book of abstracts
16.11.2023

sustainable structural design forum

ReStruct TU Delft

sustainable structural design

As the effects of climate change become ever more visible, sustainable structural design comes to increasing importance. This leads to multiple initiatives in practice and academia. At the current rate, the changes in sustainable structural design practice outpace the publication of research outcomes. In recognition of this, the Sustainable Structural Design Forum provides a platform to share and discuss new developments in both practice and academia. By inviting leading scientists and professionals from a wide range of fields, the forum aims for a holistic perspective on the current sustainability discourse. This includes theory and challenges, yet mainly focus on solutions and recent innovations. The forum has three main themes: **resource, reuse, resilience**.

RESOURCE

Conscious use of resources towards low-emission structures

A sustainable built environment relies on conscious use of resources. Using and wasting less resources, avoiding critical materials and using biobased or upcycled materials are strategies to limit resource extraction and develop low-emission structures. Knowledge about material properties and their potential in structural and architectural applications is essential for their large-scale implementation.

REUSE

Closing the loop through effective reuse of reclaimed components

The built environment contains many valuable materials and components that get wasted every day. Closing the loop by reusing, repurposing, remanufacturing, refurbishing or repairing existing components or structures cuts down both on resource extraction and waste production. This requires evaluation of properties and performance as well as design strategies for the effective re-implementation of reclaimed components in new structures. The application of circular design principles like design for disassembly can ease future reuse.

RESILIENCE

Futureproofing the built environment with resilient structures

The climate crisis, population growth and other dynamic trends bring about many uncertainties for the built environment and its building structures. A futureproof structure incorporates future changes and shocks in its design to contribute to the resilience of the building and society. Future scenarios and predictive modelling help integrate and evaluate different types of resilience in buildings and structures.

sustainable structural design

organizing committee

Dr. Stijn Brancart
Stijn is Assistant Professor of Circular and Biobased Structures. He is an architectural engineer with a deep affinity for the relation between structural form and performance. His research focuses on the reuse of structural components, timber and biobased structures.

Prof. Mauro Overend
Mauro is Professor of Structural Design and Mechanics. His research and teaching interests are at the interface of structural engineering, materials engineering and architecture which underpin the performance of high performance building envelopes and sustainable structures.

Prof. James O'Callaghan
James is Professor of Architectural Glass. He is a structural and façade engineer with over 20 years of experience. He is co-director and co-founder of Eckersley O'Callaghan. Both in research and practice, James pushes the boundaries of materiality, performance, form, energy, and the aesthetics of architectural glass.

with support of the scientific committee
Lars De Laet, Günther Filz, Catherine De Wolf,
Elias Knecht, Roberto Gentile & Daniele Perrone

about ReStruct

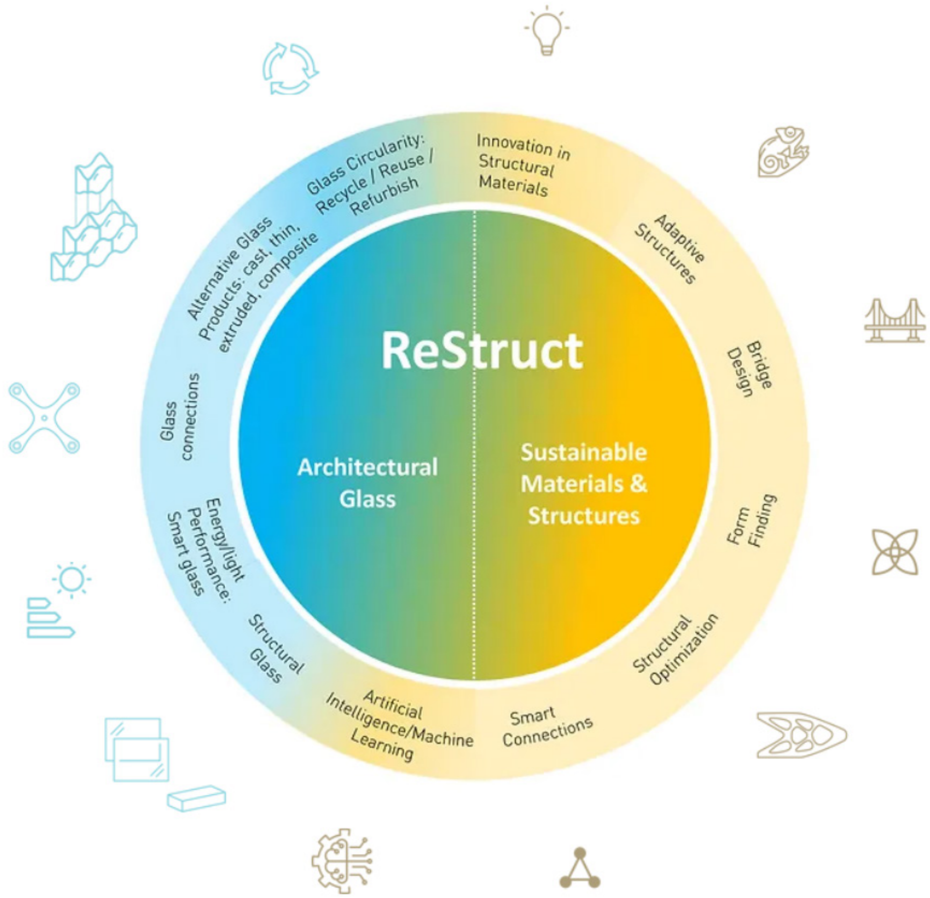
We are a multi-disciplinary teaching and research group with expertise in structural mechanics, structural materials and structural design. We engineer novel materials, explore useful mechanical characteristics, develop new structural systems and associated design methods for safe, sustainable and elegant architectural structures.

Guided by our own first-hand experience in real-world projects and research activities we educate the future generations of designers to deliver safe and sustainable structures. We collaborate with like-minded educators, researchers and practitioners locally and internationally, ranging from individual researchers to global centres of research excellence and from local SMEs to multi-national PLCs.

our mission

Our mission is to bring about this next generation of safe, sustainable and elegant structures by leading-edge research and education.Our activities are grouped in the following overlapping research themes:

Glass & Transparency including architectural and sustainable glass;
Structural Mechanics including form-finding and optimisation;
Artificial Intelligence for sustainable and resilient structures;
Adaptive architectural structures including smart and reconfigurable structures;
Bio-based architectural structures including natural and engineered bio-based materials.



sustainable structural design

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sustainable structural design forum

programme

sustainable structural design

09:00 walk-in and registration

09:30 welcome and welcome address by Michiel Kreutzer and Stijn Brancart

10:00 **SESSION 1: towards sustainable resource selection**

Charlotte Taylor Ecologically constrained structural design

Gertjan Peter Paris in practice!

10:45 coffee break

11:15 **SESSION 2A: towards sustainable timber structures (Berlage Room)**

Emily van Helmond Stepping stones in sustainable design

Toby Ronals Hybrid timber structures

Marco Donà Case-studies on cross-laminated timber

Max Salzberger Utilising the swelling of densified wood-wood connectors

SESSION 2B: towards sustainable glass structures (Room B)

Lisa Rammig Carbon neutrality and circularity in glass and façades

Michael Elstner Low carbon glass products

Mariska van der Velden & Alexandros Cannas Optimized structural design

Martien Teich Reusing flat glass

12:30 lunch break

13:30 **SESSION 3: creativity & innovation for sustainable structural design**

Ellen Leemans Adjustable systems for modular reusable plate components

Samanwita Ghosh Reformable engineered bio-composites

Hasan Hadi Abdulmeer Branching as an approach to biomimetric tectonics

Andreas Biront Textile reinforcement for mycelium-based composites

Adalberto de Paula Automated workflow for discrete timber structures

Mohammad Hassan Saleh Tabari A-T-G louvers

Juan Cruz Rojas Interlocking wood-to-wood joinery with moisture induction

14:45 coffee break

15:15 **SESSION 4A: towards resilient building structures (Berlage Room)**
Simona Bianchi Toward multi-hazard resilient buildings
Kyujin Kim Seismic and thermal resilient façades
Simone D’Amore Eco-friendly exoskeletons for enhancing resilience
Pooyan Kazemi Structural sustainability of tall buildings under seismic loads

SESSION 4B: towards reuse of structures and components (Room B)
Rebecca Hartwell Reclamation potential in the built environment
Miriam Schuster Increasing the strength of used float glass
Elias Knecht CircÛbi
Florentia Kavoura Demountable hybrid floor systems

16:30 coffee break

16:45 **SESSION 5: towards effective use of new and existing resources**
Robin Oval Can we make efficient building floor reconfigurable?
Rocco Boselli & Carmelo Guido Galante Revitalizing the past

17:30 closing remarks by Mauro Overend and James O’Callaghan

18:45 dinner at Restaurant Kruydt

session 1

towards sustainable resource and material selection

Berlage Room
10:00 - 10:45

ecologically constrained structural design

what can we build from the zero-carbon resource pool?

Charlotte Taylor
University of Bath, UK

Charlotte Taylor is a structural engineer and PhD researcher at the University of Bath where she is part of the Systems and Sustainability Research Group and UKFIRES research team. Her project titled “Ecologically constrained structural design: what can we build from the zero-carbon resource pool?” is an industry-academia collaboration with structural engineers Whitby Wood. Taylor’s interests lie in understanding the land and energy systems which support UK construction, and in questioning the material practices which promote ecological justice and building material sovereignty. Charlotte is passionate about accessible research and co-runs community workshops in practicing systems change by building from a constrained material, land, and energy resource pool.

In collaboration with **Will Hawkins and Kelly Harrison**

sustainable structural design

In the context of escalating global environmental pressures and ecological breakdown, current trajectories of material resource use in the construction sector are overwhelming the regenerative capacity of the Biosphere and exposing humanity to a high risk of destabilising the Earth system. Many proposed strategies for addressing the embodied carbon of building materials make additional demands for land, such as using more biomass for energy and more wood to replace concrete or steel. Whilst competition for finite land and energy resources is intensifying, land-use change has contributed to around on third of anthropogenic carbon released into the atmosphere and has been the single dominant driver of terrestrial biodiversity loss. An emerging research stream has exposed significant opportunities to build from the material pallet of the Technosphere that includes a large, rapidly growing diversity of complex objects that are largely metals, plastics or ‘technofossils’. However, relevant empirical analyses on the quantity and quality of these materials remain largely lacking. Thus, a critical challenge in reaching zero-emissions centres on understanding what can be built from a clearly defined Zero Carbon Resource Pool to meet building demands, within planetary boundaries and a climate-target-constrained time frame. This project, for the first time, determines the sustainable supply of zero-carbon construction materials at scale in the UK using today’s technologies. Through a comprehensive set of system-wide environmental parameters and scale relevance from field to nation, the framework provides an exhaustive evaluation of the zero-carbon resources mobilised by the construction industry and determines the land-use and energy impacts entangled with the material supply at scale. The result maps the route from the Zero Carbon Resource Pool to a regenerative built environment, navigated by regional waste streams, agricultural by-products and sustainably managed forests.

biosphere
technosphere
land-use
energy
zero-carbon resource pool

ecologically constrained structural design

Charlotte Taylor

sustainable structural design

Paris in practice!

Gertjan Peters
ABT, The Netherlands

Gertjan Peters is lead consultant at the Façades & Glass knowledge group at ABT. He was design lead for the Natural Pavilion. His intrinsic core values are sustainability and innovation. From these core values he advises clients, architects and industry professionals on façade design.

sustainable structural design

The construction sector faces enormous challenges. Not only is the housing shortage very high, lowering CO2 and nitrogen emissions in combination with stricter legislation and environmental regulations also create great complexity in project development. Other societal challenges include the energy transition and the growing exclusion of the middle class from the market for owner-occupied houses. Besides that, the building sector has the ambition to be fully circular by 2050.

But why wait until 2050?

The Natural Pavilion, part of the Dutch Innovation Experience at the Floriade Expo 2022, shows that it is already possible on an industrial scale to develop homes, schools and offices that are built fully circular, biobased, energy neutral and in close connection with nature. It is the answer to the Floriade theme 'Growing Green Cities': a new spatial and social relationship between city and country for the ever-growing urban population worldwide, without exhausting Mother Earth.
The Natural Pavilion proves that solutions are available for the shortage in energy, raw materials and housing. It showcases a more sustainable agriculture, urbanisation and climate adaptation and restores biodiversity. The pavilion is almost entirely constructed from local biobased materials and is a literal accumulation of innovations. For example, the pavilion shows the possibilities of using greenery in the living and working environment (even with stacked construction), new forms of rainwater collection and use, sustainable foundation solutions, optimal use of natural daylight, reuse of glass, natural ventilation and minimal energy consumption. The combination of a super flexible modular construction method, the industrialised construction process, the beauty and its biobased materialization makes The Natural Pavilion the epitome of circular construction.

modular
demountable
circular
biobased

Paris in practice!

Gertjan Peters

sustainable structural design

session 2A

towards sustainable timber structures

Berlage Room
11:15 - 12:30

stepping stones in sustainable design

a case study of sustainable buildings at Arup Amsterdam

Emily van Helmond
Arup, The Netherlands

After completing a bachelor in Architecture and a master in Building Engineering at the TU Delft, Emily is now working for Arup Amsterdam as a structural engineer. Besides structural engineering and architecture she is highly interested in Sustainability and Circularity and works on those projects that have high ambitons regarding sustainability. Finding ways to measure circularity and ensuring sustainable strategies and actions are applied in practice are tasks she is focussing on.

In collaboration with **Roy Crielaard**

sustainable structural design

The meaning of what a sustainable structural design is, changes. At Arup we are commited to sustainability but recognise there are many aspects to sustainable design. In this presentation a process of stepping stones is shown where sustainability is implemented on projects by our Amsterdam office.
For project HAUT, one of the tallest timber hybrid buildings in Europe, the application of timber resulted in a significant reduction of embodied carbon. This project focussed on material impact by minimising the use of carbon intensive materials in the structure by replacing concrete and steel for engineered timber where possible.
Project Echo, at the TU Delft campus, is the first energy positive university building in the Netherlands. The creation of climate zones with specific demands optimizes the heating efficiency. For this project, the solar roof produces more energy than is used by the building; including electricity for the building users, lighting and heating.
For project Elements, the complex boundary conditions required a parametric and generative approach. The team identified six key sustainability performance indicators to drive the parametric process and embed sustainability in the design, including at building scale (daylight and sun), at neighbourhood scale (wind and green spaces) and at planetary scale (energy and carbon).
In project Habitat Royale the design is nature inclusive by creating habitats on top of and below large structural cantilevers. These cantilevers also reduce energy demands by providing shade in summertime and allowing light to enter during winter. To achieve the ambitions for embodied carbon whilst recognizing timber was not feasible for the cantilevers, the floors are designed with urban mining concrete and electric arc furnace reinforcement.
With each project, our understanding of good sustainable structural design increases, and brings us closer to the goal of zero emissions in 2050.

integral design
nature inclusive
carbon neutral
parametric design

stepping stones in sustainable design

Emily van Helmond

sustainable structural design

hybrid timber structures
Atlassian Central and alternative approaches

Toby Ronalds
Eckersley O'Callaghan, UK

Toby leads the practice's Structural Engineering group in London. A keen interest in good buildings and good design has seen Toby leading award-winning projects in a variety of structural materials, including engineered timber. His interest in sustainable structural design has seen the company work on a range of standard setting projects in the UK and internationally. From London Southbank University's Hub Building - winner of the Institute of Structural Engineers award for 'Transformative sustainable design' - to the exposed timber frames of The Black + White Building and Vitsoe HQ.

sustainable structural design

Under construction, Atlassian Central in Sydney, is anticipated to be the world's tallest timber hybrid tower on completion. This unique structural hybrid of timber, steel and concrete incorporates 21 floors of full timber construction within the towers overall 42 floors. The talk showcases the structural principals of the tower covering the advantages, challenges and complexities of the approach. The talk also compares the Atlassian approach with alternative structural approaches being implemented and considered by designers in order to introduce low carbon timber construction in taller and larger structures around the world.

timber
hybrid
tall

case-studies on cross laminated timber

challenges and solutions

Marco Donà
CLT-S, The Netherlands

Marco Donà is a structural engineer with an interest in research and development. After his master studies in Padova (Italy), he achieved a PhD at Loughborough University in the UK and worked for three years as post-doc on composite panels for free-form façade applications at Cambridge University. In the last five years he has been working in the timber sector initially in the UK at B&K Structures and now at CLT-S working on timber projects across Belgium and The Netherlands.

sustainable structural design

The global human population has been growing exponentially since the industrial revolution. The scale of the growth is now such that the resulting pollution is significantly altering the climate natural equilibrium. The attention towards a more sustainable society has become one of the more suitable approach to mitigate these effects. In the construction sector this transition has revitalized timber as a sustainable resource. Its natural capability to store carbon from the atmosphere has given it growing interest. In this regard, Cross Laminated Timber (CLT) has become widespread over the last few decades. CLT consists of several layers of timber boards bonded together to form large panels, to be used for the production of floors or walls. The light weight of the material combined with the ease of manufacturing and CNC machining makes CLT particularly well-suited for offsite constructions, offering the advantage of rapid assembly and still allowing for creative architectural expression. In some cases, the increasing interest for timber-based structures has been limited by its inability to fulfil structural requirements, e.g., vibrations, acoustic, and fire. This has stimulated the development of new technologies and research efforts both in academia and industry. In the construction sector, the European Technical Approval (ETA) procedure, which allows to certify new technologies and products, is easing the introduction of new integrated systems, overcoming the material limitations and making timber suitable for more applications. In turn, this has spread the development and marketing of even more technological solutions that complement timber systems, such as connections, acoustic insulation and water proofing membranes. The presentation will go through a series of case-studies where timber related properties were initially limiting its applicability. However, thanks to the introduction of recently developed technologies, we proved timber to be a viable option. Without these systemic developments the choice of timber would not have been possible.

timber
CLT
connections
acoustics

case-studies on cross laminated timber

Marco Donà

sustainable structural design

investigating the geometric and structural potential of using the swelling of

densified wood-wood connections using digital design- and manufacturing process

Max Salzberger
TH Cologne, Germany &
Delft University of Technology, The Netherlands

Max Salzberger is a PhD Student at the Department of Architectural Engineering and Technology at TUDelft and member of the BK-Wood Group. He investigates the transfer of craft-based techniques utilising the material properties of timber for the design, manufacturing and assembly of timber joints from hand- into information-tool-technology.
He is also a researcher at the TH Cologne, where he teaches digital design and manufacturing. He has specialised in digital manufacturing from early in his professional life, dating back to his apprenticeship as a woodworker and also teaches at the chamber of crafts in Cologne.

sustainable structural design

Transitioning to a circular, bio-based economy is essential for a sustainable future. Wooden architecture is gaining popularity due to its ecological benefits, prefabrication advantages, and expanded possibilities with EWP. However, the use of energy-intensive non-bio-based connectors and artificial adhesives in timber structures and EWP production makes reuse or recycling challenging. Mono-material timber connections are beneficial for re-use and end-of-life scenarios. They have been developed by crafts-persons, geometries and proportions have been established and improved in timber structures over decades. The digitalisation of architecture and the timber industry opens new ways of processing, manufacturing and assembling timber materials & structures. Parametric design tools enable an integrtion of material-specific parameters into the design and manufacturing of connections. Wooden swelling dowels have been used for centuries in furniture manufacturing and traditional timber framing, providing a form- and friction-fit connection resistant to pullout forces. The densification of timber changes the materials characteristics, creating a denser, structurally more capable material. Moreover, it changes the swelling characteristics, resulting in faster and more pronounced swelling and higher swelling pressures. This project seeks to investigate the geometric and structural potential of utilising the swelling of densified wood-wood connectors using digital design- and manufacturing processes. An assessment of the swelling characteristics of densified wood is carried out in material experiments and a parametric connection database is established to be used as a design tool. Subsequently a method to implement the swelling characteristics into the models is developed. This database is then used to design prototypical connections. These are then manufactured, tested and further developed in an iterative research-by-design process.

timber architecture
wood-wood joints
swelling connectors
densified wood
digital design and manufacturing

session 2B

towards sustainable glass structures

Room B
11:15 - 12:30

the status quo of products, processes and services for

carbon neutrality and circularity in glass and facades

Lisa Rammig
Eckersley O'Callaghan, USA

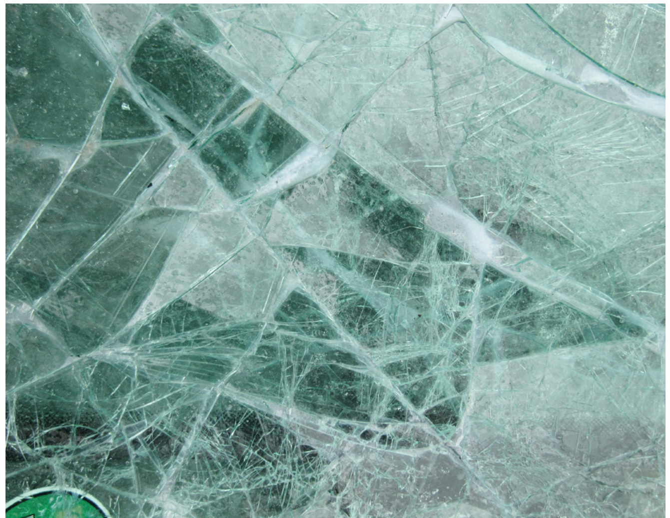
Lisa leads the teams in Eckersley O'Callaghan's California offices. She has played a significant role in its expansion, establishing a West Coast presence, and leading many of the group's most challenging projects, while she remains involved in academia and has built strong links between research and industry, helping maintain the practice's position as leaders in the field. She remains part of the Facade Research Group at TU Delft where she pursued her doctorate research and is an elected member of the Special Advisory Council of the Facade Tectonics Institute at the University of Southern California. Her teaching experience includes engagements at MIT, TU Delft, TU Darmstadt and the California Academy of Arts. Publications include scientific papers, industry journals and contributions to technical books.

In collaboration with **Linda Hildebrand**

sustainable structural design

Driven by political pressure the flat glass industry aims to be carbon neutral by 2050. For glass, the theoretical potential to become a fully circular material is very high, so several competitors within the glass industry have been dedicating their efforts to improve the environmental performance of flat glass. They vary from small steps like reducing the amount of (virgin) material in a product from very extensive adjustments like changing framework conditions and energy supply. Looking at the facade industry with focus on glass- five categories can help to structure the status analysis: Energy, Secondary Resources, Material Recovery Systems, Data and Communication, Design for Disassembly. This piece of research investigates the current status in these groups for the facade and especially the glass industry particularly with regards to its development to carbon neutrality and circularity. It presents findings from insights of an industry wide initiative which includes representatives from producing industries, like manufacturers and fabricators, design and engineering practices and academia. It reflects on the political and industry defined goals based on literature review. The results shows that competitors are facing similar challenges and respond by developing new products, machines and reshaping processes to offer services and products that are adjusted to the new requirements. It presents solutions that often work on a small scale, of which some have the potential to be upscaled. These steps are documented in order to show the potential and outline the urgency to speed up the development.

secondary material
data management systems
design for disassembly
renewable energy
LCA



low carbon glass products

the contribution of the glass industry to limit the CO2 footprint

Michael Elstner
AGC Glass Europe, Belgium

Michael Elstner has nearly 30 years' experience in the glass business and more than 20 year working in different roles in the glass industry with the engineering service for large scale projects as well the technical advisory service for the application of glass products. He is also active in association boards and working groups and standardization committees related to glass products and their application.

sustainable structural design

For reducing the embodied carbon of glass products, all the parts of the value chain need to be considered. This includes decarbonising the glass production processes along with eliminating as far as possible all CO2 emissions from the supply chain. For reducing the carbon emissions generated during the production of float glass a holistic approach is applied which includes: sustainable sourcing of raw materials, use of highly efficient melting furnaces, increased use of cullet, green energy sources, optimisation of transport between production lines for finishing processes and finally optimisation of transport for end products. Among these, one of the pillars is the increased use of cullet. Cullet comes from different sources: internal cullet, pre- and post- consumer cullet. In order to be able to use cullet in float glass production, it must be of an acceptable quality. Since there are a large number of glass products and glass types, it is essential to collect as many different types as possible. Furthermore, inspired by the waste hierarchy triangle there might be also another opportunity for glass, that is re-use. In the field of insulated glazing, re-use would mean to disassemble the product and re-use (or actually re-manufacture) the individual glass sheet to make a new product. This leads to an approach, which we call "re-manucycling". Re-manucycling is a end-of-life process, which aims to prioritize the least energy-intensive re-processing (i.e. re-manufacturing, re-cycling), taking into account the type of material and its quality. This approach brings a lot of new challenges to the glass industry, but also an opportunity for reducing the CO2 footprint of the glass industry.

low carbon glass
post- and pre-consumer
re-manucycling
cullet
reuse

advancing sustainability in high-end architecture through
optimized structural design

Mariska van der Velden & Alexandros Cannas
Eckersley O'Callaghan

Mariska developed a strong interest in structural glass ignited during her civil engineering studies at TU Delft. While there, she actively participated in the Glass Research Group and tutored an all-glass design course. Her research focused on cast glass within the laboratory and dedicated her postgraduate months to glass recycling research. Now at Eckersley O'Callaghan, Mariska is making significant contributions to glass engineering and design. She's involved in various R&D initiatives, sustainability research, and participates in EDI and social committees, highlighting her commitment to innovation and responsible engineering practices.

Alex joined Eckersley O'Callaghan in 2016 as a member of its specialist glass engineering team following 2 years working at Arup. He works on numerous complex structures with glass, steel, cables and carbon fibre for buildings and marine applications. Alex is experienced on international projects from Europe, China, Thailand and Japan. He is responsible for designing a range of large-span glass structures (12m+) and cable-net facades (20m+), to bespoke solid stainless steel details. Alex achieved ICE chartership in 2018 and drives the team's technical R&D efforts, reviewing and developing strategies to meet specific technical challenges.

In collaboration with **Graham Coult**

sustainable structural design

In the pursuit of a sustainable built environment, the conscious management of resources plays a pivotal role. Cutting overall tonnes is an efficient way of reducing the overall embodied carbon of a project. This abstract highlights the pivotal role of material usage within the context of sustainability and EOC's dedication to sustainability demonstrated through their application of optimization tools and advanced modelling techniques. By focusing on structural performance and weight reduction, EOC exemplifies how innovative engineering strategies can significantly reduce resource consumption and advance more sustainable high-end architecture.
In high-end projects and innovative architectural design, a more sustainable design practice can still be pursuit. While pushing the boundaries of material's capabilities and designing structures in such a way that less material is used, an overall more sustainable design can be achieved.
Through several case study projects, EOC will highlight how design tools have aided the design process and ultimately reduced the carbon footprint of the project, by going the extra mile in the design process and pushing the limits of the materials' capabilities.

optimization
embodied carbon
material use
design

re-using flat glass

a preliminary study with old, annealed window glass

Martien Teich
University of Applied Sciences Munich, Germany

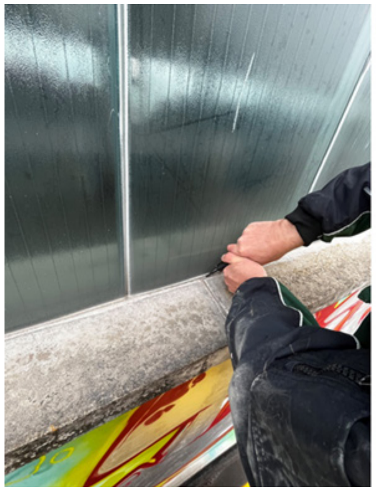
Martien has been working in the glass and façade industry for about 15 years. He was Head of Engineering and Development at seele until 2022. He is professor at the University of Applied Sciences in Munich for steel, glass, and façades since September 2022. Martien is working both with the Association of Structural Glass (Fachverband Konstruktiver Glasbau, FKG) and the Association of Flat Glass (Bundesverband Flachglas, BF) on developing concepts for re-using and re-manufacturing glass.

In collaboration with **Miriam Schuster**

sustainable structural design

The Association of Structural Glass (Fachverband Konstruktiver Glasbau, FKG) established a working group on glass sustainability, in which the authors are actively involved. In the context of re-use, the working group is currently focusing on assessment methods and possible further processing of old float glass. This prensentation highlights the current state of work.
Insulating glass windows from a 30-year-old building were dismantled, and separated into their components.
The different glass surfaces were visually assessed. One part of the glass was then processed into laminated glass. The lamination and subsequent assessment of adhesion via compressive shear and Pummel tests was conducted by two different interlayer suppliers. The other part of old glass was used to re-manufacture insulated glass. To fulfil the requirements of a state-of-the-art IGU, single old glass panes were combined with new coated glass panes. Current concepts, findings and recommendations are presented. Furthermore, the authors briefly show a project in Germany where glass bricks and alkaline cast glass in U-shaped form is re-used.

re-use
flat glass
GWP



session 3

lightning round
creativity & innovation for sustainable structural design

Berlage Room
13:30 - 14:45

adjustable building systems for modular reusable plate components

Ellen Leemans
Vrije Universiteit Brussel, Belgium

Ir. arch. Ellen Leemans is a PhD researcher at VUB Architectural Engineering. In 2022 she graduated as Master of Science in Architectural Engineering at Bruface (VUB/ULB). In her master thesis 'Designing and prototyping a lightweight modular outdoor structure', she created an optimized primary structure serving as the backbone of a secondary cladding system through modularisation and prefabrication. Today she continues this research with a focus on reusable building systems for temporary applications under the supervision of Lars De Laet and Niels De Temmerman. This research is funded by the department of VUB Architectural Engineering.

In collaboration with **Ahmed Soliman, Niels De Temmerman and Lars De Laet**

sustainable structural design

Temporary events, ranging from festivals and markets to pop-up exhibitions, have become an integral aspect of modern society, offering a more organic and temporal use of space. However, the substantial emissions and waste generated by the event sector are largely due to the temporary structures employed during these events. Excluding travel and accommodation, these structures account for 55% of all emissions for average events and produce an annual waste up to 20.4 kg per square meter (Net Zero Carbon Events, 2022) (Núñez, et al. 2009). Remarkably, by shifting to a reusable system, this waste could be reduced by a factor of 3.5 (Núñez, et al. 2009). Achieving this necessitates focusing on the structures' dismantling phase, ensuring both ease of disassembly and sustained durability. The pivotal element in enabling efficient dismantling and reassembling procedures invariably revolves around the optimization of the connection systems.
Furthermore, by prioritizing adaptability and modularity, the application potential of the components can be expanded, enabling multifunctional use while minimizing waste. Though some existing solutions of vector-active structures already offer modularity, they often necessitate secondary cladding. Therefore, the research focuses on the development of a reversible building system for modular plate components, thereby promoting the reusability of temporary structures in the event sector. The research methodology involves a geometrical exploration of relevant polyhedra to create a range of modular geometrical configurations made from plate components. Additionally, a comprehensive analysis of established connection systems will be conducted, more specifically drawing insights from scaffolding and scissor systems, and translating these insights into solutions applicable to these plate components. With this building system the research aspires to contribute to the circularity goals of the event sector.

modularity
reuse
building system
plate components

reformable engineered bio-composites

Samanwita Ghosh
Delft University of Technology; The Netherlands

Samanwita Ghosh holds a Master of Science in Building Technology from TU Delft and is a licensed architect recognised by the Council of Architecture in India. Dedicated to advancing envelope technologies, she believes integrated ecological solutions and material engineering are critical paths to develop climate neutrality within the built environment.

In collaboration with **Olga Ioannou and Mauro Overend**

sustainable structural design

Engineered bio-composites offer unprecedented potential to develop low-carbon, mechanically robust components with curvilinear surfaces, displacing the easily formable yet energy-intensive, high-carbon sheet metals. However, shaped fibre-reinforced components cannot be reformed for a second life, compromising their reuse potential and, by extension, their circular performance. This paper introduces the preliminary research results on a new low-carbon bio-composite, reformable at the end of life i.e. - bent along a curve and flattened back to a sheet without permanent deformation or loss of mechanical properties. Research on this material originated with developing a complex geometric façade cladding panel that could revert flat for reuse. The material engineering begins with the systemic selection of bio-fibres (flax), bio-resin (PLA), and a sheet-forming/reforming process - based on 'sag bending' principles to confirm 'developability' and reshape Flax-PLA (100% bio-based) sheets. Mechanical tests and surface quality assessments are then performed on the laminates; in particular, flexural strength and stiffness are measured before and after reshaping, thus demonstrating that structural properties remain within permissible design limits. Testing found that the material maintained structural integrity and retained surface quality postreforming cycles and outdoor weathering, thereby verifying its eligibility for diverse structural applications. Finally, the cradle-to-gate analysis is performed where the novel bio-composites are benchmarked with conventional virgin aluminium sheets to evaluate the global warming potential, which reveals significant embodied carbon savings. Such a material encourages resource reuse, retains product integrity at its highest embodied value throughout multiple use cycles, and forms the basis of a new generation of bio-based and reusable components. The paper also describes the steps in this research needed to develop this promising bio-composite in preparation for real-world applications. In particular, the required research on lifespan extension, environmental performance testing and production scalability of the bio-based developables aims to shift construction practices to low-emission structures reliant on local biomass. The use of fibrous biocomposites described in this paper can, in fact, adapt to urban and agricultural economies, accommodating low-tech infrastructure to enhance resource resilience against ecological uncertainties.

natural fibre reinforced composites
developable surfaces
structural reuse

branching as an approach to biomimetic tectonics in architecture

Hasan Hadi Abdulmeer
University of Innsbruck, Austria

Hasan Hadi Abdulameer is a Ph.D. researcher and Senior Lecturer at the Lightweight Structures Unit (Prof. Günther H. Filz), the University of Innsbruck, Austria. His research interests lie in bio-inspired, sustainable, lightweight structures, parametric design, and the integration of biomimetic approaches into structures and architecture.

In collaboration with **Günther Filz**

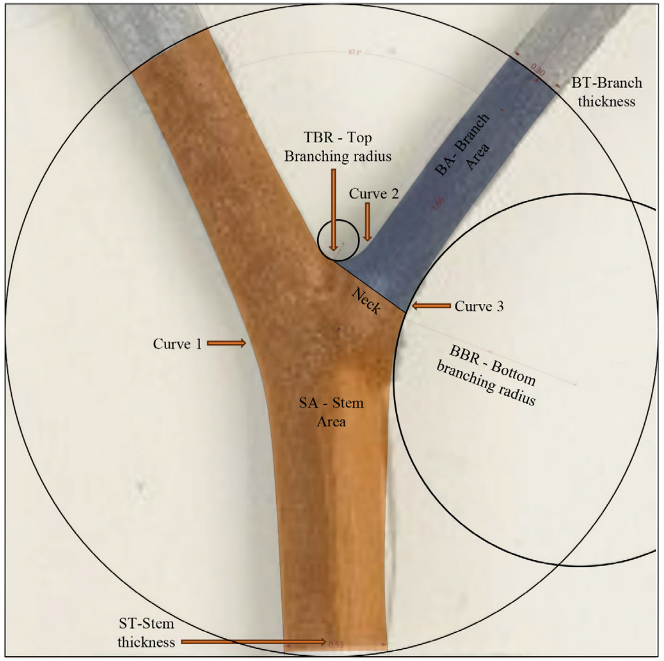
sustainable structural design

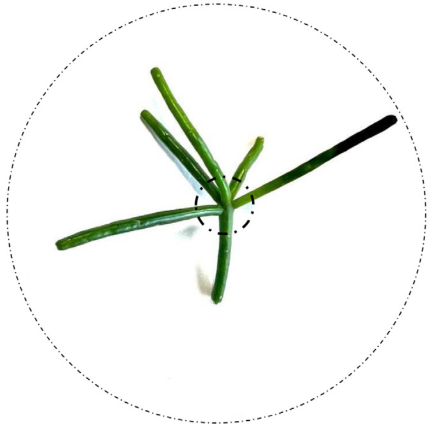
The inefficiency in resource utilization in architecture represents an urgent concern in our society. This led architects to think about new realms of design methods and architectural tectonics. Tectonics, in architecture, is a concept related to the way structural members and architectural elements are connected. Traditionally, tectonics has been viewed from craftsmanship and detail perspectives, encompassing geometric and technical aspects. However, with the rise of digital technology, a new approach, digital tectonics, has emerged, relying on computation and digital crafting. From botany, we may observe and learn about the formation of structures that exhibit optimum materials usage, multifunctionality, and aesthetic qualities at various scales. Our studies focus on the examination of processes, shapes and functionality of branching in plants that may be relevant for structures and architecture. Natural branching highlights the adaptability and versatility in plants' growth and survival strategies. Also, it provides inspiration for structural and architectural design with regard to the tectonics and topology of more efficient and sustainable structures. Our research is based on both theoretical work, such as the concepts of tectonics and biomimetics in architecture and structures, and applicable research on branching in plants for new tectonic solutions. Therefore, we extensively collect, classify, and assess branching examples from a database of 71609 plant images, with an emphasis on their geometric, structural, and connectivity aspects for architectural applications. Our geometric analyses reveal three branching categories in the vascular plant family (Tracheophyta). We find that two categories use geometric solutions while the third prioritizes tectonic solutions to optimize joint resource efficiency, which is of enhanced interest to our research. Microscopy studies of this category indicate the distinctive arrangement of cellular structures and nodal tectonics. We show examples that translated into architecture lead to the emergence of "nodeless nodes". These are characterized by spatially optimized material arrangement and novel forms of connections, as viable approach to designing multifunctional joints for material efficient artefacts that are ready for assembly and disassembly, combined with a new architectural aesthetics.

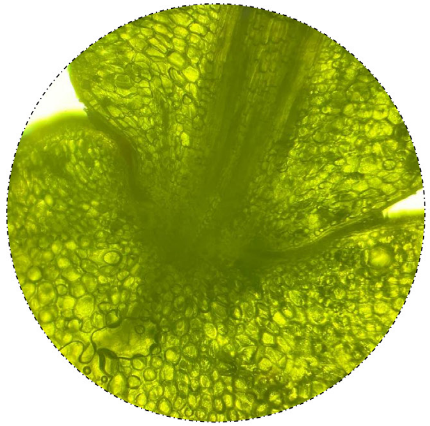
biomimetics
tectonics
branching
structures

branching as an approach to biomimetic tectonics in architecture

Hasan Hadi Abdulmeer







sustainable structural design

textile reinforcement strategies for mycelium-based composites

a review

Andreas Biront
KU Leuven, Belgium

As a recently embarked PhD researcher, Andreas is actively exploring the intersections of architecture, microbiology, and engineering at KU Leuven's Department of Architecture. With a background in aerospace engineering and integrated product design from TU Delft, his early research focuses on advancing digital fabrication technologies to enhance production efficiency in design. Andreas is enthusiastic about "Biofabrication," diving into the creation and application of biomaterials in design and architecture. His work is driven by the aspiration to contribute to ecological advancements in structural material development, marking the beginning of his journey in sustainable design and construction practices.

In collaboration with **Jan Wurm**

sustainable structural design

In light of the pressing need to address decarbonization and resource efficiency challenges in our built environment, biofabrication emerges as a game-changing technology. This presentation explores the role of biofabrication, specifically mycelium-based composites (MBC), as a pivotal solution to achieve European climate goals and foster a regenerative future.
Mycelium has proven its ability to transform organic waste and byproducts, including those from agriculture and forestry sectors, into building materials without added energy consumption or waste generation. While MBC products like acoustic absorbers and thermal insulation materials have made their mark in the market, their mechanical performance has traditionally limited their broader applications.
The focus of this presentation centers on composition strategies to enhance the compressive, flexural and tensile strength of MBC and their application potentials. We investigate the integration of woven, knitted, or felted layers of bio-based materials into the MBC substrates. By exploring the composition of the substrate material and the role of reinforcement materials, we unveil opportunities to strengthen MBC's mechanical properties.
Notably, this presentation emphasizes the transformative potential of utilizing woven and non-woven substrate mats to create form-active structures for MBC, introducing Structural Mycelium Surfaces (SMS), unlocking novel possibilities for form finding. While the current application of reinforced MBC primarily centers around formwork and serving as a structural substrate for interior objects, these innovative approaches not only facilitate the design and production of structural MBC elements but also pave the way for future research.

biofabrication
substrate
mycelium-based composites
reinforcement strategies
mechanical performance

textile reinforcement for mycelium composites

Andreas Biront

sustainable structural design

automated workflow for discrete timber structures

Adalberto de Paula
Delft University of Technology, The Netherlands

Adalberto de Paula is an alumnus of TU Delft and a system designer who looks for innovative approaches to produce sustainable outputs. His journey began with a passion for computational design and digital fabrication, leading him to research how automated construction processes can be applied to foster the circular agenda in the building environment. Before pursuing his MSc in Building Technology at TU Delft, he worked as an architect in São Paulo and studied architecture previously at UFMS, UFRGS, UNM, and UWM.

In collaboration with **Serdar Asut and Stijn Brancart**

sustainable structural design

Work less, work for everyone, automate everything, produce what is necessary, and redistribute everything. The research's vision has its roots in this statement. It is a call to action for a more equitable society, advocating for automation, reduced working hours, necessary production, and resource redistribution. In order to contribute to this vision, the study presents an innovative automated construction workflow that involves Human-Robot Collaboration for a discretized timber construction system. The focus is on the system's connectivity development that can work in the syntax of robotics and circularity. The discrete aspect acts as an interface of the combination of these areas. To demonstrate the capabilities of the system, a housing design is developed for a site in Rotterdam. The design incorporates circularity principles, including modularity, design-for-disassembly, design-for-reuse, reconfigurability, and extension of material lifespan. A combinatorial design workflow is proposed, focusing on the assembly of generic discrete elements into function-based aggregated structures that can be rearranged over time. Genericness is the key design aspect of the elements that precede a prescribed function. The research is also about a methodological system that can generate architectural objects. To prove the concept, three prototypes were made on different scales. The 1:1 prototype demonstrated the fabricability of components and their connection. The 1:5 prototype enabled the testing of the HRC assembly, while the 1:10 prototype showcased aesthetic qualities and potential design variations. The prototypes served as evidence that customized structures can be created by aggregating prefabricated discrete elements. The 1:5 HRC prototype was successfully disassembled and reassembled multiple times. This ability to be repeatedly taken apart and reused extends the lifespan and carbon storage capacity. The reconfigurable system allows for easy disassembly and reassembly of components, creating adaptable and customizable housing designs to meet changing needs.

robotic construction workflow
timber structure
discrete architecture
reconfigurability
design for disassembly

automation for discrete timber structures

Adalberto de Paula

sustainable structural design

A-T-G louvers

a novel geometry and material driven spatial syntax for flexible structures

Mohammad Hassan Saleh Tabari
University of Innsbruck, Austria

Mohammad Hassan Saleh Tabari is a Ph.D. researcher and University Assistant at the Lightweight Structures Unit (Prof. Günther H. Filz), the University of Innsbruck, Austria. He is also a co-founder of Termite Intelligence group working on smart architectural assistant in early-design. His research interests are in computational geometry, sustainable lightweight structures, algorithmic design thinking, and in using artificial intelligence for solving design problems.

In collaboration with **Fereshteh Khojastehmehr and Günther Filz**

sustainable structural design

The urgency of addressing the climate crisis has led to a critical re-evaluation of architectural construction practices, emphasizing resource efficiency and sustainability. Gridshell structures, particularly when built with natural materials like timber, have emerged as a viable option. Traditionally, the focus has been on structurally optimizing these structures for material efficiency, often leading to repetitive geometrical patterns. However, a new paradigm is emerging, one that seeks to balance material resources with architectural, structural, and environmental considerations. In this context, we present the design concept and case study of Asymptotic-Twist-Geodesic (A-T-G) Louvers as a multi-objective design solution for gridshell structures. Rather than pursuing maximal material efficiency, our approach leverages computational geometry to parametrically manipulate the gridshell profile direction. This manipulation influences visibility, density, solar gain, and glare, opening up exciting possibilities for architectural criteria such as indoor quality, radiation, and vision comfort, while creating a comparably more sustainable built environment. Specifically, our methodology and the A-T-G Louvers demonstrate how geodesic strip patterns enhance density to direct reflections, aligning profiles with the gridshell surface, while simultaneously asymptotic strip patterns, with perpendicular profiles, create architectural depth and shadow while allowing for high transparency and unobstructed vistas. The transition between these patterns is achieved through a twist of the profile's direction, resulting in a novel geometry and material driven spatial syntax. The A-T-G Louvers serves as a demonstrator of this approach, and as an efficient architectural structure showcasing its positive thermal and glare-reducing influence on interior spaces through the evaluation of long-term observation by photoresistor sensors. Promoting conscious use of resources, our holistic design method not only strives to constitute a balance between structural stability and architectural quality, but to surpass one-dimensional optimizations in the development of low-emission structures. Beyond the application shown, this approach holds the potential for larger scales, such as entire building facades and architectural structures.

gridshells
asymptotic
geodesic
twist

interlocking wood-to-wood joinery connections

with moisture induce process

Juan Cruz Rojas
Delft University of Technology, The Netherlands

Juan Cruz Rojas is a graduate from the Building Technology Master at Delft University of Technology, Faculty or Architecture and the Built Environment. He holds an Architecture degree from Universidad de Los Andes, Colombia. With his master thesis he investigated the use of wood-to-wood joinery using densification through moisture induction for social housing in Colombia.

In collaboration with **Gilbert Koskamp, Paul de Ruiter and Max Salzberger**

sustainable structural design

From a global perspective, the building industry is one of the significant factors of environmental impact on the planet. Related activities in this industry refer to 40% of total carbon emissions; 28% of this value accounts for building operations, while the remaining 12% represents the manufacturing of new construction materials. Studies have revealed that 90% of construction waste comes from demolition (Ahn et al., 2022). Wood as a construction material is an uprising in the building practice due to its carbon storage capabilities and prefabricated possibilities (Gong, 2021). Prefabricated timber constructions can benefit rural Colombia's social reconstruction with the help of digital fabrication technologies. Likewise, this method could bring better performance of materials and its End of Life (EOL) (Ahn et al., 2022). Nevertheless, research has identified wood-to-wood timber connections as a gap in the academia to tackle better design, manufacture, assembly, and deconstruction (DfMA + D) in the field (Mehra et al., 2021). The following study aims to investigate the application of CNC technologies to fabricate novel and affordable wood joinery connection solutions for the construction of rural housing in Colombia. This research emphasizes the cooperation of the wood material to moisture fluctuation, with the aim of introducing a more sustainable and efficient assembly method.

DfMA
digital fabrication
wood-to-wood connections
sawn timber
equilibrium moisture content of wood

session 4A

towards resilient building structures

Berlage Room
15:15 - 16:30

towards multi-hazard resilient buildings

simplified and more advanced assessment methods

Simona Bianchi
Delft University of Technology, The Netherlands

Simona Bianchi, Ph.D. P.E., is a Post-doctoral Researcher at the Structural Design & Mechanics Group in the Faculty of Architecture at TU Delft. Her research interests encompass earthquake-proof sustainable building technologies, risk assessment, and multi-hazard resilience analysis of buildings. Simona has collaborated with various public and private institutions, actively participating in international research projects. Since 2021, she has held a position as a board member of the fib Young Italian association. Moreover, Simona serves as the technical coordinator for the EU-funded MutiCare research project, which focuses on developing multi-hazard, low-carbon resilient solutions and a resilience-based decision-support framework and tools.

In collaboration with **Mauro Overend**

sustainable structural design

Recent disasters and climate change-induced extreme events have highlighted the urgent need to improve the resilience of buildings, but despite recent advancements in various engineering disciplines, current design procedures typically neglect the impact of multiple hazards encountered in real-world scenarios. This is a significant shortcoming because resilience cannot be accurately quantified and effective resilient-enhanced design solutions for both new construction and retrofitting projects cannot be assessed without consequence-based assessments and loss studies.
This study describes simplified and more advanced resilience-based methods for supporting design decisions for increased safety, resilience and sustainability of buildings against earthquakes, heatwaves and/or flooding. The study proposes a simple consequence-based decision-making approach accounting for economic, environmental and resilience losses. This simplified approach enables more effective investment decisions for building projects at early design stages, quantifying the effectiveness of integrated strategies in reducing overall expected losses. Furthermore, the study employs a probabilistic-based mathematical approach based on vulnerability and fragility functions, to provide a better-informed multi-risk decision-making approach. The different methods are demonstrated on a multi-story building equipped with different multi-hazard resistant technologies. The analyses include structural assessments, life-cycle analysis, and energy simulations to estimate cumulative multi-hazard losses and determine the optimal design solution for the specific case study.

multi-hazard resilience
consequence-based design
decision-making
economic losses
integrated design

a decision-support framework for designing
seismic and thermal resilient facades

Kyujin Kim
Delft University of Technology, The Netherlands

Kyujin Kim is a Ph.D. candidate in the Faculty of Architecture and the Built Environment at TU Delft. Her research topic is "Multi-hazard Resilient and Low Carbon Facade Technologies," which is part of the Horizon Europe MULTICARE project.

In collaboration with **Simona Bianchi, Alessandra Luna Navarro and Jonathan Ciurlanti**

sustainable structural design

Facades play a pivotal role in the performance of a building, serving various functions encompassing environmental, structural, and operational aspects. With the increasing number of disruptive events, building resilient facades is becoming crucial. Although facades can contribute significantly to the total post-disruption losses, yet their resilience is not sufficiently addressed in current design approaches. This study proposes a resilience-based facade design framework to support resilience-based decision making in both the early design phase and retrofitting. The framework addresses the complexity of facade design by considering multiple hazards that may impact the building's performance, with a focus on earthquakes and extreme heat. The structural layer of the facade is analysed to determine the extent of damage caused by seismic hazards. To assess the impact of heat hazards, the thermal control layer of the facade is inspected to evaluate its capacity to mitigate indoor thermal conditions.
The proposed framework can be used by configuring a facade package for inspection. This package contains seismic and thermal fragility curves of the component, generated based on the input location and building properties. The package is assessed for resilience under different hazards, with performance measured in terms of resilience loss and economic loss. A multi-attribute decision-making tool enables users to select a facade package based on its integrated resilience performance value. Alternatively, users can configure a facade package based on individual enhancements to resilience attributes. To demonstrate the decision-making method, an 18-story building is used as a case study to compare the benefits of applying infill/cladding facade systems.

façade resilience
multi-hazard approach
resilience-based design
quantitative risk assessment

eco-friendly exoskeletons for enhancing resilience

of the built environment

Simone D'Amore
Sapienza University of Rome, Italy

Simone D'Amore is a PhD candidate at the Department of Structural and Geotechnical Engineering at Sapienza University of Rome, and currently a visiting PhD at the Department of Architectural Engineering and Technology at TU Delft.
The main research interests of Simone D'Amore concern the implementation of innovative low-damage technologies for the holistic renovation of the existing building stocks. The main goal of his research is assessing the effectiveness of low-damage exoskeletons equipped with high performing "double-skin" facade system for the holistic renovation of buildings.
Furthermore, he is author of several conference and journal papers.

In collaboration with **Simona Bianchi, Mauro Overend and Stefano Pampanin**

sustainable structural design

Recent natural disasters in the form of earthquakes and extremes events associated to climate-change have further confirmed the need for an urgent effort to improve the resilience of the built environment. In parallel, resource-efficient structural design is growing in interest, and major effort has been focusing to the implementation of nearly-zero energy buildings or net zero carbon construction by using low-emission and eco-friendly materials. Despite this ambitious goal for designing new buildings, the renovation of existing ones in a low-carbon manner remains challenging. This is the case when the upgrading must address both energy performance and other resilience requirements, for example buildings featured by high seismic vulnerability and poor energy performance, that pre-date modern codes that regulate seismic design and energy performance.
Even though several solutions have been proposed for the integrated renovation of existing buildings, this study identifies the advantages of, and proposed a framework for, a holistic approach based on a novel technology implementing timber-based, low-damage external exoskeletons. The seismic-resistant low-damage technology considered is the Prestressed-Laminated (Pres-Lam) timber technology, proposed at the University of Canterbury, and implemented in several buildings around the world. The exoskeleton allows for the seismic strengthening/retrofitting of the existing building, and provides the support for a "double-skin" system, also allowing for the improvement of the energy efficiency and for architectural renovation, ensuring an holistic and integrated rehabilitation of buildings. All the components used (i.e., structural/non-structural) are based on dry connections, thereby enabling demountablity/reusability at end of life.
This study demonstrates the potential of this technology by means of structural/energy numerical simulations on a case study building. Furthermore, it points out the importance of a careful and efficient use of the resources in terms of materials used, for implementing an integrated approach that ultimately improves the resilience, efficiency, and sustainability of the built environment.

external exoskeletons
timber-based solutions
low-damage technologies

exploring structural sustainability of tall buildings subject to seismic loads

investigation of the effects of architectural forms using deep learning surrogate modelling

Pooyan Kazemi
Politecnico di Milano, Italy

Pooyan Kazemi, a building engineer, specializes in integrating AI-driven strategies and computational design methods in early-stage design. Concurrently pursuing a Ph.D. in Structural, Seismic, and Geotechnical Engineering at Politecnico di Milano, he is also a visiting researcher at DT section of AET department of TU Delft. His research focuses on merging architecture and structural engineering, specifically focusing on the development of a workflow that harnesses machine learning tools to explore architectural form of tall buildings with efficient structures under time history seismic loading. His ultimate aim is to facilitate collaboration between architects and structural engineers during the early design stage.

In collaboration with **Michela Turrin, Charalampos Andriotis, Alireza Entezami, Aldo Ghisi, Stefano Mariani**

sustainable structural design

This research explores the interplay between architectural form and tall building response to seismic loads using advanced computational methods and artificial intelligence-driven strategies. The main objective of the investigation is to optimize the design process, emphasizing cost reduction, structural efficiency, and carbon footprint while exploring various building forms. Understanding building performance is in fact crucial for cost reduction, as structural elements represent a significant percentage of the total construction expense. The research stems from a simplified seismic simulation approach during the form-finding stage, to explore diverse building forms and guide the choices in the early design phase. A significant gap in the field is claimed to be the absence of parametric seismic tools for the proposed activity. To bridge this gap, a unified workflow is here proposed by connecting architectural software with seismic simulation tools based on the OpenSees software. Additionally, the lack of a comprehensive tall building-specific seismic dataset is a critical issue; to speed up the numerical simulations, a surrogate modeling approach is employed. Specifically, the study investigates parameters influencing the architectural form of tall buildings with outer diagrids, including tapered, twisted, and curvilinear morphing from base to the top. The dynamic response to the vertical static loads and lateral seismic excitations is assessed under different ground motion scenarios and a dataset of 1000 models is selected to establish the surrogate predictive model. The dataset comprises time-histories of (inter-story) displacements and forces with a focus on critical structural components. Using a NN surrogate modeling algorithm, this research elucidates the intricate relationships between architectural choices and structural behavior, offering valuable guidance to design professionals while preserving their creative freedom.

AI-enhanced architectural modelling
tall building optimization
architectural form generation
dynamic seismic simulation

session 4B

towards reuse of structures and components

Room B
15:15 - 16:30

Rebecca Hartwell
Delft University of Technology, The Netherlands

Rebecca Hartwell is a Post-doctoral researcher in the Structural Design & Mechanics group at TU Delft. She recently completed her Ph.D. at the Dept. of Engineering at the University of Cambridge. Her Ph.D. research examined the role of material efficiency in architectural glass and façade design. This involved bridging the gap between industry and academia to develop the knowledge, tools, and technologies to promote the effective reuse and high-value recycling of building envelopes. Rebecca's current research focuses on developing reversible connections for safe and sustainable load-bearing structures for an NWO-funded demonstrator project. Alongside her research, Rebecca contributes to several cross-industry working groups, including the Centre for Windows and Cladding Technology (CWCT) and BREEAM, working to develop guidance on sustainability in façade design. She also conducts independent research consultancy in the field of material efficiency.

In collaboration with **Mauro Overend**

sustainable structural design

reclamation potential in the built environment

a design metric to assess environmental benefits beyond first use

Resource efficiency in the built environment calls for new design methods that promote the effective recovery of components. Yet, few options exist to quantitatively evaluate how decisions made at the building design-stage affect the ability to recover materials at the end of their primary life-cycle. Façade elements in particular have evolved to fulfil multiple functions. Enhanced functionality has been achieved through the use of a broader range of material resources, advanced processing methods, and more complex construction techniques which paradoxically reduce the ability to recover material resources at the end of their design life. To date, very little attention has been paid to the consequences of incorporating multiple layers of components joined by irreversible connections on the ease of disassembly and reuse. This work describes a new assessment method for the quantitative evaluation of the environmental reclamation potential (RP) over time. The reclamation potential measures the influence of material selection and construction methods on the ability to disassemble and reuse recovered building components at their end-of-life. The method accounts for the technical service lifetimes of components, including performance degradation over time, and can thus inform decisions on the most suitable recovery route: system reuse; component reuse; or recycling. The graphical outputs of the assessment are presented in the form of an RP-graph. The methodology is demonstrated on a triple-glazed façade system where the influence of component service lifetimes and replacements on reclamation potential over time is quantified. Results show that over a 100-year timeframe, the embodied carbon associated with the system increases four-fold, due to component replacements and system interdependencies. The extent to which the use of irreversible connections affect the reclamation potential of connected components at their end-of-life is also quantified and critiqued. This newly developed assessment method provides a new way to quantify the benefits of designing for multiple life-cycles in a way that preserves the embedded environmental value of building elements. Potential applications of the method to other building systems - e.g. load-bearing structural systems - will be discussed.

reclamation & reuse
multi-material systems
embodied carbon
design metric

preliminary investigations to increase the

strength of used float glass

Miriam Schuster
TU Darmstadt, Germany

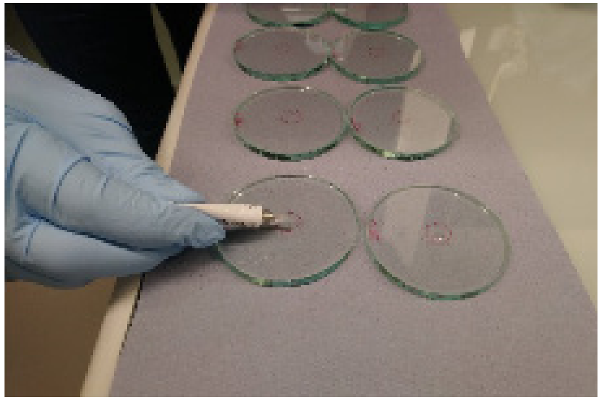
Miriam Schuster, born in 1990 in Luxembourg, studied Civil Engineering from 2009 to 2014 at University of Luxembourg and TU Darmstadt. She focused and specialized on structural engineering. After working in the Luxembourgish engineering office Schroeder&Associés she returned to TU Darmstadt in February 2016 as a researcher in the Institute of Structural Mechanics and Design (ISM+D). In January 2022, she successfully defended her phd thesis with the topic "Characterization of laminated safety glass interlayers – Thermorheology, Crystallinity and Viscoelasticity". Since then, she has been working as the head of the glass and polymer group at ISM+D.

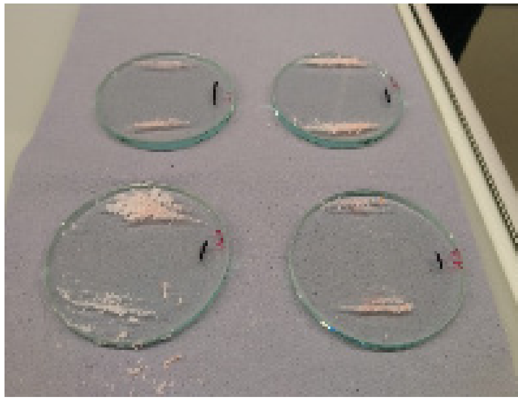
In collaboration with **Gregor Schwind and Max Brandenstein**

In order to be able to reuse glass in construction after deconstruction without re-melting, the mechanical properties - especially the strength - must be known. The bending tensile strength of glass is determined by the surface defects: the deeper the cracks, the lower the bending tensile strength. It is assumed that the surface defects are greater during the use phase and due to deconstruction and transport compared to newly manufactured float glass. The question therefore arises whether there are strengthening methods that minimise surface defects and thus increase the strength again. In our presentation, we will present the results of a preliminary study in which defined pre-damages were introduced into new float glass. Treatment with cast resin, treatment with hydrofluoric acid and heat treatment were considered as strengthening methods. The strengths of the reference series and the series with the treated samples were determined by means of double ring bending tests.

reuse
strength
crack-healing

sustainable structural design





CircÛbi

Elias Knecht
ETH Zurich, Switzerland

Elias Knecht is a scientific / teaching assistant at the ETH in Zurich. During his architectural master thesis titled “Future Learning Spaces” (2022) supervised by Prof. Momoyo Kaijima and Barbara Buser in conjunction with Prof. Catherine De Wolf, materials from three former pavilions were salvaged and incorporated into a design proposal for circular learning spaces at ETH. A path was paved for the realization of this project working alongside ETH, industry partners and experts. Elias continues to work with students integrating principles of circular economy into architectural curriculum at ETH.

In collaboration with **Catherine De Wolf and Momoyo Kajima**

sustainable structural design

CircÛbi is a pioneering building project on the campus of ETH Zurich. Led by the Department of Civil, Environmental, and Geomatic Engineering as well as the Department of Architecture respectively, this endeavour bridges the gap between real-life challenges and opportunities of circular construction, synthesizing emerging digital practices with architectural heritage preservation and innovative teaching methods. This project exemplifies ecological, socio-cultural, and economic principles of sustainable development wherein resources are maximized and waste is minimized in the build environment. The mission is to preserve the past, optimize the present, and advocate for sustainable construction practices in the future.

Facing the need for a new building on campus, this journey commenced with the demolition of three wooden pavilions, originally constructed at ETH Zurich between 1987 and 1991 to serve as temporary lecture studios. Rather than discarding all construction waste materials, a visionary initiative emerged. Students, researchers, volunteers, and professional construction workers identified, catalogued, disassembled, mediated and reallocated numerous building components, activating dozens of recipients all over Switzerland. The salvaging of the distinctive triangular trusses from the pavilions’ roofs were the basis for CircÛbi. The project’s essence lies in re-integrating the original materials into novel design solutions of various scales. The resulting spaces offer an environment for informal learning, encouraging collaboration and interaction among students and stakeholders. By re-purposing the former pavilions’ materials, a critical principle of circular construction is highlighted - transforming waste into value and ensuring that the materials we use today retain their value tomorrow.

The project serves as an educational opportunity, involving students from various departments at ETH Zurich, who participate in sustainable construction practices, gaining hands-on experience and becoming more aware of their role in meeting the challenging goals mitigating climate change.

circular construction
reuse
digital innovation
architectural heritage preservation

CircÛbi

Elias Knecht

sustainable
structural
design

technical prerequisites for
demountable hybrid floor systems

Florentia Kavoura
Delft University of Technology, The Netherlands

Florentia Kavoura is an Assistant Professor within the Steel and Composite Structures Group at the Faculty of Civil Engineering and Geosciences at Delft University of Technology. Her research and teaching interests are focused on the structural performance of demountable hybrid systems in connection and structure levels with the aim of converting the built environment into a fully circular industry. Florentia is serving as the representative of the Netherlands in the Standardization Committee NEN Staalbetonconstructies for the prEN1994-1-1 and Standards related to the design of steel-concrete hybrid structures. Also, she represents the Netherlands and TU Delft at the European Convention for Construction Steelwork (ECCS) Technical Committee 11 on Composite Structures.

In collaboration with **Yufei Zhang and Milan Veljkovic**

sustainable
structural
design

The building sector is actively researching and reviewing technical solutions for deconstruction, driven by the increasing importance of sustainability requirements, as outlined in the EU Commission's 'Green Deal,' which aims to achieve net-zero greenhouse gas emissions by 2050. Steel-concrete demountable structures consist of a skeleton made mainly of steel structural components where nearly one hundred percent of the steel is recycled or reused while they can be easily mounted, demounted, and reused with the use of bolted connections for in-situ connections. Their floor systems consist of steel–concrete hybrid beams with a steel profile connected via shear connectors to a concrete deck or a composite slab in the form of prefabricated or in situ reinforced concrete. These steel–concrete hybrid beams exhibit excellent structural characteristics, in terms of their stiffness and strength, when compared with steel or reinforced concrete beams. This is due to their ability to combine the mechanical properties of different construction materials, such as concrete in compression and steel in tension.
The main technical practice which allows for demountability and reusability of the steel-concrete hybrid structures is the use of demountable shear connectors in their floor systems. These demountable shear connectors can satisfy the need for composite interaction of the steel-concrete hybrid floor system during its service life and in parallel the need for large nominal hole clearances during execution through oversized holes in the beam flange. These oversized holes facilitate the (dis)assembly process of the floor system and address the required tolerances. This presentation will focus on the most recent technical innovations for demountable shear connectors and their overall structural performance at a real-structure floor level. Also, a comparative study on the structural performance between the traditional floor systems and the demountable floor system will be discussed.

reuse of steel structures
demountable connectors
structural performance
steel-concrete hybrid beams
circular built environment

session 5

towards effective use of new and existing resources

Berlage Room
16:45 - 17:30

can we make efficient building floors reconfigurable?

Robin Oval
Delft University of Technology, The Netherlands

Robin Oval is a structural engineer and designer working on the architecture of structural patterns. During his doctoral and postdoctoral research journey through Ecole des Ponts ParisTech, ETH Zurich, University of Cambridge, and Princeton University, Robin has developed holistic digital design & construction processes, including grammatical generative design, constrained form optimization, automated robotic construction, and augmented vernacular craft, with applications focusing on spanning structures like gridshells, shells, vaults, and floors. As an assistant professor in the Faculty of Civil Engineering & Geosciences at TU Delft, Robin is interested in topologically reconfigurable modular structures.

Buildings represent a significant part of our built environment. Floors themselves account for 60% of the mass of a building when designed as reinforced thick concrete plates, inefficient but easy-to-build structures. However, vaulted and ribbed surface structures offer mechanically efficient solutions for spanning. By following funicular forms and stress patterns, such structures minimize material use. Yet, their optimality makes them hard to reuse in new conditions at the end of life of the building. Moreover, these monolithic structures must be segmented with interfaces that include reversible joints. Designing dismountable building floors allowing for topological reconfiguration will contribute to modular and circular construction, extending the life span of our structures.

This presentation challenges designs optimized for mechanics or construction only, as we will explore trade-offs between mechanical efficiency and construction rationality, aiming for structures with low environmental impact suitable for circular construction. This endeavour requires a holistic design and construction approach, which will be highlighted by previous and current research projects, focusing on concrete building floors. These milestones towards modular segmented ribbed shells include segmented ribbed funicular shells, reconfigurable fan shells, rationalized ribbed plates, and reconfigurable ribbed plates. These novel structural systems were developed by leveraging the latest digital technologies, including generative design, combinatorial optimization, and robotic fabrication, as well as by learning from the past, from vault structures of Ancient Egypt, Medieval Spain, and Gothic England to 20th century concrete construction.

sustainable structural design

structural engineering
architected structures
structural patterns
structural design
construction technology

can we make efficient floors reconfigurable?

Robin Oval

sustainable structural design

revitalizing the past

stone-faced unitized system exploration on reuse & refurbishment

Rocco Boselli & Carmelo Guido Galante
Eckersley O'Callaghan

After a six-month internship at Eckersley O'Callaghan in early 2019, Rocco joined the company as a graduate engineer later that year. He forms part of the façade engineering group, capitalising on the knowledge he gained during his master degree in Building Engineering at Politecnico di Milano. During the internship, Rocco completed his master thesis on blast resistant façade design. After contributing to international projects such as the first Apple store in India, now he is focusing on many London refurbishment projects with the aim to improve the façade performances to meet the new standards and requirements but trying to maintain the authenticity of the existing buildings.

Carmelo joined Eckersley O'Callaghan in 2016 as a Project Engineer in the façade team and has now been promoted to Associate. He has a multidisciplinary background, with a deep understanding of building physics and structural façade and glass design. As a key figure in Eckersley O' Callaghan's Digital Design Group and a lead in our R&D program, he has technical excellence in the modelling of complex 3D building envelopes and have contributed to write bespoke environmental analysis parametric tools.

1 Exchange Square is one of the increasingly common cases of building in need of re-adaption to accommodate programme flexibility and renewed aesthetic. The building is approximately 30 years old, meaning some components in the façade have passed their original service life and need replacement, while other primary components have the potential for an extended life-span with repair and maintenance. For heritage reasons and to reduce the embodied carbon of the new works, it was desirable to retain valuable cladding surfaces, namely the granite cladding, which is supported on a steel 'mega-panel' sub-frame. Explorations on how to conserve, refurbish, and modernize the granite were explored. Research with the supply chain led to roadmaps on what would be the best scenarios for the stone components. A crucial factor was the viability of retaining the 'mega-panel' sub-frame, given the requirement to install new triple-glazed windows and increased insulation depth to align with stringent environmental certifications (Nabers 5*) the project is aiming for. To validate the structural integrity and possibility of enhancement of the mega-panels to support the additional weight, it was necessary to carefully review record drawings, carry out intrusive surveys and undertake detailed structural analysis. Different stiffening strategies were studied and optimised to minimise the addition of steel to the areas which were necessarily requiring it. Other complicating aspects that needed consideration in the façade refurbishment were: fire regulations, requiring new non-combustible insulation and the implementation of cavity barriers where feasible; and weathertightness, assuring by detailing & design that the old and new elements match and work together. An overview of the façade journey is given in the presentation, as well as the lessons learned during the process. It is stressed how a design-intensive process is valuable to remain consistent with the current sustainable and circularity goals. Given it is still an ongoing project, commentary of current steps and future plans are given, open to what the actual built façade and construction constraints will entail.

circularity
reuse
refurbishment
embodied carbon
structural analysis

revitalizing the past

Rocco Boselli &
Carmelo Guido Galante

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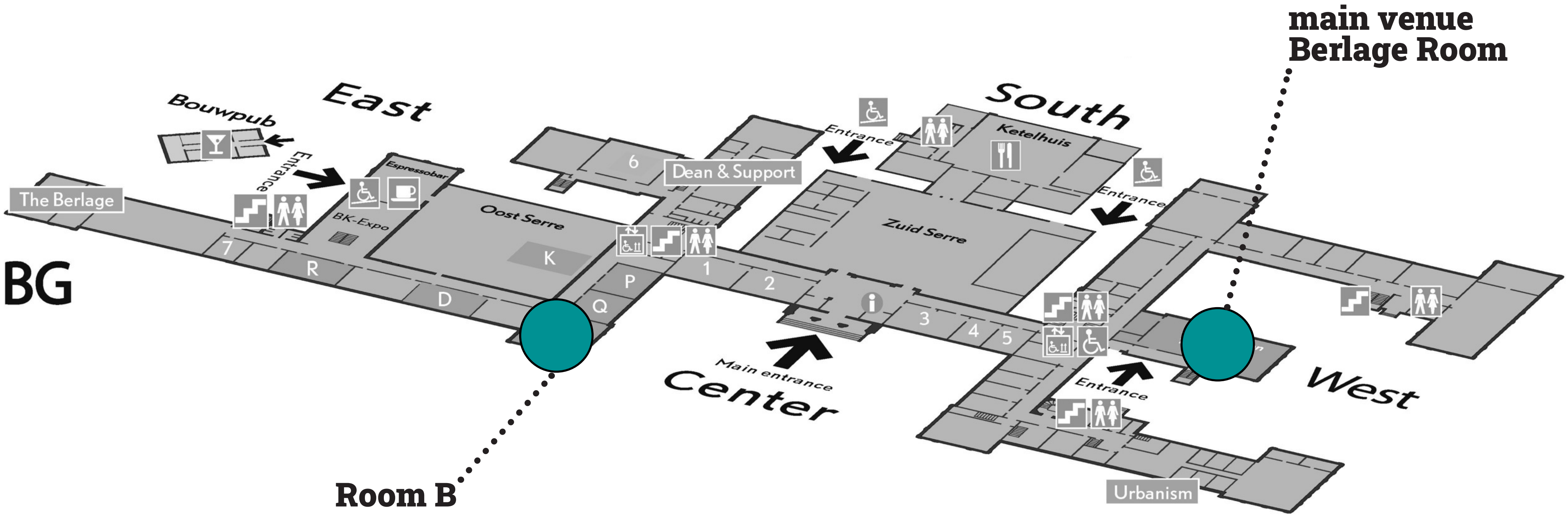

dinner at Kruydt

Restaurant Kruydt is located in the historical centre of Delft, 25 minutes walking from the Faculty of Architecture and also accessible by bus (line 60).

Address
Paardenmarkt 1
2611 PA, Delft

Time
From 18:45

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