The Glass Forum 2023

Recent Developments in Architectural Glass Research

Wednesday 15 November

Berlagezaal, Faculty of Architecture, TU Delft

Mirage by Katie Paterson and Zeller & Moye. Image by Iwan Baan

TU Delft

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9:00		Registration & coffee
9:30		Welcome Address by **Prof. Dirk van Gameren & Prof. James O' Callaghan**
9:45	Keynote	Innovation is for everybody, **Adrian Betanzos (Apple)**
10:15	Performance	Human factors in glass research, **Alessandra Luna Navarro (TU Delft)**
10:30	Performance	Smart Glass Films for Heat and Light Management in Buildings, **Stijn Kragt (TU Delft)**
10:45	Performance	A method to determine deflection limits on facade glazing based on occupant satisfaction, **Sagar Oke (TU Delft / Octatube)**
11:00	Performance	Prototyping of a dynamic thin glass unit with a switchable thermal insulation, **Patrick Ullmer (TU Delft / Frontwise Facades)**
11:15		Panel Discussion
11:30		Coffee break
12:00	Performance	A novel non-destructive method for the assessment of the strength of naturally aged glass, **Irene Sofokleous (TU Delft / Octatube)**
12:15	Performance	The Potential of Switchable Glazing in Cooling-Dominated Climates, **Etienne Magri (University of Malta)**
12:30	Performance	Seismic performance of Structural Silicone Glazed Facades, **Simona Bianchi (TU Delft)**
12:45		Panel Discussion
13:00		Lunch break
14:00	Keynote	The making of Mirage, **Christoph Zeller, Ingrid Moye, Faidra Oikonomopoulou, Telesilla Bristogianni, Alex Cannas**
14:45	New forms	Minimum mass cast glass structures under performance and manufacturability constraints, **Anna Maria Koniari (TU Delft)**
15:00	New forms	Bringing glass giants to life: finish quality exploration of complex cast glass forms on disposable moulds, **Menandros Ioannidis (TU Delft)**
15:15	New forms	UPCAST Glass: Open Technology Programme, **Faidra Oikonomopoulou, Telesilla Bristogianni (TU Delft)**
15:30		Panel Discussion
15:45		Coffee break
16:15	Keynote	Reuse in design and design for reuse, **Erwin ten Brincke (ABT)**
16:45	Circularity	Reversible connections for reusable structures, **Rebecca Hartwell (TU Delft)**
17:00	Circularity	Re-loop transparency, Maximising circularity and transparency in an insulated glass unit, **Sophia Kouvela (TU Delft / EOC Engineers)**
17:15	Circularity	Rolling in Transparency, **Grammatiki Dasopoulou (TU Delft / EOC Engineers)**
17:30		Panel Discussion
17:45		Open Glassroom project, **Jagoda Cupac (TU Dresden)**
18:00		Closing remarks by **Prof. dr. Mauro Overend & Prof dr. Michiel Kreutzer** | Networking
19:45		Dinner at historic City of Delft (included in registration)

© *Mirage* by Katie Paterson and Zeller & Moye, photo: Iwan Baan

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Foreword

Dear Glass Forum Delegate,

Welcome to the Glass Forum 2023.

With sustainability goals underpinning everything we do in the built environment, this year's Glass Forum focuses on the three pillars of performance, new forms and circularity.

This event, more than any other in the glass calendar, is where the very latest research results, design ideas and construction innovations are shared and vigorously debated between key players of the value chain, ranging from top researchers to leading-edge practitioners and future-oriented manufacturers. Another important feature is that the Glass Forum is an invitation-only event, so whether you are speaking or attending the event, you have been specially selected because you have a significant contribution to make in sharing the novel content and steering the direction in this field.

This event would not be possible without the support of many, but in particular the Glass Forum Sponsors: ABT, AGC Interpane, Bellapart, Dow, Eckersley O' Callaghan, Eyrise, HB Fuller-Kommerling, Kuraray, Octatube, Pilkington and Sedak; as well as the numerous funding bodies and industrial partners who are contributing to the research activities and who are acknowledged in the relevant presentations and project descriptions in these proceedings.

There are no passive participants in the Glass Forum so please engage in questioning, discussing, debating and following up on the several research projects showcased in the event. This vibrant interaction is what makes the Glass Forum successful. The Q&A sessions and the coffee / lunch breaks are ideal for this.

We wish you an inspiring Glass Forum and we hope that the seeds that are planted in this year's symposium will flourish into next year's fruitful collaborations.

Yours,

Dr. Faidra Oikonomopoulou

Prof. Mauro Overend

Prof. James O' Callaghan

About ReStruct Group

Profile

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.

Motivation

As the urban population grows and infrastructure ages, there is a high demand for architectural structures, but their construction and disposal consumes vast quantities of resources and generates enormous amounts of waste. Our aim is to bring about a new generation of resource-efficient, resilient and responsive architectural structures that make step-change reductions in the amount of non-renewable resources used in their construction, operation and decommissioning.

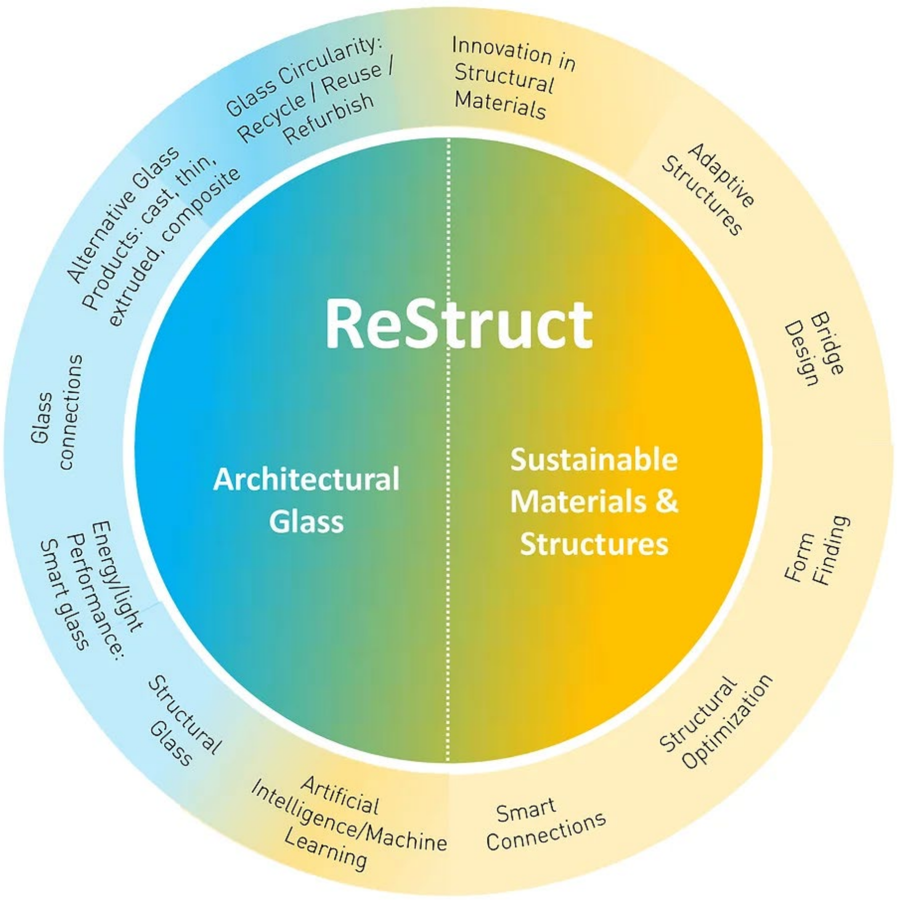
Mission & Objectives

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:

1. Glass & Transparency including architectural glass and sustainable glass.
2. Structural Mechanics including form-finding and optimization.
3. Artificial Intelligence for sustainable and resilient structures.
4. Adaptive architectural structures including smart and reconfigurable structures.
5. Bio-based architectural structures including natural and engineering bio-based materials

For more information regarding our research please visit our website: https://www.restructgroup-tudelft.nl/



Organizing Committee

Faidra Oikonomopoulou

Assistant Professor Structural Design and Mechanics

Faidra (Phaedra) Oikonomopoulou is Assistant Professor of Structural Design & Mechanics Group at TU Delft. Her research focuses on structural glass and particularly on innovative structural applications of cast glass components, on glass recycling and on the design of full-glass load-bearing structures and components. Faidra holds two MSc degrees, in Architectural Engineering by N.T.U.A. and in Building Technology by TU Delft and a PhD on structural glass by TU Delft. Faidra has been involved in the R&D of several realized cast glass structures (Crystal Houses, Glass Vault, Qaammat Pavilion, Mirage Sculpture) and her research work on structural cast glass has been exhibited in several international fairs and exhibitions. She has received several prestigious grants, awards and nominations and has given multiple invited talks in universities, companies and institutions in Europe and USA.

Mauro Overend

Professor Structural Design and Mechanics

Mauro is Professor of Structural Design & Mechanics at TU Delft. 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. Mauro studied Architecture & Civil Engineering followed by Structural Engineering at Masters level and a PhD on structural glass. After a few years of consulting engineering work in London in the fields of structural engineering and façade engineering, Mauro returned to full-time teaching and research. Since 2004 he has held tenured positions at internationally leading universities, but has retained strong links with industry. He has over 100 peer-reviewed publications on glass, building envelopes and sustainable structures to his credit. Mauro has a track record of leading international research networks in these domains and he is contributing to the drafting of international engineering design standards. He has won several international awards and his research and expertise have found applications in some of the most challenging buildings globally.

James O’Callaghan

Professor Architectural Glass

Founding Director of Eckersley O’Callaghan

James O’Callaghan is a world leading Structural Engineer widely acknowledged as an authority in the use, and design of structural glass. He is co-founder of the multi award-winning global structural engineering practice Eckersley O’Callaghan known for its pioneering and award-winning projects for clients including Apple, Google and LinkedIn to name a few. As Professor of Architectural Glass at TU Delft, James has a key role in establishing research in all areas of glass in architecture. This is helping to map out the use of glass in the urban fabric of the future and accelerate more sustainable and responsible solutions.

Keynote speakers

Erwin ten Brincke (ABT)

engineering consultant / associate partner

Erwin is a structural designer with an integral mindset and passion for glass. His creativity is at its best when he sits at the design table sketching as part of a design team. This results in safe, sustainable, manufacturable structures. His motivation is innovation and giving meaning to beauty. In the current era, innovation mainly means using our materials sustainably for the next 50 years, and beauty means making them look attractive. Erwin works at ABT, is ambassador for the innovation company Quake, is Visiting Lecturer for the Universities of Delft and Darmstadt and he serves on the Dutch standards committee for glass structures. Many students graduated on Master Thesis topics that came from him.

Adrian Betanzos (Apple)

Senior Design Manager

Adrian Betanzos leads the Architectural Materials Studio in the Real Estate & Development department at Apple Inc., where he oversees the design and innovation of their recognized storefronts worldwide. He also develops new materials and systems, with a stronger focus on glass and its structural application. His professional experience includes the design, sourcing, fabrication, assembly and construction of highly complex facade structures and high-rise buildings. He has been an Adjunct Professor for the City University of New York and NYU. He currently is a guest lecturer at UC Berkeley, but has also lectured at Columbia University, Syracuse University, California College of the Arts, Universidade Presbiteriana Mackenzie in Sao Paulo, Brazil, and at other technical facade gatherings around the world. In addition to practice, Adrian founded and lead a project for Engineers Without Borders, NYC professional Chapter to provide Sustainable Water and Sanitation solutions in a community of El Salvador.

Ingrid Moye & Christoph Zeller (Zeller & Moye)

Founders of Zeller & Moye

Zeller & Moye was founded by Christoph Zeller and Ingrid Moye as an architectural studio with offices in Berlin and Mexico City. Their practice covers a wide range of typologies and scales, from object design to large buildings, working frequently at the boundaries of architecture, art and design.
The studio has won the Panamerican Architecture Biennial Quito 2020 and has been awarded Design Vanguard by Architectural Record in 2023. Christoph Zeller and Ingrid Moye are program directors of the Visiting School Mexico for the AA London.

Faidra Oikonomopoulou & Telesilla Bristogianni (TU Delft)

Assistant Professors

Dr. Faidra Oikonomopoulou and Dr. Telesilla Bristogianni are both Assistant Professors of Structural Design and Mechanics at Delft University of Technology (NL). They have conjointly initiated and developed the research in cast glass at TU Delft, with particular focus on innovative structural applications of cast glass components and on glass recycling. Their deep expertise in the field of cast glass has cemented the research group's position as the world leader in this field. Telesilla and Faidra have been involved in the R&D of several realized cast glass structures (Crystal Houses, the GlassVault, Qaammat Pavilion, Mirage) and have received multiple awards including the *Innovation Award by the Society of Façade Engineers* (UK, 2016), the *Glass Innovation Award* (NL, 2017) and the personal *Talent met Toekomst Bouwprijs* (NL, 2017). Prototypes of their research work on structural cast glass have been exhibited in several prestigious international fairs and exhibitions. For their research, they have received several prestigious grants, awards and nominations and have given multiple invited talks in universities, companies and institutions in Europe and USA.

Alexandros Cannas (Eckersley O' Callaghan Engineers)

Associate Director

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.

Speaker abstracts and profiles

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Human Factors on Glass research

dr. Alessandra Luna-Navarro
a.lunanavarro@tudelft.nl

Alessandra is assistant professor in Façade Design and Engineering at TU Delft and a chartered engineer in Italy and the UK. In her professional activity, she has been working in wide range of different buildings and facades, from modern flagship buildings such as “La Nuvola” (Rome) to the refurbishment of the historical buildings of the Quirinale in Rome. She has a Masters’ degree in Building Engineering and Architecture from La Sapienza University of Rome and an MPhil in Energy Technologies from the Department of Engineering at the University of Cambridge. She has also obtained a PhD from the University of Cambridge by researching occupant-centred design and operation of facades. Her research was awarded with the Future Cities Fellowship at the University of Cambridge and funded by Arup, Permasteelisa and EPSRC. She collaborates with regional energy policy makers, the International Energy Agency, the CIE and CIBSE in linking evidence and innovation to policy. Currently, principal investigator or work package leader in the following European projects Smarteestory, Multicare and OpenFace.

View clarity and contrast in novel dynamic glazing technologies, from Windows to the Future project.

Children interact with a smile with Eyrise glazing, image courtesy of Eyrise-Merck – Face 2 Face research project.

Glass performance is frequently shaped by the specific needs of users. Whether it involves optimizing daylight utilization, ensuring clear views, maintaining thermal comfort, or addressing concerns related to vibration, the criteria and performance objectives are dictated by user expectations and preferences. Yet, the extent to which we truly comprehend these user requirements remains a pivotal question. Are these requirements primarily obstacles, or can they serve as opportunities to drive a more sustainable glass industry forward?

This presentation shows a curated selection of projects at TU Delft. These projects challenge, evaluate, and redefine user expectations and requirements. Topics span from enhancing view clarity through high-performance or multifunctional facades, streamlining glazing solutions, enhancing resilience against extreme heat, to introducing interactive and dynamic glazing innovations.

Research team: Pedro de la Barra, Sagar Oke, Pranay Khandhachani, Serhan Yuksel, Alina Wagner, Simona Bianchi, Eleonora Brembilla

Smart Glass Films for Heat and Light Management in Buildings

dr. Stijn Kragt
a.j.j.kragt@tudelft.nl

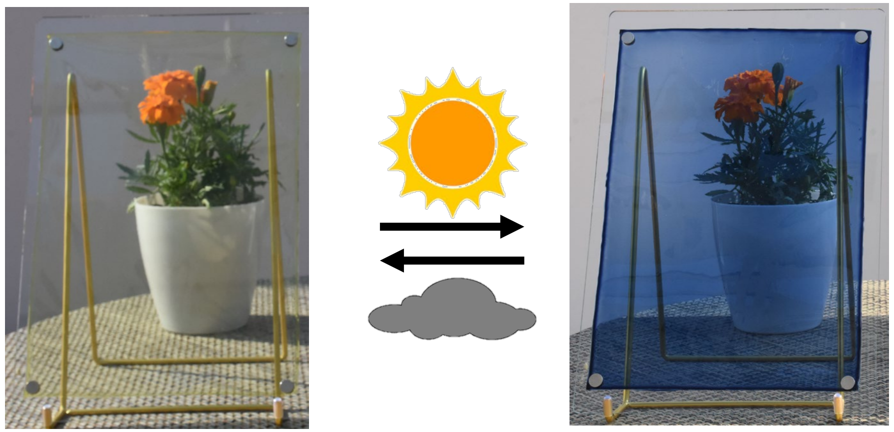
Stijn Kragt is an enthusiastic, curiosity-driven researcher and entrepreneur, aiming to help solving problems that we are facing in nowadays society. From 2019 to 2023 he was a postdoctoral researcher at the Architectural Facades and Products group at the Delft University of Technology, where he gained insights on integration and impact of innovative smart heat regulating glass films on a building's energy and daylight performance. With a PhD in chemical engineering, focusing on adaptive coating materials, he combines materials research with applications in the built environment. Currently, Stijn is fully dedicated to his start-up company ClimAd Technology, in which he aims to further develop these smart solar heat regulating glass films and realize their exploitation in the glass market.

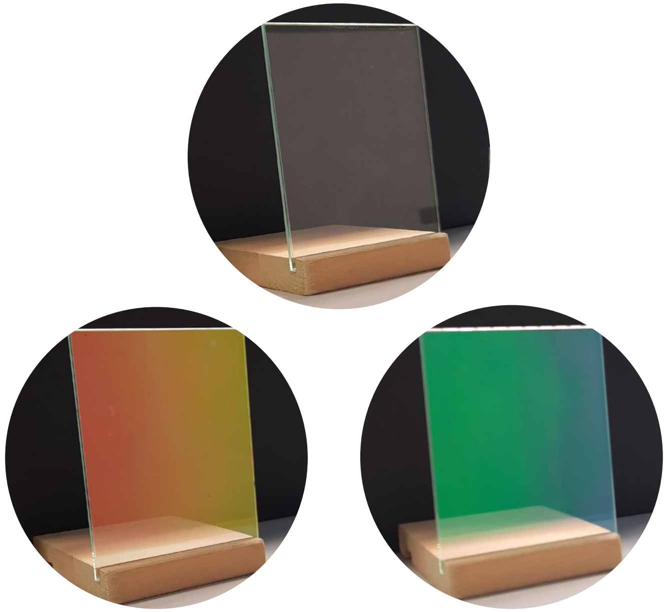
In partnership with:

ClimAd Technology   TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

The building and construction sector accounts for 36% of the global energy consumption. Over 40% of the energy used in buildings is used for heating and cooling to maintain a comfortable indoor temperature. Currently, we are consuming 3000 TWh of energy on cooling each year, a number which has increased with 33% between 2010 and 2020. This trend is expected to increase further in the coming decades due to urbanization, global rising temperatures, and increasing use of glazing area in buildings.
In this lecture, I will discuss a variety of smart glass films which impact the entrance of solar heat and daylight in buildings. The films adapt their solar heat rejection based on the outdoor sunlight intensity (photochromic) or temperature (thermochromic). They can be applied as retrofit on existing glazing or be integrated inside new glazing. We will dive into the features of these smart glass films and discuss their impact on building energy efficiency and daylight comfort. Besides color-neutral, also films with viewing-angle dependent reflective colors will be shown, providing a new tool to combine energy-efficiency with eye-catching architectural designs.

Research team:
Eleonora Brembilla and Eric van den Ham





A method for human-centred appraisal of façade design for serviceability

Sagar Oke
sagaroke@gmail.com

Sagar Oke is an architect and a building engineer with an MSc in Building Technology from TU Delft. He currently works at Octatube, Netherlands where he is involved in design engineering of complex steel and glass structures. In the past he has designed and built several houses and schools in hot and dry region of central India where he dealt with challenges related to climate response and material use. At TU Delft, his focus was on façade glazing, with respect to its structural performance and serviceability. Consequently, in his graduation thesis, he proposed a novel method to measure occupant satisfaction with deformations in façade glazing resulting from wind and climatic loading.

In partnership with:

AGC INTERPANE

1. HDR images of IGUs with different levels of deformation for comparison of optical behaviour

2. Proposed experiment setup with air pressure system for glass deformation

Material efficient design of façades by means of reducing glass thickness can save a considerable amount of embodied carbon. While this is promising from an environmental perspective, thinner glass can lead to deformations that surpass acceptable serviceability limits. These limits are governed by 'measurable' objective performance criteria such as mechanical performance, thermal efficiency, durability, optical clarity and acoustic properties. However, occupant acceptance thresholds of deformation are generally assumed to be low. Hence, glass thickness beyond serviceability limits is routinely specified. The lack of methods for quantifying occupant acceptance of glazing deformation is a barrier to a comprehensive definition of serviceability limits. This talk presents the design of a novel experimental method to measure occupant acceptance thresholds with respect to façade glazing deformation. The proposed experiment is conducted with volunteers who indicate their level of satisfaction towards deformations in glass. The deformations in glass are created by varying air pressure inside the cavity of an insulated glazing unit (IGU) using an electro-pneumatic system designed for this experiment to replicate glass behaviour under climate loading and wind loading. The thesis was able to provide a proof of concept for the experimental setup and present important observations related to mechanical behaviour and optical performance of IGUs under deformation.

Thesis mentors: Dr. Alessandra Luna Navarro, Prof. Dr. Mauro Overend

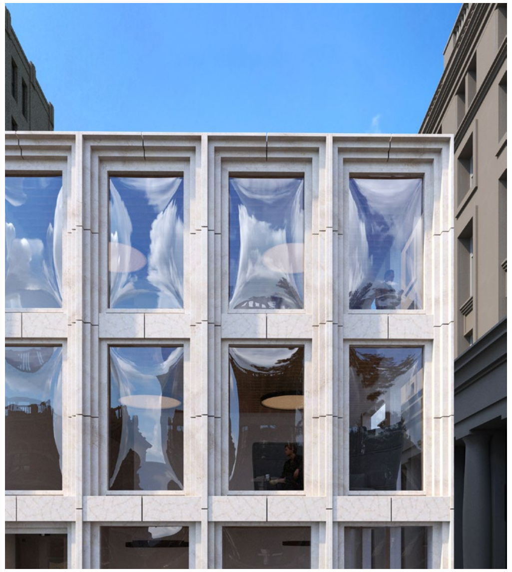
Inflatable Glazing: A Switchable Insulation Prototype

Patrick Ullmer
patrick.ullmer@frontwisefacades.nl

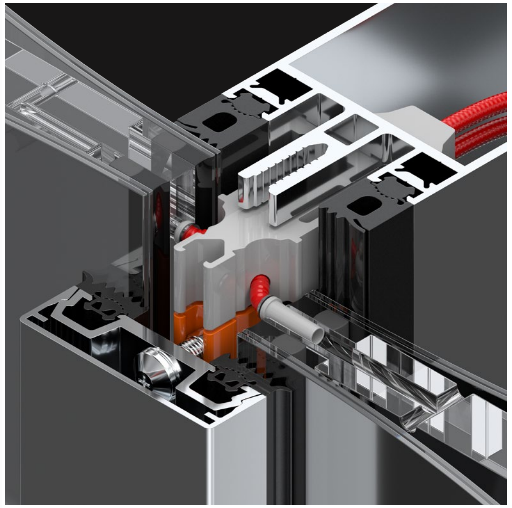
Patrick Ullmer recently graduated from the Building Technology Masters track at the Faculty of Architecture at TU Delft. Before this, he pursued his bachelor's degree in Architecture and Building Sciences at the Eindhoven University of Technology. During his studies in Delft, he primarily focused on facade engineering and computational methods, leading to his master's thesis on Inflatable Glazing. Patrick has a keen interest in envelope design and the research & development of architectural products. He is currently working as a facade engineer at Frontwise Facades in Amsterdam, where he is part of various design teams, consulting architects and developers on facade solutions.

In partnership with:

TU Delft, Eckersley O’Callaghan, H.B. Fuller / Kömmerling, AGC Europe, Frontwise Facades, Röhm, Innotech Rot



Resulting architecture using Inflatable Glazing



Custom mullion with gas supply to inflate glazing

With surface temperatures constantly on the rise due to climate change and more frequent heatwaves, super-insulated houses are already facing the risk of overheating. The challenge of dissipating heat during these hot periods is becoming increasingly complex, leading to a higher demand for energy-intensive solutions like air conditioning. This talk presents a novel glazing product capable of passive interior temperature control by changing the U-value.

The working principle is as simple as opening and closing the cavity of an insulated glass unit. Separating the glass panes reduces conduction, making the unit more insulating. When deflated, the glass is in direct contact, decreasing insulation and thus accelerating the heat transfer. Switching between these states can be favorable in several climatic scenarios to reduce the heating and cooling demand. The innovative material, thin glass was selected for its flexibility and lightweight characteristics.

It has been successfully demonstrated that inflating and deflating the glass unit can change the U-value from single-glazing to triple-glazing properties. Energy savings of up to, but not limited to, 33% can be expected compared to triple glazing. The research encompassed glass edge design, prototyping, inflation of glass, 3D scanning, a custom thermal simulation plugin, energy efficiency simulation, and structural performance. Inflatable Glazing emerges not only as a sustainable building product but also offers architects a novel glass design option.

Research team: James O’Callaghan, Marcel Bilow

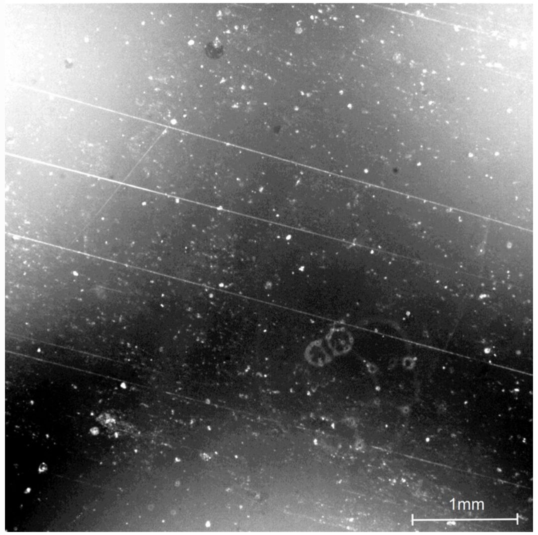
A novel non-destructive method for the assessment of the strength of naturally aged glass

Irene Sofokleous
irenesofokleous@gmail.com

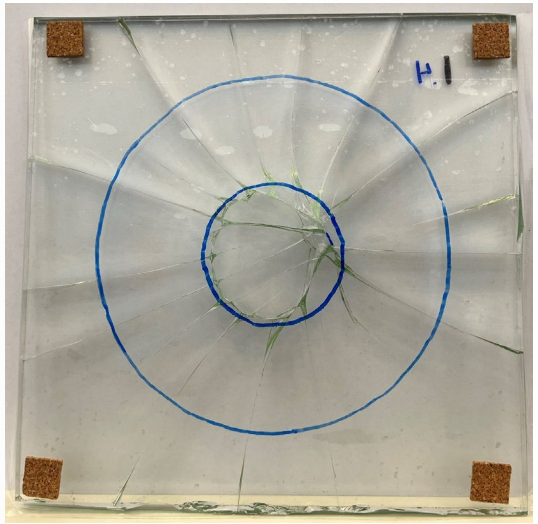
Irene graduated (MEng) in Civil Engineering in 2020 at the National Technical University of Athens (NTUA), specializing in Structural Engineering. In 2022 she completed her Masters studies (MSc) in Building Engineering, specializing in Building Technologies and Physics, at the Technical University of Delft. During her master thesis, she investigated the strength of naturally aged glass as well as non-destructive ways for assessing its performance. Since November 2022, Irene is working as a structural engineer at Octatube bv in Delft, designing challenging facades with glass, timber and steel.

In partnership with:

TUDelft abt INNOWEP GmbH MEASURING & TESTING



Damage on 50+ year old glass.



Prediction of critical defect.

This talk presents a novel method for the non-destructive assessment of the strength of naturally aged float glass and the potential for reusing float glass from building envelops. The method consists of the detection and characterization of the surface defects which govern the strength of glass by optical means, and the estimation of the associated failure stress, based on the theory of fracture mechanics. A non-destructive experimental investigation with an optical profilometer, along with destructive coaxial double ring tests on 50+ year old glass aimed to assess the feasibility and accuracy of the method. The novelty of the proposed method lies in the equipment used, namely Traceit®, which is a mobile profilometer that allows the examination of the glass surface in non-laboratory conditions. An overview is provided of the main experimental findings on the types of defects on weathered glass and their influence on the strength. The results of similar experiments on new glass are provided as a benchmark. Furthermore, the size effect on the examined weathered glass is elaborated. Finally, the proposed method is evaluated through the comparison of the predicted and the actual failure stress and possible improvements of the method are highlighted for future research.

MSc. thesis committee: M. Overend, F. A. Veer, E. ten Brincke, C. Noteboom

Etienne Magri

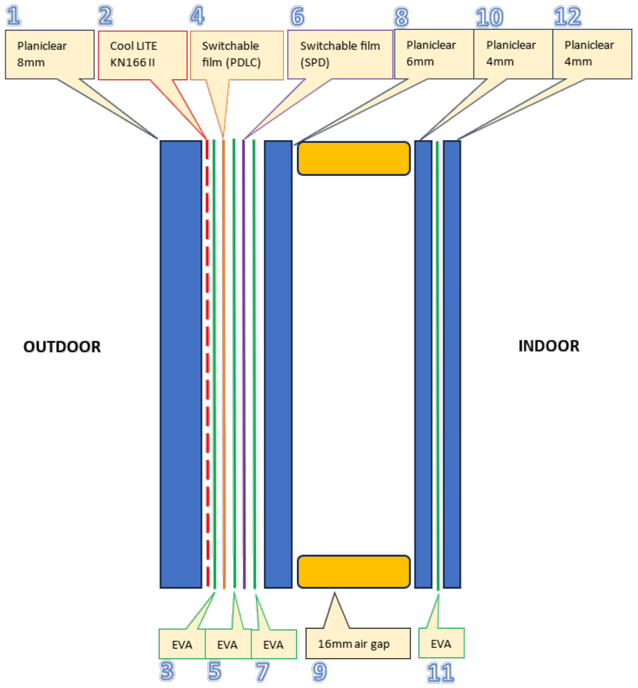
etienne.magri.99@um.edu.mt

Etienne Magri is a practicing architect and civil engineer, with over 2 years of experience in the design and construction of buildings. He graduated from the University of Malta in 1999 with a joint degree in architecture, civil and structural engineering. In 2016 he completed a Master's degree in Environmental Design with the University of Malta.

He is currently reading for a Ph.D. with the University of Malta and investigating the potential for the use of switchable glazing for buildings within a Mediterranean climate for the improvement of the energetic performance of buildings and the well-being of building occupants.

In partnership with:

Potential of switchable glazing in cooling-dominated climates



Sectional Detail of the Novel Glazing Assembly

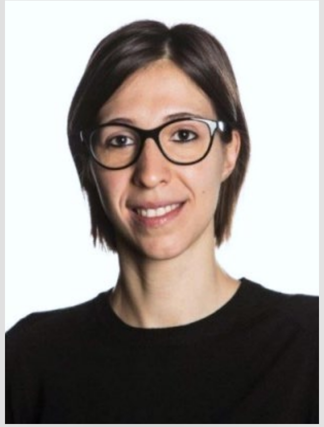
View of the Field Test Experimental Setup

The ever-increasing aesthetically driven demand for fully glazed façades poses a design challenge; not least in controlling the cooling demand and occupant well-being of such buildings, particularly in a central Mediterranean climate. High solar insolation on glazed facades not only contributes to increased cooling loads but substantially affects the quality of the indoor visual environment, particularly glare. External shading devices and more commonly, indoor blinds are often the building elements through which one achieves to some extent, indoor occupant comfort, to the detriment of outlook and views.

Switchable glazing has a great potential in achieving a compromise between occupant visual and thermal comfort yet retaining unobstructed outdoor views. In addition, the ability of these technologies to be integrated in home automation systems can make them more appealing to end users.

This novelty in this ongoing research is the investigation of the potential of a novel combination of two distinct switchable film technologies, laminated within a single IGU, providing for independent user-control over transparency and the quantity of daylight that penetrates an indoor space. The potential use of switchable glazing as a form of shading device is equally intriguing. This is equally being investigated through comparisons between the *thermal* and *daylight* performance of two identical mock-up spaces.

Seismic performance of Structural Silicone Glazed Facades



dr. Simona Bianchi
s.bianchi@tudelft.nl

Simona Bianchi, Ph.D. P.E., is a Postdoctoral Research Fellow and Lecturer at the Structural Design & Mechanics Group in the Faculty of Architecture at TU Delft. Her research focuses on risk assessment and multi-hazard resilience design, with a particular emphasis on earthquake-proof and sustainable technologies. Simona has received a prestigious Marie Curie fellowship to work on multi-performance assessment of building facades. She serves as the Technical Lead for the EU-funded MULTICARE project on multi-hazard low-carbon resilient technologies. Simona has actively collaborated with various public and private institutions through international research projects. Her extensive experience in experimental testing stems from her coordination of several industry-funded projects.

In partnership with:

PERMASTEELISA GROUP

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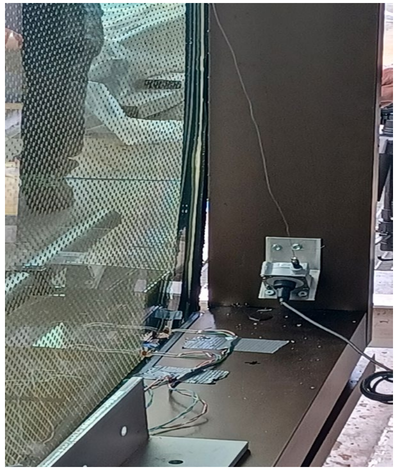
1. External view of the 4-unit specimen



2. Damage state: detachment of glazing

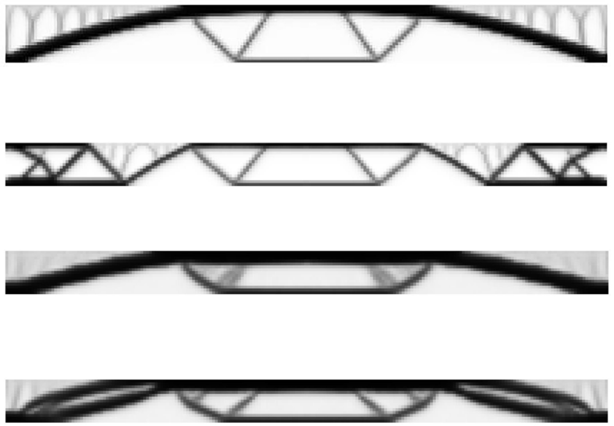
This talk presents the key findings from an extensive experimental campaign on structural silicone glazed facades. This glazing system emerges as a resilient component with the potential to enhance the seismic performance of unitized curtain walls. Despite initial studies on the seismic behavior of structural silicone glazed facades, research in this field remains limited and typically neglect the analysis of the complete sequence of damage states and the ultimate resistance of the various façade components. This experimental study aimed to collect data on the post-earthquake functionality and the failure modes of alternative facade designs, including different unit dimensions, silicone joint aspect ratios, frame stiffness and loading mode. The testing procedure involved a series of in-plane displacement-controlled crescendo tests, time histories and monotonic testing, gradually increasing the intensity levels to evaluate the progressive damage states within the façade system. This talk provides the main outcomes derived from both damage observations and data post-processing. These results offer valuable insights into the seismic behavior of structural silicone glazed facades, aiming to support the development of enhanced design guidelines and construction practices for more resilient facade systems.

Research team: Simona Bianchi, Valerie Hayez, Guido Lori, Mauro Overend, Giampiero Manara

Minimum mass cast glass structures under performance and manufacturability constraints

Anna Maria Koniari
a.m.koniari@tudelft.nl

Ir. Anna Maria Koniari is a Phd candidate at the Structural Design & Mechanics Group in the Faculty of Architecture and the Built Environment at TU Delft. Her research focuses on leveraging computational methods to challenge conventional design processes, allowing for new architectural forms and informed design decisions. She has previously been involved in the research regarding the application of Topology Optimization for the design of large monolithic cast glass structures. Particularly, she developed a customized formulation that results in forms which have minimal mass and comply with the respective manufacturing and material criteria. Currently, her Phd research lies on machine learning applications for optimization of retrofit strategies towards upgrading building energy performance.



Optimization results for different sets of input conditions.

Visualization of the final outcome.

This talk presents part of the research regarding the application of Topology Optimization (TO) for the generation of design forms that can overcome challenges inherent to the use of cast glass for the creation of large monolithic structures with light permeability. The method has a novel applicability potential, as decreased mass is associated with shorter annealing times and, thus, considerably improved manufacturability in terms of time, energy, and cost efficiency. However, since realistic TO in such structures is currently hindered by existing commercial software capabilities, the research investigates the creation of a customized formulation which concurrently incorporates annealing-related manufacturing constraints as well as criteria related to the glass material/structural properties. The proposed formulation is applied in a planar design domain to explore how different glass compositions and structural design strategies can affect the final shape, providing non-intuitive forms for each set of given input conditions. Finally, the practical aspects of the manufacturing process are briefly discussed.

Research team: Dr. Faidra Oikonomopoulou, Dr. Charalampos Andriotis

Bringing glass giants to life: surface quality exploration of complex cast glass forms on disposable moulds

Menandros Ioannidis

ioannidismenandros@gmail.com

Menandros Ioannidis has a background in Architecture and has recently graduated from Building technology MSc programme at TU Delft. For the past year he worked as student/ research assistant for ReStruct group within TU Delft deepening his understanding on glass, cast glass and glass recycling. Furthermore, with his thesis he dived into glass fabrication methods and especially glass casting on disposable moulds and structural design.

Material sponsorship:

TU Delft HA GROUP ExOne

Left to right: 1.Lab, glass culets, silica plaster moulds, 2.Refractory coatings, 3. 3D printed sand moulds

Supported by the Onassis Foundation - Scholarship ID: F ZS 018-1/2022-2023

Figure 1: Preliminary experiments, kiln casting of glass on 3DPSM using various coatings and/or protective layers at 870°C

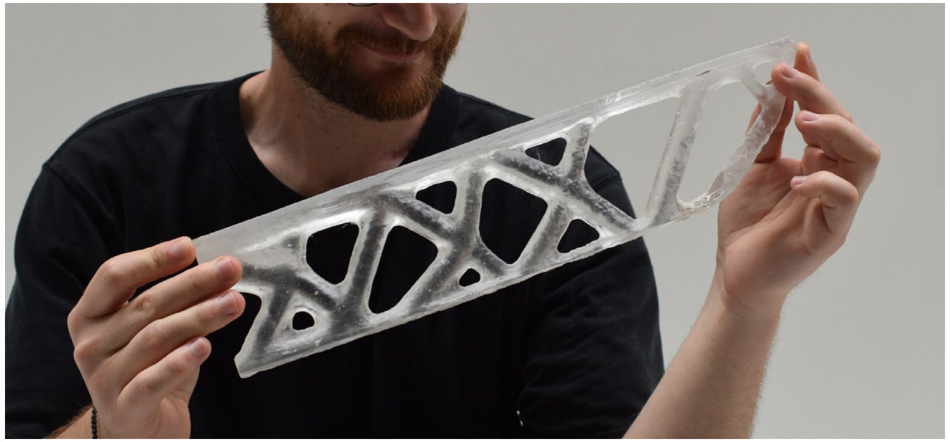


Figure 2: Scaled up prototype, kiln casting of glass on silica plaster mould using isopropanol-based coating at 870°C

This talk summarises the research done (as part of the MSc thesis of the speaker in Building Technology) exploring ways to improve surface quality and transparency on cast glass object of complex and customized forms and the use of disposable moulds.

To achieve good surface quality immediately after demoulding and reduce the need for post processing, a series of laboratory experimentation were conducted. The experiments involve the use of different types of disposable moulds: 3D printed sand moulds (3DPSM) and Silica plaster (Crystalcast), and the application of refractory coatings, coating combinations and protective layers at various maximum firing temperatures (Figure 1).

The results of those preliminary experiments are scaled up and presented as an open-end dialogue for further research (Figure 2).

Team: Dr. Faidra Oikonomopoulou, Dr. Telesilla Bristogianni, Dr. Marcel Bilow, Anna Maria Koniari

UPCAST GLASS: Open Technology Programme

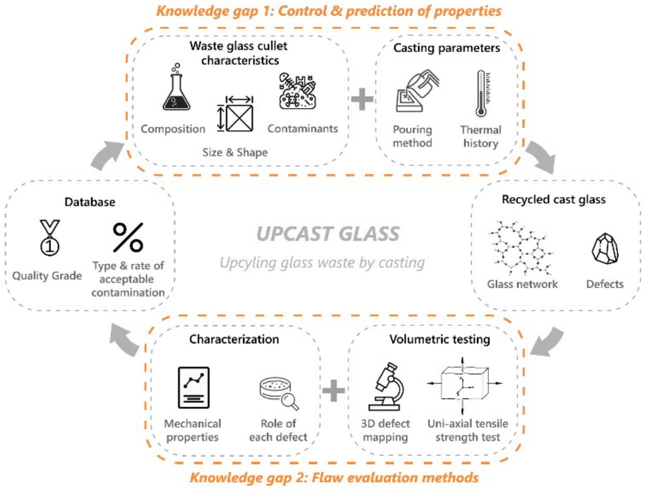
dr. Faidra Oikonomopoulou
f.Oikonomopoulou@tudelft.nl

dr. Telesilla Bristogianni
t.Bristogianni@tudelft.nl

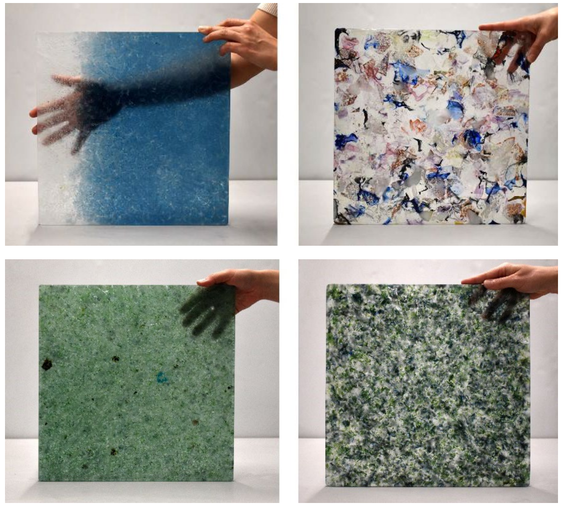
Dr. Telesilla Bristogianni and Dr. Faidra Oikonomopoulou are both assistant professors at the Structural Design & Mechanics Group in the Faculty of Architecture at TU Delft. Their joined research focuses on structural and architectural applications of cast glass and glass recycling via casting. Together they have been involved in the R&D of several realized cast glass structures, such as the Crystal Houses in Amsterdam, the LightVault in UK, the Qaammat Pavilion in Greenland and the Mirage Sculpture in California, USA. They have received multiple grants and awards for their research on cast glass, including a recent Open Technology NWO grant by the Dutch Research Casting on UPCAST GLASS: Recycling of glass via casting.

UPCAST GLASS user committee:

Vlakglas Recycling Nederland, Maltha Glasrecycling Nederland, Corning Inc, Eckersley O' Callaghan Engineers, MVRDV Architects



Fundamental knowledge gaps /key innovations addressed in UPCAST GLASS regarding the control, prediction and evaluation of recycled cast glass



Cast glass panels made of various glass waste

Glass recycling provides opportunities for recovering materials and reducing production energy demand, but most non-container glass is currently down-cycled or landfilled at end-of-life, because glass production processes cannot accommodate the contamination and compositional variations of waste glass streams. The research project UPCAST GLASS addresses this by exploring a novel casting process for recycled glass that accommodates recipe variations and contaminants from a broad range of waste glass streams, by developing new methods for assessing the influence of defects in the engineered recycled glass components and by providing a database of material properties and design guidelines for recycling waste glass into high-value products. To achieve these goals, the research team will conduct systematic prototyping, material characterization and mechanical testing at the TU Delft laboratory facilities in the faculties of Architecture and the Built Environment and of Civil Engineering and Geosciences, and will work closely with key recycling organizations, glass manufacturers and engineering offices.

Research team: Dr. Faidra Oikonomopoulou, Dr. Telesilla Bristogianni, Prof. Mauro Overend.
The project will run for 4 years and will be supported by the TU Delft Glass Research Group, Vlakglasrecycling Nederland, Maltha Glass Recycling, Corning and EOC Engineers.

Reversible connections for reusable structural components

dr. Rebecca Hartwell

R.C.Hartwell@tudelft.nl

Rebecca Hartwell is a Post-doctoral researcher in the Structural Design & Mechanics group at TU Delft. She has a MEng in Material Science (University of Manchester), and her Ph.D. research (University of Cambridge) 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 academic research, Rebecca contributes to several cross-industry working groups, working to develop guidance on sustainability in façade design.

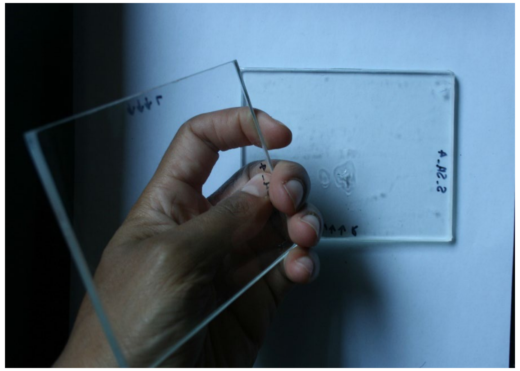
In partnership with:

Eckersley O'Callaghan, Carpenter + Lowings, ABT, Ove Arup & Partners, MVRDV

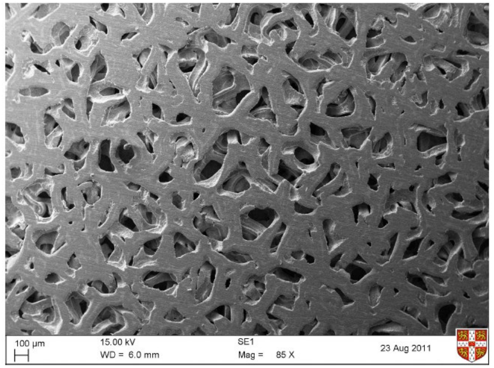
Soldered glass connection

Existing load-bearing glass structures are often composed of multi-material components connected in increasingly complex ways with little consideration for disassembly. In this talk, the latest findings from the NWO-funded application-oriented demonstrator project, *ReSolved,* will be presented. The new joining technology developed in *ReSolved* aims to target life-cycle inefficiencies in load-bearing multi-material components.

In this research, a novel fabrication method has been developed to produce soldered-glass connections. Early experimental results indicate promising interfacial adhesion between the glass and solder. The steps taken to understand the fracture behaviour of connections via digital- and scanning electron microscopy and XRF analysis will be presented. The nature in which these findings are informing recent trials in selective debonding methods will also be discussed. Methods to structurally-optimize the stiffness of the joint through additive manufacturing of the metallic solders; incorporation of soldered composite foams; and selective deposition will be reviewed. The wider aim of incorporating reversible, yet durable, connection methods that promote life-cycle efficiency in load-bearing designs will be critiqued.



Separated PVB-laminated glass

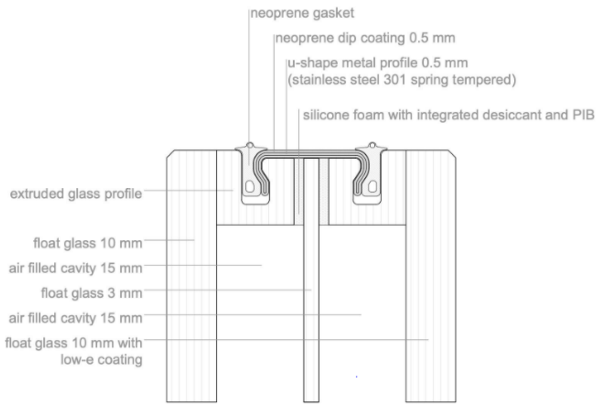


SEM image of Nickel foam

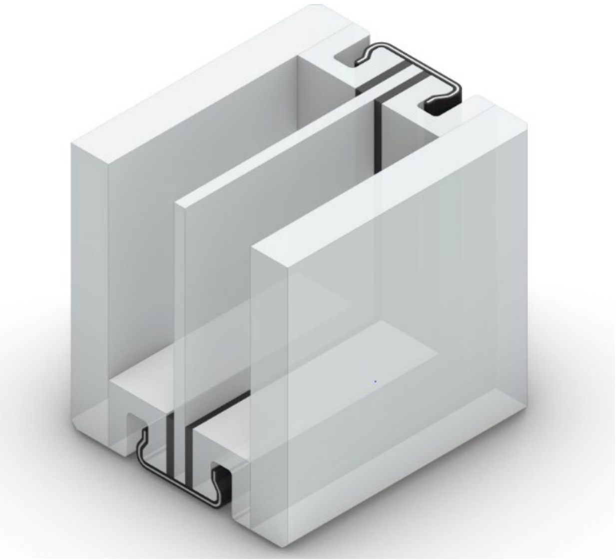
MSc, MEng,
Sofia Angeliki Kouvela
sophia@eocengineers.com

Sofia Angeliki Kouvela is an Architect and Façade Engineer currently working at Eckersley O'Callaghan Engineers in Paris. Sophia has four years of in-depth work experience in architectural design and construction and valuable experience in innovative design in the field of facade engineering and circularity. She completed her Building Technology Master in TU Delft where her thesis 'Re-loop Transparency' was awarded with the circularity award for 2022 in the category materials and components. Sophia joined the Eckersley O'Callaghan facade engineering group of the Paris office in November 2022. Her role as a facade engineer includes collaborating with the architects, detailing of complex facade systems, performing thermal calculations and thermal modelling and exploring and integrating sustainable and circular strategies into the proposed facade design.

Re-loop Transparency



2d detail of the proposed edge seal design



3d representation of the proposed edge seal design

The talk presents the Building Technology graduation thesis that focuses on the research by design of a fully demountable insulated glass unit which corresponds to the circular economy principles, conducted by Sofia Angeliki Kouvela in TU Delft during the academic year 2021-22, with the title "Re-loop Transparency, Maximizing circularity and transparency in an insulated glass unit". The talk focuses on the concluded innovative design proposal that constitutes an alternative to the edge seal connections currently used in the assembly of insulated glass units. The design consists of two float glass panes externally, as in a typical IGU, and an innovative alternative connection that replaces the spacer bar and secondary seal of the typical IGU. The role of the spacer bar is taken by glass extruded in linear slotted profiles. The extruded glass elements are then bonded to the edge of the float glass panes by the process of heat fusion. The replacement of the structural silicone secondary seal is achieved through a simple mechanical clamping connection. The use of a reversible connection and the lack of use of contaminating factors, that prohibit the recyclability of glass, instead of permanently bonding structural silicones, ensures a truly circular IGU design. The talk ends with the conclusions regarding the feasibility of the project and suggestions for further research.

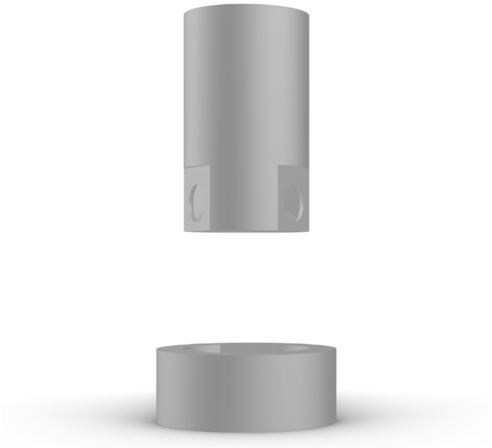
Research team:
Student: Sofia Angeliki Kouvela
First mentor: Faidra Oikonomopoulou
Second mentor: Marcel Bilow

Rolling in Transparency: Exploring the potential of embedding connections in cast glass components

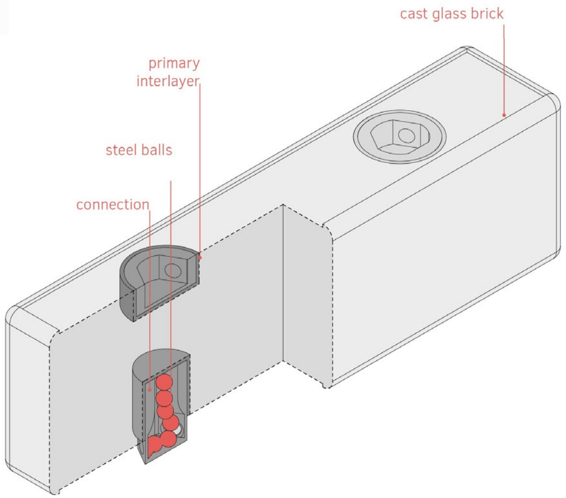
MSc,MEng Grammatiki Dasopoulou

grammatiki@eocengineers.com

Grammatiki Dasopoulou is an Architect and Building Technology Engineer, currently working as a Façade Engineer for Eckersley O'Callaghan engineers in Paris. Her dual background in Architecture and Engineering enables her to apply her knowledge to a variety of façade engineering solutions for new and refurbishment projects in France and international. Her experience spans across medium and large-scale projects from the early design stage until construction, while she is experienced in delivering execution calculations related to thermal breakage analysis of complex glass façade systems. In 2020 Grammatiki graduated with an honourable mention from the Building Technology track at TU Delft. Her thesis work explored an innovative locking mechanism for cast glass bricks which led to a patent of a novel structural connection system for vertical components. Grammatiki alongside her colleagues was awarded the second prize in the 2017 Greek National Competition, "Colour in Architecture". The project explored various facade engineering principles by developing a system of movable louvers on an abandoned building.



1. The novel connection system



2. The novel locking mechanism embedded in a cast glass block

This talk presents the research about a novel, concealed yet fully reversible connection system that has been designed to provide the easy assembly and disassembly of the cast glass bricks without compromising the overall transparency. The embedded connection incorporates a system of internal paths, apertures, and a set of magnetizable balls. The locking mechanism is activated/deactivated with the aid of a magnetic field. The initial inspiration for the new connection system came from the technical difficulties introduced by the existing cast glass connections, such as the irreversible nature of the adhesively bonded cast glass blocks of the Crystal Houses façade. Could we develop a new connection system for cast glass bricks that grants a controllable and calculable structural performance, demountability, and equally importantly, it remains visually discreet without significantly compromising the overall transparency? The novel connection has been developed according to a fundamental design principle: the mechanism operates without any manual intervention - actually, there is no external access to the connection, preventing thus inconsistencies due to human error. The internal design of the two-part connection will be extensively described, leading to a comprehension of the assembly and disassembly sequence of the cast glass blocks. The presentation will finally highlight the further applicability of this novel connection system: could we possibly apply this innovative locking mechanism to other materials and building systems?

Research team: Grammatiki Dasopoulou, Dr. Faidra Oikonomopoulou and Dr. Marcel Bilow.

Open GLASSroom project

dr. Jagoda Cupać
jagoda.cupac@tu-dresden.de

Jagoda Cupać is a researcher and lecturer at the Institute of Sustainable Building Construction at the Faculty of Civil Engineering at TU Dresden. She's been working in the field of glass and façade engineering, in practice and research, for the past 13 years. She earned her PhD degree at EPFL on the topic of Post-tensioned glass beams. In recent years, her focus in research has been glass circularity and reuse of end-of-life components. Meanwhile, in education of civil engineering students, she's been exploring innovative practices, with emphasis on interdisciplinarity, creative thinking, active learning and open education. This year she co-organised Circular Design Challenge, an international student competition in reuse of end-of-life components. Presently, she leads the Open GLASSroom project.

In partnership with:

abt, ARUP, Bellapart, Eckersley O'Callaghan, Octatube, Permasteelisa Group and the International Year of Glass 2022.

Despite its popularity, glass is still considered a highly specialised material, rarely taught at technical universities and certainly not at the same level as more commonly applied materials, such as steel, concrete and timber.

open glassroom

This Erasmus+ project brings together an international community of glass experts in developing a common future-oriented glass curriculum. Together we produce high-quality educational materials on glass design & engineering, digitalise and share them as Open Educational Resources on the platform Open GLASSroom. We address fundamental and emerging topics in research and innovation, including sustainability of glass in construction. Our aim is to consolidate existing knowledge and create synergies between students, educators, researchers and practitioners across Europe. The project is led by six universities - Technische Universität Dresden, Delft University of Technology, Czech Technical University in Prague, University of Rijeka, Universitat de Girona, Politecnico di Bari, and supported by industrial partners. This talk is an open call for contributions to all glass experts and enthusiast who would like to share their built projects and research on glass.

Project team: Lisa Batzdorf, Aline Bergert, Adriana Bjelanović, Telesilla Bristogianni, Neboša Buljan, Francesco Carlucci, Jagoda Cupać, Martina Eliášová, Francesco Fiorito, Christian Louter, Faidra Oikonomopoulou, Laura Oberender, Mauro Overend, Angelica Rota, Zdeněk Sokol, Daniel Trias

Co-funded by the European Union

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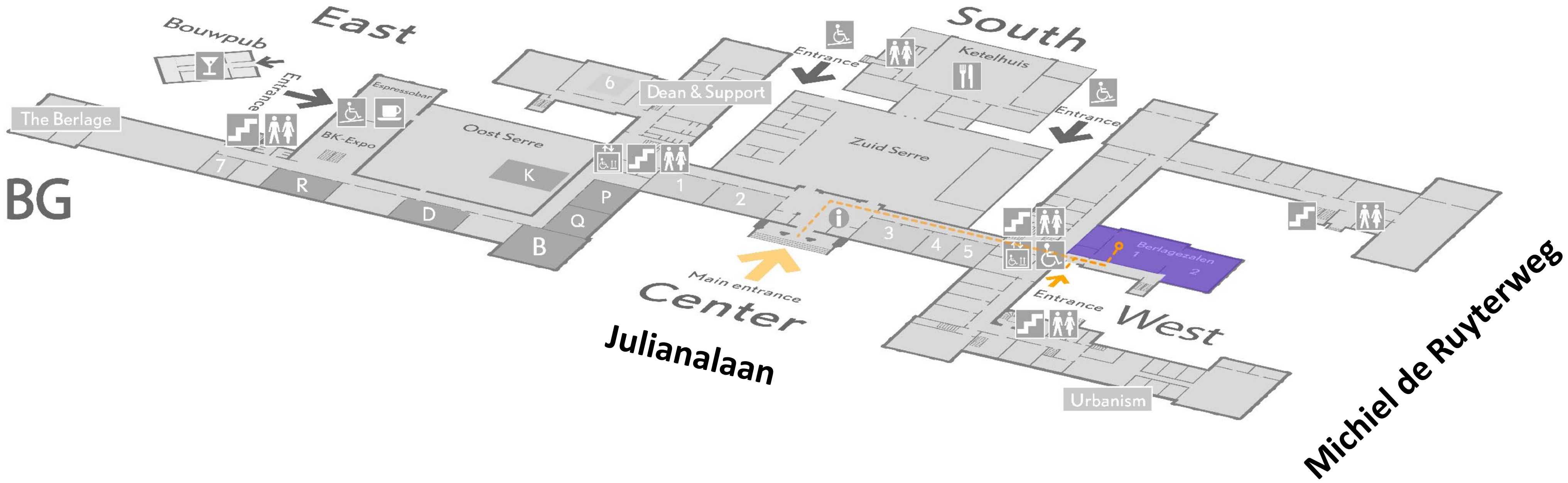
Directions - Venue

The Glass forum 2023 will take place at the TU Delft campus at the **Berlagezalen** (in purple), on the ground floor of the faculty of Architecture, **Julianalaan 134, 2628BL, Delft.**

We recomend that you use the West entrance (bright orange arrow) of the building as it is closer to the venue. In case you access the building through the main entrance you can follow the dashed orange line.



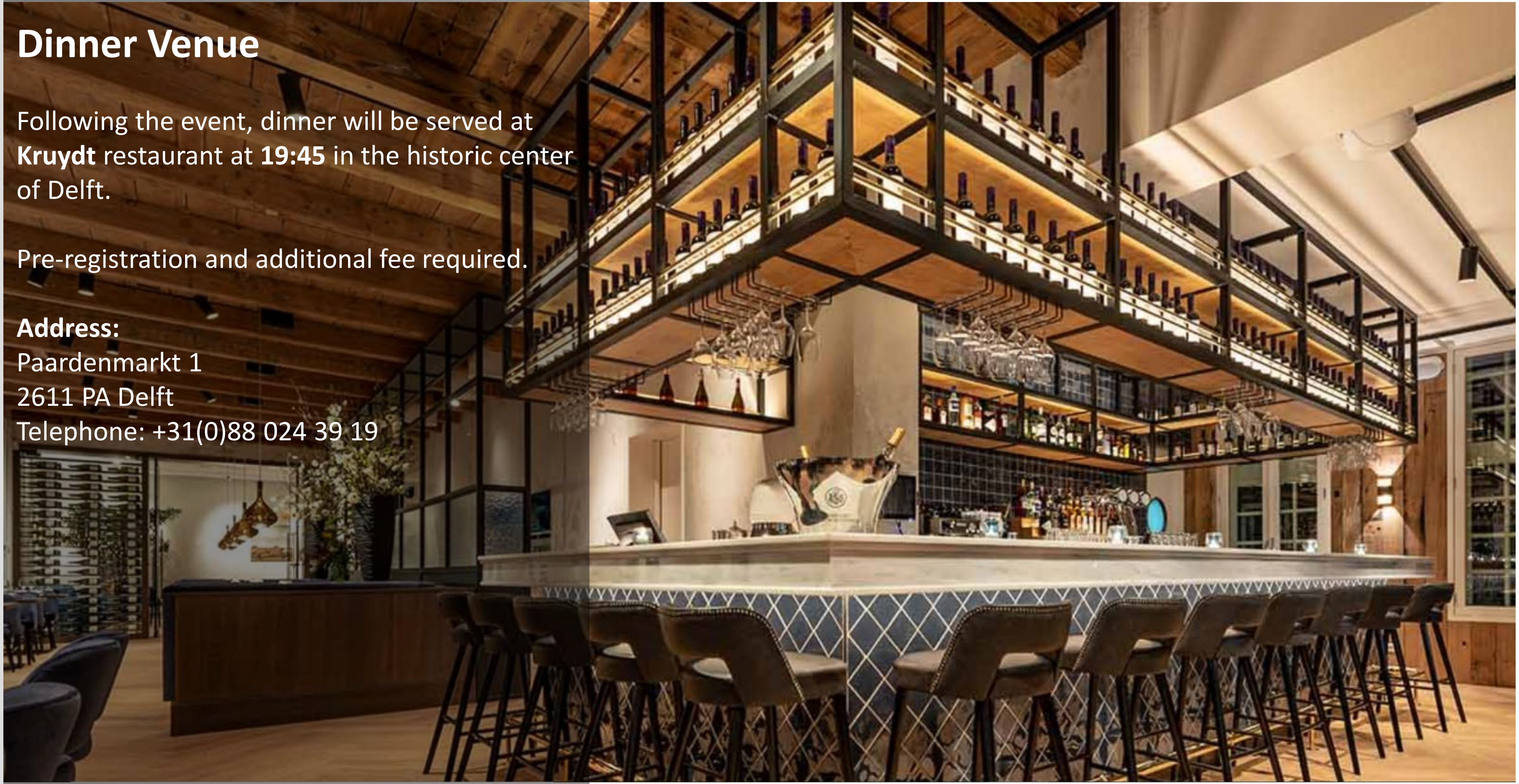
TU Delft | Bouwkunde

Dinner Venue

Following the event, dinner will be served at **Kruydt** restaurant at **19:45** in the historic center of Delft.

Pre-registration and additional fee required.

Address:
Paardenmarkt 1
2611 PA Delft
Telephone: +31(0)88 024 39 19



The Glass Forum 2023

Recent Developments in Architectural Glass Research

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