Engineered Skins 2018 Proceedings

Recent developments in Glass and Façade Engineering at the University of Cambridge

UNIVERSITY OF CAMBRIDGE

gFT glass & façade technology research group

Contents

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6th September 2018
Christ's College, Cambridge

9.30	Coffee & Registration
10.15	Welcome Address
10.30	Keynote: Structural stability and the seduction of curved skins **Prof Allan McRobie (CUED)**
11.15	Coffee Break
11.45	A new generation of responsive and energy efficient building envelopes **Michalis Michael**
12.00	Façade Impulse: Stretching the envelope beyond human comfort **Alessandra Luna Navarro**
12.20	Affective Buildings **Mark Allen**
12.40	Switchable Insulation for Thermally Adaptive Building Envelopes **Hanxiao Cui**
13.00	Lunch
14.00	Keynote: Buildings as material banks: A horizon 2020 research project **Kiruthiga Balson (BRE)**
14.40	Regenerative approach to façade engineering with a focus on end-of-life challenges **Rebecca Hartwell**
15.00	Large scale composite-glass structures **Dr Carlos Pascual**
15.25	Coffee Break
16.00	Environmental durability of FRP-based high performance building envelopes **Isabelle Paparo**
16.25	Efficient panelised façade systems for complex geometries **Florence Maskell**
16.50	Analytical solutions of laminated glass panels subject to blast loading **Socrates Angelides**
17.15	Digital tools for the early-stage design of prefabricated facades **Jacopo Montali**
17.40	Closing remarks and future direction **Dr Mauro Overend**
18.00	Networking and pre dinner drinks followed by dinner (optional)

Dear Symposium Delegate,

Welcome to the 9th annual Engineered Skins symposium organised by the Glass and Façade Technology (gFT) Research Group at the University of Cambridge. This one-day event consists of keynote talks by eminent speakers and presentations on the recent research undertaken within gFT.

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 Arcon, Dow, Interpane, Kingspan, Kömmerling, Merck, Northglass, 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 member of our group 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,

Dr Mauro Overend
Research Group Coordinator

The Glass and Façade Technology Research Group

www.gft.eng.cam.ac.uk

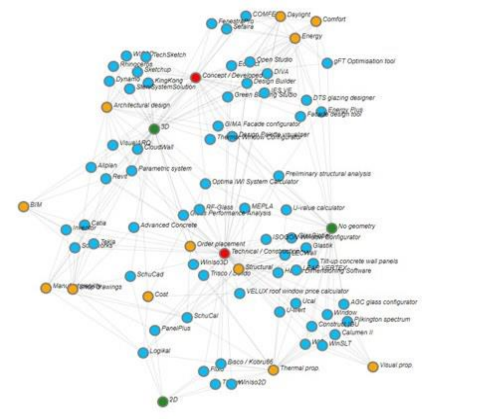
The Glass and Facade Technology (gFT) research group aims to address real-world challenges and disseminate knowledge in the field of glass structures and façade engineering by undertaking fundamental, application-driven and inter-disciplinary research.

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.

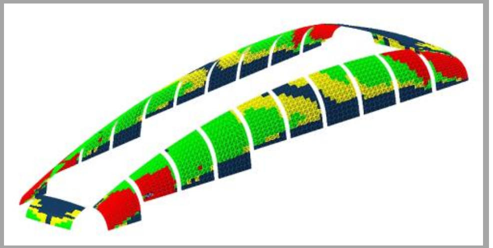
Mauro Overend ***mo318@cam.ac.uk***

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.

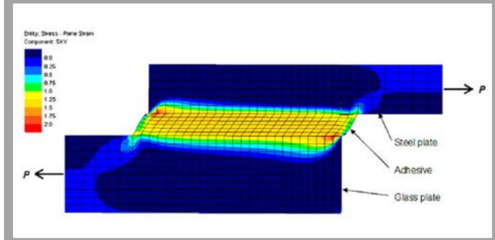


Force-directed layout classifying the currently-available facade design tools

gFT researches emotion recognition for driving adaptive building technologies

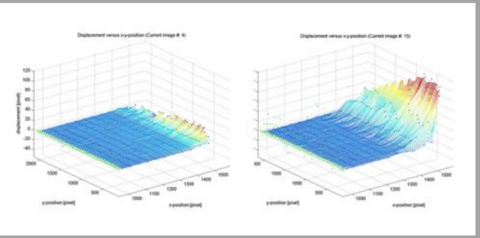


Manufacturability assessment of cold bent glass roof

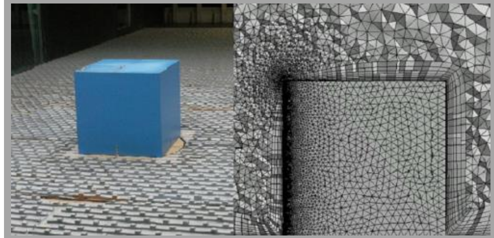


Finite Element Analysis of bonded steel-glass joint

Glass fractography with optical microscope



Delamination in PVB through-crack-tension test



Wind tunnel test (left) and corresponding CFD mesh (right) for wind pressure on facades

Keynote Speakers

Prof Allan McRobie - Structural stability and the seduction of curved skins

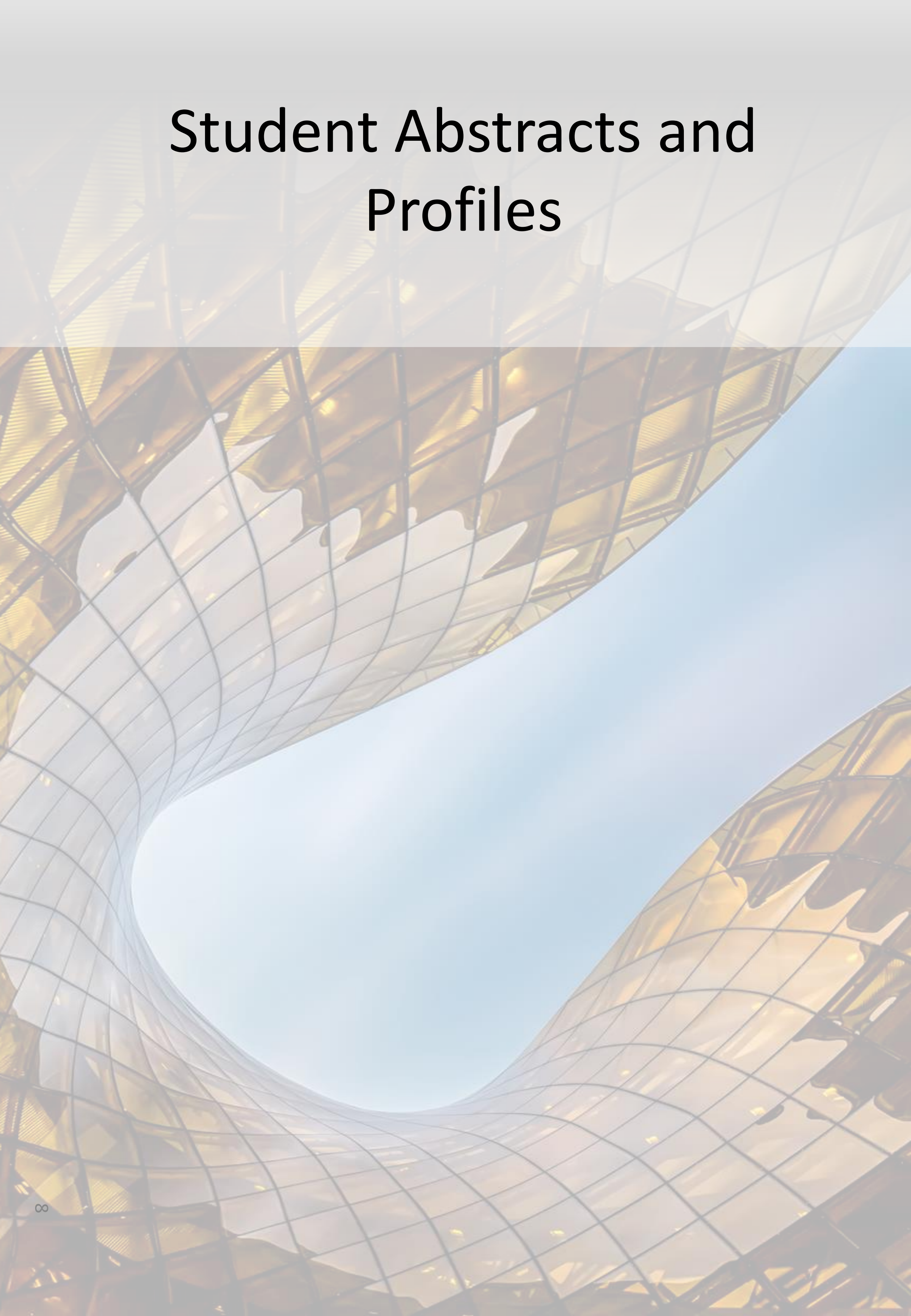
Allan McRobie's research interests are in structural engineering, with particular focus on complex dynamic load environments such as wind excitation of bridges and crowd loading, together with extreme value theory for rational risk management associated with "high consequence, low probability" events that can lead to structural failure. Allan has further interests in water and sanitation infrastructure, particularly in megacity slums.

Keynote Speakers

Kiruthiga Balson - Buildings as material banks: A horizon 2020 research project

Kiru is a sustainability consultant with 10 years of professional experience, in advising clients, design professionals and contractors on environmental issues. Kiru believes that integrated multi-disciplinary thinking with a focus on long-term benefits is the key to delivering sustainable communities and cities.

Kiru is naturally strategic in her thinking and enjoys collaborative working. Kiru is an active participant in the local community improvements and aspiring to be a social entrepreneur.



Student Abstracts and Profiles

Michalis Michael
mm834@cam.ac.uk

Michalis joined the gFT research group in May 2018 starting with his Mres project. In 2017 he graduated in Engineering(MEng)at the University of Cambridge, qualified in Aerospace and Aerothermal Engineering, Energy, Sustainability and the Environment. His re-search interests lie in sustainable buildings. His research project, during his MEng year was based on plume and ventilation theory. He developed a mathematical model estimating the rate of smoke filling a room and the 'available safe egress time' for the occupants. He was funded by the Cambridge European Bursary. In 2017, he joined the Future Infrastructure and Built Environment (FIBE) CDT at Cambridge, funded by the EPSRC. He will continue for his PhD with the gFT research group working on the new generation of multi-functional, responsive and energy efficient building envelopes for improving their overall performance whilst reducing their impact on the environment.

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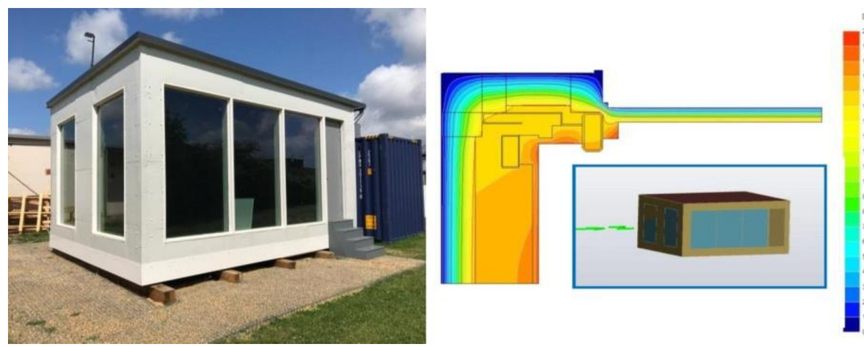
A new generation of responsive and energy efficient building envelopes

Recent developments in smart materials and sensing technologies provide an unprecedented opportunity to develop a new generation of façades in the form of engineered smart systems that can dynamically respond to the fluctuating external conditions and internal demands of buildings. However, it has been identified that there is a lack of effective simulation tools that can comprehensively model the dynamic behavior of adaptive envelopes and their control strategies. This constitutes a limitation/barrier for engineering design, control and product development, which has motivated the undertaking of this research.

The MRes project reviewed the emerging technologies, control strategies and simulation tools for adaptive façades and conducted building performance simulations to assess their ability to predict and design adaptive façades for the next generation of healthy, productive and resource-efficient buildings. Two simulation tools, EnergyPlus and Physibel-Bisco were found to be the most flexible and stable simulation tools for conducting building performance simulations.



1 | Photo of MATE Lab (Mobile Adaptive Technologies Experimental Lab) at the University of Cambridge with part of simulation in Physibel-Bisco.

Notes

Alessandra Luna Navarro

al786@cam.ac.uk

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 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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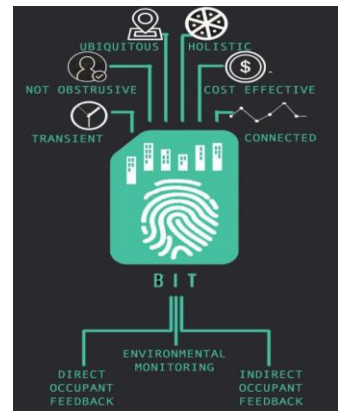
ARUP

Façade Impulse: Stretching the envelope beyond human comfort

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 multisensorial 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 polling station to collect high-frequency user feedback. Initial results and future short-term work are presented and discussed.

1 | MATE-lab research facility



2 | Characteristics of BIT

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Affective Building

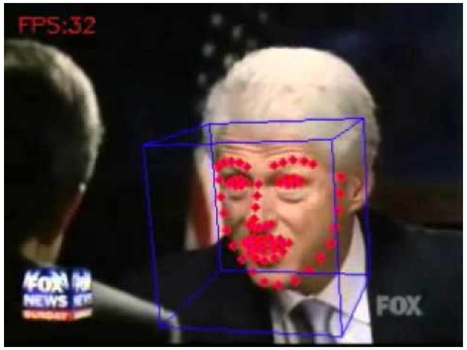
Mark Allen
mca41@cam.ac.uk

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 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 well-being.

In partnership with Microsoft, Trimble, EPSRC Pioneering research and skills, bre

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. While buildings have traditionally been controlled on their physical, environmental conditions, problems still persist in the optimization of the indoor environment for occupant health, comfort and well-being. This talk first provides a broad overview of existing research (outside of the built environment) to examine how people in other sectors are using facial expressions in research. A small study then examines this new way of capturing information on occupants, and then investigates how it might be used in buildings. Building occupants were monitored using Raspberry Pi cameras mounted under their desktop monitors, whilst simultaneously capturing their response on a web based survey. This research shows the possibilities of using new ways to gather high quality and high frequency data from building occupants to help in the control and design of buildings.

1 | Octocam. A raspberry PI that captures images



2 | Software in action

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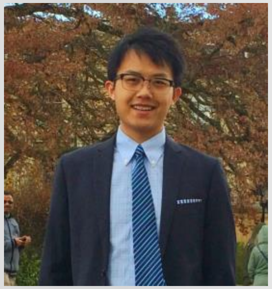
Switchable Insulation for Thermally Adaptive Building Envelopes



Hanxiao
hc426@cam.ac.uk

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 commenced 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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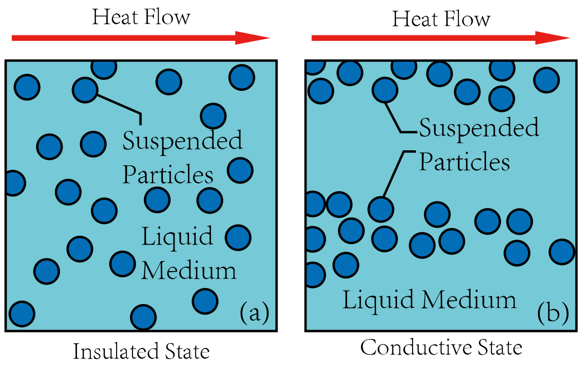
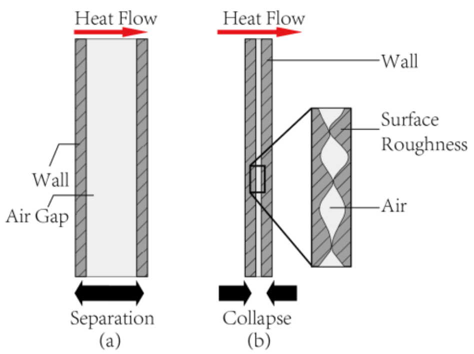
CAMBRIDGE COMMONWEALTH EUROPEAN AND INTERNATIONAL TRUST

CHINA SCHOLARSHIP COUNCIL 国家留学基金管理委员会

Switchable thermal insulation, in the form of an opaque panel 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. Pioneering 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 aim of my research is to advance the understanding of switchable insulation, by reviewing the existing technologies in a systematic manner with a particular focus on their working principles, theoretical performance and improvement opportunities. The presentation therefore summarises the fundamental principles that govern the heat transfer across switchable insulation, followed by an extensive review of switching mechanisms. Finally, I will discuss the performance of reviewed switchable insulation technologies limitations and their potential improvements.



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



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

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Rebecca Hartwell
rh668@cam.ac.uk

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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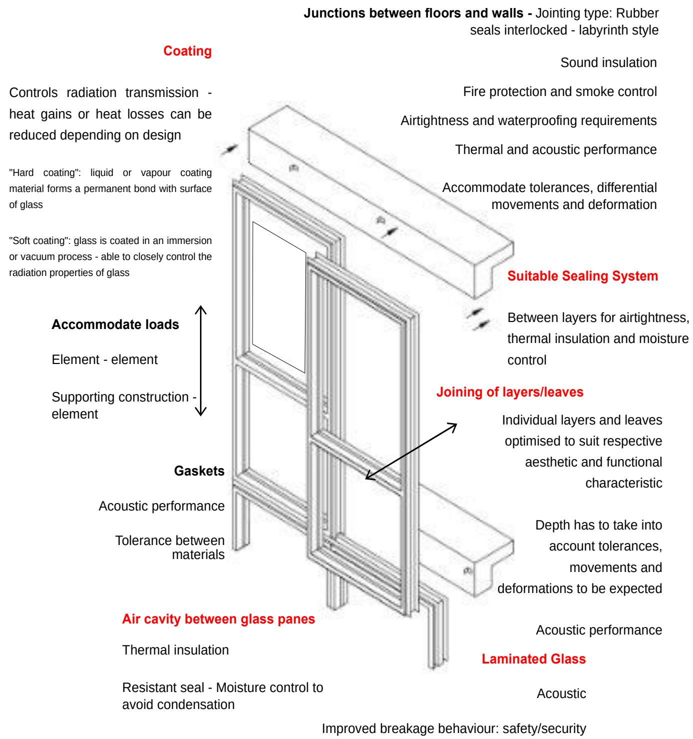
Addressing end-of-life challenges in façade design



1 | Hierarchy of typical curtain walling unit and functions with existing limitations to design for deconstruction highlighted (in red)

In the past few decades, the building envelope has evolved significantly in design complexity to meet increased legislation on energy performance during building operation. Unlike components in the automotive industry, facades are often designed without consideration for end-of-life and the process of recovery of constituent materials is rarely considered at design stage. Meanwhile, the demands for slim and thermally efficient building envelopes are leading to hybrid composite façade systems that are difficult to take apart at end-of-life.

This study aims to first understand the existing barriers and motivations towards the recovery of façade materials through a semi-structured interview with several stakeholders from the façade supply-chain. Subsequently, in order to highlight the significance of the 'missed opportunities' for end-of-life materials as a new resource, the environmental benefits that can be obtained from façade reuse have been quantified in a model for reclamation energy of an existing façade system using a life-cycle impact assessment applied to four different end-of-life scenarios. Further, the existing technical barriers to reuse have been highlighted with reference to the interconnectivities of a curtain walling system and a review of the methods that hold potential to improve component reuse such as debonding, delamination and coating removal. Such methods have been evaluated in terms of feasibility with the aim to quantify their effectiveness through future experimental research.

As low-carbon and zero energy buildings (ZEBs) become more of a reality, it is important to look for ways to improve the end-of-life opportunities for façade systems to avoid simply shifting the energy use in the material lifecycle and maximise the useful lifetime of all components.

Notes

Carlos Pascual
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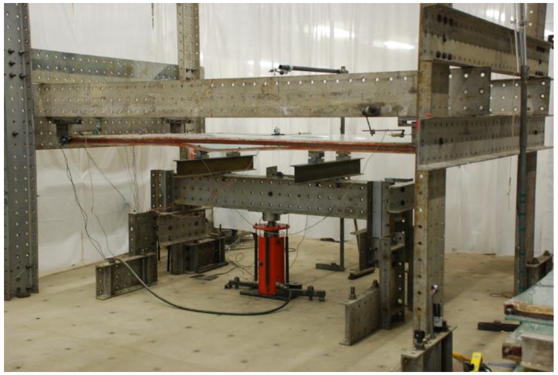
Dr Carlos Pascual joined the gFT group in April 2015 as postdoctoral Research Associate. He leads EPSRC-funded research on a new generation of multifunctional FRP-Glass composite panels that have the potential to meet architectural, building physics and structural performance requirements in building façade applications. He joined gFT from École Polytechnique Fédérale de Lausanne (EPFL) where he spent five years as research and teaching assistant, first at the Structural Concrete Laboratory and then at the Composite Construction Laboratory where he completed his PhD thesis on translucent load-bearing GFRP envelopes for daylighting and solar cell integration in building construction. Prior to this Carlos graduated in Civil Engineering at Universitat Politècnica de València in 2008 and worked as structural engineer in the design of lightweight glass fiber-reinforced polymer (GFRP) structures for building and bridge construction.

In partnership with AGC INTERPANE, DOW, EPSRC Engineering and Physical Sciences Research Council, KÖMMERLING, ARUP, FIBERLINE COMPOSITES

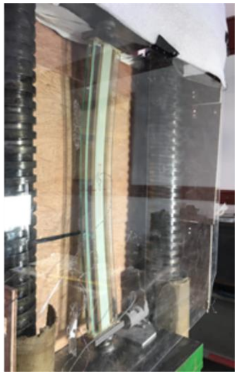
Large-scale composite glass structures

Traditionally, glazed curtain wall systems for building envelopes are function-separated layered systems: insulated glazing units clad the building externally and provide transparency and thermal insulation, and bulky metallic profiles protrude into the building to hold the cladding in place, e.g. mullions spanning between floors. In this configuration the glazing units are infill panels attached to the frame by means of flexible shear connections resulting in limited composite action between the frame and glazing. Alternatively a slimmer, lighter and mechanically efficient envelope system can be designed by merging cladding and frame into a single and robust component: a multifunctional composite glass unit. In this assembly the structural profiles are sandwiched between, and structurally bonded to, load-bearing glass panes.

Experiments on large-scale components have shown that composite glass structures can efficiently resist transverse loads (bending tests, Figure 1) and vertical loads (buckling tests, Figure 2) and can significantly outperform traditional glazing components. However the results of these tests have demonstrated that large-scale components may exhibit significant shear-lag effects and reach axial instability at high loads. Recently developed analytical tools can support the design of large-scale components.



1 | Bending test on 3.5 x 1.5 m2 composite glass panel



2 | Buckling test on 1-m long composite glass strut

Notes

Isabelle Paparo
idjp2@cam.ac.uk

Isabelle-Denise Paparo joined the gFT research group in January 2015. She graduated (B.Sc. and M.Sc.) in civil engineering at the RWTH University Aachen, Germany in 2014; including a 6-monts exchange period at Technion, Haifa. She completed her Masters studies in Structural engineering with final Master project focusing on the edge strength of chemically toughened glass carried out at the gFT research group in Cambridge. Her PhD project on the structural performance of freeform FRP building envelopes is supervised by Dr Overend. Her research is funded by EPSRC and Friedrich-Ebert-Stiftung.

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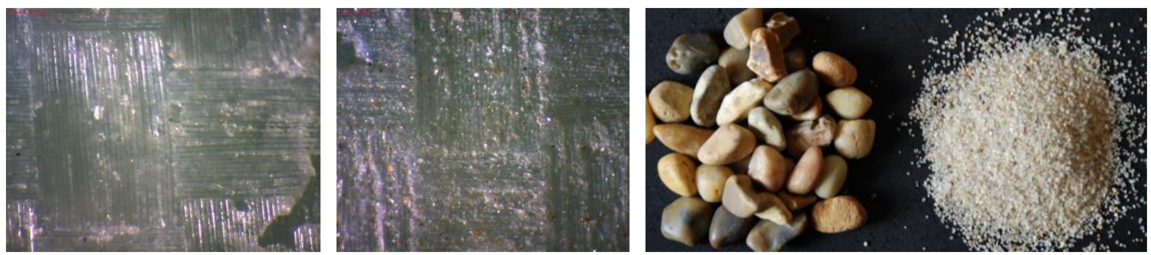
Environmental durability of FRP-based high performance building envelopes

Geometrically complex building envelopes are popular in contemporary architecture but conventional design approaches involve complex build-ups which often become problematic and costly. Sandwich panels consisting of Fibre-reinforced Polymers (FRP) facings bonded to lightweight cores have successfully been used in other industries and can potentially provide an integrated, structurally and thermally efficient solution for complex building envelopes. The design of the few FRP building envelopes to-date tends to be bespoke and involves costly and time-consuming prototype testing. This research aims to extend the limited knowledge on the long-term performance of FRP sandwich panels under realistic building envelope conditions which is essential for establishing a reliable design method that would ultimately enable a widespread use of FRP sandwich panels in buildings.

The governing design parameter of sandwich structures is their stiffness, as the deflection in service state usually introduces the strictest design limitations. The mechanical approach of a sandwich structures relies on the perfect bond between facings and core. It is therefore essential to assess the short and long-term bonding behaviour of the facings and core interface. To do so the mechanical properties of GFRP sandwich panels are evaluated prior and after the artificial ageing in order to determine its structural performance. The artificial ageing is representative of real-world conditions and consists of sand abrasion representing windborne debris abrasion, water immersion replicating life span exposure to high moisture /humidity levels, freeze-thaw cycles combined with a sustained constant load (15% or 35% of short-term failure load) which aims to represent real world applications such as cladding and should favour the creep deformation of the foam core. The degradation of the sandwich panels are evaluated for each parameter separately and in combination; a total of 9 Series are investigated. Ultimately, the testing program assesses the influence of the humidity within the sandwich panel on its structural performance, when subjected to freeze-thaw cycles.



1 | Surface finish prior and post sand abrasion (left), abrasion medium (right)

Notes

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 complex building and facade design and is working in partnership with Newtecnic Ltd, conducting research into new technologies implemented on live projects internationally. Her research is centred around technologies for complex facade design and construction, with a current focus on the connection of fibre reinforced ultra-high-performance concrete (UHPC) panels to a steel structures.

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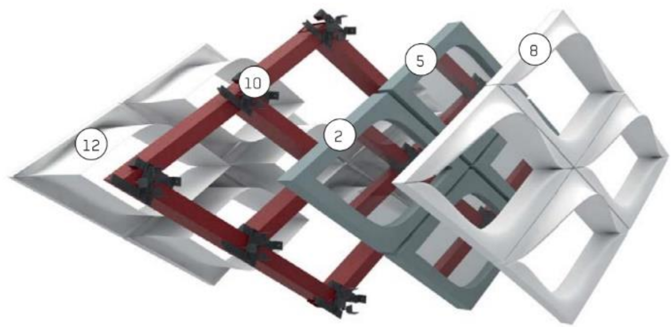
newtecnic
building·engineering·technology

Efficient panelised façade systems for complex geometries

In the built environment there is increasing interest in free-form building design, these buildings spark the interest and imagination of their users. Their geometry is complex often leading to an inefficient conservative facade system design, due to a lack of accurate analysis within time constraints of the design stage. A greater understanding of emerging facade materials and technologies is needed, to allow system designs to be formed according the strengths 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 stress concentrations. In building envelope panel systems, connections are a critical area due to the concentration of stresses and the safety implications should they fail. Knowledge of the behaviour of emerging materials is crucial in creating efficient panelised facade systems which enable complex buildings to be realized, with reduced amounts of materials and efficient manufacture and assembly processes.



1 | Panelised facade system for KAFD Metro Station

2 | Experimental testing of steel connection in UHPC material

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Analytical solutions of laminated glass panels subjected to blast loading

Socrates Angelides
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Socrates studied Civil Engineering at Imperial College and worked for 3 years at DNVGL as a Structural Engineer in the Oil and Gas industry designing offshore structures. In 2016 he joined 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 under the supervision of Dr James Talbot and the support of Dr Mauro Overend.

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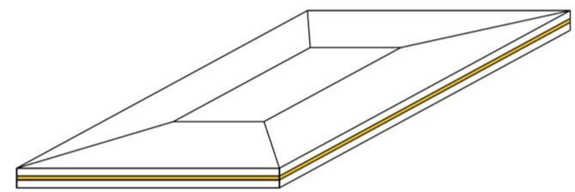
Explosion incidents from terrorist attacks have intensified the requirement for blast resilient buildings. As a result, glazed facades of commercial and residential buildings, often include laminated glass panels that are more ductile and can prevent fragmentation injuries from occurring. However, the response of laminated glass panels to blast loads, especially the post-fracture response, is a complicated multi-disciplinary topic that has recently attracted significant research efforts.

This research aims to improve the understanding of this behaviour, through the development of a theoretical framework that can describe the blast response of laminated glass panels and determine the influence of individual parameters. The repeated failure patterns observed from different blast tests will be investigated in detail. Additionally, dynamic rigid-plastic analytical solutions will be developed to predict if failure will occur for a given pressure time-history. This will involve the extension of the upper bound theorem of plasticity to account for large-deflections, dynamic intense loading and tensile tearing.

1 | Plastic hinge developed in laminated glass beam following the fracture of both glass layers (Delince et al., 2008)



2 | Collapse mechanism for laminated glass panel under intense dynamic loading

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Digital tools for the early-stage design of prefabricated facades

Jacopo Montali
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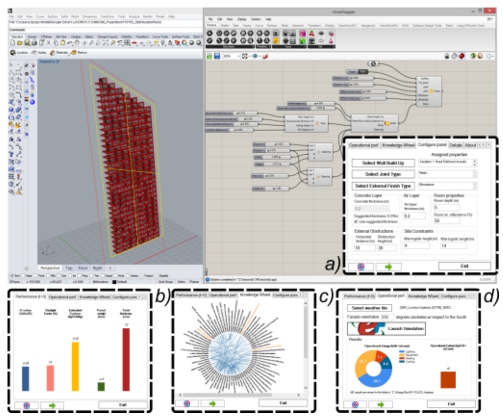
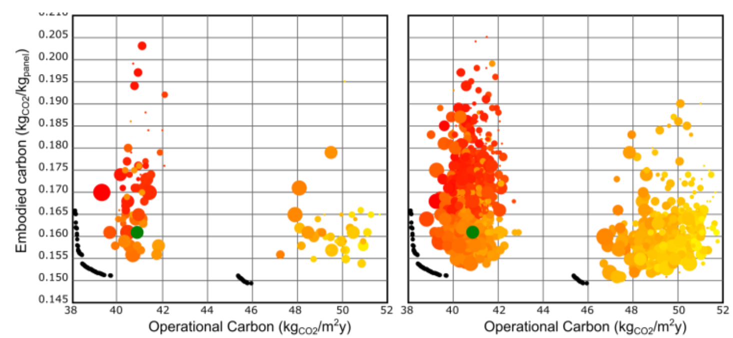
When it comes to productivity, the construction sector is commonly known to be the cow's tail when compared to others, such as manufacturing. Whilst the reasons are many, fragmentation of the design & construction process is probably crucial, as the absence of key design stakeholders leads to design solutions that require many time- and resource-consuming design iterations. In my research, I have developed a Grasshopper-based plugin rich in design & manufacturing knowledge to support the design of specific precast facade panels: the plugin is conceived to bring upstream in the design process (i.e. conceptual stages) heuristic and explicit knowledge normally utilised later (e.g. detailed or even construction stages). In this talk, I will show the results of a field study in which facade consultants were actively involved in a design task using the digital tool. I will underline the limitations and opportunities of digitally-assisted design approaches. I will then conclude by illustrating a combined application of design optimisation and web-based visualisation techniques to concurrently support engineering analysis and architectural design.

Jacopo Montali started his PhD program at the gFT research group in April 2015. After his graduation in Structural Engineering at the University of Parma, he worked as a structural engineer for 2 years as a consultant engineer on façade systems and LEED certification for 3 years. He is a LEED AP since June 2013. His academic research, funded by Laing O'Rourke and EPSRC, focuses on the development of digital tools to support and optimise the early-stage design for manufacture of facades.



1 | The Grasshopper-based digital plugin



2 | Interactive web-based visualisation of optimisation analyses

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LAING O'ROURKE

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Evening Dinner

Evening Dinner
Christ's College

(18.00 pre-drinks)

Menu:

Char-grilled Vegetables with Mozzarella & Olives
(Artisan bread with olive oil & balsamic vinegar)

*****

Noisettes of Lamb with Green Peppercorn & Cream Sauce
Roquefort Cheesecake with Balsamic Pears (VG)
Vegetable en Croute with Onion Chutney (VE)
Bouquet of seasonal Vegetables
Parisian Potatoes

*****

Summer Pudding & Cream

*****

Tea, Coffee , Herbal Infusions & Mints

Notes