location in Central Europe – Warsaw (52°13' N), the research utilizes numerical analyses and local weather data to understand the energy gains from these systems by considering their orientation and the sun's path throughout the year. Key findings indicate the energy increase for each of analyzed tracking system compared to static flat panels, demonstrating the closeness of the results obtained in the case of appropriately selected single-axis versus dual-axis systems. This research contributes to optimizing the use of PV panels on canopies in renewable energy for Central Europe, offering valuable insights for professionals in the field.

SESSION 3

Session Chair: ***BOB MARTENS***

3.2

066

Graph Neural Networks for Node Classification and Attribute Allocation in Architectural BIM

Wassim Jabi, Yang Li

Building Information Modelling (BIM) marks a notable shift in architectural design, extending beyond simple digital reproductions by capturing the spatial, physical, and operational characteristics of structures. Unfortunately, these representations are often complex in nature and difficult to inspect, analyze, and understand which can lead to errors and omissions during model construction. This research aims to leverage graph machine learning systems, utilizing learned datasets, to detect and rectify these issues, improving model quality and minimizing costly mistakes. To illustrate the application of graph neural networks in this domain, this paper applied a graph-based geometric and topological editor coupled with a graph neural network to a real-world dataset of residential building complexes. The developed workflow operates by converting traditional architectural floor plans into graph-structured data, enabling precise node classification predictions. The paper details the overall workflow, data preparation and conversion, hyperparameter optimization and experimental results. Comparing the performance of various graph neural network models has validated the efficiency of the chosen prediction model in processing and analyzing architectural floor plans, achieving an overall accuracy rate of approximately 95%. The paper concludes with a discussion of the potential and limitations of graph-based machine learning methodologies within the architectural domain and an outline of future work plans.

297

Building Information Model Analysis Through Large Language Models and Knowledge Graphs

Angelo Massafra, Ugo Maria Coraglia, Giorgia Predari, Riccardo Gulli

The advent of Large Language Models (LLMs) seems to mark a break between past and present in the methods of structuring knowledge, making it possible today to transfer this capability to machines even in a sector like AECO, always been information-intensive but resistant to technological transition. In terms of knowledge, the most established paradigm has been Building Information Modelling (BIM), with IFC functioning as the main schema for standardizing the industry's information. Added to this are knowledge graphs that, emerging with semantic web technologies, allow storing knowledge in structures consisting of nodes and edges with semantic meanings. Nevertheless, a barrier to the widespread adoption of BIM is its accessibility. Querying BIM models is often limited for stakeholders without digital skills, who may struggle to access the vast amount of information stored in these complex informative models. In an attempt to outline one of the possible uses of LLMs in BIM, this research proposes a method for querying BIM models through textual prompts aimed at analyzing a selected case study. In the workflow, a BIM model is first realized. Then, data is integrated into a knowledge graph. Next, ChatGPT's LLMs are used to activate query functions for the analysis of the graph. The results of the queries are displayed in a user-friendly graphical user interface. The study's outcomes offer insights for researchers and industry professionals, highlighting emerging research potentials for LLMs in the field.

201

A Surface Modeling Method for Indoor Spaces from 3D Point Cloud Reconstructed by 3D Gaussian Splatting

Keiji Hashizume, Tomohiro Fukuda, Nobuyoshi Yabuki

Building information modeling (BIM) is becoming increasingly important in architectural projects, and the implementation of BIM in new construction projects is progressing. On the other hand, many existing buildings do not have BIM data, so it is necessary to create it from scratch. A common method for converting existing buildings to BIM is scan-toBIM, using techniques such as laser scanning or photogrammetry. However, laser scanning provides accurate point cloud data but requires expensive equipment, while photogrammetry is generally cost-effective but has lower accuracy point cloud data. Another approach for creating BIM from 2D images is to use neural radiance fields (NeRF). However, NeRF faces challenges in terms of data accuracy and processing speed when dealing with large or complex scenes. In contrast, 3D Gaussian Splatting is an emerging computer vision technology that uses machine learning to reconstruct 3D scenes from 2D images faster than NeRF, with comparable or better quality. Therefore, this study proposes a method to create surface models consisting of floors, walls, and ceilings as a preliminary step to creating BIM data for existing indoor spaces using 3D Gaussian Splatting. First, point cloud is generated using 3D Gaussian Splatting, followed by noise reduction. The point cloud is then classified based on height. Subsequently, processing such as extraction of boundary primitives from the point cloud of the floor and classification of feature points are performed to estimate the shape of the floor. Finally, ceilings and walls are created based on height and floor shape. The results of validation confirm an error of between 0.01m and 0.5m in the generated surface models. This study proposes a novel attempt to create 3D models using 3D Gaussian Splatting, contributing to the generation of BIM data for existing buildings.

223

Development of Structure-Specific Architectural BIM Object Automatic Generation Technology for Reverse Design Based on Deep Learning

Taehoon Kim, Geunjae Kim, Soon Min Hong, Seungyeon Choo

This research developed a technology for classifying architectural objects based on point cloud data and creating Building Information Modeling (BIM) models in the reverse engineering process. This research analyzed the limitations in the process and current advancements in point cloud-based object recognition and classification technology, leveraging semantic segmentation. The classification method employed a semantic segmentation-based network to classify objects into desired classes within 3D point cloud data. Specifically, the TD3D network, known for its superior performance, was utilized in this study, with publicly available datasets used for training. Moreover, the developed algorithm for creating architectural object BIM models was specifically designed based on the simplest structure and form, namely reinforced concrete structure. In conclusion, the study aimed to develop technology more aligned with the fundamental purpose of performing reverse engineering in an architectural context. Analysis of validated architectural structures revealed that, despite deviating from actual measurement times, concrete-reinforced structures demonstrated the highest performance.

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A Holistic Documentation and Analysis of Timber Roof Structures in Heritage Buildings Using Scan to HBIM Approaches

Panayiotis N. Panayiotou, Odysseas Kontovourkis

There is a great need for holistic documentation and management of heritage buildings using Historic Building Information Modelling (HBIM) frameworks. Limitations can be found in current literature regarding the accuracy, the level-of-detail, and the required attributes of final HBIM models, especially in cases where digital information intents to be used for the documentation of heritage timber roof structures. Previous research works indicate that geometry is created by the extrusion of the cross sections of the beams, and the usage of existing 2D drawings leading to simplified geometries in HBIM. This results in an absence of critical information, for example the bending of the wood, and its pathology. In this study, a novel Scan-to-HBIM methodology is exemplified and applied in heritage timber roof structures, which includes the implementation of recent remote sensing technologies for capturing the as-built data, with high levels of accuracy both in geometry as well as in pathology. In terms of geometry, algorithmic processes are used, that integrate parametric and BIM environments for the automatic creation of timber roof frames from point cloud data, which are adjustable to the abnormalities found in heritage buildings. As regards to pathology, high-resolution textured mesh models are created from photogrammetric procedures, which indicate in detail any possible defects to the existing timber elements. Detailed geometry and pathology are further analyzed, and a BIM database is created for documenting the typology, materiality, and level of damage to timber components. The methodology is tested on a Franko-Byzantine Timber roof Church in Cyprus, which includes a complex timber structural system.

SESSION 3 (ONLINE)

Session Chair: ***GABRIEL WURZER***

3.3

322

Mindscape. Research of high-information density street environments based on electroencephalogram recording and virtual reality head-mounted simulation

Yijiang Liu, Xiangyu Guan, Lun Liu, Hui Wang

This study aims to investigate, through neuroscientific methods, the effects of particular architectural elements on pedestrian spatial cognition and experience in the analysis and design of walking street spaces. More precisely, this paper will describe the impact of the density variation of storefront signs on the brainwaves of passersby in East Asian city walking streets, providing strategies and guidelines for urban development and renewal. Firstly, the paper summarizes the research method through the review of research questions and related literature; secondly, the paper establishes experiments via this path, analyzing results and indicators through data processing; finally, suggestions for future pedestrian street design are proposed based on research and analysis results.

101

Application of Artificial Neural Network for Predicting UValues of Building Envelopes in Temperate Zone

Jiaqi Yu, Kening Guo, Zishen Bai, Zitong Wen

Due to the global energy deficit, building energy consumption has become a significant issue in recent years. Many researchers have focused on building energy consumption simulations to manage energy consumption accurately and provide a comfortable indoor environment for occupants. In building energy simulations, accurate input of building parameters is essential. As important thermal parameters, the thermal transmittance (Uvalue) of building envelopes can affect building operational energy consumption. In most building energy simulation studies, the U-value was set to the theoretical U-value which was a fixed value. However, the U-value constantly varies due to several environmental impacts, especially fluctuating air temperature and relative humidity (T/RH). Thus, the Uvalues are dynamic in actual situations, and inputting dynamic U-values into building energy simulations can reduce the gap between the simulation and the actual situation. In this study, the dynamic U-values of conventional cavity envelopes in temperate zones were predicted by an artificial neural network (ANN) model. Firstly, the in-situ dynamic U-value measurement was conducted in Sheffield, the UK, from summer to winter in 2022. The heat flow meter method was applied, and the tested envelope was a conventional cavity envelope widely used in the UK. The indoor and outdoor T/RH were measured and recorded as well. Then, the measured data were applied to train the optimal ANN model. The input parameters included the indoor and outdoor T/RH, and the output parameter was the dynamic U-value. Finally, the prediction results obtained by the optimal ANN model were closely correlated with the measured dynamic U-value. This quantitative study of dynamic U-values examined the relationship between dynamic U-values of conventional cavity envelopes and environmental factors, which can provide reliable information for improving the inputting patterns of building parameters and the accuracy of the building energy simulation.

061

Multi-Objective Optimization of Iranian Windcatchers Based on Building Energy Consumption and Indoor Thermal Comfort

Haojun Wang, Yulin Chen, Hainan Yan

In recent years, the emphasis on enhancing building energy efficiency has intensified, particularly regarding the adoption of passive strategies to reduce energy consumption. In hot areas, natural ventilation and cooling methods play a vital role in reducing energy consumption and providing comfortable indoor environments. Iranian windcatcher is selected as the subject of this study. This research aims to provide a workflow for finding the optimal spatial form of windcatcher based on building energy consumption and indoor thermal comfort. Kharmani's School located in Yazd is selected for case study. Firstly, a parametric model is built, allowing the spatial form of the windcatcher to be controlled through ten parameters. Then 1000 samples are created and undergo energy consumption simulation and indoor thermal comfort simulation to get two metrics: Energy Use Intensity (EUI) and Thermal Comfort Percentage (TCP). Two datasets are established by recording each sample's parameters with its corresponding EUI or TCP. Ultimately, based on the datasets, the windcatcher is optimized with the application of back propagation (BP) neural network and (Non-dominated Sorting Genetic Algorithm II) NSGA-II algorithm, aiming to minimize its EUI and maximize PMV, which represents the lowest building energy consumption and the best indoor thermal comfort.

005

Exploring Virtual Reality's Role in Assessing Public Spaces for Children: An embodied design approach

Yuchen Zheng, Lingchuan Chen, Xiangduo Meng, Tian Tian Lo

This study introduces a pioneering methodology that leverages Virtual Reality (VR) technology to facilitate architects in the evaluation and enhancement of public spaces' accessibility for children. By integrating immersive VR experiences, architects are empowered to embody a child's perspective within simulated environments, thereby promoting empathetic design practices and identifying existing accessibility barriers. The primary aim of this paper is to investigate the utility of immersive VR environments in enabling architects to comprehend and address the navigational challenges that children encounter in public spaces, which are traditionally designed with adult users as the focal point. An outcome of this study is the development of a VR design tool, followed by both qualitative and quantitative analysis based on its application by 25 architecture students and professionals. The findings underscore the tool's effectiveness in facilitating an empathetic design approach towards creating more accessible environments for young users. Moreover, the study proposes a novel architectural design workflow wherein architects can import initial design models into VR for further refinements aimed at enhancing accessibility for children. Ultimately, this paper positions VR as a transformative instrument for architects, advocating for its adoption as a useful method in the design and evaluation of public spaces with a keen focus on improving accessibility for children. Additionally, this research scrutinizes the current limitations of VR technology in architectural practices and proposes a series of recommendations for future research to refine and broaden its application.

406

From Past to Present. A study of AI-driven gamification in heritage education

Sepehr Vaez Afshar, Sarvin Eshaghi, Mahyar Hadighi, Guzden Varinlioglu

The use of Artificial Intelligence (AI) in educational gamification marks a significant advancement, transforming traditional learning methods by offering interactive, adaptive, and personalized content. This approach makes historical content more relatable and promotes active learning and exploration. This research presents an innovative approach to heritage education, combining AI and gamification, explicitly targeting the Silk Roads. It represents a significant progression in a series of research, transitioning from basic 2D textual interactions to a 3D environment using photogrammetry, combining historical authenticity and immersive gameplay. It features AI-driven characters developed in Unreal Engine, which provides heritage insights augmented by personalized interactions, highlighting the importance of collaborative tools like interactive quizzes for enriching education and promoting critical thinking and community among learners. In conclusion, this research underlines the transformative impact of AI and gamification in heritage education enhancement, integrating real-time voice conversation and interactive pedagogical methods into immersive 3D environments as a supplementary tool.

105

A Data-Driven Model for Sustainable Performance Prediction of Residential Block Layout Design Using Graph Neural Network

Zhaoji Wu, Mingkai Li, Wenli Liu, Zhe Wang, Jack C.P. Cheng, Helen H.L. Kwok

Performance evaluation plays a pivotal role in sustainable architectural design, guiding the design direction towards sustainable objectives. Building simulations based on physical modeling are commonly adopted for performance prediction, but the high computational cost hinders their applications in early design stages that require prompt feedback. Surrogate models have been proposed to emulate the expensive high-fidelity building simulation models using data-driven models. Several studies have been conducted to develop surrogate models for sustainable performance prediction of residential block layout design, but the features proposed by these studies were based on specific cases and cannot represent general residential block layout design. To overcome this gap, this study proposes a novel surrogate model for multi-objective sustainable performance prediction based on graph neural network (GNN), which can be adopted in practical early design stages of residential block layout design. First, a graph schema is proposed to represent the general topological relations among components in residential block layout design. Second, an architecture using graph attention network (GAT) is proposed for multiple sustainable performance predictions. Third, a dataset is established based on parametric design models of residential blocks and simulations of sustainable performance, including energy consumption, daylighting, and thermal comfort. Fourth, the proposed surrogate model using the proposed architecture are trained and fine-tuned to learn the relationship between the residential block design and sustainable performance. Finally, the proposed model is evaluated in terms of accuracy, comparing with benchmark models using graph convolutional network (GCN) and artificial neural network (ANN). The results show that the proposed model (GAT) outperforms the benchmark models (GCN and ANN). The proposed model can achieve a satisfactory accuracy with small CV(RMSE)s of 11.97%, 7.88% and 10.11% in terms of energy use intensity (EUI), annual comfort hour (ACH) and useful daylight illuminance (UDI) in the test dataset.

SESSIONS SCHEDULE DAY 2

4.1

SESSION 4.1

THURSDAY 12.09.2024 • 10:30-12:00

ROOM: LRC012

Session Chair: ***BRANKO KOLAREVIC***

DIGITAL FABRICATION II

099	**Human-Machine Collaboration as a Concept for Hybrid Digital and Analog Fabrication and shared Intelligence between Desktop Robotics, Mycelium and Humans**	*Benjamin Ennemoser, Jesús Manuel Frías, Emanuel Diaz-Suarez, Sergio Davis Espinoza Aguirre*
182	**Applied Artificial Ossification for Adaptive Structural Systems. Adaptable structures when loads change in the course of their service life through the application of a bionic geometry optimization algorithm**	*Jan Fiebig, Rolf Starke, Ilija Vukorep, Karen Eisenloffel*
290	**Exploration of Incremental Sheet Forming for Application in Formwork Techniques**	*Wen-Chun Hsieh, Yu-Ting Sheng, Shih-Yuan Wang*
049	**The Application of Robotic Fabrication in Reinterpreting Traditional Chinese Joinery. The Dougong capital**	*Jiangyang Zhao, Asterios Agkathidis, Davide Lombardi, Hanmei Chen*
053	**DesignBuild Project of a 3D Printed Concrete Shell with a Segmented and Stereotomic Construction Concept**	*Anton Brodmann, Efstathios Damtsas, Christoph Schult, Benjamin Spaeth, Michael Herrmann*
344	**Morphology and Ornamentation. Robotic fabrication of a biocomposite relief**	*Peter Massin,Kilian Bauer*

4.2

SESSION 4.2

THURSDAY 12.09.2024 • 10:30-12:00

ROOM: LRC014

Session Chair: ***PIA FRICKER***

SMART CITIES

080	**Enhancing Lexicon Based Evaluation of Urban Green Space Characteristics and Perceptions with a Large Language Model**	*Wenpei Li, Jiaqian Wu, Christiane M. Herr, Rudi Stouffs*
038	**MORPHOLOGIES OF VISUAL PERCEPTION AND URBAN ACTIVITIES. Simulation model of new points of interest**	*Asya Natapov, Mingyang Li*
222	**Visualise Energy Saving Potentials in Settlement Development. By linking transport and energy simulation models for municipal planning**	*Stefan Bindreiter, Yosun Sisman, Julia Forster*
371	**MARSH. An innovative model for integrating water sensitive urban design in architectural practice**	*Kyratsoula-Tereza Papanikolaou, Ioannis Sibetheros, Katherine Liapi, Evangelia Vlachaki*
191	**Reversing Urban Food Deserts. Data-driven adaptive food networks for urban resilience**	*Margarita Chaskopoulou, Tasos Varoudis*
145	**What Is the Difference Between Image and Real-World Scenes in Street Visual Walkability Perception. A case study of a university campus**	*Yuchen Xie, Yunqin Li, Jiaxin Zhang, Anqi Hu*

4.3

SESSION 4.3

THURSDAY 12.09.2024 • 10:30-12:00

ROOM: LRC019

Session Chair: ***TOMOHIRO FUKUDA***

DESIGN TOOLS AND DEVELOPMENT II

311	**On calculating Syntactic Properties in the Regulatory Drawings of Spaces. Emerging patterns and computational processes of syntactic enfranchisement**	*Mattheos Papavasiliou*
046	**Grid to Star Network Transformation. Developing a Topological Assessment and Transformation Model to Enhance Spatial Memory and Route Learning for Wayfinding**	*Anat Talmor-Blaistain, Maayan Merhav, Dafna Fisher-Gewirtzman*
172	**Wilderness as a Factor of Urban Planning. Using data-driven methods for imagining rewilded cities**	*Adam Varga, Imrich Vaško, Shota Tsikoliya*
227	**A Novel Parametric Method for Assessing View Towards Green in the Early Stages of Urban Design**	*Payam Madelat, Francesco De Luca*
041	**Multi-Species Prototypes for Sustainable Environments. How does a living wall design affect air pollution in a typical street section?**	*Tanya S. Saroglou, Surayyn U. Selvan, Laura Windorfer, Yasha J. Grobman, Shany Barath*
167	**Building Energy Efficiency Estimations with Random Forest for Single and Multi-Zones**	*Ammar Alammar, Abdulrahman Alymani, Wassim Jabi*
261	**Estimating Relative Pedestrian Crowd Distribution. A visibility-graph-based analysis workflow for malls during early design stage**	*Yuqin Zhong, Zhi Sheng Tan, Panagiotis Mavros, Christoph Hölscher, Bige Tunçer*

SESSION 4

Session Chair: ***BRANKO KOLAREVIC***

4.1

099

Human-Machine Collaboration as a Concept for Hybrid Digital and Analog Fabrication and shared Intelligence between Desktop Robotics, Mycelium and Humans

Benjamin Ennemoser, Jesús Manuel Frías, Emanuel Diaz-Suarez, Sergio Davis Espinoza Aguirre

This study examines the use of natural materials combined with advanced desktop robotic fabrication in the AEC industry, aiming to reduce CO2 emissions and embodied carbon through sustainable practices. It investigates the use of desktop robotics to create complex rope structures, reinforced with mycelium, blending human and machine efforts. Traditional ropemaking is integrated with digital techniques, including procedural modeling and mycelium cultivation, to innovate fabrication methods. The research highlights a 20-25% increase in structural rigidity through mycelium reinforcement, tackling digital-physical alignment challenges and via photogrammetry, augmented reality, and digital twins. Results suggest the viability of small-scale robotics for sustainable construction, particularly in resource-abundant rural areas, despite limitations in robot capacity. The study promotes sustainable building practices in the AEC sector, emphasizing human-machine collaboration and natural materials, setting the stage for future exploration in robotic applications and sustainable methodologies.

182

Applied Artificial Ossification for Adaptive Structural Systems. Adaptable structures when loads change in the course of their service life through the application of a bionic geometry optimization algorithm

Jan Fiebig, Rolf Starke, Ilija Vukorep, Karen Eisenloffel

This study explores the “Artificial Ossification” algorithm’s application in real-world structures, inspired by human bone formation. It uses agents mimicking bone-building and degrading cells to iteratively optimize structures for equilibrium through the Finite Element Method. The research proposes a 3D printing pen method for material addition or removal, mirroring natural bone adaptability and sustainability. Initial tests on 3Dprinted models showed promising results, leading to more rigorous comparisons between conventional and algorithm-optimized structures. Findings confirm the algorithm’s practicality for adaptive, optimized structural design, with potential applications in architecture, engineering, and beyond. The study also highlights the method’s sustainability, repairability, and scalability, suggesting its relevance for future research in adaptive materials and design methods.

290

Exploration of Incremental Sheet Forming for Application in Formwork Techniques

Wen-Chun Hsieh, Yu-Ting Sheng, Shih-Yuan Wang

This research explores the application of Incremental Sheet Forming (ISF) technology in concrete formwork to enhance efficiency and sustainability in construction. Traditional formwork methods suffer from inefficiency and limited customizability, prompting the need for alternatives. In the 1930s, the emergence of pneumatic formwork marked a significant advancement in the construction industry. Subsequently, alternatives such as hanging cable net formwork, CNC milling, and other digital fabrication methods have offered greater flexibility in designing complex geometries. However, challenges persist in scalability and understanding material properties. Despite advancements, the industry still seeks solutions to optimize design and minimize waste in construction formwork techniques. Incremental sheet forming (ISF), a versatile manufacturing technique, enables the rapid production of complex 3D shapes from sheet materials while reducing resource consumption. This research employs a 0.6mm thick aluminum alloy sheet processed with a 6-axis robotic arm, integrating digital design-to-fabrication workflow for precise control. Experiments focus on comparing ISF formwork with other digital fabrication formwork, exploring design control methods, and concluding with concrete casting. Challenges remain in understanding the interaction between concrete properties and the ISF process, especially for large-scale structures. Leveraging ISF in concrete formwork offers the potential to redefine construction practices, balancing design flexibility, sustainability, and customization. This research contributes to advancing construction methods and underscores opportunities for future research in ISF formwork applications.

049

The Application of Robotic Fabrication in Reinterpreting Traditional Chinese Joinery. The Dougong capital

Jiangyang Zhao, Asterios Agkathidis, Davide Lombardi, Hanmei Chen

The Dougong (bracket set), consisting of wooden blocks (Dou) and bow-shaped brackets (Gong), is a typical structural element in traditional Chinese timber buildings. Its primary function is to transfer roof loadings to pillars. Applying the Dougong in contemporary design offers significant advantages, including cultural continuity, sustainability, and seismic performance. However, its complex geometries, installation methods, and connections make their use in contemporary timber architecture challenging. Robotics have been increasingly adopted in timber architecture in recent decades, opening new possibilities for reinterpreting the Dougong. This paper presents a file-to-fabrication framework for applying the Dougong in contemporary design. A column was used to test the feasibility of the workflow. The paper also emphasises the crucial role of human-robot cooperation in minimising collisions caused by differences between the positions of components in the real lab and Rhinoceo3D. It also proves that a workable gap between the tenon and mortise could maximise the success rate of its robotic fabrication and ensure the stability of the column.

053

DesignBuild Project of a 3D Printed Concrete Shell with a Segmented and Stereotomic Construction Concept

Anton Brodmann, Efstathios Damtsas, Christoph Schult, Benjamin Spaeth, Michael Herrmann

This work presents and reflects the pedagogic DesignBuild approach of a computational developed and digital fabricated project. It examines the proactive role of these projects in contributing to scientific advancement by defining future research issues for the novel construction system. The approach, based on the integration of the entire digital process into architectural education and the collaborative, autonomous work with industrial partners, is analysed and viewed in perspective. Focusing on the topic of digital fabricated overhanging concrete structures, the developed construction system consists of discrete 3d printed segments. These are assembled into doubly curved shell structures in a stereotomic manner. The learning contents and outcomes in the digital design process as well as in the digital and rework fabrication processes are examined under considerations of possibilities and limitations. Consequently, the resulting future research issues for this construction system are discussed as the main findings. Its adaptability to other architectural applications and its productivity, quality and sustainability arguments serve for the conclusive evaluation of the impact and potential on in the building sector.

344

Morphology and Ornamentation. Robotic fabrication of a biocomposite relief

Peter Massin,Kilian Bauer

Morphology and Ornamentation investigates experimental design and fabrication studies following the theory of the Digital and the Ornament in architecture. The research identifies the traits of morphological correlations between digital design processes and features of CAM machinery. This paper presents a CAM fabricated wall relief, 'Postdigital Textrin', developed at the Department of Experimental Architecture in 2023 as part of the funded research project "Fragments of postdigital Ornamentation". The project aimed to develop an economic and ecological design process for the fabrication of relief panels while simultaneously investigating the aesthetic attributes of the technological framework. The methodology utilises non-structural robotic printing, mainly with biocomposites. Significant findings could be made by understanding the print specifications, the material, and the path design during the iterative experimental phase. Based on the developed process, 12 m² or 32 individual panels of puzzle-like polygonal silhouettes had been economically and efficiently fabricated and seamlessly assembled. The project contributes to the investigation of sustainable and digital crafting strategies while identifying technology and compounding data as aesthetic drivers.

SESSION 4

Session Chair: ***PIA FRICKER***

4.2

080

Enhancing Lexicon Based Evaluation of Urban Green Space Characteristics and Perceptions with a Large Language Model.

Wenpei Li, Jiaqian Wu, Christiane M. Herr, Rudi Stouffs

Evaluating Urban green space Characteristics and Human Perceptions (UCHP) is crucial for landscape design and management due to their impact on public health. Online park reviews provide valuable insights into human-environment interactions, enabling the large-scale evaluation of UCHP. However, existing approaches to classify online park reviews commonly ignore text context, leading to low precision of UCHP quantification and supervised approaches are rarely applied due to huge cost. To improve the precision and effectiveness of UCHP quantification, we propose a novel workflow comprising five stages: custom lexicon creation, design of labels for a Large Language Model (LLM), sentence classification using lexicon and LLM, and performance evaluation using a manually annotated dataset and four metrics: precision, recall, accuracy, and F1 score. To examine the performance of the LLM, we compared the classification of 15 UCHP using LLM, lexicon, and lexicon+LLM. The analysis involved utilizing online park review sentences from Google Map and TripAdvisor using the proposed workflow. The higher precision, accuracy and F1 score demonstrate that combination of lexicon and LLM yields the highest performance, followed by using only lexicon and then solely LLM. This performance evaluation demonstrates the validity of the proposed LLM-aided workflow, providing a practical, reliable, and efficient alternative to the lower performance of unsupervised methods, or costly supervised classification methods. We discuss the limitations of lexicon+LLM and outline new opportunities for LLM application in landscape studies.

038

MORPHOLOGIES OF VISUAL PERCEPTION AND URBAN ACTIVITIES. Simulation model of new points of interest.

Asya Natapov, Mingyang Li

Urban planners and designers have long standing interest in quantifying urban dynamics and activity patterns effectively. However, many existing approaches focus solely on street networks, overlooking the functional aspects of the built form, while urban form significantly shapes the city landscape. Considering urban form and activities provides a more comprehensive view of the urban realm. This paper delves into the reasons behind the emergence of urban activity patterns and explain why cities exhibit specific morphologies in this regard. The paper introduces a novel model simulating the emergence of diverse points of interest i.e., urban uses and activities. It operates on the premise that pedestrian movement, on an aggregated scale, is influenced by urban form and its spatial elements, particularly visual attributes. It employs a network approach that combines traditional network analysis and multi-agent simulation. The developed model simulates the emergence of sightlines—imaginary lines between a hypothetical pedestrian's eyes and points of interest. These sightlines play a pivotal role in urban design, shaping pattens of activities in various urban configurations - squares, plazas, alleys, parks, and street layouts. The model is exercised on synthetic urban environments, resemble real modern cities. Simulation outcomes reveal distinct evolution pattens based on variety of sightline lengths. In settings with poor visibility conditions, new points of interest tend to cluster near existing ones. Conversely, where the city morphology supports better perception, points of interest drift toward main street intersections. Therefore, the method outlined in this paper, connects the built environment with urban usage, capturing urban dynamics through visually guided pedestrian behaviour.

222

Visualise Energy Saving Potentials in Settlement Development. By linking transport and energy simulation models for municipal planning

Stefan Bindreiter, Yosun Sisman, Julia Forster

To achieve Sustainable Development Goals, in addition to the switch to sustainable energy sources and energy-efficient buildings, transport offers a major lever for reducing energy consumption and greenhouse gases. The increasing demand for emission-free mobility (e.g. through electromobility) but also heat pumps has a direct impact on the electricity consumption of buildings and settlements. It is still difficult to simulate the effects and interactions of different measures as sector coupling concepts require comprehensible tools for ex ante evaluation of planning measures at the community level and the linking of domain-specific models (energy, transport). Using the municipality of Bruck an der Leitha (Austria) as an example, a digital twin based on an open data model (Bednar et al., 2020) is created for the development of methods, which can be used to simulate measures to improve the settlement structure within the municipality. Forecast models for mobility (Schmaus, 2019; Ritz, 2019) and the building stock are developed or applied and linked via the open data model to be able to run through development scenarios and variants. The forecasting and visualisation options created in the project form the basis for the ex-ante evaluation of measures and policies on the way to a Positive-Energy-District. By identifying and collecting missing data, data gaps are filled for the simulation of precise models in the specific study area. A digital, interactive 3D model is created to examine the forecast results and the different scenarios.

371

MARSH. An innovative model for integrating water sensitive urban design in architectural practice

Kyratsoula-Tereza Papanikolaou, Ioannis Sibetheros, Katherine Liapi, Evangelia Vlachaki

This paper introduces MARSH (Model for Assessment of Runoff and Stormwater Harvesting), an architect-friendly urban water model designed for 3D stormwater scenario assessments, integrating Water Sensitive Urban Design (WSUD) principles into architectural practice. Developed in the context of a funded research project UBWARMM (Urban Best Management Practices Model for Rainwater Management) and implemented in Grasshopper, MARSH serves as a comprehensive 3D toolkit for architects to evaluate stormwater scenarios effectively. The purpose of the model is to facilitate sustainable stormwater management and therefore runoff mitigation, and rainwater harvesting enhancement. Key components, including the Time Period Precipitation Calculator, Incident Radiation Analyses, BMP Library, Rainwater Harvesting Cistern Component, Roof/Inner Block Void Runoff Calculator, and Runoff Visualization, contribute to MARSH's robust structure. The conceptualization outlines precise data requirements, incorporating historical climate data and geometry datasets. Assessing Best Management Practices (BMPs) performance, MARSH delivers both numerical outputs (irrigation percentages, runoff reduction) and visual representations. MARSH's objectives encompass simplified processes, light data entry, accurate simulation, flexibility, a userfriendly interface, and result visualization. The research explores estimation methods, utilizing the Penman-Monteith equation for BMPs irrigation demands and the Soil Conservation Service Curve Number (SCS-CN) method for runoff estimation, addressing challenges related to runoff control and irrigation considerations. The model's adaptability, user-friendly interface, and visualization tools facilitate informed decisionmaking, in regions where WSUD integration is of critical importance. Validation through a case study in Athens provides insights for future studies, showcasing adaptability to different timeframes and scalability for city-scale applications. The potential of MARSH for both micro and macro-level stormwater management applications is also discussed in the paper.

191

Reversing Urban Food Deserts. Data-driven adaptive food networks for urban resilience

Margarita Chaskopoulou, Tasos Varoudis

Dense urbanization highlights the need to explore metabolic processes and mechanisms for developing resilient and adaptive solutions to ecological challenges. The recent pandemic intensified the pressure to re-evaluate the existing urban foodscapes by revealing disparities in food accessibility. Studies indicate that food deserts are present even in the centre of metropoles, bringing forth the question of the relation between food, segregation and urban morphology. This research introduces a Machine Learningassisted computational tool that evaluates food networks and identifies optimal new spatial configurations based on curated data analytics, unsupervised machine learning models and space syntax. Its primary focus is the creation of a unified model connecting urban morphology, socioeconomic and temporal data. The output provides the planners and local authorities with a set of possible intervention patterns for food-related functions aiming to assist decision-making processes.

145

What Is the Difference Between Image and Real-World Scenes in Street Visual Walkability Perception. A case study of a university campus

Yuchen Xie, Yunqin Li, Jiaxin Zhang, Anqi Hu

In recent years, an increasing number of studies have utilized Street View Images (SVI) to assess the Visual Walkability Perception (VWP) of urban streets. However, the results of walkability perception obtained through image scene evaluation may differ from those obtained in actual real-world scenes. To address this issue, this study proposes a methodology aimed at contrasting the disparities between based on image scene evaluation and real-world scene evaluations. We analyze eye-tracking data collected using desktop and glasses eye-trackers and conduct comprehensive comparative analyses of perception between images and real-world scenes using deep-learning vision and feature interpretation models. The findings indicate certain disparities between based on image scene evaluation and real-world scene perception in terms of street VWP. Future work will involve employing crowdsourced data for broader perceptual data collection and integrating other sensory data for further investigation.

SESSION 4

Session Chair: ***TOMOHIRO FUKUDA***

4.3

311

On calculating Syntactic Properties in the Regulatory Drawings of Spaces. Emerging patterns and computational processes of syntactic enfranchisement

Mattheos Papavasiliou

This paper describes the development of a substantially different way of comparing. architectural plans. The paper introduces the analysis and composition of architectural. spaces using "invisible" regulatory drawings that attribute calibrations to the geometry of the floor plans, opening the way to comparisons and evaluations Is part of a larger research project that analyzes the computational part of introducing research methodology to train new architecture students to understand the geometry of floor plans. that describes space. Research is currently focused on bringing together a substantial body of house plans by various architects with educational value for students.

046

Grid to Star Network Transformation. Developing a Topological Assessment and Transformation Model to Enhance Spatial Memory and Route Learning for Wayfinding

Anat Talmor-Blaistain, Maayan Merhav, Dafna Fisher-Gewirtzman

Wayfinding is the cognitive process of determining and following a path from one location to another. During navigation, a route-learning process occurs in which individuals encode spatial information. Older populations and individuals with cognitive difficulties face challenges in spatial learning and navigating complex environments. This study builds on Merhav and Fisher-Gewirtzman (2023), which suggests that starshaped pedestrian paths, containing a distinct center through which all paths pass between origins and destinations, improve spatial memory and learning abilities for wayfinding compared to grid networks, benefiting all age groups. The research aims to bridge the

gap in the analysis of pedestrian network topological shapes by developing a quantitative analytical model to evaluate how close each network is to a grid-type or a star-type and potentially transform these networks, from a grid-type into star-type topology. The proposed model suggests a methodology for assessing and modifying network topologies through spatial manipulations. The model utilizes a combination of open-source components (such as Space Syntax axial analysis and the Galapagos optimization plugin) and combines novel computational tools (python code) to rank nodes in the network and identify networks where isolated areas were created during the optimization process.

172

Wilderness as a Factor of Urban Planning. Using data-driven methods for imagining rewilded cities

Adam Varga, Imrich Vaško, Shota Tsikoliya

Recognizing the ecological challenges, the paper explores data-driven workflow for urban and landscape planning through the incorporation of rewilding as a crucial factor of computational design. The proposed methodology unfolds in stages, beginning with comprehensive data collection, followed by data interpretation, creation of an informed space and its materialization. Variety of geographic, statistical and spatial data can be used to inform a dynamic digital space. This low-fidelity environment is then used as an informed space for deploying computational design tool, namely growth algorithm on a scale of city planning. Design techniques were tested on a case study considering identification and restoration of wetlands lost to urbanization. This paper explores the intersection of data-driven digital methods and urban planning, emphasizing the pivotal role of rewilding in shaping urban landscapes. Proposed digital workflow allows designers for territorial mapping and better informed decision-making with regard to ecosystem functions integration and restoration.

227

A Novel Parametric Method for Assessing View Towards Green in the Early Stages of Urban Design

Payam Madelat, Francesco De Luca

Enhancing the wellbeing of the residents in a building entail consideration of visual connection with natural elements in the urban environment. Current approaches for evaluating the presence of green elements in the field of view primarily concentrate on floorplans. Thus, they are not efficient to evaluate large areas such as blocks and neighborhoods during the building massing design phase due to uncertainties regarding the building interiors. To tackle this limitation, we developed a method, and a metric called the Building Visible Green Index (BVGI) to assess the ability of building facades to connect interior spaces with the surrounding green environment. The parametric workflow performs ray-casting from façade samples, detects obstructions, and analyzes the intersections with green elements. BVGI allows for the early-stage evaluation of urban design solutions for many buildings by measuring the weighted proportion of visible green elements such as lawns and trees. The paper showcases the parametric workflow of the BVGI method and its potential in one case study.

041

Multi-Species Prototypes for Sustainable Environments. How does a living wall design affect air pollution in a typical street section?

Tanya S. Saroglou, Surayyn U. Selvan, Laura Windorfer, Yasha J. Grobman, Shany Barath

This paper studies the effect of trees and living walls designs in the urban environment, as a measure for increasing biodiversity and enhancing urban air quality. The chosen location is a neighborhood plot in the Mediterranean climate of Tel Aviv, with vibrant pedestrian activity. Simulations are performed using the urban pollution dispersion tool in ENVI-met, for a high-traffic and a low-traffic inner city road, with a focus on airborne particle matter (PM) concentrations. Results depict a winter day that air quality standards were moderate. The different scenarios, with and without trees, and different % of living wall designs and vegetative volumes brought about considerable reductions in airborne PM concentrations. However, the reductions still failed to reach WHO recommended air quality standards. Results point out towards a more holistic framework of green infrastructure strategies that may also include green walls, bicycle routes, less vehicle access, and more.

167

Building Energy Efficiency Estimations with Random Forest for Single and Multi-Zones

Ammar Alammar, Abdulrahman Alymani, Wassim Jabi

Surrogate models (SM) present an opportunity for rapid assessment of a building's performance, surpassing the pace of simulation-based methods. Setting up a simulation for a single concept involves defining numerous parameters, disrupting the architect's creative flow due to extended simulation run times. Therefore, this research explores integrating building energy analysis with advanced machine learning techniques to predict heating and cooling loads (KWh/m2) for single and multi-zones in buildings. To generate the dataset, the study adopts a parametric generative workflow, building upon Chou and Bui's (2014) methodology. This dataset encompasses multiple building forms, each with unique topological connections and attributes, ensuring a thorough analysis across varied building scenarios. These scenarios undergo thermal simulation to generate data for machine learning analysis. The study primarily utilizes Random Forest (RF) as a new technique to estimate the heating and cooling loads in buildings, a critical factor in building energy efficiency. Following that, A random search approach is utilized to optimize the hyperparameters, enhancing the robustness and accuracy of the machine learning models employed later in the research. The RF algorithms demonstrate high performance in predicting heating and cooling loads (KWh/m2), contributing to enhanced building energy efficiency. The study underscores the potential of machine learning in optimizing building designs for energy efficiency.

261

Estimating Relative Pedestrian Crowd Distribution. A visibility-graph-based analysis workflow for malls during early design stage

Yuqin Zhong, Zhi Sheng Tan, Panagiotis Mavros, Christoph Hölscher, Bige Tunçer

This paper introduces a visibility-graph-based workflow for early stages of architectural design, aimed at estimating relative pedestrian crowd distribution in shopping malls. Traditional methods like Agent-Based Modeling (ABM) and Space Syntax analysis face challenges in early design phases due to extensive data or configuration needs and lack of detail respectively. Our approach uses visibility graph as the foundation and generates visit probabilities and Chains of Activities (COAs) from empirical studies, balancing accuracy, accessibility and efficiency. The workflow's integration within designers' familiar design interface allows for rapid prototyping and assessment of design iterations, making it a practical tool. Validation through a case study in a shopping mall in Singapore demonstrates the workflow's accuracy, with results showing strong similarity to both ABM and observed data, but with significantly less time and resource demands. This workflow offers a novel solution for early-stage design, providing a swift and accurate means to evaluate pedestrian dynamics and optimize design layouts.

5.1 SESSION 5.1

MATERIALS AND FORM I

THURSDAY 12.09.2024 • 13:30-15:00

ROOM: LRC012

Session Chair: ***A. BENJAMIN SPAETH***

166	**A Machine Learning Approach to The Inverse Problem of Self-Morphing Composites**	*Gal Kapon, Arielle Blonder, Guy Austern*
181	**Computational Simulation of Anisotropic Self-Morphing Materials in Architectural Design**	*Yitzchak Vaknin, Eran Sharon, Arielle Blonder*
160	**Visualizing Frustration. Computational simulation tool for 'Frustrated Ceramics'**	*Ofri Dar, Omri Y. Cohen, Eran Sharon, Arielle Blonder*
128	**Exploring Robotic Fabrication Using Stimulated Soil**	*Roni Hillel, Tom Shaked, Michael Tsesarsky, Aaron Sprecher*
087	**Discrete Interlocking Formwork for Non-Developable Surfaces. A computational solution to complex geometries**	*Po-Yu Hsieh, June-Hao Hou*

5.2 SESSION 5.2

BIM II

THURSDAY 12.09.2024 • 13:30-15:00

ROOM: LRC014

Session Chair: ***ARMANDO TRENTO***

254	**Sustainability Data Analytics. An Integrated Data-Informed Approach for Assessing the Sustainability of Design Alternatives**	*Hassan M. Sadeghi, Halil Erhan, Ahmed M. Abuzuraiq*
353	**ReUse with BIM. Connecting architectural salvage centres to your BIM software**	*Lukas Gschweitl, Matthias Lang-Raudaschl, Dalel Daleyev and Milena Stavric*
333	**Synergizing BIM Processes in Architectural Education. Computing design-environment resonances via parametric modelling, dataflow scripting and performance simulation integration: a pedagogic demonstration**	*Carlos E. Favero Marchi, Urs L. Hirschberg*
409	**BIM-Driven Curriculum for Integrated Design Studios. Maintaining data interoperability and design flexibility**	*Andrzej Zarzycki*
225	**What Density for Net Zero Energy? A trade-off between energy use, renewables, and indoor thermal comfort for high-rise residential precincts in tropical climates**	*Praveen Govindarajan, F. Peter Ortner, Elif Esra Aydin*
217	**A BIM-based Virtual Reality Evacuation Simulation for Fire Safety Management**	*David Stephen Panya, Taehoon Kim, Minji Heo, Seungyeon Choo*

5.3

SESSION 5.3

EXPERIMENTATION I

THURSDAY 12.09.2024 • 13:30-15:00

ROOM: LRC019

Session Chair: ***RUDI STOUFFS***

010	**Science Fiction, Software Friction, Spatial Fantasies Architectural speculations as a resource for digital design**	*Ilayda Memis, Nick Förster, Frank Petzold*
034	**Spatial Interpretation in a Text-to-image Accelerated Architectural Design Process. Investigating diffusion models in sketch, preliminary and final design stages**	*Elien Vissers-Similon, Theodoros Dounas*
057	**Diffused Tomography. Design ideation on architectural models through image sequences**	*Mathias Bank, Johannes Schlusche, Shervin Rasoulzadeh, Kristina Schinegger, Stefan Rutzinger*
085	**A Data-Driven NLP Approach to Analyzing Framing and Reframing in Design Protocols**	*Hernan Casakin, Hadas Sopher, Or H. Anidjar, John S. Gero*
360	**Impacts of Human Energy-Related Behaviours on the Energy Efficiency of Adaptive Building Façade. A Review**	*Wen-Ting Li, Han Fang, Michele W. T. Mak, Ornella Iuorio*

SESSION 5

Session Chair: ***A. BENJAMIN SPAETH***

5.1

166

A Machine Learning Approach to The Inverse Problem of Self-Morphing Composites

Gal Kapon, Arielle Blonder, Guy Austern

Composite materials are valued in architecture for their remarkable strength-to-weight ratio and ability to shape intricate structures. However, conventional methods relying on single-use molds raise environmental concerns. Recent advancements in moldless fabrication, particularly self-morphing techniques, leverage geometric frustration— internal stresses generated by material architecture. Uniaxial shrinkage in composites, traditionally seen as distortions, can be harnessed to create a self-shaping mechanism, enabling the achievement of complex geometries by varying fiber orientations. This paper addresses the inverse problem of self-morphing composites, aiming at the generation of production plans from desired designs for morphing. We propose leveraging machine learning, notably Convolutional Neural Networks (CNNs), to predict fiber layouts using 2D data matrices. The paper outlines the use of simulations to construct a dataset for training CNN models to predict the fiber layouts required to achieve design geometry. The contribution of this work is to advance digital design and simulation methods and tools towards the implementation of self-morphing matter in architectural fabrication.

181

Computational Simulation of Anisotropic Self-Morphing Materials in Architectural Design

Yitzchak Vaknin, Eran Sharon, Arielle Blonder

This study introduces a computational simulator designed for materials that morph due to internal stresses, applied to architectural contexts. This approach marks a significant evolution in architectural practices, highlighting a shift towards sustainability, adaptability, and responsiveness in design. These materials present new challenges in architectural design, necessitating advanced computational tools for form-finding to predict complex behaviors not easily inferred from initial conditions. Our simulator, integrated with Grasshopper and using the Kangaroo Physics plugin, aims to enhance shape-finding processes for these materials, providing reliable shape predictions and broadening design possibilities. Focusing on anisotropic materials, particularly fiberbased polymer composites, the simulator enables designers to create structures that can adapt to various conditions. This capability extends the potential for sustainable and innovative architectural solutions, moving beyond traditional design constraints to embrace the complexities of material behavior and interaction. Utilizing sophisticated algorithms and models, the tool facilitates early simulation and visualization of materials and structures, bridging theoretical concepts with practical applications.

160

Visualizing Frustration. Computational simulation tool for 'Frustrated Ceramics'

Ofri Dar, Omri Y. Cohen, Eran Sharon, Arielle Blonder

This paper introduces a novel approach to sustainable construction through 'Frustrated Ceramics', a self-morphing clay material system, offering an on-site mould-less shaping method. The system consists of two clay bodies with different shrinkage rates, layered to form a flat sheet. The shrinkage difference drives a geometrical incompatibility during firing process that results in the emergence of a complex 3D shape. Through the analysis of physical experiments, based on the theory of incompatible shells, an understanding of key material properties of the system is established. Specifically, the determination of Young's moduli ratio of the different clay bodies during critical morphing moments at the kiln is defined. This material property proves essential for the adjustment of an initial simulation tool to the case of morphing clay, enhancing our ability to predict Frustrated Ceramics' morphing results. Further improvements of the simulation also include meshing and gravity considerations . Both material calibration and the simulation code support the newly developed design feature of variable thickness ratio, expanding control and morphological freedom. Combining physical experiments, digital simulation and physics theory, this study aims at providing architects with a predictive understanding of this energy-efficient 'Frustrated Ceramic' system, promoting its accessibility and future adoption in the architectural field.

128

Exploring Robotic Fabrication Using Stimulated Soil

Roni Hillel, Tom Shaked, Michael Tsesarsky, Aaron Sprecher

The concrete industry's significant CO2 emissions and material usage have driven a shift towards sustainable construction, with a renewed focus on using local materials like soil, now made viable for modern construction through advancements in robotic fabrication. A key challenge with local soil is enhancing its strength for construction. The Microbially Induced Calcium Carbonate Precipitation method (MICP), which harnesses bacteria to harden soil, has emerged as a solution. Typically, MICP relies on exogenous bacteria cultivated in controlled environments, a resource-intensive process which is often challenging to apply in natural soil conditions. This paper proposes MICP through biostimulation of locally sourced soil bacteria, simplifying the process and allowing for on-site applications. This study explores the potential of MICP by stimulation in construction, utilizing advanced robotic fabrication techniques. We aim to reduce the environmental footprint of traditional concrete methods and minimize waste while increasing efficiency and precision using local soil by employing robotic fabrication techniques. Our findings are based on strength, mechanical, and performance tests, as well as experiments in formative and additive manufacturing of domes, using a custom robotic 3D printing extruder in a lab setup. These experiments confirm the feasibility of using local soil for sustainable construction. The results encourage further research to scale up the manufacturing process and enhance the material's structural strength. This research bridges the gap between traditional local material usage and modern construction technologies, offering a sustainable pathway for the construction industry.

087

Discrete Interlocking Formwork for Non-Developable Surfaces. A computational solution to complex geometries

Po-Yu Hsieh, June-Hao Hou

Shotcrete 3D concrete printing (SC3DCP) technology offers vast potential for digital fabrication and structural engineering. However, it faces limitations with complex geometries involving non-developable surfaces. To address these technical challenges from a computational perspective, this research introduces an adjustable formwork system based on a discrete interlocking mechanism. The proposed model consists of an octagonal, porous unit inspired by chainmail. By utilizing the unique chainmail pattern and interlocking parts, the proposed form ensures: (1) a wide range of flexibility at each node that can be applied to various types of curved surfaces; (2) can be reused overtime by adjusting each interlocking part; (3) print-in-place capability without external supports, reducing assembly complexity compared to traditional engineered formwork systems. Overall, the research aims to reduce geometric constraints in the construction domain through a novel, practical method.

SESSION 5

Session Chair: ***ARMANDO TRENTO***

5.2

254

Sustainability Data Analytics. An Integrated Data-Informed Approach for Assessing the Sustainability of Design Alternatives

Hassan M. Sadeghi, Halil Erhan, Ahmed M. Abuzuraiq

This study presents an interactive visualization strategy for evaluating design alternatives' sustainability, driven by data from building information modelling (BIM) and life cycle assessment (LCA). After outlining a workflow, we identified the key interaction features of sustainability data to evaluate and improve LCA performance. The low-fidelity prototype, called Green Plans, is presented as a design analytics system aiming to describe these key features. The prototype uses parallel coordinates and Sankey diagrams to examine how form, material, and envelope affect sustainability, and the analytic hierarchy process (AHP) is used to inform the conceptual design. Sustainability is evaluated using key metrics such as global warming potential (GWP), energy consumption, and greenhouse gas (GHG) emissions. The study proposes design data visualization and suggests improvements in simulation, comparative analysis, and integration with design tools.

353

ReUse with BIM. Connecting architectural salvage centres to your BIM software

Lukas Gschweitl, Matthias Lang-Raudaschl, Dalel Daleyev and Milena Stavric

This paper examines the potential for enhancing the efficiency of planning with ReUse Components (RUCs) in construction projects. It discusses the current practices, focusing on how Digital Salvage Centres (DSCs) can contribute to the trade of RUCs. The paper identifies challenges in the current workflow, such as the manual matching process and the lack of standardized interfaces with Building Information Modelling (BIM) software. It proposes a streamlined approach for integrating RUC data into BIM models automatically. The method involves web scraping, data validation, and the generation of Industry Foundation Classes (IFC) entities. The paper concludes by discussing the potential impact of the proposed approach and outlining future research directions, including the development of a functional prototype and collaboration with DSCs.

333

Synergizing BIM Processes in Architectural Education. Computing design-environment resonances via parametric modelling, dataflow scripting and performance simulation integration: a pedagogic demonstration

Carlos E. Favero Marchi, Urs L. Hirschberg

This paper addresses challenges in harnessing the full potential of Building Information Modelling (BIM) as an architectural design instrument, from a pedagogical perspective. It introduces a plural and flexible BIM framework that integrates parametric modelling, data-flow scripting and design performance simulation techniques creatively in the design process. The framework is demonstrated through an academic endeavour, where students explored the articulation of distinct workflows, departing from the yet-fresh Rhino.Inside.Revit technology to evaluate ecological implications of architectural design. This involved computing potential resonances existing between building form (material and geometric configurations) and environmental conditions (such as solar exposure, energy performance and embodied carbon dynamics) over two proposed application scenarios: Stage 1 and Stage 2. Additionally, the paper presents an inventive teaching methodology that revolves around adopting masterpieces as Architectonic Models of complex systems, while designing from the perspective of a third—an embodied avatar.

409

BIM-Driven Curriculum for Integrated Design Studios. Maintaining data interoperability and design flexibility

Andrzej Zarzycki

This paper presents a curricular model for an integrated design studio focused on BIMdriven processes, satisfying the NAAB 2020's student performance criteria SC.5 and SC6. These criteria emphasize quantifiable, evidence-based design thinking by requiring the provision of "measurable environmental impacts" and "measurable outcomes of building performance." The studio, serving as a capstone project, integrates accessible design, user and regulatory requirements into building assemblies, structural and environmental systems, and life safety, underscoring the importance of measurable building performance outcomes. The adoption of computational design tools, particularly Building Information Modeling (BIM), facilitates engagement in environmental and user-focused simulations and ensures data interoperability throughout the design and post-occupancy phases. Utilizing a comprehensive set of tools, including life-cycle assessment (LCA) and energy modeling, the curriculum advances beyond simple simulations to support decision-making and multi-objective optimizations. This approach enables a new form of design thinking that incorporates a broader set of variables and considerations, encouraging students to meet various environmental impact and performance benchmarks, including LEED v.5 Certification points and Architecture 2030 energy standards. The integration of scenario simulation tools empowers students to autonomously advance their projects within a framework of constraints, marking a pedagogical shift towards faculty acting as learning facilitators and promoting student autonomy in design evaluation.

225

What Density for Net Zero Energy? A trade-off between energy use, renewables, and indoor thermal comfort for high-rise residential precincts in tropical climates

Praveen Govindarajan, F. Peter Ortner, Elif Esra Aydin

With advancements in Architectural Design Optimization (ADO) and Building Performance Simulation (BSP) tools, achieving Net Zero Energy (NZE) buildings is feasible by optimizing the balance between energy demand and on-site renewable energy generation. However, this poses several challenges in land-scarce urban areas, where onsite NZE is achievable with the tradeoff between development density (i.e., gross plot ratio - GPR), regions on-site for photovoltaic deployment, and energy efficiency associated with indoor thermal comfort (ITC). This study introduces a method to optimize high-rise residential precincts for NZE and ITC goals in tropical cities: Chennai and Singapore. The research evaluates design parameters related to urban layout, building geometry, and building performance through simulation-based optimization workflow. Though using a scalarized single-objective optimization (SOO) approach, this study identifies optimal densities of greater than 3.6 GPR for Chennai and 3 GPR for Singapore, meeting nearzero goals while ensuring adequate comfort. In conclusion, this applied methodology provides insights into the trade-offs between site density, indoor comfort, and net zero goals for tropical NZE urban developments.

217

A BIM-based Virtual Reality Evacuation Simulation for Fire Safety Management

David Stephen Panya, Taehoon Kim, Minji Heo, Seungyeon Choo

In contemporary design and construction engineering, Building Information Modeling (BIM) technology significantly influences the evolution of fire safety. This research explores the intersection of fire safety and virtual reality (VR) by introducing an innovative emergency evacuation simulation method grounded in BIM technology. The study aims to establish a robust framework for emergency evacuation simulations by synthesizing fire dynamics, evacuation strategies, and BIM-based VR technologies. By bridging the theoretical-practical gap, the research endeavors to provide stakeholders in the construction industry with a toolset that prioritizes safety while enhancing designs for safer building projects. The study incorporates fire simulation utilizing CFAST, a representative zone model from the Korean National Institute of Standards and Technology. CFAST divides the fire room into high-temperature upper and lowtemperature lower layers, assuming a uniform thermal and chemical environment. It interprets fire phenomena through principles such as mass conservation, the first law of thermodynamics, and the ideal gas equation. The study employs Cellular Automata (CA) to design an agent's reaction and behavior for evacuation. This involves creating a model based on CA rules, determining state changes, and designing behaviors accordingly. The study also focuses on formulating a calculation for evacuation time, refining it based on key factors. The integration of CFAST and CA, along with models for fire and evacuation simulations, enhances the accuracy and utility of evacuation simulations. The research introduces computational models and BIM models in a visually immersive experience in VR across 3 types of fire emergency scenarios.

SESSION 5
Session Chair: ***RUDI STOUFFS***

5.3

010

Science Fiction, Software Friction, Spatial Fantasies Architectural speculations as a resource for digital design

Ilayda Memis, Nick Förster, Frank Petzold

Dystopic despair and utopian promises manifest a dichotomy dominating architectural and urbanistic discourses on digital technologies. This schism leaves only little room for critical-but-productive research and design perspectives. In this paper, we explore the figure of architectural science fiction to interrogate the historical roots, material disposition, and urban imaginaries underlying today's urban digitization projects. Therefore, we discuss architectural speculation and science fiction as a central resource for contemporary digital design research and education. We will describe the methods and outcomes that we collaboratively developed in an academic design studio. Our approach consisted of three phases with shifting scales and media, investigating the computational utopias as science fiction narratives, as technological systems, and lastly, as critical visions for city planning today. Instead of isolated technical solutions, the participants developed complex architectural perspectives on digital technologies, incorporating spatial aspects, historical trajectories, and multiple stakeholders' perspectives.

034

Spatial Interpretation in a Text-to-image Accelerated Architectural Design Process. Investigating diffusion models in sketch, preliminary and final design stages

Elien Vissers-Similon, Theodoros Dounas

The introduction of diffusion models – artificial intelligence models originally used as text-to-image generators – poses several questions for the architectural design process. Firstly, could diffusion models enhance those design processes? Secondly, what is the relationship between innovative image generators and traditional methods of representation derived from projectional geometry? This paper studies the results of such an accelerated design process by 76 masters students of architecture, which lasted 6 weeks and covered the sketch, preliminary and final design stages. We define spatial interpretation moments as the inflection points the during human-machine interaction when the designer translates 2D images into 3D spatial design concepts. The spatial interpretation moments mostly occur in the transition from sketch to preliminary design and during preliminary design. Spatial interpretation moments' inherent opportunity is to use diffusion models both as a communication and a design tool to rapidly test spatial design intentions. This paper showcases examples of the captured spatial interpretation moments regarding the designer's ability to actively design and the impact of spatial dimensions, spatial composition and spatial abstraction. Moreover, this paper suggests the use of annotations to capture spatial interpretation moments for future research and proposes boundaries to investigate the relationship between diffusion models and other methods of representation.

057

Diffused Tomography. Design ideation on architectural models through image sequences

Mathias Bank, Johannes Schlusche, Shervin Rasoulzadeh, Kristina Schinegger, Stefan Rutzinger

The paper outlines a novel methodology for applying AI-driven style transfer to complex 3D architectural models. It involves a sequential process of slicing, training, video-guided diffusion, and reconstruction to transform existing 3D models based on textual descriptions into new stylistic forms. This approach enables architects to explore diverse design concepts, focusing on spatial composition, visual appearance, and tectonics. The results demonstrate the potential of AI in enhancing early-stage design ideation, offering new perspectives on interior-exterior relationships in architecture through AI-generated 3D models.

085

A Data-Driven NLP Approach to Analyzing Framing and Reframing in Design Protocols

Hernan Casakin, Hadas Sopher, Or H. Anidjar, John S. Gero

This study introduces a novel data-driven approach to quantitatively characterize and measure framing and reframing (F-RF) behaviors during design problem-solving. F-RF are cognitive processes which shape problem understanding and solution development in design. Quantitative measurement methods for F-RF remain largely unexplored. The proposed approach utilizes protocol analysis combined with Natural Language Processing (NLP) algorithms to track the occurrences and re-occurrences of design concepts expressed verbally while designing. Specifically, NLP algorithms are employed to identify F-RF, enabling the systematic tracking of F-RFs and their corresponding semantic values. By calculating the semantic value of concepts and frames, the approach enables determining how a concept and a frame differed from the previous occurrences. A case study of an architect and a student demonstrates this data-driven approach. The proposed methodology holds potential for the development of systems capable of providing real-time feedback to students and professional designers, supporting and enhancing their framing skills during the design process.

360

Impacts of Human Energy-Related Behaviours on the Energy Efficiency of Adaptive Building Façade. A Review

Wen-Ting Li, Han Fang, Michele W. T. Mak, Ornella Iuorio

Amid growing imperatives for heightened building energy efficiency and occupant comfort, adaptive façades have garnered significant attention and research efforts aimed at refining their structure and techniques to achieve energy savings. However, studies frequently overlook the consideration of human factors that impact the energy performance of adaptive façades, with limited discussions on potential solutions. In this review study, an investigation is undertaken to firstly delineate the challenges posed by occupant disruptive behaviour to the expectation of adaptive façade operations. Secondly, this study focuses on reviewing gamification design and implementation techniques aimed at enhancing operational efficiency and fostering increased user engagement. Findings from this review indicate that occupant-oriented adaptivity is crucial for the effective operation of adaptive façades, underscoring the importance of incorporating occupantempowered control when automation systems are involved. Furthermore, the review highlights the necessity for gamification implementation methods to align with the unique characteristics of the building type and its occupants. Particularly, achieving a balance between extrinsic and intrinsic motivation appears as crucial. This study serves as a foundational resource for researchers and practitioners seeking to leverage the gamification for enhancing data communication and collection by promoting users' engagement and positive behavioural change within the context of building adaptive façades - users interaction.

6.1

SESSION 6.1

MATERIALS AND FORM II

THURSDAY 12.09.2024 • 15:30-17:00

ROOM: LRC012

Session Chair: ***TIMO CARL***

391	**Reed Fiber Thermal Design. A computational method and model for thermal design based on the organisation of fibrous material directionality**	*Anke Pasold, Isak Worre Foged*
072	**Equilibrium Morphologies. Interactive modeling for form-finding of fabric structures**	*Fabian Eidner, Alina Turean, Samuel Leder, Mathias Maierhofer, Tobias Schwinn, Achim Menges*
390	**Climate-responsive Hygroscopic Wood Bilayers Programmed via Laser Modification**	*Sabrina Lee, Gracey Zhong, Catherine Lian, David Correa*
027	**BarBend. Parametric and reversible solid wood bending Through CNC Cutting**	*Bat-El Hizmi, Almog Ben-Yosef, Amit Aidlin, Yoav Sterman*
092	**Multi-material Gradient Additive Manufacturing. A data-driven performative design approach to multi-materiality through robotic fabrication**	*Ricardo Mayor Luque, Nestor Beguin, Sheikh Rizvi Riaz, Jessica Dias, Sneham Pandey*

6.2

SESSION 6.2

VR-AR

THURSDAY 12.09.2024 • 15:30-17:00

ROOM: LRC014

Session Chair: ***WOLFGANG DOKONAL***

196	**The Advancement in Web-Based Mixed Reality Systems. A multi-user perspective sharing for future landscape studies**	*Soushi Futamura, Tomohiro Fukuda, Nobuyoshi Yabuki*
116	**Enhancing Immersion in Virtual Spaces. PhytualBlend - a real-time interaction system for seamless physical feedback**	*Tiantian Lo, Yuhong Wu, Gerhard Bruyns, Daniel K Elkin*
195	**Advancing Building Façade inspection. Integration of an infrared camera-equipped drone and mixed reality**	*Ryuto Fukuda, Tomohiro Fukuda, Nobuyoshi Yabuki*
330	**Virtual Reality in Architectural Design Revisited**	*Pascal Mosler, Maximilian Gehring, Wolfgang Dokonal, Uwe Rüppel*
014	**Exploring Phygitalization in Architecture Comparative analysis of the reality of digital and physical experiences in relationships of humans and space**	*Shu Ting Magdalene Chang, Ho Nam Marco Lee, Chin Kit Peter Pan, Tian Tian Sky Lo*

6.3

SESSION 6.3

EXPERIMENTATION II

THURSDAY 12.09.2024 • 15:30-17:00

ROOM: LRC019

Session Chair: ***CHRISTINA DOUMPIOTI***

025	**Urban Street Space Analysis with Spherical Box-Counting. Holistic digital Gestalt analysis of architecture in urban space**	*Matthias Kulcke and Wolfgang E. Lorenz*
081	**Shadow Optimisation of Low-impact Temporary Architecture to Improve Climatic Comfort in Urban Spaces**	*Rossella Siani, Francesco De Luca*
054	**Jammed Rubble. A building system concept for granular architecture from mixed mineral waste**	*Hana Svatoš-Ražnjević, Maria Wyller, Eva Schad, Achim Menges*
238	**Aspen Leaves as a Biological Role Model for a Triboelectric Wind Energy Harvesting Building Facade System. Generating Power Through the Movement of Leaves in the Wind**	*Carlotta Mace, Khyati Danak, Morgan Jacobson, David Correa*
296	**Surface Articulation as Structural Leverage in Large Scale 3D Printing**	*Pavlos Fereos, Kilian Bauer, Eftychios-Nicolaos Efthimiou*

SESSION 6

Session Chair: ***TIMO CARL***

6.1

391

Reed Fiber Thermal Design. A computational method and model for thermal design based on the organisation of fibrous material directionality

Anke Pasold, Isak Worre Foged

This study develops and subsequently examines a computational design method based on bespoke fibre-based material explorations, whose thermal properties are integrated into the investigation model for explorative testing and making prototypes for evaluation and discussion. The thermal conductivity of the fibers' polar orientation, in gradients between transverse and parallel, is measured and analysed for heat transmission properties (uvalues) within each physical material sample to be utilised to inform the model. The computational studies are developed through a bespoke computational design model composed around the analysis and generation of variations of a composite, modular wall structure. These studies are based on subdivision algorithms as an underlying approach for segmentation, modularity and dimensional scalability within the model. The dataset of the material investigation is translated into resulting digital representations, allowing synthetic (computed) samples to be generated within an outer wall application context, enabling the composition of both insulating and ventilating properties within the same wall segment and from the same base material.

072

Equilibrium Morphologies. Interactive modeling for form-finding of fabric structures

Fabian Eidner, Alina Turean, Samuel Leder, Mathias Maierhofer, Tobias Schwinn, Achim Menges

While primarily admired for their material efficiency and aesthetic potentials, form-active fabric structures also offer original solutions to architectural design, modulating spaces with pliable and soft surface qualities. Their application, however, is hindered by the need for a profound understanding of the relationship between morphology, structure, and materialization. To comprehend and resolve these interdependencies, architects and engineers employ the means of form-finding. Existing form-finding methods for fabric structures exist either in purely digital or purely physical mediums. This paper introduces a cyber-physical form-finding method that seeks the equilibrium state of highly articulated fabric structures through sensorial modeling and emergent behavior of interacting forces. By embracing the softness and inherent responsiveness of elastic fabrics, this research presents an interactive form-finding approach for form-active material system where real-time shape adjustments are performed through hands-on manipulation. The developed design interface enables designers and user to swiftly explore numerous fabric morphologies in their equilibrium, suggesting intuitive tangible means of design communication.

390

Climate-responsive Hygroscopic Wood Bilayers Programmed via Laser Modification

Sabrina Lee, Gracey Zhong, Catherine Lian, David Correa

Wood is a hygroscopic material that experiences directional swelling when it undergoes changes in moisture content. This anisotropic property can induce bending in bilayer structures; a reaction that is usually undesired in building construction but is now being studied as a means of creating climate-responsive architectural systems. While there are extensive studies describing how to change the bending direction by altering wood grain orientation and composition during lamination or via 4D printing, there is no known method of modifying the curvature direction after the bilayer has been made. In this paper, laser cutting is presented as a novel post processing method that precisely and efficiently manipulates the directional swelling of commercially available bilayer wood composites. The documented tests in this paper utilize ¼" thick C4 PureBond Maple Plywood, which is made of a thicker, primary (active) layer of wood that is laminated between two thinner, secondary (constraining) layers of wood. When a conventional laser cutter is used to cut and engrave patterns on this pre-laminated material, unique curling deformations, including bi-directional curling, can be achieved. The architectural potential of the resulting bilayer tailoring mechanisms was demonstrated through the development of a proof-of-concept climate-responsive architectural facade system. Further exploration and refinement of this new method could significantly impact the commercial development of responsive facades by facilitating the mass use and customization of multi-directional climate-responsive mechanisms. This process will ultimately reduce costs and carbon consumption by taking advantage of readily available wood products' innate material properties.

027

BarBend. Parametric and reversible solid wood bending Through CNC Cutting

Bat-El Hizmi, Almog Ben-Yosef, Amit Aidlin, Yoav Sterman

Computational and robotic approaches for bending wood include cutting kerfs and slits that generates flexibility in the wood or using external fixtures to keep the wood bent while in tension. In both cases, the bent configuration is maintained using glue or external fixtures, making it challenging to unbend the wood back to its straight configuration. The paper presents a novel method for parametric and reversible solid wood bending inspired by kerfing and Active Bending. The aim is to create a computational method in which, for any curve that consists of arcs and straight lines, a cut pattern is generated that allows the bending of a solid wood beam to match the input curve. The suggested approach is based on splitting an arc into two parts, connected by a thin bar along the grain direction. The bar is elastic and allows for manual bending. While bending, the precise CNC cutting of the arcs forces the wood to take the intended bending shape while maintaining tension. A bowtie inlay locks the bending in place. Once the locking is removed, the wood may be unbent. The research explores the limitation of the suggested method in terms of the possible bent radii and conducts compression tests to evaluate the strength of the bentwood. Two main advantages of the suggested approach are demonstrated. The first is creating curved profiles out of timber wood, which is limited in width. The second advantage is material efficiency when cutting curved profiles from plywood panels. Our computational bending method enables designers to prototype and construct DIY furniture and temporary structures with a simple assembly.

092

Multi-material Gradient Additive Manufacturing. A data-driven performative design approach to multi-materiality through robotic fabrication

Ricardo Mayor Luque, Nestor Beguin, Sheikh Rizvi Riaz, Jessica Dias, Sneham Pandey

Buildings are responsible for 39% of global energy-related carbon emissions, with operational activities contributing 28%, and materials and construction accounting for 11% (World Green Building Council, 2019) It is therefore vital to reconsider our reliance on fossil fuels for building materials and to develop new advanced manufacturing techniques that enable an integrated approach to material-controlled conception and production. The emergence of Multi-material Additive Manufacturing (MM-AM) technology represents a paradigm shift in producing elements with hybrid properties derived from novel and optimized solutions. Through robotic fabrication, MM-AM offers streamlined operations, reduced material usage, and innovative fabrication methods. It encompasses a plethora of methods to address diverse construction needs and integrates material gradients through data-driven analyses, challenging traditional prefabrication practices and emphasizing the current growth of machine learning algorithms in design processes. The research outlined in this paper presents an innovative approach to MMAM gradient 3D printing through robotic fabrication, employing data-driven performative analyses enabling control over print paths for sustainable applications in both the AM industry and our built environment. The article highlights several designed prototypes from two distinct phases, demonstrating the framework's viability, implications, and constraints: a workshop dedicated to data-driven analyses in facade systems for MM-AM 3D-printed brick components, and a 3D-printed brick facade system utilizing two renewable and bio-materials—Cork sourced from recycled stoppers and Charcoal, with the potential for carbon sequestration.

SESSION 6

Session Chair: ***WOLFGANG DOKONAL***

6.2

196

The Advancement in Web-Based Mixed Reality Systems. A multi-user perspective sharing for future landscape studies

Soushi Futamura, Tomohiro Fukuda, Nobuyoshi Yabuki

The use of mixed reality (MR) shows potential for facilitating smoother consensus-building processes. However, conventional MR systems face the challenge of synchronizing changes to 3D models across multiple devices. To address this issue, a proposed solution is to establish a server PC that all devices can connect to. This allows for the sharing of the MR space, including 3D models, among the devices. In MR systems used for landscape assessments, the 3D model data displayed can become extensive, leading to increased processing load for MR rendering. To address this issue, a proposed solution is to perform MR rendering on the server PC. Additionally, to improve communication in the shared MR space, the user's sharing gaze direction is being considered. However, using this technology in outdoor environments presents challenges. This paper presents a system that enables real-time sharing of MR images and location information, including gaze direction, among mobile devices. The system allows users to view the MR images of others, facilitating the exchange of opinions even from remote locations. The prototype system was verified for real-time performance and confirmed to display combined MR images of self and others and map images, at approximately 10 frames per second. The study contributes to improving communication among stakeholders and facilitates effective decision-making in landscape assessments.

116

Enhancing Immersion in Virtual Spaces. PhytualBlend - a real-time interaction system for seamless physical feedback

Tiantian Lo, Yuhong Wu, Gerhard Bruyns, Daniel K Elkin

As an extension of physical space, VR and MR technologies offer convenient solutions for spatial and product design by providing immersive user experiences. Nevertheless, these technologies are limited in their ability to provide physical feedback, which can lead to a perceived disconnection between visual, auditory, and bodily sensations. This paper introduces PhytualBlend, an innovative real-time interaction system designed to enhance the physical feedback experience within virtual environments. The system employs perceptual and executive hardware driven by development boards as its hardware components. User's operation on physical entities can be synchronized seamlessly to server-based virtual world through a local information hub, including position, orientation, and haptic interaction. Diverse interaction modes within the virtual world trigger corresponding feedback in the physical space, encompassing tactile vibrations, thermal sensations, visual illumination, and object deformations. Our prototypical demonstrates remarkable performance, achieving a frame rate exceeding 60 frames per second with imperceptible network latency. The modular design of PhytualBlend enables efficient and scalable expansion of various physical feedback, interactive modes, and new virtual environments. PhytualBlend bridges the gap between the virtual and physical worlds, enabling remote collaboration participants to experience and interact with virtual contents in a more tangible and realistic manner.

195

Advancing Building Façade inspection. Integration of an infrared camera-equipped drone and mixed reality

Ryuto Fukuda, Tomohiro Fukuda, Nobuyoshi Yabuki

Routine inspections of building facades are crucial to ensure structural safety and operational integrity. Recently, the use of drones equipped with infrared (IR) cameras has greatly improved inspection efficiency. However, determining exterior wall anomalies from infrared thermography is difficult for non-experts and requires simplified understanding and visualization. In this study, we propose a new system that combines a drone equipped with an IR camera and mixed reality (MR) technology. The system aims to detect and display likely delamination in the building envelope in real time, and to display MR data simultaneously with past inspection data so that past and current conditions can be easily compared. In the proposed method, both an IR camera and an RGB camera are mounted on a drone. The average surface temperature is calculated from the captured IR video frame images, and a thresholding process is used to identify hot regions that indicate potential anomalies; MR is used to superimpose the detected anomalies on the RGB images, providing an intuitive visualization. By storing the detected areas on a wall surface in a virtual space, the MR display at the next inspection will also allow comparison with past inspection results. This study presents a comprehensive solution for advancing building façade inspections that combines drone technology, infrared imaging, and the efficiency of MR to facilitate safer and more informed decision-making in building maintenance.

330

Virtual Reality in Architectural Design Revisited

Pascal Mosler, Maximilian Gehring, Wolfgang Dokonal, Uwe Rüppel

This paper gives an overview of several years of joint efforts of two European universities to develop a workflow that enables architects to use Low-Cost Virtual Reality (VR) based on Head-mounted display systems (HMD) in the architectural design process. The main goal was to find out if using VR in the design process can be beneficial for the design process, provide additional insights within reasonable effort and enable people working in the field with little scripting and programming experience to make use of these systems. To make this possible, we wanted to have some simple commands in the virtual environment to change the geometry of the design. In our workshops, students of architecture worked with students of civil engineering with a focus on computer science. The workflow is based on Unity as a software platform to prepare the geometry for the virtual world. We developed scripts for manipulating building parts such as walls and windows. The goal is that these scripts developed by the engineering students can be used with little adaption within the scripting skills of architects for new geometries. The project was already presented at several international conferences where we presented our experiments with self-developed low-tech interfaces and workflows using VR in the design process. With this paper, we give an overview of different VR platforms and summarise and finalise our findings based on the insights we gained with our joint student workshop.

014

Exploring Phygitalization in Architecture Comparative analysis of the reality of digital and physical experiences in relationships of humans and space

Shu Ting Magdalene Chang, Ho Nam Marco Lee, Chin Kit Peter Pan, Tian Tian Sky Lo

Contemporary designers utilize extended reality (XR) to merge the physical and digital realms, aiming to create immersive user experiences, a concept known as "phygitalization." However, current studies predominantly focus on the visual aspects of XR, resulting in underdeveloped XR systems. This research aims to address this gap by examining the role of haptic experiences in enhancing immersion within the virtual environment, thereby bridging the divide between the physical and digital worlds. The research methodology involved a literature review to explore relevant terminologies related to physics, space, experience, senses, and human perception. Subsequently, an experiment was conducted to investigate the impact of connectivity between the physical and digital worlds on human perception. The experiment involved participants using a VR headset to interact with virtual "sand" and then directly interacting with different physical materials that have similarities and differences to the virtual environment, aiming to investigate (a) the incorporation of real objects in (b) interior and exterior virtual settings and (c) the disparities between physical and virtual materials. The study results showcased that by combining XR with physical haptic experiences, it is possible to enhance immersion in the virtual environment, contributing to the development of "DataDriven Intelligence", while recognizing that it may not fully substitute the physical world. This research seeks to explore the relationship between humans and space in both digital and physical experiences and paves the way for investigating how the integration of XR in architectural contexts can influence human perception, sensory abilities, and experiential encounters.

SESSION 6

Session Chair: ***CHRISTINA DOUMPIOTI***

6.3

025

Urban Street Space Analysis with Spherical Box-Counting. Holistic digital Gestalt analysis of architecture in urban space

Matthias Kulcke and Wolfgang E. Lorenz

Spherical box-counting of urban street spaces is a novel method developed and refined by the authors to produce highly specific topological fractal fingerprinting of architecture in relation to observer position and in the context of the accompanying surroundings. The use of 360-degree spherical panoramas as input data and basis for fractal measurement lies at the center of this method. A holistic approach toward architectural and urban design, balancing between simplicity and complexity of all Gestalt qualities, needs to take the influence of every (especially man-made) object in view into consideration. This research shows that Gestalt complexity is linked to the observer's viewpoint as well as the Gestalt complexity of all objects visible from the viewer's position. This is another decisive step toward holistic fractal and overall digital Gestalt analysis of urban spaces.

081

Shadow Optimisation of Low-impact Temporary Architecture to Improve Climatic Comfort in Urban Spaces

Rossella Siani, Francesco De Luca

Urban spaces face threats from climate change, including phenomena like urban heat islands, impacting cities across different latitudes. This research aims to develop a performative architecture enhancing outdoor seating comfort in summer while minimizing ecological impact. We used an algorithmic approach in design and comfort analysis, following circular economy and carbon sequestration principles. A case study in Parma, Italy, is the subject of experimentation. The project targets creating surfaces to maximize shade for seating areas, using Rhino / Grasshopper / LadyBug Tools software and a solar parameter morphogenesis approach. Materials like local bamboo and recycled wood are chosen for performance and sustainability. The design is tailored to Parma's latitudes and takes advantage of climate simulations. UTCI index tests climatic comfort, comparing results between the emerged project and a flat roof. Construction experiments in bamboo and wood were part of the design and analysis process.

054

Jammed Rubble. A building system concept for granular architecture from mixed mineral waste

Hana Svatoš-Ražnjević, Maria Wyller, Eva Schad, Achim Menges

The research presented in this paper aims to expand the design and fabrication space for building with mixed mineral construction and demolition waste (rubble) by utilizing granular jamming in combination with lightweight textile containers. Despite the wide availability of rubble and the persistence of destructive demolition processes, there has been relatively little research on its application in architecture. Often considered a lowquality material, rubble, a granular material, has the inherent potential to form structurally stable geometries through confinement. In this paper, we aim to take advantage of this quality and present a rapidly deployable building system and fabrication concept for compression-based vertical building components. The research methods consist of rubble analysis and categorization, and the development of packing, layering and pouring strategies tested through physical prototyping. Although in its early stages, the research demonstrates the potential of bringing unprocessed rubble back into architecture as a low-cost sustainable material resource for large-scale aggregate structures to combat one of the world's largest waste streams.

238

Aspen Leaves as a Biological Role Model for a Triboelectric Wind Energy Harvesting Building Facade System. Generating Power Through the Movement of Leaves in the Wind

Carlotta Mace, Khyati Danak, Morgan Jacobson, David Correa

Biological role models are a growing focus of research in wind energy harvesting technology. Rotational elements (blades)are well known but there have been limited studies looking at galloping instability (fluttering effect) for electricity harvesting via the triboelectric effect. Some previous studies have demonstrated the potential of galloping blades, or triboelectricity, by coupling with piezoelectric systems. However, there are not any known studies that have studied the potential architectural implementation of these systems in building applications. Here, a bio-inspired mechanism is presented that combines bio-mechanical properties observed in the distinctive fluttering of the Aspen (Populus Tremuloides) leaves, to test the potential for adaptive building facade systems that can produce electricity in response to the low-speed winds found in urban environments. The research outlines the principles behind the distinctive fluttering pattern of the Aspen leaf, also known as torsional galloping, and shows a 3DP strategy to create functional models that can replicate its motion. The bio-inspired actuator was subsequently coupled with a proof-of-concept triboelectric set-up to evaluate its potential for energy harvesting. Lastly, a speculative design for an urban building application was proposed to assess the technical and aesthetic implications of these types of systems. We hope that this initial investigation can contribute towards the future development of smart, adaptable, and sustainable integrative façade systems that will use local environmental conditions to harvest energy and therefore reduce reliance on non-renewable energy.

296

Surface Articulation as Structural Leverage in Large Scale 3D Printing

Pavlos Fereos, Kilian Bauer, Eftychios-Nicolaos Efthimiou

As large-scale robotic 3D printing continues to gain traction in architecture, design and construction, the necessity to develop fabrication-inherent strategies and guidelines to overcome generic limitations of the method becomes increasingly apparent. To contribute to this process, this paper presents three prototypes that explore the concept of surface articulation through geometry manipulation as structural leverage in large scale robotic 3D printing. Each of the three prototypes addresses a specific architectural task with increasing ambition to incrementally challenge the hypothesis. The three research pieces are a three-meter tall, leaning Column, an ornamental Throne and a two and a half meters tall, cantilevering Lamp-post. While the three prototypes represent only a small series of case studies, they are nonetheless diverse and demonstrate situations of different structural stresses, ranging from tension to compression to bending. In the attempt to counteract these structural stresses, all three prototypes pursue the notion of geometry manipulation in the appearance of surface articulation. While the approach to improve surface rigidity through complexity and folding has been known for a long time, it is inherent to the nature of digital design and fabrication, which could revive surface ornamentation in additive manufacturing. The three objects presented, which together form the Trilogy of Additive Hyper-Ornamental Prototypes, aim to contribute to this process by showcasing initial explorations into surface articulation as structural leverage in large scale 3D printing and the aesthetics inherent to this process in order to inspire further research.

7.1 SESSION 7.1

DIGITAL DEVELOPMENTS II

THURSDAY 12.09.2024 • 17:30-19:00

ROOM: LRC012

Session Chair: ***ASTERIOS AGKATHIDIS***

398	**Design principles of a memorable space in VR. Analysis of spatial parameters influencing affordance and logic in placement of mnemonic objects**	*Adam Novotník, Lukáš Kurilla*
309	**Digitizing the Past for the Future. A guideline for developing AR-CH applications in situ for urban heritage interpretation and management**	*Yueying Zhang*
161	**The AI's Cognition of the Cultural Characteristics Underlying Chinese Courtyeard Dwelling. A visual perception-based approach for Siheyuan plan classification using machine learning and convolutional neural networks**	*Yuyang Wang, Xingwu Li*
382	**Economy and Community as Bottom-Up Drivers for Design. Creating coordinating dashboards for architectural design**	*Marie Smets, Elien Vissers-Similon, Theodoros Dounas*
141	**A Simulation Framework for Space-Use Alignment in Adaptive Environments**	*Ben Drusinsky, Sivan Grodsky, Eduard Haiman, Davide Schaumann*

7.2 SESSION 7.2

IT IN HERITAGE

THURSDAY 12.09.2024 • 17:30-19:00

ROOM: LRC014

Session Chair: ***ANTONIO FIORAVANTI***

042	**A Phygital Approach in Architecture for Preserving Dong Minority's Crafting Heritage**	*Siyue Zhang, Tian Tian Lo*
339	**Automated Generative Design in Archaeological Reconstruction of Greek Architecture. Utilizing parallel shape grammars in Shape Machine**	*Yichao Shi, Myrsini Mamoli, Chunlan Wang*
068	**A Combined Approach for Image-based Virtual Reconstruction of Damaged Architectural Heritage. A case study of St. Rudolf Church in Banostor**	*Vesna Stojakovic, Isidora Djuric, Milos Obradovic, Tamara Miljkovic*
147	**Integration of Photogrammetric Survey Technique with Hygrothermal Assessment for Architectural Heritage Survey and Analysis. A case study of Dragon Pagoda in China**	*Xiaolu Wang, Ying Liu, Hanfang Liu*
252	**An Ontology-Driven Approach for Geometry Segmentation and Interpretation in Architectural Heritage/archaeology**	*Cassia De Lian Cui, Stefano Cursi, Davide Simeone, Antonio Fioravanti, Edoardo Currà*

7.3 SESSION 7.3

EDUCATION I

THURSDAY 12.09.2024 • 17:30-19:00

ROOM: LRC019

Session Chair: ***ANDRZEJ ZARZYCKI***

035	**AI-Assisted Design. Utilising artificial intelligence as a generative form-finding tool in architectural design studio teaching**	*Asterios Agkathidis, Yang Song, Ioanna Symeonidou*
047	**Integrating Artificial Intelligence Rendering Tools in Design. Integrating AI as teaching methods in architectural education**	*Abdulrahman Ahmed A Alymani*
352	**Fostering Collective Creativity in Architectural Education. Embracing Collaborative Objects as a Design Media in Academia**	*Alexander Grasser-Parger, Urs Leonhard Hirschberg*
190	**Towards a Fully Virtualised Architectural Design Studio. A holistic VR-based framework from conception to final design**	*Mohammed Faraj Al-Suwaidi, Asterios Agkathidis, Adonis Haidar, Davide Lombardi*
151	**Visualizing Urban Transformations using a 3D Cellular Automaton**	*Nirmala Maja Salkic, Gabriel Wurzer, Wolfgang E. Lorenz*
210	**Embedding Systems Platform Arduino and Robotics into Architectural Education. A project-based approach combining computational design and digital fabrication**	*Yangzhi Li, Adam Fingrut, Sevgi Altun*

SESSION 7

Session Chair: ***ASTERIOS AGKATHIDIS***

7.1

398

Design principles of a memorable space in VR. Analysis of spatial parameters influencing affordance and logic in placement of mnemonic objects

Adam Novotník, Lukáš Kurilla

This paper extends our previous research on using memorable spaces displayed in virtual reality (VR) for learning while utilizing various memory techniques such as Method of Loci (MoL). For this method we need to identify design guidelines for an easily memorable space which provides enough opportunities to create mnemonic devices in order to make the method efficient. Therefore, we explored various design principles of memorable space and experimentally tested them with users to find patterns and verify their validity. Experiments focused on exploring composition, atmosphere and affordance of the space. Users were placing mnemonic devices in the VR environment and we observed and measured their behavior and usage of the given space. From gathered data we defined several design principles which were either predicted or discovered during the testing. We summarized our findings and outlined guidelines for designing memorable spaces and further research. Furthermore, data from the memory testing once again indicate efficiency of the method and ability of the users to memorize a long list of consecutive numbers.

309

Digitizing the Past for the Future. A guideline for developing AR-CH applications in situ for urban heritage interpretation and management

Yueying Zhang

This research presents an extensive exploration of Augmented Reality (AR) in the context of cultural heritage (CH), particularly within the dynamic landscape of Smart Cities. It aims to offer a practical guide for the selection of advanced development tools for crafting AR-CH applications, starting with an assessment of the technical characteristics of mobile AR and moving on to a practical evaluation of core recognition methods. The study reveals the interplay between virtual augmentation and physical heritage elements that is critical for the enhancement of urban heritage sites. A proposed framework within the paper not only seeks to deepen the interpretive experience but also to facilitate public engagement and foster collaborative heritage management. By rigorously evaluating the functionalities of prominent AR Software Development Kits (SDKs) and conducting hands-on experiments, this research aims to provide an exhaustive resource for developers. It advocates for innovative, accessible, and cross-platform AR experiences that bridge the past with the future, enabling broader interaction and participation in heritage conservation and management.

161

The AI's Cognition of the Cultural Characteristics Underlying Chinese Courtyeard Dwelling. A visual perception-based approach for Siheyuan plan classification using machine learning and convolutional neural networks

Yuyang Wang, Xingwu Li

Siheyuan is a Chinese courtyard dwelling type in which the traditional culture is embedded. From the viewpoint of a spatially determinist understanding of culture, this study identifies the morphological characteristics of Siheyuan in a plan view constrained by Chinese culture. Based on the Visibility Graph Analysis (VGA) of the Siheyuan layouts, this study considers people's visual perception in Siheyuan courtyards to classify the variants by using machine learning and computer vision techniques. According to the results of a clustering analysis of the feature vectors extracted from VGA maps, the spatial characteristics reflecting cultural connotation in Siheyuan design are captured. The findings could be used to support designing new Siheyuan-style dwellings and Siheyuan heritage preservation.

382

Economy and Community as Bottom-Up Drivers for Design. Creating coordinating dashboards for architectural design

Marie Smets, Elien Vissers-Similon, Theodoros Dounas

In our paper, we show that, from an economic and environmental point of view, neighbourhoods could benefit from a circular architectural design approach, as creating an actual circular economy and community asks for more organisation than purely spatial planning. By using design as a driver both for a self-sustained economy and for architectural design, we provide a pathway for architects to be involved beyond their singular architectural design outputs We believe that our paper is significant in developing alternative, bottom-up mechanisms for developing and managing architectural designs and its afterlife. The dashboard and digital infrastructure developed through the paper can also be used by other researchers to expand the cases where our method can be applied.

141

A Simulation Framework for Space-Use Alignment in Adaptive Environments

Ben Drusinsky, Sivan Grodsky, Eduard Haiman, Davide Schaumann

Recent advancements in the Internet of Things (IoT) and adaptive architecture created new opportunities for designing environments that dynamically respond to human needs. However, architects lack the tools and methods to design architectural responses that meet dynamic space-use requirements. This paper introduces a multi-agent simulation framework for space-use alignment in adaptive environments that includes dynamic and reconfigurable architectural components, such as tables and movable partitions. The proposed approach generates, simulates, evaluates, and selects optimal adaptability strategies to meet activity requirements while also considering space affordances, occupant preferences, and the availability of limited dynamic components to be allocated at the same time. We demonstrate this approach in a preliminary case study in a workplace setting. The results indicate that the proposed framework can automatically identify space-use allocation strategies for dynamically changing activity requirements, which maximize space utilization, people experience, and activity performance. This approach could help architects, engineers, and designers explore alternative adaptability strategies, contributing to a shift toward human-centered and responsive environments.

SESSION 7

Session Chair: ***ANTONIO FIORAVANTI***

7.2

042

A Phygital Approach in Architecture for Preserving Dong Minority's Crafting Heritage

Siyue Zhang, Tian Tian Lo

This study explores the integration of physical and digital realms ("phygital") in architectural practice, focusing on preserving the intangible cultural heritage of the Dong minority in China amidst modernization and diaspora challenges. Utilizing Extended Reality (XR) technologies, including Augmented Reality (AR) glasses and Electromyography (EMG) wristbands, the study proposes a virtual crafting space that replicates traditional Dong crafting activities (e.g., wood carving, weaving, and jewellery making) to bridge physical distances within the Dong diaspora. This approach not only facilitates the participation of diaspora members in their ancestral crafting practices but also plays a crucial role in preserving their cultural heritage. The study demonstrates the potential of phygital methodologies to revolutionize architectural education and practice by merging traditional craftsmanship with digital innovation, thereby enhancing creative expression and contributing to the conservation of cultural heritage.

339

Automated Generative Design in Archaeological Reconstruction of Greek Architecture. Utilizing parallel shape grammars in Shape Machine

Yichao Shi, Myrsini Mamoli, Chunlan Wang

The reconstruction of historical architectural structures presents significant challenges due to a lack of historical information and the complexities of classical architecture. Traditional reconstruction techniques frequently fall short of capturing the variability and complexities inherent in ancient designs. This study proposes a novel approach that combines parallel shape grammar and computer-aided design (CAD) using the Shape Machine, an advanced shape grammar interpreter. Taking the Ionic Porch at the Sanctuary of the Great Gods in Samothrace as a case study, this method suggests variations of elevations and plans for buildings using limited archaeological evidence, architectural data, and Vitruvian principles of classical design to create shape grammars for the Ionic Porch. These grammars capture this Hellenistic monument's architectural details and are integrated into the Shape Machine for precise manipulation. Besides automating architectural plans and elevations, our method includes visual scripting to document the reconstruction process. This helps us understand the Ionic Porch's architecture and follows the London Charter's principles of technical accuracy, historical authenticity, and archaeological integrity in reconstruction.

068

A Combined Approach for Image-based Virtual Reconstruction of Damaged Architectural Heritage. A case study of St. Rudolf Church in Banostor

Vesna Stojakovic, Isidora Djuric, Milos Obradovic, Tamara Miljkovic

As our heritages continue to face ongoing risks of damage, virtual heritage reconstructions are often used as a valuable resource for presentation, dissemination, and archival purposes. This paper aims to establish a combined image-based approach for the virtual reconstruction of St. Rudolf's Church in Banostor. We employ structure-frommotion (SfM) image-based surveying techniques for measurement and reconstruction. SfM enables a high level of automation and results in detailed point clouds, however requires a high level of photo consistency and sharpness. The method is applied to virtual reconstructions of both existing remains and the collapsed parts. We demonstrate how photosets taken without the necessary SfM surveying parameters can still be utilized for the virtual reconstruction of non-existing or damaged heritage.

147

Integration of Photogrammetric Survey Technique with Hygrothermal Assessment for Architectural Heritage Survey and Analysis. A case study of Dragon Pagoda in China

Xiaolu Wang, Ying Liu, Hanfang Liu

The integration of photogrammetric survey techniques with hygrothermal assessment offers a comprehensive approach to architectural heritage survey and analysis. This study focuses on the Dragon Pagoda in China, constructed during the Yuan Dynasty using limestone and traditional brick masonry. By leveraging photogrammetry, highly reliable 3D models capturing the spatial and textural characteristics of the Pagoda are generated. These models are then integrated into hygrothermal simulations using WUFI Plus to assess the building's structural health and resilience against weathering processes such as surface recession, thermal stress, and freeze-thaw cycles. The study demonstrates that climate parameters significantly impact the deterioration of stone building materials. The results from the hygrothermal simulations reveal detailed insights into the temperature and humidity transfer within the Pagoda's materials, enabling a thorough damage risk assessment. The innovative combination of photogrammetric data with hygrothermal assessments provides valuable insights for the long-term preservation and restoration of historical buildings, addressing the challenges posed by climate change and ensuring the durability of cultural heritage structures.

252

An Ontology-Driven Approach for Geometry Segmentation and Interpretation in Architectural Heritage/archaeology

Cassia De Lian Cui, Stefano Cursi, Davide Simeone, Antonio Fioravanti, Edoardo Currà

Digital information systems are widely used for heritage documentation and management activities. The creation of 3D models based on different survey techniques, like photogrammetry and laser scanning, allows a fast collection of the studied assets in the form of geometry dimensions and point clouds. However, the raw geometric information and the mesh/solid converted data need to be associated with semantic annotation, defined as external and formalized knowledge of the architectural artifact. This paper proposes a workflow using Semantic Web-related technologies to support point cloud segmentation activity of archaeological artifacts. The suggested approach is based on analyzing and integrating different layers of information through three main phases: the digital acquisition phase, the geometry creation phase, and the semantic enrichment phase. The defined framework is then applied to the archaeological case study of Tivoli to highlight how the workflow can significantly improve the quality and effectiveness of data segmentation in the existing heritage documentation processes by providing a solid basis for the generation of detailed and semantically enriched geometric information models. Finally, the creation of this system prototype will give overall support to aid the interpretations and value recognition of heritage sites thanks to the capability of representing and managing the categories (in Aristotle's sense) and the uniqueness of concepts applied to this peculiar and paradigmatic case study.

SESSION 7

Session Chair: ***ANDRZEJ ZARZYCKI***

7.3

035

AI-Assisted Design. Utilising artificial intelligence as a generative form-finding tool in architectural design studio teaching

Asterios Agkathidis, Yang Song, Ioanna Symeonidou

Artificial Intelligence (AI) tools are currently making a dynamic appearance in the architectural realm. Social media are being bombarded by word-to-image/image-toimage generated illustrations of fictive buildings generated by tools such as 'Midjourney', 'DALL-E', 'Stable Diffusion' and others. Architects appear to be fascinated by the rapidly generated and inspiring 'designs' while others criticise them as superficial and formalistic. In continuation to previous research on Generative Design, (Agkathidis, 2015), this paper aims to investigate whether there is an appropriate way to integrate these new technologies as a generative tool in the educational architectural design process. To answer this question, we developed a design workflow consisting of four phases and tested it for two semesters in an architectural design studio in parallel to other studio units using conventional design methods but working on the same site. The studio outputs were evaluated by guest critics, moderators and external examiners. Furthermore, the design framework was evaluated by the students through an anonymous survey. Our findings highlight the advantages and challenges of the utilisation of AI image synthesis tools in the educational design process of an architectural design approach.

047

Integrating Artificial Intelligence Rendering Tools in Design. Integrating AI as teaching methods in architectural education

Abdulrahman Ahmed A Alymani

This paper introduces an innovative teaching approach for architectural design studios, emphasizing the integration of AI-rendering tools to enhance student learning and creativity. The method begins with conventional site analysis, followed by an in-depth study of a micro-home case study to deepen understanding. Students' progress from traditional 2D plans to conceptual 3D massing, facing challenges in integrating case studies into their designs. To address this, an AI-rendering engine is incorporated, allowing students to add intricate details and apply various case studies directly onto their 3D models. This visual approach aids understanding and application of architectural concepts. The paper discusses how this approach helps students overcome integration challenges and fosters creative exploration. Findings suggest that this method enriches architectural education, offering a new dimension to design studio learning.

352

Fostering Collective Creativity in Architectural Education. Embracing Collaborative Objects as a Design Media in Academia

Alexander Grasser-Parger, Urs Leonhard Hirschberg

This paper presents a comprehensive exploration of the pedagogical implications and methods of integrating collaborative objects into architectural education and computeraided architectural design. Over the past five years, our approach to education in design studios has embraced the concept of collaborative objects - digital objects augmented with networking capabilities. This conceptual framework allows for various forms of interaction and contribution to the design: from synchronous to asynchronous to distributed design activities. This has various consequences, both formal, as several people contribute to the creation of an architectural form, and informal, as the real time design process becomes a very social, human-centered, and community-driven activity - creating a wide variety of open, participatory architectures. Throughout multiple design studios, students engaged in hands-on projects, navigating the technical aspects of computational design as well as the intricacies of teamwork and collective creativity. This approach not only enhanced their understanding of digital architecture but also fostered a rich environment for collaborative learning and creativity. Our approach combined theoretical underpinnings with hands-on applications, ensuring a balanced educational experience. This paper reports on the key methods and concepts, their implications, and how they evolved over this period of extensive research by design on collective creativity in architectural education.

190

Towards a Fully Virtualised Architectural Design Studio. A holistic VR-based framework from conception to final design

*Mohammed Faraj Al-Suwaidi, Asterios Agkathidis, Adonis Haidar, Davide Lombard*i

While Virtual Reality (VR) is gaining popularity in the architectural design field as a visualisation tool, emerging tools like Google Blocks, SketchVR and Gravity Sketch (GS) further utilise VR's immersive capabilities. Design toolsets such as 3D sketching, modelling and interaction within the virtual space, with six degrees of freedom of movement and rotation in the virtual space, enable a fully immersive design approach. We continue utilising these immersive toolset capabilities to expand our previous research on incorporating VR tools in the early stages of the architectural design process throughout an academic semester project. This paper aims to further extend this research approach by embracing a fully virtualised architectural design studio and exploring all the design stages through Virtual Reality. Our findings highlight the framework's strengths and challenges, revealing diverse approaches and design outcomes from participants throughout the semester. Evaluation methods include student surveys, External Examiner reports, focus group interviews and researcher/lecturer observations. Additionally, a comparison is made with non-virtualised design studio outputs running concurrently, utilising the same site and design brief.

151

Visualizing Urban Transformations using a 3D Cellular Automaton

Nirmala Maja Salkic, Gabriel Wurzer, Wolfgang E. Lorenz

Urban transformation is key to achieving more livable and sustainable cities. However, modelling this evolution is highly non-trivial since there are many factors at play that manifest themselves in the built (or: non-built/restored) environment. In our most recent work, we have represented urban change as rules of a three-dimensional Cellular Automaton. With these rules we represent a variety of retrofitting options - additive (e.g. densification through roof extensions, facade greening, installation of solar panels) or subtractive (e.g. soil descaling), that lead to urban change as an emergent outcome. The editing of rules is embedded into a web-based visualization which acts as a test-bed and platform we have used in a design studio setting and can thus report on our lessons learned in that context.

210

Embedding Systems Platform Arduino and Robotics into Architectural Education. A project-based approach combining computational design and digital fabrication

Yangzhi Li, Adam Fingrut, Sevgi Altun

This paper investigates integrating robotic fabrication technologies within architectural pedagogy, aiming to develop effective teaching strategy tailored for a diverse group of students, including postgraduate and undergraduate students. Robotics is an essential technology in Industry 4.0, providing a wide range of capabilities in the manufacturing field. The rapid advancement of robotic arms in various industries has opened new possibilities for architectural education. Many architecture schools worldwide have established experimental laboratories equipped with robotic arms, creating opportunities for students to explore beyond the traditional scope of CNC manufacturing. However, professional courses on integrating robotic construction technologies into architectural education are scarce. This research aims to explore using robots as an open interface for problem-solving, geometry exploration, and programming in architectural education, catering to the students' diverse backgrounds and skill levels. By utilizing robotic construction technologies, students can engage in hands-on experimentation, fostering the adoption of digital fabrication techniques.

SESSIONS SCHEDULE DAY 3

8.1

SESSION 8.1

FRIDAY 13.09.2024 • 10:30-12:00

ROOM: LRC012

Session Chair: ***DAVIDE LOMBARDI***

AUTOMATED FABRICATION II

249	**Repurposing Material Through Real-Time Point Cloud Reconstruction and Human-Robot Collaboration. Integrating real-time point cloud reconstruction and body detection**	*Yuemin Gong, Yangzhi Li, Adam Fingrut*
420	**Deep Agency. Towards human guided robotic training for assembly tasks in timber construction**	*Sarvenaz Sardari, Selin Sevim, Pengfei Zhang, Gili Ron, Samuel Leder, Achim Menges, Thomas Wortmann*
367	**Rethinking Bamboo Roof-Based Architecture of Indonesian Traditional House Using Parametric Design and Automated Fabrication Techniques**	*Ahmad Mansuri, Asterios Agkathidis, Davide Lombardi, Hanmei Chen*
180	**Use of Genetic Optimisation Algorithms in the Design of 3D Concrete Printed Shell Structures**	*Jurij Licen, Taole Chen*
095	**Formwork optimization for complex 3D Concrete Printing. A unified theoretical, digital, and experimental framework**	*Vasilis Andreou, Odysseas Kontovourkis*

8.2 SESSION 8.2

AI IN DESIGN II

FRIDAY 13.09.2024 • 10:30-12:00

ROOM: LRC014

Session Chair: ***IMMANUEL KOH***

300	**AI-Infused Design. Merging parametric models for architectural design**	*Adam Sebestyen, Ozan Özdenizci, Robert Legenstein, Urs Hirschberg*
253	**Cartographies of Immersive Fractality. An exploration of collective emotive responses in urban settings through Machine Learning**	*Daijia Ke, Akbar Agniputra, Zhaoyan Feng, Ilin Wu, Ilaria Di Carlo, Annarita Papeschi*
215	**Comparison of GAN-based Spatial Layout Generation Research. Focusing on AIBIM-Spacemaker and GAN-Based Prior Research**	*Hyejin Park, Hyeongmo Gu, Soonmin Hong, Seungyeon Choo*
153	**Enhanced Landscape Visualization of Post-Structure Removal. Integrating 3D reconstruction techniques and diffusion models through machine learning**	*Shinya Tsurunaga, Tomohiro Fukuda, Nobuyoshi Yabuki*
242	**Architectural Dramaturgy. A total and endless theatre with multimodal artificial intelligence**	*Immanuel Koh and Man Lin Saw*
011	**Viewing History through the Lens of Artificial Intelligence Classification of late Ottoman and early Republican period buildings in Türkiye with Convolutional Neural Network (CNN)**	*Emirkan Burak Yılmaz, Funda Tan Bayram, Cem Balcan, Esra Arslantürk, Şeyda Arslan Ercan, Yusuf Sinan Akgül*

8.3 SESSION 8.3

EDUCATION II

FRIDAY 13.09.2024 • 10:30-12:00

ROOM: LRC019

Session Chair: ***AULIKKI HERNEOJA***

078	**Embracing the Creative Nexus. Integrating artificial intelligence, philosophy, and artistic discourse in architectural education**	*Anders Hermund, Henrik Oxvig, Jacob Sebastian Bang*
338	**Hybrid Workflow for Feedback using Extended Reality and 3D Scanning Systems**	*Sarah Blahut, Harun Faizi, Marie-Therese Harnoncourt-Fuchs*
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SESSION 8
Session Chair: ***DAVIDE LOMBARDI***

8.1

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Repurposing Material Through Real-Time Point Cloud Reconstruction and Human-Robot Collaboration. Integrating real-time point cloud reconstruction and body detection

Yuemin Gong, Yangzhi Li, Adam Fingrut

Human-robot collaboration in construction has become an emerging field in computeraided construction due to robots' high efficiency and precision performance in simple processes and repetitive tasks. However, the complex construction site environments and diverse shapes of construction materials present challenges for human-robot collaborative construction. Most construction robots lack computer vision recognition and perception of preassembled parts, which require proper positioning and lack interactive capabilities. In this paper, we propose a system called the Human-Robot Collaboration (HRC)to address these challenges and enhance the assembly of construction walls using recycled materials from construction and demolition waste. The HRC system leverages dual Kinect Azure devices for point cloud fusion and employs a segmentation algorithm specifically designed for this purpose. This enables fast and accurate point cloud reconstruction of recycled parts. The control terminal, implemented using the Grasshopper plugin Machina, provides a real-time display of the 3D geometric model of the target structure and the reference grasping points to achieve UR10e robotic assembly. Additionally, the Kinect Azure human body tracking algorithm ensures workers are alerted and stop in time when entering the workspace. Overall, this research presents an enhanced collaborative and sustainable solution for human-robot construction scenarios, ensures the safety of robotics construction, and offers feasibility and guidance for future automation in construction sites.

420

Deep Agency. Towards human guided robotic training for assembly tasks in timber construction

Sarvenaz Sardari, Selin Sevim, Pengfei Zhang, Gili Ron, Samuel Leder, Achim Menges, Thomas Wortmann

Automating robotic assembly in architectural construction is challenging due to material uncertainties and the buildup of tolerance experienced in assembling many parts. Implementing AI technologies, including various machine learning algorithms in robotic assembly, has demonstrated significant potential for robots to respond to this uncertainty. This research builds upon previous implementations of singular algorithms by combining haptic teaching with deep reinforcement learning (DRL) in a single workflow to improve robot autonomy in responding to uncertainties in timber assembly. Haptic teaching bridges the gap between simulation and reality inherent to DRL, while DRL improves the generalizability of haptic teaching and speeds up the agents' learning process. The developed workflow is tested through various lap joint assembly experiments. The effectiveness of this combined approach is assessed through various experiments that refine and evaluate the methodology, providing valuable insights into enhancing robot capabilities to manage material uncertainties and deviations. Additionally, this research considers the evolving role of human workers in collaborative construction environments with robots.

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Rethinking Bamboo Roof-Based Architecture of Indonesian Traditional House Using Parametric Design and Automated Fabrication Techniques

Ahmad Mansuri, Asterios Agkathidis, Davide Lombardi, Hanmei Chen

Indonesian traditional houses are well known as roof-based architecture due to the names of the houses given by the type of roof shape. The roof is the distinctive dominance of the house geometry in the overall size and body proportions, which aims to respond to the tropical climate and solar radiation. The roof structure is made of timber and bamboo with a non-rigid structure using traditional rope and palm fibre joints. Parametric design and digital fabrication have disruptively boosted the progress of complex emerging bamboo architecture design and structures over the past few years. However, it has remained challenging because bamboo construction relies heavily on manual fabrication and handoperated assembly. Seeing this opportunity, we attempt to parametrically design and robotically fabricate the bamboo roof structure, automate the process, and move forward from the traditional method towards digital fabrication. Our verification design experiment object is a typical hyperbolic paraboloid bamboo roof scale prototype. Our findings highlight the advantages and challenges of bamboo-based structure design, robotic fabrication process, and novel opportunities for contemporary Indonesian bamboo architecture.

180

Use of Genetic Optimisation Algorithms in the Design of 3D Concrete Printed Shell Structures

Jurij Licen, Taole Chen

A transition from disparate data to interconnected and contextually integrated data is currently causing a paradigm shift in the architecture industry. The need for fabricationaware architectural representation models, that enable designers to interface with today's data-intensive manufacturing technologies, is a direct consequence of new concepts such as smart fabrication, automation and vertical integration. Compared to conventional concrete casting methods, 3D Concrete Printing (3DCP) offers a wide range of advantages, particularly the ability to create complex geometry. A lack of computational modelling techniques that link design and production for 3DCP is currently making it difficult to predict the printability of designs. This research presents a unified design-to-fabrication framework using machine learning (ML) that is customized for freeform steelreinforced 3DCP shell structures. 3DCP is used to create incrementally cast sacrificial formwork. In particular, the segmentation process is fed back into the design process using genetic optimization for a fabrication-aware design model. The framework is validated with a series of physical experiments.

095

Formwork optimization for complex 3D Concrete Printing. A unified theoretical, digital, and experimental framework

Vasilis Andreou, Odysseas Kontovourkis

3D Concrete Printing (3DCP) revolutionizes architecture with speed and sustainability. Yet, current methods mainly use extrusion in 2.5 dimensions, limiting complex shapes. Challenges remain in achieving intricate morphologies, such as non-conventional cavity walls, as well as overcoming limitations posed by overhanging structures, and inclined surfaces with protrusions, leading to exploration of additives like chemical accelerators. However, uncertainties in effectiveness persist, posing challenges in strength and handling. Overcoming these limitations is vital for unlocking 3DCP's full potential in construction. This study delves into the

underdeveloped digital formalization and prevention of failure modes in 3DCP for intricate 3D morphologies, particularly focusing on the challenges encountered in the construction of overhangs and subsequently cavity wall construction, using aggregate support materials as formwork. It introduces a structured selection process, leveraging Finite Element Analysis (FEA), to understand the crucial role of lateral pressure in supporting these complex structures. Theoretical analysis, rooted in earth pressure analysis theory, informs the selection of appropriate aggregate materials, which are then validated through experimental testing. This comprehensive approach uncovers essential attributes for support materials, enabling alignment with various formwork families based on specific requirements like insulation or reusability. Through a series of physical prototyping, including cylinder samples produced via robotic 3DCP, the practical applicability of these findings is solidified. Ultimately, this study contributes significant insights into optimizing 3DCP methodologies for complex geometries, bridging a critical gap in formalization and advancing the field of 3DCP.

SESSION 8
Session Chair: ***IMMANUEL KOH***

8.2

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AI-Infused Design. Merging parametric models for architectural design

Adam Sebestyen, Ozan Özdenizci, Robert Legenstein, Urs Hirschberg

This paper presents ongoing work on developing 3D Generative AI tools based on parametric models to facilitate novel types of Design Space Exploration (DSE) to overcome human biases and expand the range of feasible design solutions. By integrating parametric models and neural networks, the study demonstrates how 3D-mesh based datasets generated from different parametric models can be combined in deep learning to create more diverse design spaces. Specifically, we compare training on the same datasets with an unconditioned Variational Autoencoder (VAE) and with conditioned Denoising Diffusion Models (DDMs). We present a novel approach of mixing DDM design spaces and contrast this method with our previous work using a VAE. The paper compares the outputs of VAE and DDMs, highlighting their respective strengths and weaknesses, and proposes a hybrid generative AI model combining both approaches to harness their complementary advantages.

253

Cartographies of Immersive Fractality. An exploration of collective emotive responses in urban settings through Machine Learning

Daijia Ke, Akbar Agniputra, Zhaoyan Feng, Ilin Wu, Ilaria Di Carlo, Annarita Papeschi

Recent advances in machine learning technologies offer avenues for a more efficient analysis of large photographic and text-based datasets, facilitating a deeper understanding of the fundamental characteristics inherent in the immersive representation of the urban environment. It is known that automatic fractal processing in the human visual system triggers positive emotive responses to the environment. The project explores the correlation among fractal aesthetics, visual perception, and emotional responses in urban settings, developing an integrated evaluation method that uses the data-scraping of existing online photographic media from Flickr and Google Street View (GSV). Taking the area of Southbank in London (UK) as a case study, the study initially employed a sentiment analysis method rooted in the Lexical dictionary from TextBlob. Further, an extensive online GSV urban scenery dataset was built via Google API. The photographic dataset was then evaluated by fractal dimension as a quantitative index to measure the complexity of fractal patterns. Concurrently, to enhance the comprehension of the composition of urban form, a semantic segmentation method for image analysis was implemented. A comparative evaluation of the data collected indicated the key role of fractal patterns described by vegetation in the generation of positive emotional responses, underscoring with methodological rigour the potentially transformative impact of the experience of fractal patterns and green infrastructures in open urban spaces.

215

Comparison of GAN-based Spatial Layout Generation Research. Focusing on AIBIM-Spacemaker and GAN-Based Prior Research

Hyejin Park, Hyeongmo Gu, Soonmin Hong, Seungyeon Choo

Recent advancements in Large Language Models (LLM) and the emergence of ChatGPT are rapidly progressing Generative AI models, suggesting the possibility of AI replacing human creative activities. In architecture, where outcomes depend on human creative thinking, the pre-planning stage is crucial. Architectural planning involves decisions on mass, space layout, and space program, aiming for optimal design with a significant impact on subsequent stages. Creating a client-centric design within a given time prompts architects to search for diverse reference materials. However, finding comparable spatial layouts is challenging due to the predominant focus on materials, construction methods, and details. This study introduces AIBIM-Spacemaker, a Generative Adversarial Network (GAN)-based program we developed for generating spatial layouts through graphical composition of space programs. Focusing on a house with limited space usage but versatile layouts, the study collected 10,000 raster-based floor plan images, creating a training dataset annotated for spatial elements. Training this dataset using the YOLO model enabled automatic extraction of vector-based data representing spatial relationships from raster-based images. A GAN trained on this data resulted in AIBIM-Spacemaker, allowing users to create diverse spatial layouts. Executing a graph with nodes representing spaces and edges denoting relationships between doors and windows using the trained GAN produced varied spatial layouts. Verification, comparing actual ground truth values, GAN-generated outcomes, and architect-provided values confirmed the program's effectiveness in the planning stage. Performance was verified by comparing the program, learning method, dataset, and results developed in this study with previous studies on GAN-based spatial layout generation. This study identifies the potential for AI-based spatial layout generation, enhancing planning efficiency and contributing to intelligent design automation, with anticipated positive impacts on planning task efficiency.

153

Enhanced Landscape Visualization of Post-Structure Removal. Integrating 3D reconstruction techniques and diffusion models through machine learning

Shinya Tsurunaga, Tomohiro Fukuda, Nobuyoshi Yabuki

In urban redevelopment, demolition of existing buildings often occur and landscape assessment plays an important role in avoiding various environmental issues. Both residents and professionals should be involved to create a virtual three-dimensional (3D) space after demolition, which would enable even non-experts to understand the future landscape. Research efforts aimed at creating virtual 3D spaces by removing unnecessary objects utilize techniques such as neural radiance fields (NeRF). These techniques reconstruct spaces into virtual 3D spaces from RGB images by removing redundant objects. However, a challenge

arises from the low-quality images generated from the resultant space. Additionally, methods for reconstructing 3D images face limitations in acquiring images of portions previously obscured by structures slated for demolition. This often leads to numerous artifacts in 3D reconstruction after structure removal, which hinders accurate space construction. This study proposes a system that integrates 3D Gaussian splatting, capable of high-quality 3D reconstruction through machine learning, and image completion processing using a diffusion model. This integration aims to reduce the impact of artifacts in 3D reconstruction after building removal in complex and largescale urban areas. This will contribute to the intuitive understanding and decision-making of non-experts, such as residents, in future landscape assessments after building removal.

242

Architectural Dramaturgy. A total and endless theatre with multimodal artificial intelligence

Immanuel Koh and Man Lin Saw

Close to a century ago, Walter Gropius proposed the highly influential but unrealised project 'Total Theatre' (1927). The project captured Gropius' adapted formulation of 'Gesamtkunstwerk'('total work of art') as 'Total Design' within the Bauhaus, and more specifically, in relation to 'The Theatre of the Bauhaus' (1924). The 'Total Theatre' was Gropius' attempt to dynamically reconfigure the previously static relationship between actors and audience into one that is participatory and filmic in spatial layout. Around the same time in history, shortly after designing the set for Eugene O'Neill's 'The Emperor Jones' in 1924, Frederick Kiesler began to conceptualise his 'Endless Theatre' (1926). In the former, Kiesler created a constructivist stage space with moving walls/floors/ceilings animating in-sync with the play's narrative and producing cinematographic effects similar to those found in films. For both Gropius and Kiesler, the theatre is a fertile ground for incorporating the latest technologies to prototype a 'totally' multimodal and 'endlessly' generative form of architecture. Against the backdrop of such past intellectual efforts in architecture, and that of today's rapidly foregrounding of Large Language Models (LLMs) and Large Multimodal Models (LMMs) in artificial intelligence (AI) within the architecture discipline, the paper posits that it is timely to revisit this conceptual cross-fertilisation of theatre and architecture – architectural dramaturgy. In doing so, the research aims to extend Gropius's and Kiesler's concept of the 'total' and the 'endless' respectively through the lens of the 'computational'. The first experiment uses different datasets from existing established theatre creators to train and promptengineer relevant AI models, namely a text-to-text model for playwright Arthur Miller, a text-to-image model for director Ivo van Hove, and a text-to-audio model for composer Stephen Sondheim. In improving the coherence of the results, the second experiment replaces unimodality with multimodality leveraging a single source of video data (the poignant "To be or not to be" soliloquy from Shakespeare's Hamlet) to formulate a human-in-the-loop interpretative framework by utilising a combination of text-image-toimage model and text-image-to-video model, and further postprocessed with image inpainting model and image-to-3D model. With the deliberate bracketing of site, programmes and other specificities typical of an architecture project, the research demonstrates how concepts borrowed from theatre when layered with multimodal AI could extend the discipline's longstanding conception of a total and endless architecture.

011

Viewing History through the Lens of Artificial Intelligence Classification of late Ottoman and early Republican period buildings in Türkiye with Convolutional Neural Network (CNN)

Emirkan Burak Yılmaz, Funda Tan Bayram, Cem Balcan, Esra Arslantürk, Şeyda Arslan Ercan, Yusuf Sinan Akgül

This study employs Convolutional Neural Networks (CNNs) to classify late Ottoman and early Republican period buildings in Türkiye, offering a unique lens through artificial intelligence (AI) to examine architectural styles. By training on a specially curated dataset, including images of 16 architects' works, the study achieves accuracy rates of 84.65% for a limited architect dataset and 74.08% for the full architect dataset. EfficientNet emerges as the optimal architecture, surpassing Baseline, VGG, and ResNet models. Through t-Distributed Stochastic Neighbor Embedding (t-SNE), the model visualizes relationships among architects' styles. This research not only provides a new perspective on Turkey's architectural heritage but also establishes a platform for future AI-driven architectural analyses and design paradigms.

SESSION 8

Session Chair: ***AULIKKI HERNEOJA***

8.3

078

Embracing the Creative Nexus. Integrating artificial intelligence, philosophy, and artistic discourse in architectural education

Anders Hermund, Henrik Oxvig, Jacob Sebastian Bang

In the realm of architectural education, a multidisciplinary approach that unites art, science, and philosophy can catalyze novel perspectives. This paper outlines the intentions and outcome of a PhD course, "Artificial Intelligence in Architectural Research," inviting exploration of these diverse domains within architectural pedagogy. The research question in relation to establishing novel ways of embracing AI technology while maintaining a focus on the core values of teaching architectural research methodologies is thus: how can we through art, philosophy, and scientific approaches teach the principles and applications of artificial intelligence for architects? The paper will introduce how we establish a didactical framing marrying artistic, scientific, and philosophical facets to empower students to reimagine architectural practice in the age of AI. They gain tools for visionary architecture that embraces technology and reflects on societal and philosophical dimensions. We discuss the outcome of the course by examining the students' work and feedback and conclude that the intention of the course methodology can be traced throughout the process from analogue to digital and that valuable novel realizations and understandings are created by persistently insisting on a cross-disciplinary approach to AI in relation to architectural research and creation.

338

Hybrid Workflow for Feedback using Extended Reality and 3D Scanning Systems

Sarah Blahut, Harun Faizi, Marie-Therese Harnoncourt-Fuchs

The research presented questions standard representational tools used in methods for project analysis and presentation in teaching. The experiment presented tests a hybrid workflow relying on extended reality and 3D scanning systems, creating a feedback loop in each step, expanding on current research. The work aims to leverage the potential in using advanced technology in a series of case studies, carried out by a group of 25 architecture students in three steps. The goal was for students to learn essential skillsets for

Rhino 3D, 3D scanning methods, and virtual (VR) and mixed reality (MR) systems for analyzing complex architectural structures. The experiment was conducted using hybrid workflows, in groups of two and three, to enhance a research task of analyzing the design and construction of a timber pavilion. The three steps in the analysis are based on the initial reconstruction of the pavilion in Rhino 3D, establishing key aspects of the structure as 3D model data. In this initial step, MR systems are implemented to test, review, and adjust the digital 3D model in an interactive immersive environment. In the following step, the assembly logic identified in the structure is tested by using MR systems developed for fabricating a scaled physical model. In the final step, the physical model built in the previous step is 3D scanned. The resulting 3D model data is compared with the initial Rhino 3D model data assisted with VR systems and are evaluated for legibility, accuracy in execution, and degrees of fidelity. The approach offers a hybrid learning context that established feedback loops within interactive, immersive environments. This also enhanced the learning task and production of complex spatial structures and 3D data, also highlighting areas for improvement. The hybrid workflow has provided other opportunities for future work through the integration of other advanced technologies and further testing in scalable iterations within in the design and building process.

106

Developing a Hybrid Learning Environment for Architectural Robotics

Serdar Aşut

The physical infrastructures needed for hands-on learning can be enhanced for efficiency and flexibility, meeting the rising student interest and adapting to the evolving educational landscapes. This article presents the ongoing development of a Hybrid Learning Environment (HLE) that adopts a blended approach to teaching robotics in design disciplines like architecture, building technology, and industrial design. Common platforms cannot replicate the experience of a physical learning space with tangible tools and materials, which are essential for hands-on learning in design education. This project tackles these concerns through an HLE that integrates VR and Robotics. The HLE includes a digital twin of the physical workspace created using a game engine. Different methods were explored to establish communication between physical and virtual environments. The empirical analysis of a preliminary version of the HLE demonstrates that it can enhance learning by making it more intuitive and engaging, making it easier to understand the complex operations of the robotic arm. The study also highlights further research directions, including addressing network security and latency issues, integrating multisensory approaches, and tackling the challenges in collaborative learning activities.

121

A Non-linear and Divergent Digital Learning Resource for Design Computation

Serdar Aşut

This paper presents a novel approach to developing Digital Learning Resources (DLR) for Design Computation (DC). Learning DC requires the students to develop cognitive skills in algorithmic thinking and practical skills in using specific software. Few learning resources integrate cognitive and practical skills, often prioritizing the skills related to tool use with a focus on software functionalities. They typically follow linear narratives in audio-visual or text-based tutorials, which do not align well with the essence of computational thinking. The DLR presented in this paper is a self-paced learning resource that integrates a web of interconnected concepts, methods, tools, and instructions on a non-linear interface, and it aligns better with the divergent qualities of computational design thinking. It is developed for an MSc-level course that introduces computational design. This paper presents its design and implementation, evaluation of its pilot use, and directions for future improvements.

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Timber Joinery Database. Documenting and designing traditional and contemporary wood-wood connections in a teaching environment utilizing an online OER platform

Max Salzberger, Tobias Scheeder, Jan Jurek Waters, Marco Hemmerling

The rapid advancements in technology call for a new approach to disseminating knowledge, emphasizing inclusivity, open accessibility, and collaborative intelligence. This shift towards an inclusive, open-source community facilitates global online connections that enhance the exchange of techniques and knowledge, further enabled by digital planning tools integrating design and execution seamlessly. Such advancements have revived interest in timber joints, combining traditional craftsmanship with digital design and manufacturing innovations. The Timber Joinery Database was established to preserve and expand this heritage by creating an open-source online platform for documenting both traditional and innovative timber joints. The development of the database included the structuring, design and technical conception as well as the integration of the first entries for evaluation. This work allows for the continuous implementation of joint analyses, developments and physical models production, bridging traditional craftsmanship with modern manufacturing methods. As the database evolves, it is enriched with more parameters and a parametric framework to cater to user-specific customization needs, ensuring the project's relevance and application in current and future timber joinery practices. This initiative represents a blend of tradition and innovation, leveraging digital tools and open-source principles to advance the field of timber joinery.

9.1 SESSION 9.1

STRUCTURES

FRIDAY 13.09.2024 • 13:30-15:00

ROOM: LRC012

Session Chair: ***IOANNIS MIRTSOPOULOS***

115	**Low-Tech Bamboo Constructions. Introducing a cable-strut approach for resource-limited conditions**	*Po-Yu Hsieh, June-Hao Hou*
183	**Kerf Canopy. Exploring the aesthetics and structural performance of kerf-bent timber structures**	*Renate Weissenböck, Timo Carl, Agnes Weilandt, Roger Loho*
298	**Parametric Design and Geometric Optimization for Deployable Domes. Based on the icosahedron frequency with hexagonal modules**	*Omar Fabrisio Avellaneda Lopez, Marilena Christodoulou, Marisela Mendoza*
004	**Application of a Vertical Effective Crank–Slider Approach in Reconfigurable Buildings through Computer-Aided Algorithmic Modelling**	*Louiza Irodotou, Stefanos Gkatzogiannis, Marios C. Phocas, George Tryfonos, Eftychios G. Christoforou*
089	**Cast Adaptive/Kinetic Façades The application of sand casting on manufacturing the adaptive/kinetic facades**	*Jingwen Chen*
308	**Generative Design and Fabrication in the Development of an Adaptive Canopy System with Thin-Film Photovoltaics**	*George Tryfonos, Marios C. Phocas, Eftychios G. Christoforou, Maria Matheou*

9.2 SESSION 9.2

DESIGN TOOLS AND DEVELOPMENT III

FRIDAY 13.09.2024 • 13:30-15:00

ROOM: LRC014

Session Chair: ***VESNA STOJAKOVIC***

071	**Two-Way Connection between Grasshopper and Matlab for the First SIMP-Based Multi-Material Topology Optimisation Plugin for Grasshopper**	*Efstathios Damtsas, Thanh T. Banh, Dongkyu Lee, Michael Herrmann*
185	**An Investigation into Form Blending in Architecture Through Generative Form-Finding and Optimization Procedures. A form-finding methodology**	*Wilhelm Neusser, Mauricio Morales-Beltran, Işik Ülkün Neusser, Manfred Berthold*
146	**Research on Ventilation-Oriented Complex Building Design Using the WRF-CFD Downscaling Method. A case study of residential building design**	*Zhichao Yu, Xinyuan Hao, Ziyu Tong*
036	**Resilient Green Building Envelopes. A computational method for holistic sustainability assessments and interdisciplinary design decision-making**	*Surayyn Uthaya Selvan & Francesca Mosca, Katia Perini, Yasha J. Grobman & Shany Barath*
114	**ZoeLength. Framework for indoor measurement from a single interior image for the popularization of AI interior design**	*Xinyu Su, Zidong Liu, Mingzhuo Yang, Daniel Koehler*
263	**Tactile Painting. Assistive Toolbox for Visual Impairment**	*Karen Kuo, Yunsong Liu*

SESSION 9

Session Chair: ***IOANNIS MIRTSOPOULOS***

9.1

115

Low-Tech Bamboo Constructions. Introducing a cable-strut approach for resource-limited conditions

Po-Yu Hsieh, June-Hao Hou

Despite the rapid development of building technologies, low-tech construction methods using local materials are still preferred in resource-limited areas. The question addressed in this research is how design computations can be integrated into a localized building process. This research is conducted in collaboration with an architectural practice at the NYCU campus in Hsinchu, an area rich in bamboo resources. Given the contextual challenges of limited time and technical expertise, the research aims to develop a tectonic framework for bamboo structures, which includes (1) form-finding iterations combining reciprocal frame and tensegrity structures, (2) an advanced cable-strut connection approach utilizing local resources and the inherent flexibility of bamboo culms, (3) a decoupled assembly process enhanced by computational tools, and (4) practical application in the final project.

183

Kerf Canopy. Exploring the aesthetics and structural performance of kerf-bent timber structures

Renate Weissenböck, Timo Carl, Agnes Weilandt, Roger Loho

The traditional craft technique of “wood kerfing” allows the bending of flat boards into 3D-geometry through a series of incisions (“kerfs”), thereby lending wooden structures a soft and pliable aesthetic. This method offers rich design potentials, driven by the interplay of material properties and geometric principles of the incisions. The incisions naturally weaken the wood, resulting in reduced material stiffness, which often poses a significant challenge to application kerf-bent timber structures at building element scale. This work addresses the dual challenge of achieving both soft aesthetics and loadbearing capacity. We explored design opportunities of kerfed wood in conjunction with a structural application through a 1:1 scale demonstrator with a footprint of 12 m². To enhance fabrication efficiency, traditional craftsmanship was combined with state-of-theart CNC technology, significantly streamlining the complex manufacturing process. Additionally, we developed strategies to gain a better understanding of the structural behavior of “soft” wood materials through FEM simulation. This approach allowed us to correlate the precise digital design- and simulation-models with - sometimes unpredictable - physical outcomes, exploring the tension field between material agency, geometry and structural performance.

298

Parametric Design and Geometric Optimization for Deployable Domes. Based on the icosahedron frequency with hexagonal modules

Omar Fabrisio Avellaneda Lopez, Marilena Christodoulou, Marisela Mendoza

The systems of deployable structures domes with straight bars are directly related to the geometry of solids. They are lightweight, modular, and transformable systems. This research relates to the design of deployable structures with articulated straight bars, with the purpose of being habitable and offering a solution to the light and traditional architecture. In particular, it refers to the design of deployable domes with articulated straight bars, starting from the transformation of the icosahedron using deployable hexagonal modules. With the possibility of changing its scale when increasing its frequency. In addition, has aims at a parametric design method for deployable domes or shells with straight bars of equal articulated dimension, stabilized with a flexible or rigid architectural covering. The process is defined as quick assembly. The optimization method employed is based on transforming the icosahedron and varying its frequencies. The process consists of optimizing deployable hexagonal modules with bars of equal length following geodesic patterns. Using visual programming algorithms using Rhinoceros + Grasshopper, geometric optimization results are achieved with deployable hexagonal modules applied to different dome frequencies. The system offers efficient solutions to temporary shelters, portable greenhouses, scenarios for medium and largescale events, and everything related to light and transformable architecture.

004

Application of a Vertical Effective Crank–Slider Approach in Reconfigurable Buildings through Computer-Aided Algorithmic Modelling

Louiza Irodotou, Stefanos Gkatzogiannis, Marios C. Phocas, George Tryfonos, Eftychios G. Christoforou

Elementary robotics mechanisms based on the effective crank–slider and four–bar kinematics methods have been applied in the past to develop architectural concepts of reconfigurable structures of planar rigid-bar linkages (Phocas et al., 2020; Phocas et al., 2019). The applications referred to planar structural systems interconnected in parallel to provide reconfigurable buildings with rectangular plan section. In enabling structural reconfigurability attributes within the spatial circular section buildings domain, a vertical setup of the basic crank–slider mechanism is proposed in the current paper. The kinematics mechanism is integrated on a column placed at the middle of an axisymmetric circular shaped spatial linkage structure. The definition of target case shapes of the structure is based on a series of numerical geometric analyses that consider certain architectural and construction criteria (i.e., number of structural members, length, system height, span, erectability etc.), as well as structural objectives (i.e., structural behavior improvement against predominant environmental actions) aiming to meet diverse operational requirements and lightweight construction. Computer-aided algorithmic modelling is used to analyze the system’s kinematics, in order to provide a solid foundation and enable rapid adaptation for mechanisms that exhibit controlled reconfigurations. The analysis demonstrates the implementation of digital parametric design tools for the investigation of the kinematics of the system at a preliminary design stage, in avoiding thus time-demanding numerical analysis processes. The design process may further provide enhanced interdisciplinary performance-based design outcomes.

089

Cast Adaptive/Kinetic Façades The application of sand casting on manufacturing the adaptive/kinetic facades

Jingwen Chen

The escalating focus on sustainability across diverse domains has instigated multifaceted strategies to achieve this objective, encompassing modifications in resource utilization and the incorporation of renewable energy sources alongside recyclable materials. In the realm of architecture, the façade serves not only as an aesthetic feature but also as a regulator of both interior and exterior environments, with kinetic facades emerging as a dynamic solution. Unlike the dynamic external conditions and active building occupants, architecture, as a whole, remains relatively stationary. As integral components of architectural design, kinetic facades are purposefully engineered to actively and dynamically modulate external environmental conditions to align with occupant requirements. This paper delves into the specific realm of cast kinetic joints within the broader context of kinetic facades in architecture. As sustainability gains prominence, the study focuses on the manufacturing processes of these crucial components, narrowing its scope to the use of sand casting. With its rich historical legacy and inherent adaptability, this technique emerges as a focal point for crafting kinetic joints. The analysis delves into crucial considerations, including design intricacies, scale dynamics, and material selections, emphasising the potential of sand casting as a sustainable method for manufacturing these dynamic and active architectural elements. Through a meticulous examination of the intricacies associated with kinetic joints, this study aims to provide targeted insights into the viability of sand casting, thereby providing a refined exploration of its role in advancing sustainability within the realm of kinetic facades.

308

Generative Design and Fabrication in the Development of an Adaptive Canopy System with Thin-Film Photovoltaics

George Tryfonos, Marios C. Phocas, Eftychios G. Christoforou, Maria Matheou

The development of energy efficient and sustainable open public spaces may be achieved through use of urban elements that encompass the function of renewable energy production and shading. Presently, the use of photovoltaic systems in open public spaces remains essentially unexploited, given the fact that they are typically installed on the ground due to the relatively heavy weight structure of the silicon-based photovoltaic modules. In achieving increased implementation potential and energy production performance, an adaptive lightweight canopy structure with integrated thin-film photovoltaic modules is currently developed. The structure's configuration and the photovoltaic modules orientation adapt to the sun movement, in improving energy production. A lightweight structural unit of a cable net spanning an aluminum frame supports a secondary system of struts and continuous cables in two directions, responsible for the support of the photovoltaic modules and actuation of the system. Minimization of material use, construction time, energy consumption and operation costs are aimed at through parametric design, automated fabrication, structural and technical simplicity and minimum number of actuation components. Thus, the concept development is based on geometrical parameters controlled in Grasshoper plug-in for Rhinoceros software, which defines the geometrical characteristics and verifies the associated kinematics. Furthermore, the digital algorithm archives the system components design through automated fabrication of the system joints in small scale, and enables numerical investigation of the load-deformation behavior of the system in externally linked FiniteElement Analysis software CSI SAP2000. The prototype concept development serves as case example of an interdisciplinary design process followed with digital parametric design tools.

SESSION 9

Session Chair: VESNA STOJAKOVIC

9.2

071

Two-Way Connection between Grasshopper and Matlab for the First SIMP-Based Multi-Material Topology Optimisation Plugin for Grasshopper

Efstathios Damtsas, Thanh T. Banh, Dongkyu Lee, Michael Herrmann

Multi-Material Topology Optimisation (MMTO) is not currently available for Architects as it requires complex and highly technical commercial software. Single Material Topology Optimisation (SMTO), however, is readily available for Architects within software that they frequently use such as Grasshopper. This research examines the first ever SIMP-Based MMTO plugin for Grasshopper which is freely available and tailored for use by Architects. It explains how the plugin works and compares its results against benchmark examples from commercial software, literature, and existing SMTO plugins for Grasshopper.

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An Investigation into Form Blending in Architecture Through Generative Form-Finding and Optimization Procedures. A form-finding methodology

Wilhelm Neusser, Mauricio Morales-Beltran, Işik Ülkün Neusser, Manfred Berthold

'Form-blending' is a computational design tool rooted in the animation industry and utilized by 3D programs originally developed for cartoon films. At the turn of the millennium, architects and designers started utilizing 'form-blending' to design gradual shapes. However, since these form-blended geometries per se, have their genesis rooted in merging irregular patterns, they do not necessarily embrace structural principles. Thus, the use of 'form-blending' tools does not guarantee geometries adhere to any generic structural rationale. To address this problem, a comparison discussing the pros and cons of optimization methods and tools regarding their potential for integration into 'form-blending' was initiated. The outcome of this process suggested the development of a methodology incorporating discretization, finite element model, and multi-objective optimization in connection with tools such as 'form-blending', to generate geometries with structural logic. This methodology aims to enable architects and designers to receive structural feedback during the design process and to generate variants based on structural objectives. In a case study employing form-blended shapes, the methodology was tested to evaluate the methodology's applicability and performance. The results exhibited form-blended geometry based on structural rationale and form-finding principles. Thus, supporting architects with a methodology to employ computational tools such as 'form blending' to design and generate variants of shapes based on a structural logic for further structural development.

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Research on Ventilation-Oriented Complex Building Design Using the WRF-CFD Downscaling Method. A case study of residential building design

Zhichao Yu, Xinyuan Hao, Ziyu Tong

Ventilation-oriented design aims to improve natural ventilation during the building design and optimization process. However, previous studies have focused merely on simplistic models, mono-scale climatic conditions, or single design problem. Building design is an integrated multiscale process, and accordingly, the external conditions for ventilation simulation should be targeted to different scales of the design process. To address these issues, this paper proposes a ventilation-oriented design framework for complex building design that combines the progressive design approach with the 3-domain nested ventilation simulation method based on WRF-CFD. Moreover, the boundary conditions are set to be appropriate for each design phase, with distinct evaluation indicators. To demonstrate its efficacy, this research takes the design process of a residential building located in the main urban area of Nanjing, China as a case. The results show that our design method can provide architects with multidimensional ventilation design information as references, and contribute to a better urban living environment based on ventilation-oriented complex building design.

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Resilient Green Building Envelopes. A computational method for holistic sustainability assessments and interdisciplinary design decision-making

Surayyn Uthaya Selvan & Francesca Mosca , Katia Perini, Yasha J. Grobman & Shany Barath

Urbanisation catalyses environmental degradation, leading to reduced ecosystem services and compromised human well-being. To mitigate negative anthropogenic impacts, cities draw on sustainable and resilient design strategies. Among these solutions are green envelopes, which are highly beneficial in densely populated environments. However, existing sustainability methods lack a comprehensive framework to holistically evaluate the influence of green building envelopes. This paper introduces a computational method for the holistic sustainability evaluation of green envelopes, focusing on climate change and material usage impacts through strategic indicators. By employing a hybrid multicriteria decision-making model, our method facilitates the generation and selection of optimised design alternatives aimed at enhancing environmental resilience. We examine the trade-offs between alternatives, prioritising various objectives related to architectural and sustainability performances. The results show that accounting for climate change and material use impacts enhanced trade-offs between design alternatives without compromising key architectural considerations. This research provides valuable insights for resilient envelope designs amidst rising urban environmental complexities.

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ZoeLength. Framework for indoor measurement from a single interior image for the popularization of AI interior design

Xinyu Su, Zidong Liu, Mingzhuo Yang, Daniel Koehler

Applying Artificial Intelligence Generated Content (AIGC) to interior design makes it possible for anyone to take on the role of a designer. Size is crucial to interior design, and distance measurement has become an essential component allowing to integration of image generation in industrial supply chain processes. This paper explores a new framework for indoor measurement based on a single interior image. Without any reference and camera calibration, our method ZoeLength can estimate the target size by taking a photo with the simplest mobile device. We achieved this by constructing a simplified camera model, incorporating cutting-edge depth estimation technology, ZoeDepth and Depth Anything, and object detection technology, Grounding DINO. To increase the accuracy of measurement, we trained a depth estimation model specifically for indoor scenes using our own collected dataset. Experimental results from multiple aspects demonstrate the reliability and validity of the proposed method and its application value to real-world scenarios.

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Tactile Painting. Assistive Toolbox for Visual Impairment

Karen Kuo, Yunsong Liu

This paper proposes a novel framework aimed at enhancing accessibility and inclusivity in architectural representation for visually impaired individuals. Traditional methods of architectural representation predominantly rely on visual stimuli, thereby excluding individuals with visual impairments from fully engaging with and comprehending architectural designs. Through a comprehensive review of existing tactile systems, including the Braille system and Feelipa, we identify the limitations of current methodologies in conveying spatial and color information effectively. Building upon these insights, our research introduces a pioneering approach that integrates color temperature—a fundamental aspect of human perception—and haptic feedback to facilitate tactile comprehension of architectural designs. By associating specific shapes with primary colors based on their perceived temperature, our framework establishes a symbiotic relationship between tactile stimuli and visual cues, thereby fostering a more intuitive understanding of color relationships and spatial configurations. Theoretical discourse, empirical experimentation, and practical application are employed to elucidate the theoretical underpinnings and practical implementation of our proposed framework. Through this interdisciplinary approach, we aim to revolutionize the way architectural representations are perceived and interpreted by visually impaired individuals, thereby fostering greater inclusivity and empowerment within the architectural discourse.

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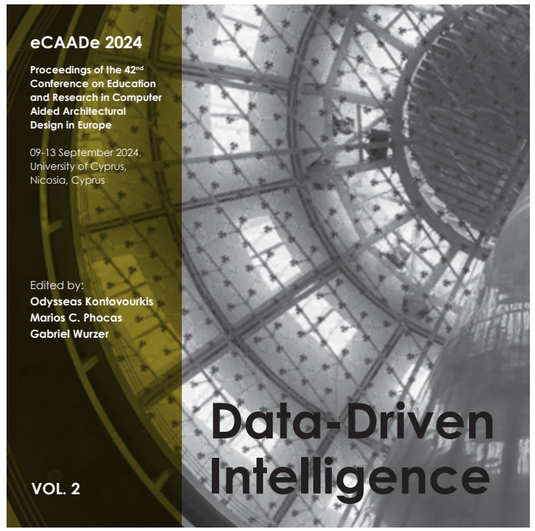

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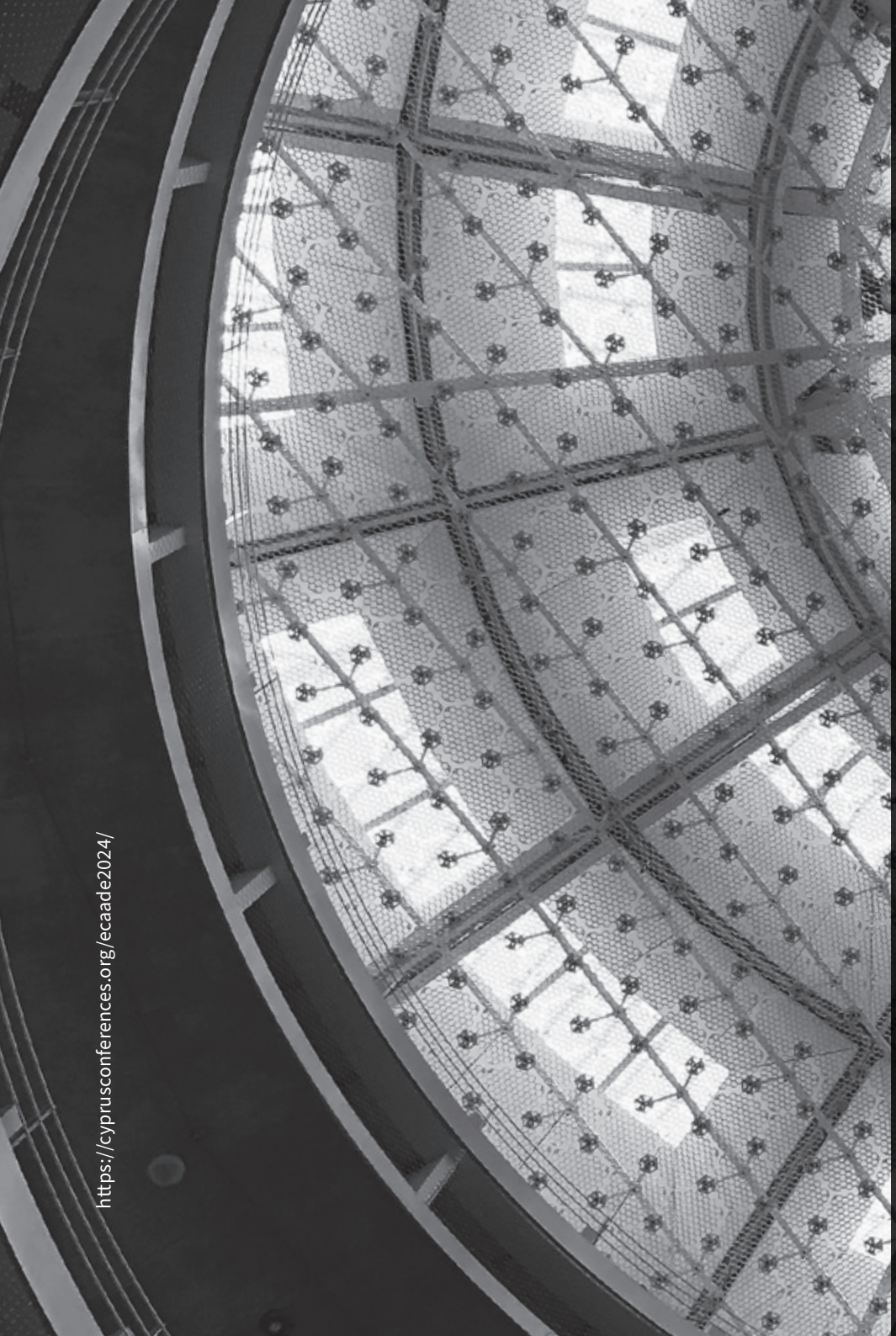

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