sk engineered s 2019

Sharing recent developments in Glass and Façade Engineering

gFT glass & façade technology research group
TU Delft
UNIVERSITY OF CAMBRIDGE

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engineered skins 2019

Dear Symposium Delegate,

Welcome to the 10th annual Engineered Skins symposium organised by the Glass and Façade Technology (gFT) Research Group at the University of Cambridge. This one-day event will run in a similar way to our recent symposia, but in addition to the two keynote speakers and the researchers from the University of Cambridge we will also be joined by researchers from TU Delft who will present some of their recent research findings in the symposium. The symposium will therefore be an opportunity to learn about the recent research developments from two of the leading universities in this field.

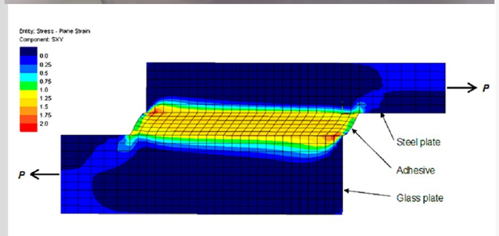
This is a free invitation-only event, to which a select group of industrial and academic partners have been invited. We would like to thank AGC Interpane, Dow, Eyrise, Kingspan, Kommerling, Seele, Trosifol and Tuchschmid for sponsoring this event. We would also like to thank the numerous funding bodies and industrial partners who are contributing to our research activities. These are acknowledged in the relevant presentation and project descriptions in these proceedings.

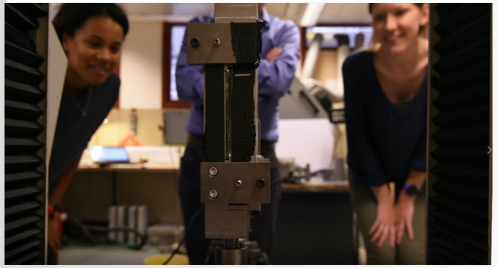
We welcome feedback on the day's events and on the individual research projects and we are happy to provide further information if required. Please feel free to approach any of the presenters with questions. You will also receive an email inviting you to give feedback / request information after the event.

I hope you enjoy the day and that you find our research stimulating and useful.

Best wishes,

Mauro Overend





The Glass and Façade Technology Research Group

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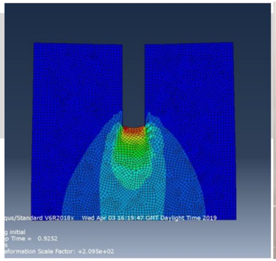

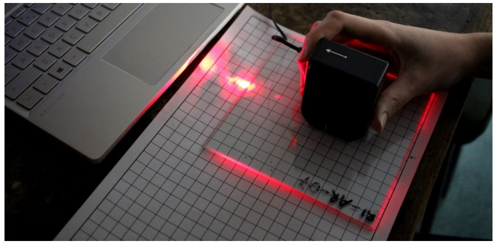

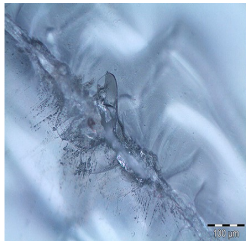

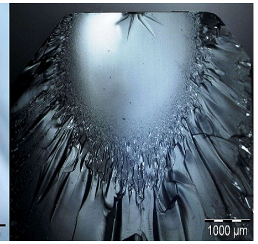

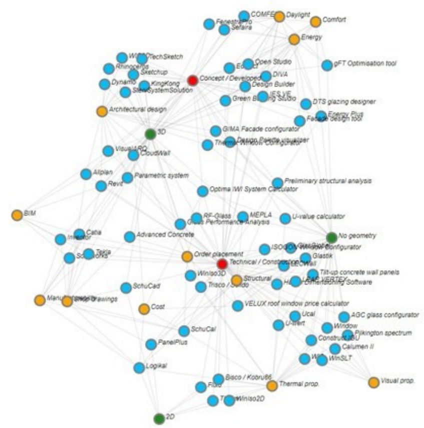

The Glass and Facade Technology (gFT) research group aims to address real-world challenges and disseminate knowledge in the field of glass structures and façade engineering by undertaking fundamental, application-driven and inter-disciplinary research.

The Glass and Façade Technology Research Group aims to provide solutions to real-world challenges in the field of structural glass and façade engineering through fundamental and application-driven research. The challenges range from **reducing the energy use** in buildings and achieving a **higher level of environmental comfort**, to improving the **mechanical performance of glass** and of other **novel materials** used in façade, through to improving the **façade design / construction processes**.

The research group consists of a core group of researchers within the Department of Engineering at the University of Cambridge. This is supported by a network of researchers in other centres of excellence worldwide. Most of our projects are grant-aided or industry-funded research and involve close collaboration with industrial partners such as glass producers and processors, cladding manufacturers, façade contractors, consulting engineers and architectural practices.

Mauro Overend mo318@cam.ac.uk M.overend@tudelft.nl

Dr Mauro Overend founded and leads the Glass & Facade Technology Research Group at the University of Cambridge where he is also is a Senior Lecturer in Building Engineering Design at the Department of Engineering and a Fellow of Christ's College. Mauro is a chartered engineer with several years of consulting engineering experience in the fields of structural engineering and façade engineering. His research at Cambridge is at the interface of structural response and environmental performance of building envelope systems and glass in particular, which are central to the development of the next generation of resilient, low energy and productive buildings. Dr Overend has more than 80 peer-reviewed publications to his credit and leads / serves on several international committees related to glass and façade engineering. He is a founding member and joint Editor-in-Chief of the Glass Structures & Engineering Journal. He has founding and leading roles in the European Research Network on Structural Glass and the European Research Network on Adaptive Facades and in 2015 was appointed by the European Commission to help draft the Glass Eurocode. Mauro's research and engineering expertise has been used on some of the most challenging and high profile buildings worldwide and he has received several international awards for his research on glass and facade engineering such as: the Guthrie-Brown medal (2011), The IStructE Research Award (2012), the IABSE Prize (2013), the Bright Ideas Award (2014) and in 2016 he was elected to the College of Fellows of the US-based Façade Tectonics Institute. Mauro is in the process of moving to TU Delft where he has accepted the Chair of Structural Design & Mechanics.

Keynote Speakers

Miriam Dall'Igna, Foster & Partners

Miriam Dall'Igna is a senior computational designer/researcher with experience on the design of complex forms for manufacturing and construction.

She explores novel ways to resolve design problems by integrating building physics and geometry. She brings the latest technological innovations in performance driven algorithmic design, robotics, advanced manufacturing and kinetic/adaptive systems to the core of her work. Part of her tasks are the development, experimentation and implementation in architectural practice of state-of-the-art software and hardware.

She is currently focusing in the research of goal-oriented autonomous robotic systems and additive manufacturing for complex geometry large scale construction in harsh environments. Her background is in architecture and computer science.

Keynote Speakers

Prof. ir. R. Nijsse, TU Delft: Adventures in Corrugated Glass

Prof.ir. R. Nijsse

Rob Nijsse (Amsterdam, 1953) graduated in 1979 from the TU Delft, faculty of Civil Engineering. Started to work as structural engineer at the consulting engineering office ABT in 1979, became senior advisor in 1991, up to now, and was member of the board of directors from 1996- 2007. From 2003 up to 2007 he was appointed as a part time professor at the University of Gent (B) in Structural Engineering. In 2007 he was appointed as part time professor at the Technical University of Delft, Faculty of Architecture and in 2010 also as part time professor in Building Engineering at the faculty of Civil Engineering and Geo-sciences. Professor Nijsse has started, and is leading, a section of the Stevin II lab in Delft, dedicated to Structural Glass applications.

Corrugated Glass Facades

Four projects have been worked out at ABT with a corrugated glass façade;

- Casa da Musica in Porto (Portugal). Architect OMA, completed in 2005
- Museum at the Stream (MAS) in Antwerpen (Belgium). Architect Neutelings Riedijk, completed in 2010.
- National Library in Doha, Qatar. Architect OMA, completed in 2017.

Taipei Performing Arts Center (TAPC) in Taipei, Taiwan. Under construction, to be completed in 2019.

In these facades corrugated glass panels were incorporated to provide strength and stiffness to glass panels of large sizes. Also in laminated (safety) glass and Insulated Glass Units (IGU). The architectural appearance of a building benefits from the corrugate-ness of the glass. In this buildings the glass has to withstand earthquakes and typhoons.

Speaker Abstracts and Profiles

Façade Impulse: How the façade affects occupants

Alessandra Luna-Navarro

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Alessandra research interests are in adaptive façades and human comfort, energy demand and sustainability in the built environment. In 2013, she graduated with distinction in Building Engineering and Architecture at Università degli Studi "La Sapienza" in Rome. She is a chartered civil engineer in Italy and in UK with CIBSE and worked in building services engineering, fire safety and building design for a broad range of large buildings. In 2016, she successfully completed an MPhil in Energy technologies at the Department of Engineering at the University of Cambridge, and she joined the gFT research group to pursue a PhD on adaptive façades and human comfort. Her PhD research is funded by Permasteelisa, Arup and EPSRC.

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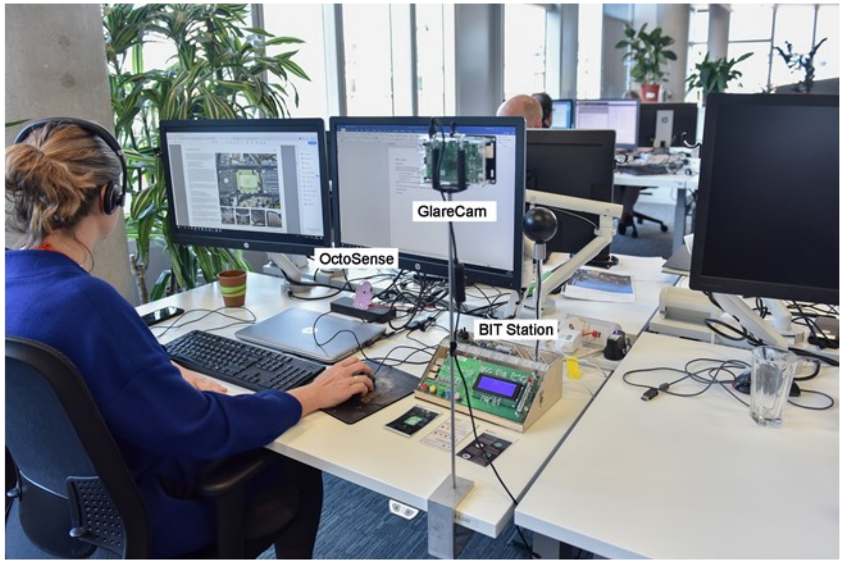
Façades are the primary means of modifying undesirable external conditions to achieve a desirable internal environment Their energy efficient performance has often been associated with low energy buildings. However, the building envelope has a very significant and more direct impact on occupants beyond energy efficiency. As multi-sensorial filters, façades have the potential of connecting occupants to the outdoors, while simultaneously moderating the energy and mass flow to positively impact occupant comfort, satisfaction and productivity. In order to understand their impact on human factors, the Façade Impulse research project aims to stretch the intelligent and smart envelopes beyond human comfort, to include their interaction with occupants. This presentation presents the methodology and experimental facility developed to assess the transient and multi sensorial effects of alternative façades technologies.

Façade Impulse was born as a joint project between the University of Cambridge, Arup and Permasteelisa. A bespoke test cell, called MATELab has been built in order to validate and quantify the façade effect on office like environments in the UK In parallel, experiments in real offices have been performed with a novel IoT sensor toolkit called BIT to collect high frequency user feedback.

1 | Novel test facility called MATELab



2 | New IoT toolkit called BIT

Affective buildings

Mark Allen
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Mark began his PhD in October 2016 under the supervision of Dr Mauro Overend as part of the Glass and Façade Research Group (GfT) and Future Infrastructure and Built Environment Centre for Doctoral Training (FIBE CDT). After graduating in Civil Engineering from Durham University in 2014, he worked as a route engineer for the High Speed Two railway project. In 2015, he joined the FIBE CDT at Cambridge, completing his Masters in Research in August 2016 (also under the supervision of Dr Overend) titled 'Buildings Inspired by Nature'. His PhD research explores the idea of using video data to try to 'gauge' occupant comfort and well-being in buildings. The ultimate aim is to integrate this into a smart building architecture, controlling a building based on the optimisation of occupant comfort and well-being rather than the minimisation of energy use.

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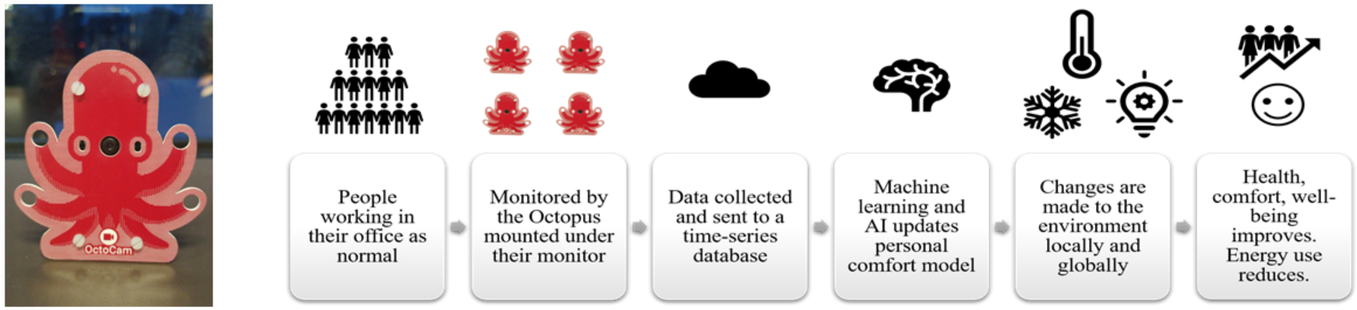
In the last few decades, the energy consumption of individual buildings has been steadily improving. As a result, research efforts are shifting more towards acquiring a deeper understanding of occupant comfort, health, and well-being in the built environment. However, existing techniques used to measure and predict the comfort of occupants have seen little change since Fanger and are often infrequent and/or disruptive to occupants. New research attempts are hence focusing on methods to gather more data, more frequently, and less intrusively.

Facial expressions and movements are one of the major forms of communication between people. They also provide the basis for a growing research area in human computer interaction, known as affective computing. This little explored source of data is the one gathered from real-time videos of occupants, the so-called facial action units (FAU). These are the facial movements and positions that constitute the basic elements of emotions. Using software developed in the realm of affective computing, building occupants were monitored for a period of 2 weeks, whilst also completing surveys that gathered information about the office environment, and their work and personal life. Results found that there are indeed some significant differences in average values of FAUs between occupants. Further studies and ideas are also discussed. These findings aim to show the potential of using FAUs to assist in the control and design of buildings in a more human-centric manner.



1 | Octopus (left) and data schematic diagram of data process (right).

Occupant well-being through switchable, electrochromic glazing

Etienne Magri
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Etienne Magri is a practicing architect and civil engineer, with over 20 years' 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 with a focus on the thermal performance of spaces fitted with different types of glazing systems in a cooling-dominated climate.

He is currently reading for a Ph.D. with the University of Malta in collaboration with the University of Cambridge UK, during which he will be investigating the potential for the use of electrochromic glazing for buildings within a Mediterranean climate to improve on the energetic performance of buildings and the well-being of building occupants.

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, especially in a central Mediterranean climate. This research delves into the ever-important need to design for occupants and for designers to keep in mind, first and foremost, occupant well-being rather than aim solely to create energy-efficient buildings.

Nowadays, the need for occupant comfort and its direct effect on productivity cannot be ignored. Studies show that occupant well-being is directly related to a range of environmental factors, particularly daylight distribution, glare and indoor air temperature. The use of external shading devices and more commonly indoor blinds are often the adopted approaches to attempt to achieve indoor occupant comfort, frequently to the detriment of views. Electrochromic glazing has a great potential in a cooling-dominated, central Mediterranean climate to achieve a compromise between occupant visual and thermal comfort whilst retaining unobstructed outdoor views. Still in its early stages, this research will attempt to investigate the potential benefits of electrochromic glazing in a real-life office environment and this presentation further introduces the objectives for a field study within two identical offices, having a South-South-East orientation, located in a central Mediterranean climate.

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Unlocking the re-use potential of glass façade systems

Rebecca Hartwell

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Rebecca Hartwell joined the gFT research group in October 2017. She graduated in Material Science and Engineering (MEng) at the University of Manchester in 2015; including a 1-year placement at Siemens Magnet Technology, Oxford. Subsequently, Rebecca continued to work as a research assistant at the International Centre for Advanced Materials - University of Manchester, to develop research in understanding the role of microstructure in the failure of insect cuticle using X-Ray Computed Tomography. In 2016, she joined the Future Infrastructure and Built Environment (FIBE) CDT at Cambridge, and is currently working to develop novel design strategies and technologies for improving the reuse and recyclability of building envelopes.

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Increasing legislation on building energy performance in use has stimulated façade design to evolve to serve numerous functions and meet complex technical requirements. Perhaps paradoxically, to achieve this goal, an increase in the use of materials, processing methods and construction techniques has reduced the ability to recover material that is high-value in terms of embodied carbon at the end of its first use. This research undertakes a multi-methodology approach to decouple technological improvements in façade design with the ability to recover material through:

1. A review of the existing behavioural barriers and motivations as outlined by industry through online survey (>50 respondents) and follow-up interviews. Term categorization was used to interpret the findings and develop a quantitative evaluation of the main barriers and potential drivers to façade re-use.

2. A framework has been developed for assessing the reclamation potential in terms of environmental impact of different façade designs, with consideration of component service life and different potential recovery scenarios, with the aim of considering re-use options in early-stage design.

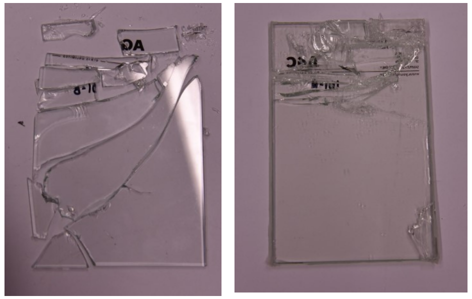
3. Addressing technological challenges in recovery for re-use

   i.) To enable re-use from *existing designs* (stock available from refurbishment and demolition): Laminated glass (glass-PVB-glass) and adhesive sealings are two limiting factors. Within this research, a standardized experimental test jig has been developed to evaluate interfacial separation of glass-PVB.

   ii.) Meeting existing functional requirements through re-use focused *new design* strategies: Further research will consider alternative design methods to deliver the same functional requirements with disassembly and re-use as an early-stage design parameter.

1| Barriers to façade re-use as perceived by façade industry stakeholders

2| Bespoke laminated glass testing jig



3| Interfacial separation of laminated glass samples

Connection design for UHPFRC façade panels

Florence Maskell
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Florence is currently undertaking a PhD as part of the gFT group, following her Meng in Architectural Engineering design at the University of Sheffield. She has interests in intelligent building and facade design, particularly in response to the rise in complex geometry design. Her research is centered around technologies for complex facade design and construction, with a focus on the connection design of fibre reinforced ultra-high-performance concrete (UHPC) panels to the supporting structure.

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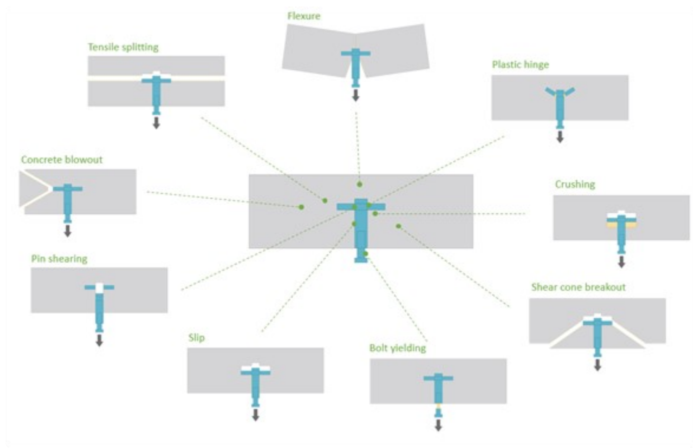
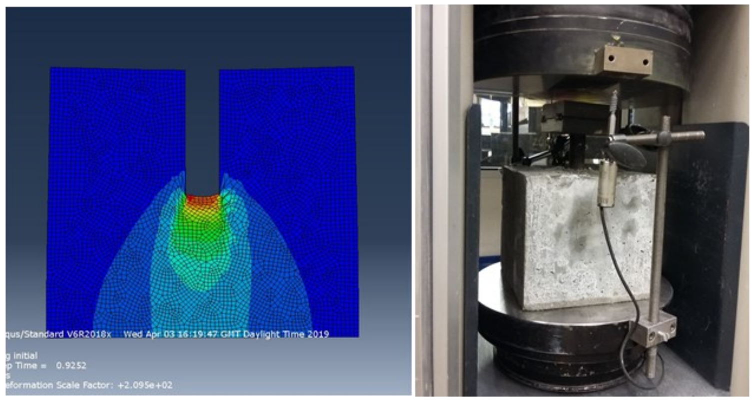
As is common with emerging facade materials and corresponding technologies, a greater understanding is needed to tailor system designs to the characteristics of the technologies used. Ultra-high performance concrete (UHPC) is an emerging material technology which shows great potential for use in panelized facade systems. Due to its high durability and flexural strength, components made from UHPC have a longer design life, as well as using less material in their initial design. However, there is a lack of clarity surrounding the specific behaviour of the material particularly in response to local stress concentrations. In panel systems connections are a critical area due to the concentration of stresses present and the safety implications should they fail. The aim of the presented project is to further understand the mechanical fracture behaviour of high performing fibre reinforced cementitious materials such as UHPFRC under localised stress concentrations through a series of experimental testing at different levels. The data collected will then be used to inform design methods and strength calculations for embedded connections in this material, particularly focused on façade applications.



1 | Failure mechanism diagrams



2 | Image of confined bearing and FE analysis

RE^3 Glass: Recyclable, Reducible and Reusable cast glass components for structural and architectural applications

Telesilla Bristogianni
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Faidra Oikonomopoulou
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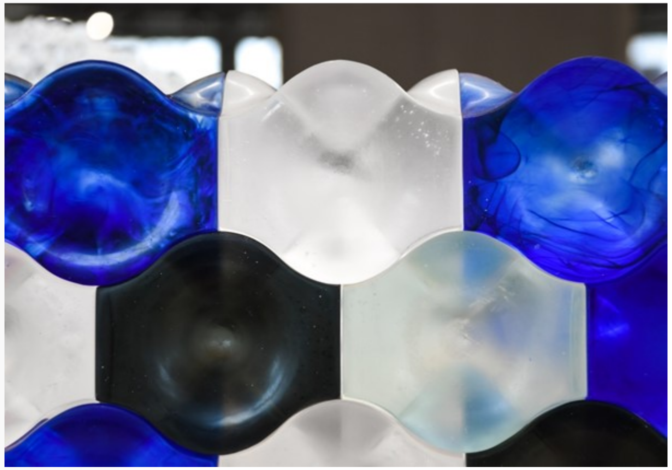
Faidra Oikonomopoulou and Telesilla Bristogianni have both joined TU Delft in 2014 as PhD/researchers focusing on structural applications of cast glass. They both hold a diploma degree of Architect Engineer (NTUA) and a MSc degree in Building Technology (TU Delft). Faidra and Telesilla were deeply involved in the research and development of the adhesively bonded cast glass block system for the Crystal Houses façade. Together they supervised as quality control engineers the entire construction of the Crystal Houses façade and even built together with the crew the first 1.5 meter of the glass wall. For their work in the Crystal Houses the two PhD/researchers have received multiple awards, including the Innovation Award 2016 by the Society of Façade Engineers and the Talent met Toekomst Bouwprijs 2017. Through this project they discovered the architectural potential of cast glass, but also saw the engineering challenges involved. This is when they conceived the idea of Re^3 Glass; a reversible system out of recycled cast glass components. The project was awarded a 4TU.Bouw Lighthouse award, nominated for the New Material Award 2018 and exhibited at Venice Design 2018, Dutch Design Week 2018, Milan Design Week 2019 & Vitra Schaudepot.



Although glass can take almost any shape and colour envisioned, in the field of structural glass, the material is mainly conceived as a 2D transparent element. Escaping this two-dimensionality, the Crystal Houses Façade in Amsterdam, designed by MVRDV and developed by the TU Delft structural glass research group, proved the architectural and structural potential of cast glass in creating three-dimensional, robust and freeform all-glass structures. The Re^3 Glass project continues in this path, enhancing the system's sustainability performance and tackling previously faced challenges such as the excess material use, the permanent bonding & the non-recyclability of glued components. For the casting of the components, waste glass is employed. Currently, despite the common notion that glass is 100% recyclable, the majority of everyday discarded glass objects are neither reused nor recycled. In fact, recipe mismatching or contamination from coatings or adhesives result in the down-cycling or disposal of otherwise top quality glass. Through the project, everyday glass waste, from Pyrex® trays and artware, even mobile phone and computer screens, are redirected from the landfill to the building sector. In addition, cavities and notches are introduced to the design, to achieve lightweight yet strong components and reduce the required material and CO_2 emissions during production and transportation. Finally, the developed interlocking shapes result in a stable and stiff system, while circumventing the use of adhesives. This allows for easy assembly and disassembly, and favours the reuse and recyclability of the components. Following this threefold approach, experiments at the TU Delft Glass Lab with different geometries, glasses and cooling techniques, have resulted in a wide range of clear, coloured, translucent and opaque, marbled glass elements that can form circular, strong & aesthetically intriguing structures.

Novel liquid laminated glass connections

Stratis Volakos

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Stratis graduated (MEng) in Civil Engineering in 2014 at the National Technical University of Athens (NTUA) and he completed his Masters studies (MSc) in Analysis and Design of Earthquake Resistant Structures in 2016 at the same university. During 2016-2017, he worked as a junior structural engineer in Athens and then he joined the gFT research group in October 2018. His PhD research is on façade design with special interest in novel composite connections for glass structures under the supervision of Dr Mauro Overend. His project is funded by EPSRC, Arup, Koemmerling and Seele.

The architecturally driven demands of lightness and transparency have increased rapidly the use of glass in buildings in the last decades. A key role in all glass applications is given to connections since the stress concentrations that occur when forces are transferred between components, endanger the structural efficiency of such structures due to the inherently brittle nature of glass. To date, autoclave embedded laminated glass connections represent an emerging promising method for connecting glass. Its main advantage is that it combines the enhanced post-breakage behaviour of laminated glass with the benefits of adhesive bonding and of the well-established semi-automatic manufacturing process of autoclave lamination. However, the use of autoclave in conjunction with vacuum bag result in increased manufacturing cost and also residual stresses arise during the lamination process due to the differential thermal expansion between the glass and the insert that often cause glass breakage.

Therefore, this research project aims to develop a novel liquid embedded laminated glass bonding technique by using transparent cold-poured resins in an attempt to avoid the aforementioned problems associated with the autoclave lamination process. To this end, the long-term performance of cold-poured resins will be investigated to identify their mechanical behaviour in relation to variations in temperature and humidity. Additionally, the compatibility of different types of insert material will be examined in order to find a cost-effective option which also offers sufficient structural and aesthetic performance. The overall performance of the proposed connection will eventually be compared to other novel glass bonding techniques (e.g. welding) to ensure its superiority in terms of ease of design, manufacturability, structural and aesthetic performance.

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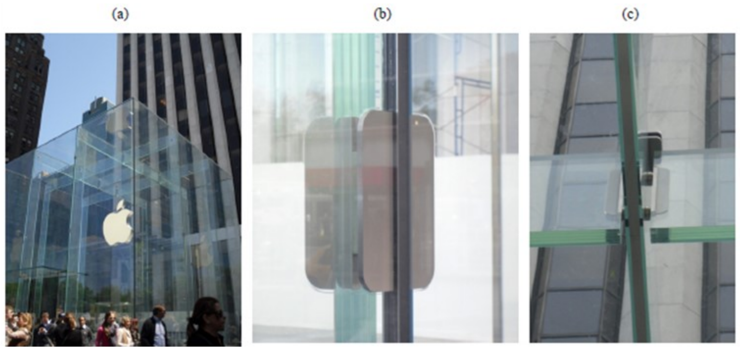

a) Global view of Apple Retail store in New York b) Close view of embedded laminated connection between column and façade panel c) Close view of embedded laminated connections between roof beams

Fill-in-Glass Restoration: A new approach for the consolidation of our built heritage

Lida Barou
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Lida Barou joined the TU Delft *Glass & Transparency research Group* in July 2016. After her studies in Architectural Engineering (MArch) and Building Technology (MSc) she has been actively involved in innovative glass research on cast glass. During the last three years Lida has been part of the 4TU.Lighthouse Projects *Restorative Glass* and *RE^3 Glass* and recently started her PhD research, funded by ABT Engineering Consultancy, where she also works as Building Engineer. Her passion for architecture, heritage and innovation is combined in her research on *Restoration with Glass*, which comes as continuation of her MSc thesis and has been awarded with the WTA Monumenten Preis 2017.

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abt ingenieurs in bouwtechniek

Materiality has been one of the most controversial topics in restoration and conservation practices, sparking heated debates on aspects of reversibility, minimum intervention and authenticity. Our ambition to consolidate the decayed historic structures often conflicts with our ambition to leave the monuments as intact as possible. While, traditional materials bear the risk of conjecture between old and new elements, modern materials may appear imposing over the existing ones and impair their authentic image. Glass is proposed as a possible answer to this on-going materiality debate. Transparency enables the simultaneous perception of both the original and ruinous state of the monuments, relating the past to the present setting. Although nowadays we encounter a variety of contemporary glass architecture in a historic context (usually in the form of protective canopies or adjacent assemblies) the integration of glass in existing structural elements is little explored.

This research investigates the potential of integrated glass elements in decayed historic buildings that actively contribute to the improvement of their stability and structural integrity. Focus of the study is the compatibility between the different materials, stressing the importance of connectivity as the most challenging and yet unknown aspect. Aim of this study is to design, develop and experimentally assess various connection concepts between glass and historic materials (stone, ceramic brick and timber) based on case studies. Aspects of manufacture, assembly and maintenance as well as the principle of compatibility on aesthetic, structural and functional levels are also addressed. The results of this research will form a methodology on how to approach such restoration strategy and will unfold the spectrum of possible applications of structural glass as restoration material and its integration in hybrid structures in general.

1 | Restoration proposal of Bembo's Bastion with an interlocking cast glass masonry (MSc thesis)

2 | Artistic restoration of an old flourmill by C.Varotsos

3 | Restoration of Timoleonte's Wall by F. Minissi

Blast response of laminated glass

Socrates Angelides
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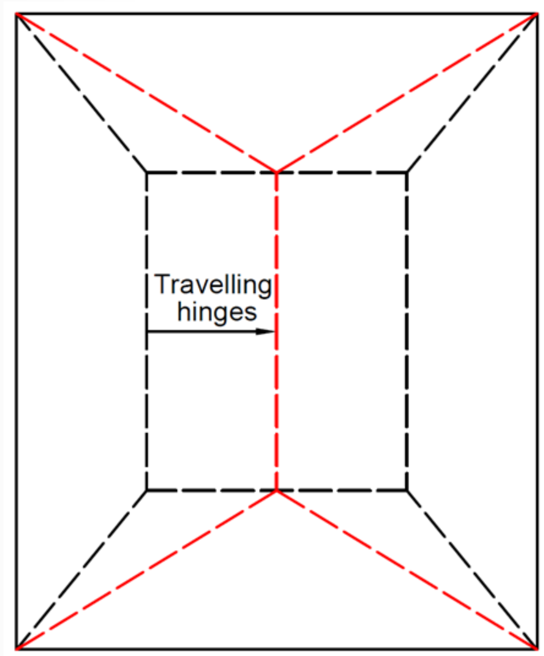
Socrates Angelides studied MEng Civil Engineering at Imperial College London and worked for 3 years at DNVGL as a Structural Engineer in the Oil and Gas industry designing offshore structures. He joined in 2016 the Future Infrastructure and Built Environment CDT in the University of Cambridge and is currently researching the structural response of laminated glass panels subjected to blast loads.



1 | Collapse mechanism under intense loading that leads to travelling plastic hinges

Laminated glass panels are increasingly used to improve the blast resilience of glazed facades, as part of a wider effort to mitigate the threat posed to buildings and their occupants by terrorist attacks. The blast response of these ductile panels, however, is still only partially understood and requires bridging of the knowledge gap between the fundamental behaviour at material level and the response observed in full-scale blast tests. To enhance our understanding of the structural response of laminated glass and bridge this knowledge gap, this research adopts a ‘first principles’ approach and investigates the effects of high strain-rate associated with blast loading, in-plane restraint offered by blast-resistant frames and inertia effects. These are studied by developing simplified analytical beam models for all stages of deformation, with a view to improving on current analysis methods, and validated through a cost-effective experimental programme. The hope is that practicing engineers will benefit from a more efficient and sustainable design method that utilises the full capacity of the material.

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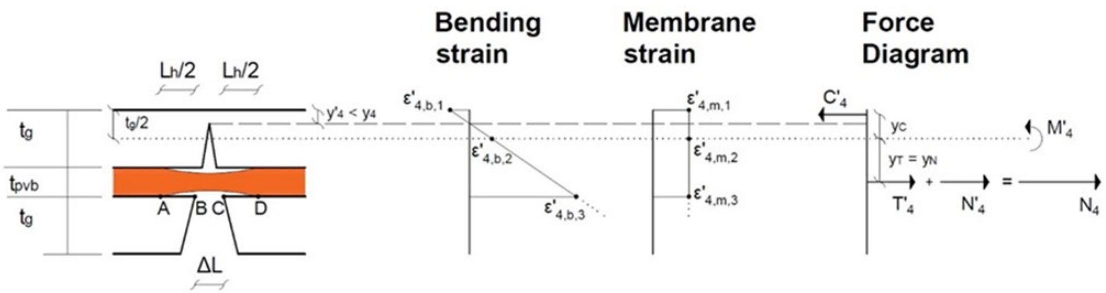
2 | Combined bending and membrane action in post-fracture response of laminated glass



Vector active glass structures

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Ate Snijder joined the Glass and Transparency Research Group at Delft University in 2014. He holds a B.Sc. and M.Sc in architecture from University of Cape Town and Delft University. Next to teaching structural design and structural glass design at the faculties of Architecture and Civil Engineering at TU Delft he is involved in research on glass and the realization of several (glass) structures both with the university and independently.

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Extruded glass sections such as tubes and rods have been available for some decades. The use of tubes as struts in building structures has been investigated and applied in practice. Currently research is being conducted by the Glass & Transparency group, in cooperation with glass producer Schott, to explore new/further application of the extruded glass sections in structures.

Together with students, in an educational setting, a number of prototypes and structures have been build using the extruded glass elements. Experience and data gathered during these courses has been put towards constructing two demonstration structures: The Glass Truss Bridge and The Glass Swing. These have demonstrated the technology to be viable and more experiments and applications for Glass struts are coming up.

1 | Glass Truss Bridge (left), Glass Swing (right)

Recent developments in composite glass structures

Carlos Pascual Agulló

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Dr Carlos Pascual Agulló has recently joined the company Bellapart as Research Engineer and investigates the development of large-scale and slim composite glass modules for building envelopes. Prior to this he was a post-doctoral Research Associate at the gFT Research Group (Cambridge) where he led EPSRC-funded research on mechanically-slim and thermally-efficient GFRP-glass composite panels. He joined gFT from EPFL (Lausanne) where he completed his PhD thesis on translucent and load-bearing GFRP envelopes for daylighting and solar cell integration. He graduated as Civil Engineer at Valencia and worked there as structural engineer in the design of GFRP structures for building & bridge construction.

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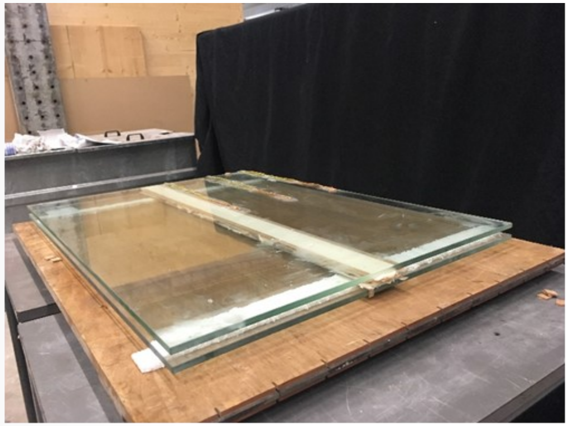

Fig. 1. Composite glazing panel with central spine

Fig. 2. Four-point bending test on composite panel

The integration of frame and glass panes into a single composite sandwich structure allows for the design of large-scale and mechanically-slim glass modules for transparent building envelopes. In this configuration the frame, e.g. made of glass fibre-reinforced polymer (GFRP) profile, is sandwiched and adhesively-bonded in between glass face sheets (Fig. 1).

In recent years, the gFT group has produced substantial experimental and analytical work to evaluate the feasibility of design and the flexural and buckling responses of this type of composite sandwich structures. However limited research had been done to-date to evaluate the mechanical contribution of wide face sheets. In fact, shear-lag effects (i.e. the non-uniform distribution of axial stresses across the width) tend to develop in large face sheets and can reduce their mechanically-effective width. Experimental data is therefore required to evaluate this effect.

In the present work, an experimental campaign has been performed to measure shear-lag effects in composite glazing panels. To this purpose four composite panels of dimensions 700 x 1000 mm^2 were tested under four-point bending loads up to failure (Fig. 2). Panels with different frame configurations (central and lateral spines) and adhesive materials (epoxy and silicone) were evaluated. The face sheets were equipped with strain gauges to monitor the distribution of stresses – and displacement transducers measured the deflections of the panels. The results of the tests, and the comparison with analytical predictions, will be presented and discussed.

Towards innovative glazing technologies for comfort and energy saving improvements in office buildings

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In 2017, Michalis graduated in Engineering (MEng) at the University of Cambridge, qualified in Aerospace and Aerothermal Engineering, Energy, Sustainability and the Environment, funded by the Cambridge European Bursary. In 2017, he joined the Future Infrastructure and Built Environment (FIBE) CDT at Cambridge, funded by the EPSRC. Michalis joined the gFT research group in May 2018 starting with his MRes project. His research interests lie in sustaina-ble buildings. His research project, during his MEng year, was based on plume and ventilation theory and his research project during his MRes year titled `A new generation of responsive and energy-efficient building envelopes'. Michalis is continuing for his PhD, with the gFT research group, working on the research project `Innovative glazing technologies for comfort and energy-saving improvements in office buildings.

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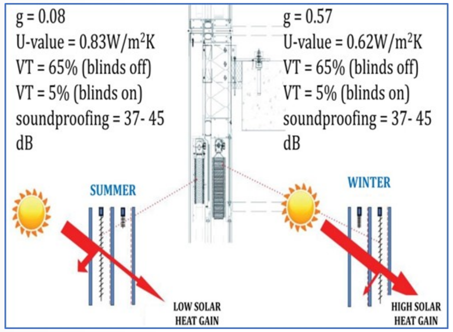
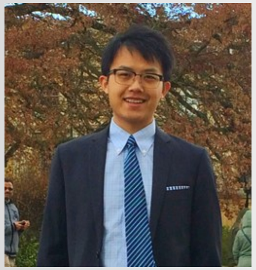


1|Performance characteristics of closed cavity facade.

Buildings are at the pivotal centre of our lives. We spend, on average, 87-90% of our time in buildings (Environmental Protection Agency (EPA), 2018). The characteristics of a building, its design, its look and feel and its technical standards not only influence our productivity, our well-being, our moods and our interactions with others, but they also define how much energy is consumed in and by a building, particularly for heating, ventilation, cooling and lighting. The envelope of a building has an important and direct effect on its overall performance and whole-life cost. Glazing is particularly critical because it is the most vulnerable envelope part to heat gain and heat loss that counts for around 42% of energy consumption (U.S Department of Energy). However, conventional glazing technologies have relatively poor performance characteristics which cause significant heat losses during winter and undesired heat gain in summer.

This study aims to develop an innovative high-performance closed cavity facade technology combining static and dynamic glazing technologies with associated solar radiation control strategies in order to, besides achieving a high thermal resistance, also be able to continuously control (harvesting or rejecting) the incident solar radiation optimizing the incoming thermal and lighting flows. In this regard, the main objective of this research is to investigate the thermal and visual performance of glazing technologies and glazing systems' solutions, in the context of low-energy office buildings with large seasonal heating and cooling loads variations, without compromising the indoor environmental quality (IEQ). Experimental research will be used, in combination with numerical simulations and optimization methods, to assess and optimize the overall performance of glazing systems and associated solar shading devices. The ultimate aim is to devise and develop an innovative high-performance closed cavity facade technology, incorporating new adaptive features like switchable technologies and advanced control strategies, in order to achieve optimized configuration and geometry for maximizing energy saving in office buildings whilst minimizing the whole-life cost and ensuring the required IEQ level. At a preliminary case study, simulating the performance of the MATELab office-like experimental facility, two scenarios were studied, one with CCF incorporating shading system and control strategies and the other one without any shading system. The study concluded that the employed shading system and control strategy resulted in a yearly reduction of 68% and 58% in lighting and cooling energy consumption respectively.

Switchable insulation technologies for thermally adaptive building envelopes



Hanxiao Cui
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After completing his BEng in Architectural Engineering at University of Nottingham, Hanxiao joined the gFT group in 2014, working on the switchable insulation technology and its thermal performance in the built environment. To advance the understanding of this technology, he pursued his PhD in 2015 under the supervision of Dr. Mauro Overend. He is currently working on the development and testing of a novel switchable thermal insulation technology, with a particular focus on its thermal performance, switching and actuation mechanisms.

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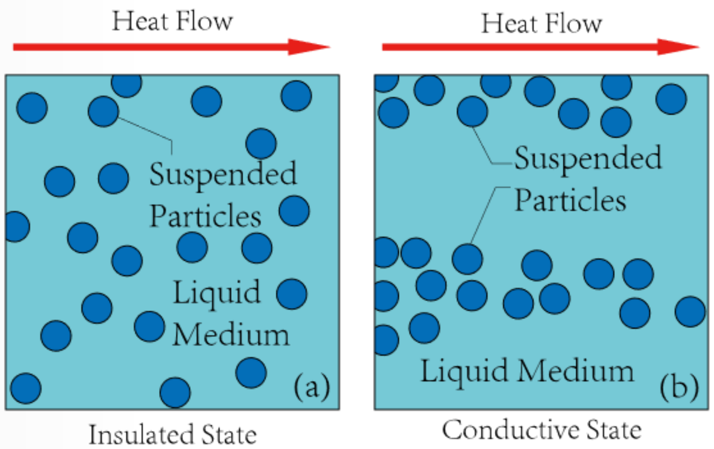
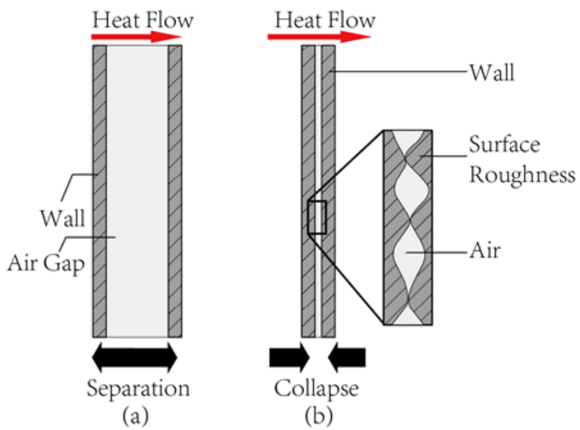
Thermally switchable thermal insulation, in the form of an opaque panels that alternate between a thermally conductive and insulated states, can be an effective means of regulating the thermal environment by selectively harvesting heat from the indoor and outdoor environments. Extensive work has been undertaken by researchers to develop switchable insulation technologies for thermal regulation in the built environment, automobiles, and aerospace applications, where conventional space heating and cooling technologies are either too bulky or too energy consuming to meet design requirements. The presentation starts with a brief overview of heat transfer and switching mechanisms that govern the heat transfer across switchable insulation. Then, the conceptual prototype of a novel switchable insulation will be proposed. Finally, I will discuss the application potential of this novel insulation technology for building applications.



1 | The Insulated and Conductive State of Suspension-based Switchable Insulation



2 | The Expansion and Collapse of a Mechanical Contact Switchable Insulation

Smart textile skins

Paul-Rouven Denz
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Mr. Denz studied architecture at the University of Stuttgart and the E.T.S.A. Madrid. He gained a wide range of experience during showcase building and research projects on sustainability in Germany and abroad. He also successfully participated in architectural and innovation competitions. Paul-Rouven Denz worked among others at Foster & Partners (London), Werner Sobek (Stuttgart), Fraunhofer IAO (Stuttgart), IBK2 (University of Stuttgart, Stuttgart), Gutierrez-delaFuente Arquitectos (Madrid) and ATOL architects (Shanghai). At Priedemann Facade-Lab Mr. Denz focuses as Head of R&D on research on new façade technologies, materials, systems and planning processes. Since 2017 Paul-Rouven Denz is also a PhD guest researcher at TU Delft, Faculty of Architecture and the Built Environment.

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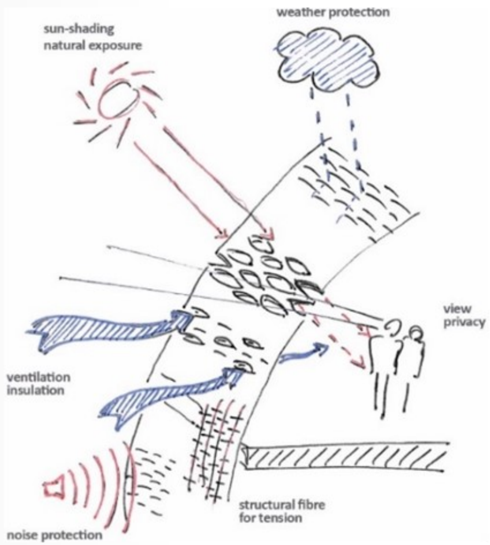
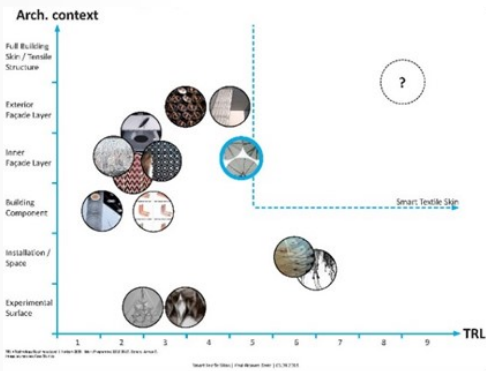
priedemann facade lab



1 | Potential Textile Skin functions



2 | Mapping of Smart Textiles in architecture

Smart Textile Skins can provide valuable solutions for the building skin due to multifunctional systems, interactive surfaces and energy- and resource-efficient solutions. For example shape-memory-alloy enhanced textile structures can be operated self-sufficiently to open and close surfaces enabling sun control. But so far certain restraints, from façade requirements as well as (smart) textile properties, have withhold the implementation of Smart Textile Skins. Analyzing and unifying necessary requirements will help overcome these restrains and link different stakeholders. To facilitate the acceptance and usage of Smart Textile Skins its feasibility has to be verified according to functional and constructional integration into façade systems.

Therefore first concepts as sun-shading devices shall be developed, give basis for future Smart Textile Skins and unite first partners such as architects, textile-designers, textile industry and façade planning. Based on an analysis of state of the art in textile building skins and Smart Textiles an overview of systems, case studies and current research will be given. By interviewing stakeholders from building construction and textile industry and through regulations and system and product properties and requirements current restrains and future potential can be defined. Thus leading to the development of Smart Textile Skins solutions starting from sun-shading devices. Several concepts shall be investigated and real-size demonstrators built. These concepts will than be tested, evaluated and compared to state-of-the-art façade systems to prove its feasibility.

Finally leading to a basic guideline for future Smart Textile Skin developments as conclusion and outlook.

Additive manufacturing with multi-materials

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Adam Pajonk started his PhD program at the TU-Delft - Architectural Facade and Product research group in September 2018. He graduated in Architecture (M.A.) at the University of Applied Sciences Muenster, Germany in 2015. Subsequently, Adam continued to work as a research assistant at the Digital Laboratory – Uni Muenster, doing research on a novel processing method for soft foam – InFoam Printing. His PhD project on Large-Scale Additive Manufacturing with Multi-Materials is supervised by Prof. Dr. Knaack and Prof. Blum. His academic research is funded by the University of Applied Sciences Muenster.

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FH MÜNSTER
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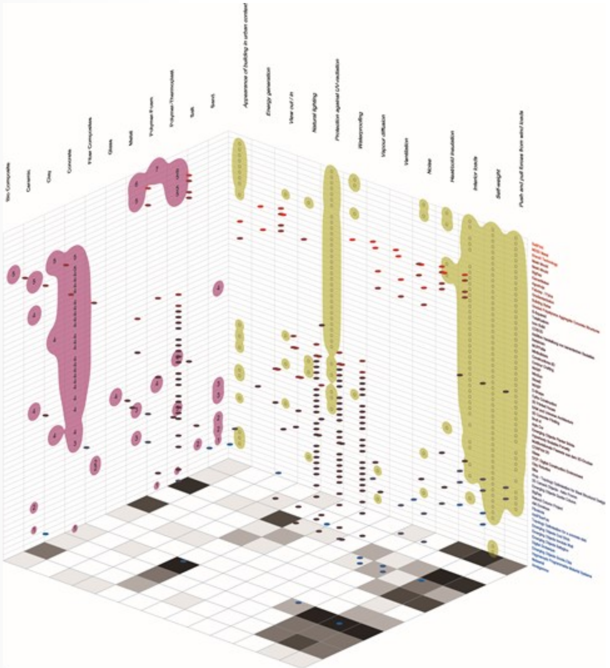
MSA FB Architektur
Münster School of Architecture



1 | Overview of the project analysis based on additive manufacturing and the integration of multiple assembly steps

While complexity of building envelopes increases in order to meet building regulations and emerging demand for novel functionalities, assembly processes of building envelopes remain mainly the same. Causing higher assembly complexity and thereby higher costs and longer construction times. A possible change could be introduced by the emerging technology of additive manufacturing. This process enables a shift from a conventional assembly of singular parts to an integration of multiple assembly steps within one coherent process.

The objective of this research is to propose a novel manufacturing method, based on additive manufacturing, with the focus on combining multiple assembly steps. First, this research aims to understand the relation between different manufacturing methods, based on large-scale additive manufacturing and the ability to incorporate and/or control multiple assembly steps through a comparison of applications and derived functions as well as process parameters.

Subsequently, a refined manufacturing method will be developed and evaluated via prototypes. Finally, the proposed manufacturing method will be tested and evaluated, similar to the initially investigated additive manufacturing projects.

In this talk, I will present the results of the first step, the review of current large-scale additive manufacturing projects. I will explain the used method for this analysis and discuss the gained overview. Further, the most appropriate additive manufacturing methods as well as possible gaps for further refinement will be presented.

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Evening Drinks Reception and Dinner

Christ's College

18:30
Drinks Reception

19:30
Evening Dinner

Grilled Goats Cheese with Beetroot & Walnut Salad

(Artisan Bread Balsamic Vinegar & Olive Oil)

*****

Supreme of Guinea Fowl in Red Wine Sauce

(Game Chips & Watercress)

Open Ravioli with Squash & Porcini Mushrooms (V)

Bouquet of seasonal Vegetables

Dauphinoise Potatoes

*****

Tarte Tatin with Vanilla Ice Cream

*****

Tea, Coffee , Herbal Infusions & Mints

Notes