Engineered Skins 2017

Recent development in Glass and Façade Engineering, University of Cambridge

Proceedings

Department of Engineering
Trumpington Street
Cambridge

UNIVERSITY OF CAMBRIDGE

gFT glass & façade technology research group

Contents

Symposium Sponsors

Programme - 7th September 2017

Department of Engineering

09:30 Coffee & Registration

10:15 Welcome Address, *Prof Simon Guest*

10:30 Keynote: Data Driven and People Centred Design of Buildings, *Dr Shrikant Sharma, Buro Happold*

11:15 Coffee Break

11:45 Capturing Occupant Wellbeing Through Facial Expressions, *Mark Allen*

12:05 Façade impulse: Adaptive façade effects on holistic human comfort and satisfaction, *Alessandra Luna Navarro*

12:25 Regenerative approach to façades with a focus on end-of-life challenges, *Rebecca Hartwell*

12:40 Switchable insulation technology: Theory and application, *Hanxiao Cui*

13:00 Lunch

13:45 Keynote: Resource Efficiency in Construction and the Built Environment, Dr. Jonathan Cullen, Department of Engineering, *University of Cambridge*

14:30 Review of connections for FRP Sandwich Panel Systems, *Dr Marco Doná*

14:50 Environmental durability of FRP-Based Building Envelopes, *Isabelle Paparo*

15:10 Digital tools for the early-stage design of prefabricated facades, *Jacopo Montali*

15:30 Coffee Break

16:00 **Developments in FRP-Glass Composites,** *Dr Carlos Pascual Agulló*

16:25 Wind Engineering of Glass Facades, *Dr Kenneth Zammit*

16:50 The strength of aged glass, *Dr Corinna Datsiou*

17:15 Influence of Ageing on Post-Fracture Performance, *Caroline Butchart*

17:40 Closing remarks, *Dr Mauro Overend*

18:30 Dinner at Christ's College *(optional)*

UNIVERSITY OF CAMBRIDGE

gFT glass & façade technology research group

Dear Symposium Delegate,

Welcome to the 8th 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 Interpane, Kömmerling, Northglass, Seele 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 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 may also complete the feedback / request-for-information form at the back of the proceedings.

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

Best wishes,

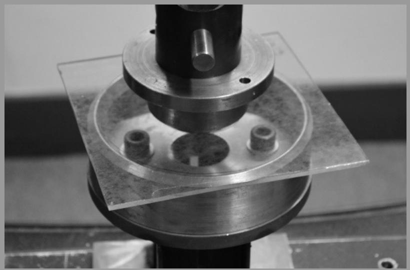
Dr. Mauro Overend

Research Group Coordinator

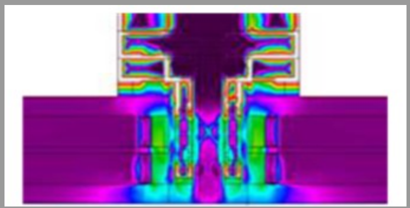
The Glass and Façade Technology Research Group

www.gft.eng.cam.ac.uk

Micrograph of critical flaw in glass.

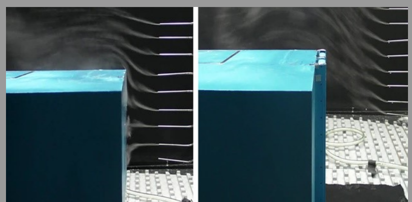


Coaxial double ring tests on glass.



Novel unitised systems: Thermal conductivity of edge of panel (glass-mullion interface).

Photoblastic measurements of residual stresses on glass: SCALP calibration.



Wind tunnel (smoke) test on façade with external shading.

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.

Dr. Mauro Overend

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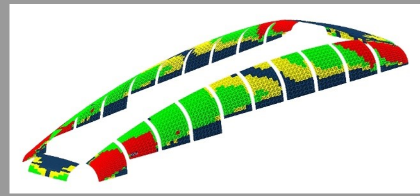
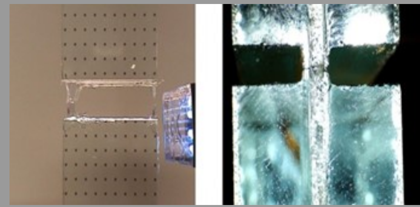
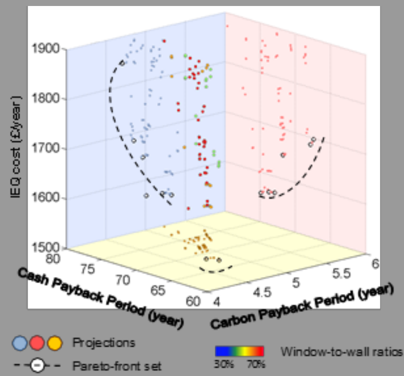
Mauro is a senior lecturer in Building Engineering Design at the Department of Engineering, University of Cambridge and he is Fellow of Christ' s College. Mauro is a chartered engineer with several years of consulting engineering experience in the fields of structural engineering and façade engineering. He founded and leads the Glass & Façade. Technology Research Group at the University of Cambridge which undertakes research on the structural and environmental performance of glass and building envelope systems. Mauro has more than 80 peer-reviewed publications to his credit and he serves on several national and international committees related to glass and façade engineering. In recognition of his research on glass and façade engineering he was he was awarded the Institution of Structural Engineers' Guthrie-Brown medal, the IABSE Prize and he was elected to the College of Fellow of the Façade Tectonics Institute in the US.



Building envelope information modelling: Manufacturability assessment of curved glass roof.



Trough-crack tension test for laminated glass.



Multi-objective design optimisation of façade design.

Optimisation of adaptive glazing thermos-optical properties.

WELCOME ADDRESS

Prof Simon Guest	Welcome address

Simon Guest is a Professor in Structural Mechanics and the Head of Civil Engineering at the Department of Engineering, University of Cambridge. His teaching is in structural mechanics, and his research straddles the border between traditional structural mechanics, and the study of mechanisms. ; this academic area turns out to encompass many interesting technologies and provide many exciting and challenging problems. He is a fellow of Trinity Hall and currently Head of Civil Engineering.

KEYNOTE SPEAKERS

Data Driven and People Centred Design of Buildings

The talk will introduce innovations that can truly supercharge the buildings and spaces – in terms of operational performance, environmental impact and, above all, the people we design these spaces for. The trick is to use a data driven and people centred approach, backed up by powerful data analytics, modelling and simulation technologies that are highly visual, engaging, interactive, immersive, and responsive in real time. Combining this approach and tools with the experience and deep engineering insights allows one to engage with the client and stakeholders at an unprecedented level – often within a live workshop environment… interactively shaping, sizing, and optioneering the various elements of the buildings, facades and services with real time analysis and feedback.

Dr Shrikant Sharma
Buro Happold

Shrikant leads Buro Happold Engineering's technology development. He runs the Smart Space offer that delivers advanced modelling and sophisticated simulations to deliver simple, innovative solutions to complex engineering problems. The team produces smart, intuitive, flexible and highly visual tools for rapid / real-time space analysis, shape optimisation, crowd flow simulations, and Big Data visualisation. The team's people-centred design approach uses an insight into people's behaviour, activities and journeys to enhance space use, visitor experience and operational effectiveness of buildings and urban spaces.

Dedicated to putting people at the heart of building and urban designs, Shrikant is also multi-discipline in thinking. He actively engages in research and development of technologies. He has led the development of a number of sophisticated BIM-integrated modelling and simulation tools such as SmartForm – our realtime shape optimisation and sculptural design tool, SmartMove – a highly intuitive tool to simulate, analyse, and visualize crowd flow in buildings and urban spaces, and SmartViz – a powerful data visualisation tool an interactive dashboard tool for rapid visualisation of large data sets in a dynamic, spatial and graphical format.

Shrikant has a particular focus on embracing, developing and combining sophisticated modelling tools and emerging technologies, and presenting them as simple, intuitive, engaging and interactive optioneering tools and dashboards. This brings evidence at the heart of the decision making and at the same time engages the users and stakeholders at an early stage of planning and design.

KEYNOTE SPEAKERS

Resource Efficiency in Construction and the Built Environment

Global demand for energy and material services is causing strain on planet earth in the form of resource shortages and damaging by-products, with the release greenhouse gas emissions from fossil fuel combustion presenting a serious threat to the long-term stability of the climate. The challenge of Resource Efficiency is to deliver future energy and material services—mobility, thermal comfort, sustenance--while at the same time reducing resource use and environmental impact. In this talk I will describe our research efforts, as part of the Resource Efficiency Collective, to map resource resource flows and reveal the options available for using resources more efficiently.

Dr Jonathan Cullen
University of Cambridge

Jonathan is the University Lecturer in Energy, Transport and Urban Infrastructure at the University of Cambridge and a Fellow of Fitzwilliam College. He studied Chemical and Process Engineering at the University of Canterbury, New Zealand. After 10 years working in industry and in development work in Peru, he moved to Cambridge for the MPhil in Engineering for Sustainable Development. Jonathan then completed a PhD with the title Engineering Fundamentals of Energy Efficiency before taking up the role of Research Associate and then University Lecturer.

Jonathan's research interests include whole energy systems and energy and material demand reduction. His energy research aims to characterise physical efficiency limits for energy devices, systems and services and to provide consistent frameworks for evaluating energy demand reduction options and emissions abatement strategies. Jonathan also works on material efficiency options for reducing demand for materials. This work is described in the book, Sustainable Materials: with both eyes open (available for free download from www.withbotheyesopen.com).

gFT RESEARCH GROUP ABSTRACTS

Mark Allen
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After graduating from Durham University in Civil Engineering, Mark worked for the High Speed 2 rail project as a Route Engineer for 1 year before joining the Future Infrastructure and Built Environment CDT in the University of Cambridge. His research interests lie in sustainable buildings (shipping containers and soil based construction) and more recently, nature as an inspiration for novel and adaptive building design and control systems.

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Capturing Occupant Wellbeing Through Facial

Occupant well-being is a hot topic right now as businesses begin to look at ways in which they can improve their productivity and creativity in increasingly competitive markets. Further, people themselves are in creasingly interested in their own health and well-being, as evidenced by the increased use of smart watches and other health monitoring devices. There is a body of evidence suggesting that time spent in nature is incredibly beneficial for our health and well-being which is supported from a psycho-evolutionary standpoint. Yet, most people spend over 90% of their time indoors. It is clear that the design of the indoor environment is vital for the health and well-being of occupants. This project explores a new and experimental idea: that emotion and speech recognition software's can be used to remotely and non-intrusively measure the wellbeing of building occupants. Figure 1 shows how this might work with an example of Microsoft's own emotion recognition software in action. With further development, this idea could lead to buildings automatically adjusting their own parameters (such as temperature and CO2 levels) based on the perceived comfort of its occupants. Further, it could create an evidence database for 'design for well-being' that is currently lacking. Several case studies are planned to test this technology (figure 2), in combination with more traditional methods of measuring occupant wellbeing, giving a multi-method approach. Some research is being done on the use of wearable technology to measure well-being, but there is only one example of the integration of emotion recognition in a smart environment, a hospital. Properly integrated into a building, this technology will make our buildings more intelligent and increase occupant well-being, whilst creating a database of evidence to help guide design and control strategies.

1.

2.

1. An angry and disgusted looking President Trump, analysed using Microsoft's Emotion API (source: typepad.com)
2. A 'well-being' sensor (or Raspberry PI and Webcam)

Alessandra Luna Navarro

al786@cam.ac.uk

Alessandra research interests are in adaptive façades, human comfort and satisfaction and energy efficiency for the 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, in the same department, to pursue a PhD on adaptive façades and human comfort and satisfaction. Her PhD research is funded by Permasteelisa, Arup and EPSRC.

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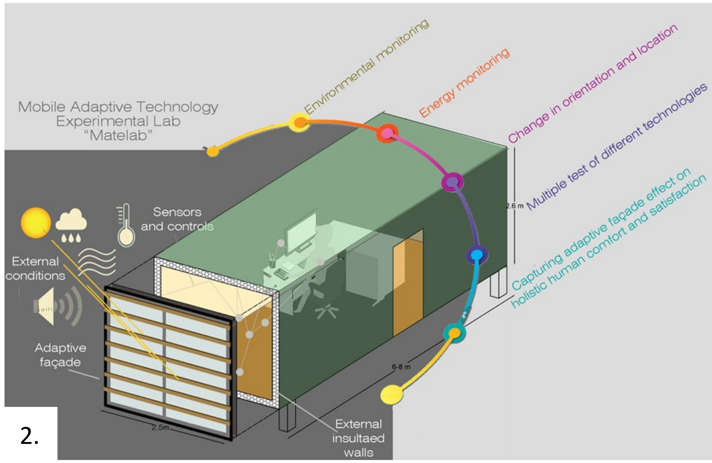
ARUP

PERMASTEELISA GROUP

Façade impulse: Adaptive façade effects on holistic human comfort and satisfaction

"Façade impulse" aims to capture the effect of adaptive façade on user holistic comfort and satisfaction, in order to identify the most effective design features that enhance occupant satisfaction and productivity. Adaptive façades are façades that can interact with the user and vary the flow of energy through the building envelope in response to the external weather and indoor needs. The adaptive technologies range from opening a window to electrochromic glazing. In this sense, adaptive façades are "multisensory filters" between interior and external environments. It has been shown that technologically advanced adaptive facades can outperform sealed super-insulated buildings in terms of reducing energy demand and creating more natural and healthier conditions inside buildings, but the major barrier to their uptake in real-world buildings is the largely unknown relationship between occupants and technology. This is arguably a key part of the wider and pressing need to carefully consider human factors in the development of technological solutions for future cities. Fig.1 shows the main areas of research within the PhD project. The interaction between façades and occupants lies at the centre of this research, which explores: (i) the demands of occupants in terms of holistic comfort and satisfaction; (ii), the occupant interaction with the environment and, in particular, with façades; and (iii) the façade perceptible effect on environmental characteristics according to the distance. This PhD research will address this main knowledge gap providing an early-stage design tool and methodology to assess and predict façade effect on user satisfaction and holistic comfort. The investigations will be performed experimentally in both real offices and a mobile test facility (Fig. 2). Preliminary results from early explorative investigations and research will be presented in this talk.

1.



2.

1. Wren Diagram

2. MATElab - Mobile Adaptive Technology Experimental lab

Rebecca Hartwell

rh668@cam.ac.uk

Rebecca Hartwell joined the gFT research group in 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 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, recently submitting her Masters dissertation titled '*A regenerative approach to facade engineering with a focus on end-of-life challenges*', with the aim of continuing PhD research in this area.

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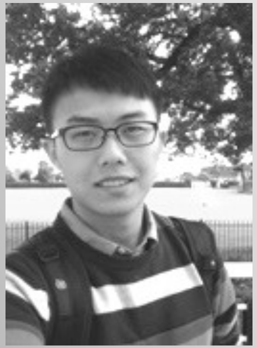
Regenerative approach to façades with a focus on end-of-life challenges

The building sector has seen a continuous drive to improve energy performance in use in response to increased legislation that recognises the negative externalities of growing energy consumption. Improved energy efficiency has been made possible by advances in the design of the building envelope to incorporate composite materials and more integrated technologies. The effectiveness of these new designs has been largely quantified in terms of its improvements to operational energy. 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 minimise waste and maximise the useful lifetime of all components used. This study aims to demonstrate establish the existing problem of the increasing embodied energy in the curtain walls through three example case studies taken from buildings completed over the last few decades. Based on literature research and stakeholder interviews, the study also aims to assess the barriers and opportunities for the façade systems at end-of-life – with a focus on the aluminium curtain wall systems - and how these might be improved. This study is kindly supported by:



Hanxiao Cui

hc426@cam.ac.uk

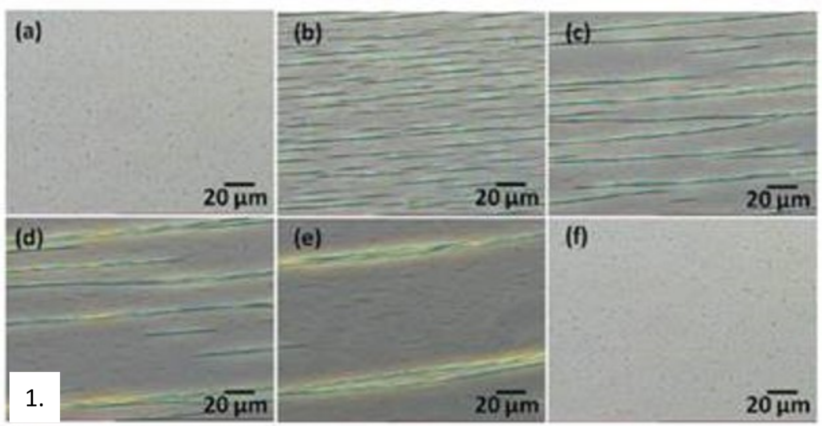
Hanxiao joined the gFT group in 2014 and completed a MPhil in Engineering in 2015. Before coming to Cambridge, he graduated from the University of Nottingham with a first-class degree in Architectural Environment Engineering. Currently, he is pursuing his PhD under the supervision of Dr Overend and working on adaptive facade technologies with a broad interest in architectural technology and computation.

Funded By:

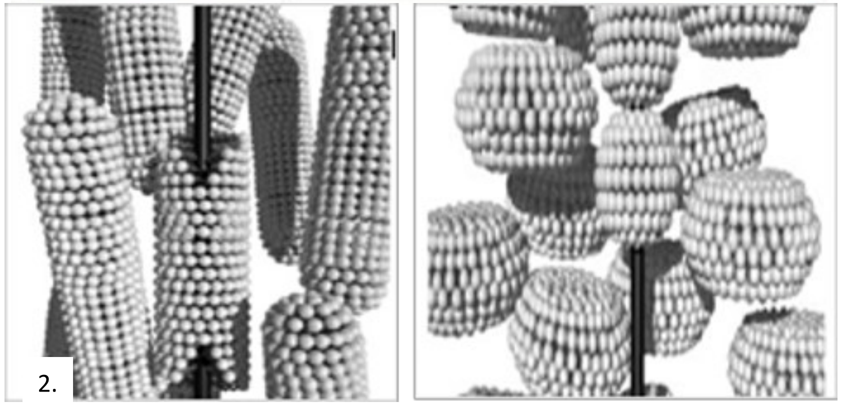
CHINA SCHOLARSHIP COUNCIL

Switchable insulation technology: Theory and application

Switchable thermal insulation, an opaque panel capable of alternating between thermally conductive and insulated states, is considered as an alternative route to regulate thermal environment by selectively harvesting heat from external environment. Extensive work has been undertaken by researchers to develop switchable insulation technologies for thermal regulation in automobiles, and aerospace applications, where conventional space heating and cooling technologies are either too bulky or too energy consuming to meet design requirements. To advance the understanding of switchable insulation technologies, the aim of this review is to outline the existing technology routes in a systematic approach with a particular focus on their working principles, achievable performance and improvement opportunities. Finally, we present the outlook for switchable insulation technologies for applications in building envelopes



1.



2.

1. Microscopic images of kerosene-Fe3O4 nanofluids with φ = 5%: (a) without external magnetic field, (b-e) in presence of steadily increasing magnetic field, and (f) after removal of magnetic field. Failure mode of an FRP double lap joint

2. Schematic illustrations of the mechanism of CNT alignment in a lyotropic nematic LC host. The CNT (a vertical black rod in the center of each picture) is in fact completely encapsulated, but here only partially covered by surfactant molecules for clarity.

Marco Doná

md709@cam.ac.uk

Dr Marco Donà is a post-doctoral Research Associate in the Glass & Façade Technology (gFT) Research Group since June 2015. His current research focuses on the development of novel connection systems and corresponding design methods for geometrically complex building envelopes. He completed a masters degree in Structural Engineering at the University of Padova, obtained a PhD in Structural Engineering at Loughborough University on “Static and dynamic analysis of multi-cracked beams with local and non-local elasticity”, and worked as research associate on experimental validation of non-local theories for wave propagation in heterogeneous materials.

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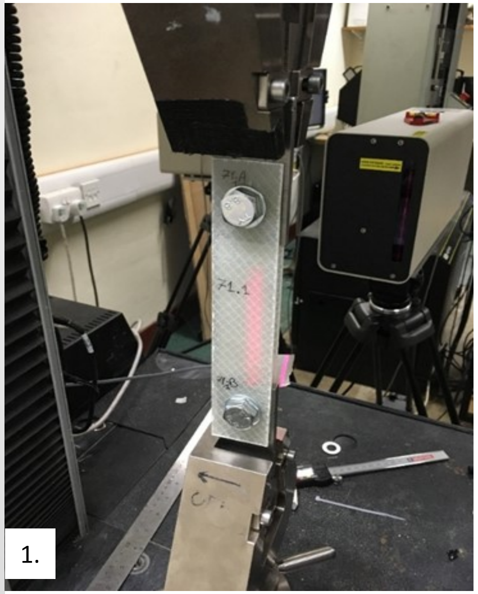
façade design + engineering + technology

Review of connections for FRP Sandwich Panel Systems

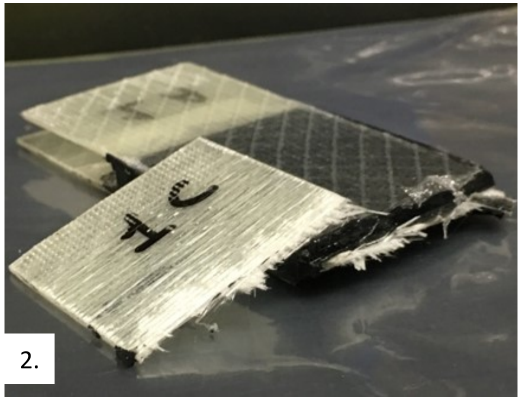
Fibre reinforced polymer (FRP) laminates and a core material (e.g. foam or balsa) can be combined together to form a sandwich system with improved performance. The resulting lightweight composite panel can be formed in large panels of any shape, it therefore has the potential to be an efficient alternative solution for free-form building envelopes. The large size of the self-supported panels together with the reduced number of joints allow for a rapid installation and a smaller secondary structure. Additional benefits includes the improved thermal performance and a lower risk of water penetration.



1.

However having few joints leads to higher stress concentration at the connection points. Indeed one of the most critical part of the design of an FRP sandwich panel, and of a building assembly in general, is the connection between two different components. It is at these points where loads are transferred from one element to the adjacent one causing stress concentration which can be critical for the performance of the whole system. During the design, the several unknowns usually lead to oversizing of the connection especially for FRP system due to its anisotropy and brittleness.

This presentation will focus on connection types used for FRP sandwich panel systems. It will give an overview of the current technologies and will present some of the most recent solutions, including 3d printed and hybrid metal-frp system. Furthermore, the results of a series of testing on the material properties of the different components of a sandwich system (FRP laminate, foam core) as well as on adhesive, bolted and hybrid single lap joint will be presented and discussed. These results form the basis for next steps which include full scale tests of existing and novel connections suitable for FRP sandwich panel systems.



2.

1. Image during the test of an FRP laminate with bolted connection
2. Failure mode of an FRP double lap joint

Isabelle Paparo

idjp2@cam.ac.uk

Isabelle-Denise Paparo joined the gFT research group in January 2015 after graduating (B.Sc. and M.Sc.) in Civil Engineering from RWTH University Aachen; including a 6-months exchange period at Technion, Haifa. Her PhD project focuses on the application and structural performance of freeform FRP building envelopes and is supervised by Dr Overend. Her research is funded by EPSRC and the Friedrich Ebert Foundation.

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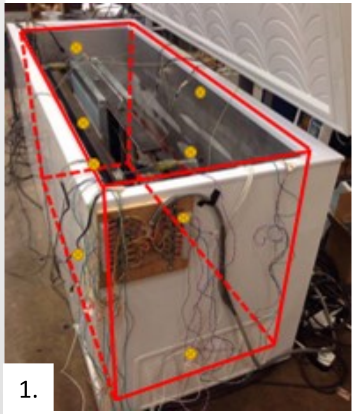
PREMIER COMPOSITE TECHNOLOGIES LLC

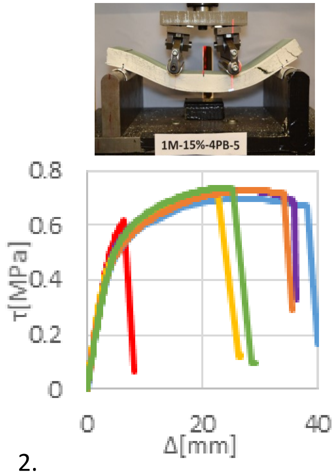
Environmental durability of FRP-Based Building Envelopes

There are many examples of Fibre reinforced polymer (FRP) materials in the broad field of construction, but only a few in façade applications. FRP sandwich panels in facades are highly bespoke elements, thus leading to the lack of representative data on long-term durability behaviour of FRP sandwich panels subjected to natural weathering conditions to which facades are subjected. The design life of facades is not specified explicitly in current design standards; it is generally suggested to be part of the design life of the entire building which is deemed to be a minimum of 50 years. However, this is rarely achieved without major means of refurbishment. Hence, materials used in façade systems should be designed to withstand significant visual and mechanical deterioration under varying weathering conditions for the given period of time; incorporating regular inspections and maintenance cycles. These cycles depend on the materials' response to façade-like natural weathering such as the simultaneous influence of several environmental agents, e.g. UV radiation, humidity/ moisture, heat and freeze-thaw cycles.



1.

The overall research goal of this project is to investigate the environmental durability of GFRP – Foam sandwich panels subjected to artificial façade-like weathering. This talk presents the outcomes of the first long-term artificial ageing testing program, which has been conducted to identify the effects of freeze-thaw cycles in combination with sustained loading, which is deemed to represent permanent load, such as tiling of the façade panel. The flexural response of Glass fibre reinforced polymer – Polyethylene terephthalate foam (GFRP–PET) foam sandwich panels subjected to 100 and 200 freeze-thaw (F/T) cycles with and without sustained loading of 15% and 35% of their ultimate static failure load are evaluated using a 4-point bending set up. It was found that the effect of F/T cycles and the sustained loading have only minor effects on the structural performance such as stiffness and strength, whereas with prolonged ageing a shift in failure modes from core shear failure to local foam indentation followed by face sheet crushing was observed.



2.

1. Distribution of thermocouples within the environmental chamber

2. Core shear failure and τ-Δ –response in 4PB test of specimens after 100 F/T cycles

Jacopo Montali

jm2026@cam.ac.uk

Jacopo Montali is a Civil Engineer with 5 years of work experience in the construction sector. After obtaining his Master Degree in Structural Engineering at the University of Parma, Italy, he worked for 2 years as a Structural Engineer and for 3 years as a Facade Consultant. During this period, he worked on large projects such as the Ferrari Nuova GeS in Maranello by Wilmotte Associés and the New Headquarters of the Piedmont Region by Massimiliano Fuksas in Turin. He is a LEED AP since 2013. He now in his final year of a PhD on Integrated Early-Stage Design and Manufacture of Façades at the gFT group. He is supervised by Dr. Overend and funded by EPSRC and Laing O'Rourke.

Funded By:

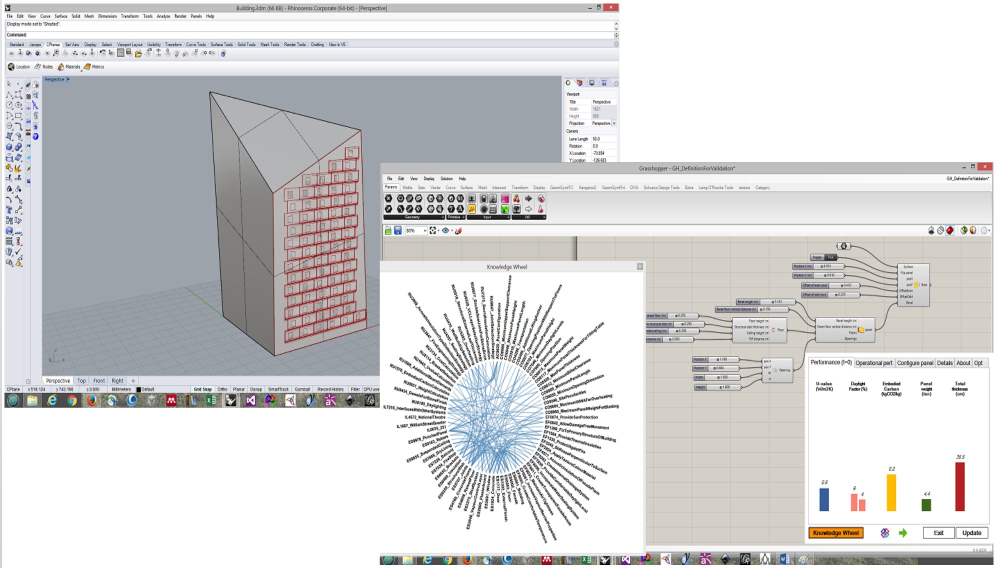
EPSRC Engineering and Physical Sciences Research Council

LAING O'ROURKE

Digital tools for the early-stage design of prefabricated facades

Today's facade systems and products are characterised by increasing complexity, due to stringent regulations and performance requirements. Facades must also provide a specific aesthetical expression to the building. Prefabricated products guarantee high quality and performances, as well as aesthetical variety, although their main design features must be defined as early as possible. Late-stage adjustments always come at a cost.

In this presentation, I will show an approach for creating knowledge-based digital tools to support the design of specific systems from specific manufacturers. The proposed approach builds upon traditional facade engineering as well as knowledge management, information technology and data visualisation techniques. Based on a case-study of a product manufactured by Laing O'Rourke, an example of such approach is demonstrated. The tool helps the user configure the facade product to assess a variety of performances at early-design stages. The tool also follows a Design for Manufacturing and Assembly approach, given the product-based nature of the prefabricated system: a set of constraints has to be met by the facade to be considered easy to manufacture. Those constraints come from heuristic and/or explicit knowledge. The digital tool, which is based on Rhinoceros / Grasshopper, also provides users with instantaneous feedback about the aesthetic appearance of the configured panelization scheme. Once the facade system is properly configured, opportunities for its optimisation are explored through a novel approach that considers both aesthetical and performance-based requirements.



1.The digital, knowledge-based engineering tool for configuring precast concrete panels manufactured in the Explore Industrial Park (Laing O'Rourke).

Carlos Pascual Agulló

carlospascualagullo@hotmail.com

Dr Carlos Pascual Agulló joined the gFT group in April 2015 as postdoctoral Research Associate. He is leading the EPSRC-funded research on multifunctional FRP-Glass composite panels that have the potential to meet architectural, building physics and structural performance requirements in façade applications. He joins gFT from EPFL where he completed his PhD thesis on translucent load-bearing GFRP envelopes for day-lighting and solar cell integration. Prior to this Carlos graduated in Civil Engineering at València in 2008 and worked as structural engineer in the design of GFRP structures for building & bridge construction.

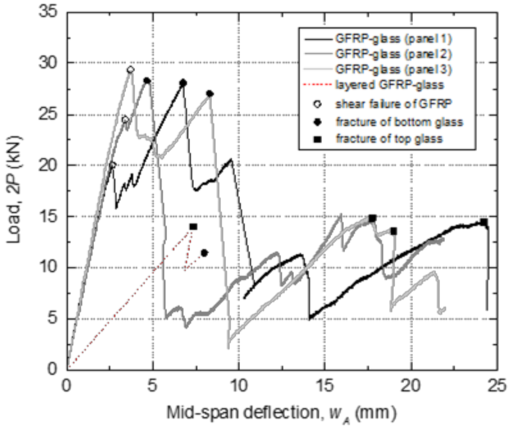
Developments in FRP-Glass Composites: Towards a new generation of transparent, lightweight, and energy efficient building envelopes

Recent developments in glass engineering, bonding technology and fibre-reinforced polymer (FRP) materials provide an unprecedented opportunity to develop a new generation of glazing unit: FRP-Glass Composites. In these novel components, high strength glass panes are structurally bonded to slim, stiff and thermally insulating FRP profiles, thereby forming a composite sandwich component. These FRP-glass components can provide step-change improvements in strength, stiffness, robustness and operational energy efficiency, thereby providing a slim, lightweight, and energy efficient glazed building envelope.

However to-date there is very limited research on the mechanical response of such sandwich glazing panels. This presentation will provide recent results from three streams of research in our on-going work on FRP-Glass composites, namely:

1. The flexural and post-fracture response of FRP-Glass and Steel-Glass composite panels (Fig 1). The work is based on a four-point bending configuration of FRP-Glass and Steel-Glass sandwich panels bonded with epoxy and acrylic adhesives , respectively, that were investigated by: (i) experimental destructive testing; (ii) numerical modelling and; (iii) a novel analytical tool. The results show the influence of the core material and the adhesive on the mechanical performance and that significant post-fracture capacities can be achieved.

1. (a)



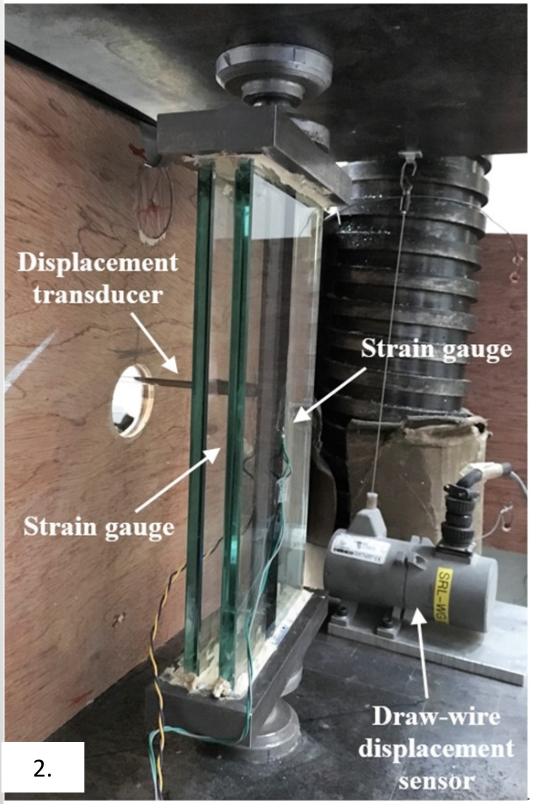
1 (b)

1. (a) Small scale FRP-glass vision panel with narrow face sheets tested in four-point bending and (b) experimental results – response of a non-composite (layered) panel is shown for comparison.

Developments in FRP-Glass Composites: Towards a new generation of transparent, lightweight, and energy efficient building envelopes

2. The performance of glass composite struts in which FRP-Glass and Steel-Glass composite struts are assembled and tested to destruction in an in-plane loading configuration (Fig 2). This work involves the characterisation of the constituent materials, improved end connections and the validation of an analytical model for determining the buckling behaviour of the composite struts.

3. Feasibility of cold bent FRP-Glass panels in which FRP profiles are structurally bonded along the perimeter of a square glass plate in a flat configuration (Fig 3). Articulated joints at the 4 corners of the FRP frame allow the panel to be subsequently bent at ambient conditions. This work explores the optical quality of the cold bent panel, the characterises of the constituent materials and describes the assembly of the FRP-Glass prototype.



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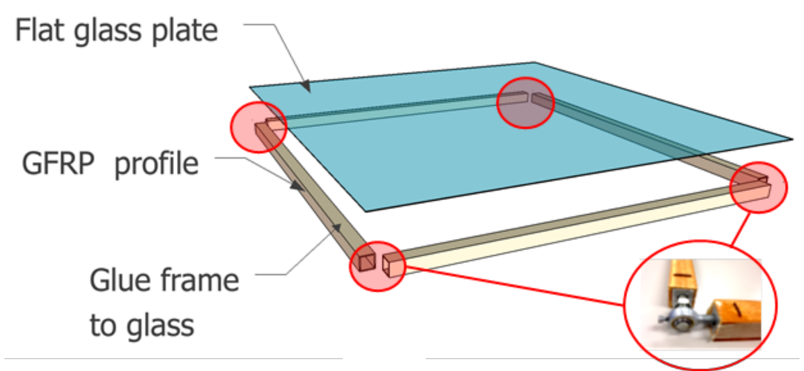

3.

2. FRP — Glass composite strut

3. FRP — Glass composite panel for cold bending applications

Caroline Butchart

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Caroline is a Project Engineer at Eckersley O'Callaghan with experience ranging from design of concrete and steel multi-storey towers, to bespoke glass elements including stairs and skylights. She is passionate about R&D, leading this area in their structures team.

Prior to joining EOC, she spent 4 years with the Glass and Façade Technology group at Cambridge University and two years as a Structural Engineer at WSP. Caroline's PhD research investigates post-fracture performance of laminated glass, with the aim of developing empirical equations for predicting this.

She also spent time investigating novel laminate build-ups. Notably glass laminated with high strength Gorilla glass, performed in collaboration with EOC and Corn-

Funded By:

EPSRC
Engineering and Physical Sciences
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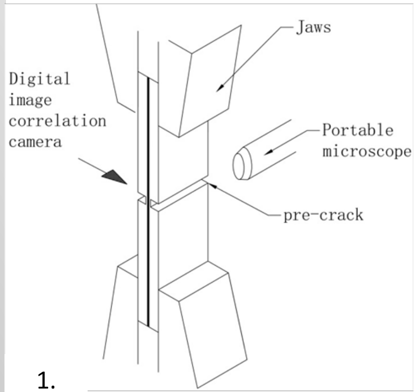
Influence of Ageing on Post-Fracture Performance

Little is known about the post-fracture performance of weathered laminated glass, specifically regarding interlayer bulk mechanical behaviour and its adhesion to glass. When redundant load paths cannot be provided, validation of the post-fracture performance is by full scale destructive testing. These full-scale tests are always carried out on newly manufactured glass. Investigations to date have focused on how the appearance of laminated glass is altered by various weathering procedures. Little has been done to investigate how these same weathering procedures alter the post-fracture mechanical performance.

This research examines the weathered post-fracture performance. The influence of weathering is studied for small scale PVB laminates. Through crack tensile (TCT) tests were performed on weathered laminates and compared to newly manufactured specimens.

Three different weathering classes were considered; two artificially weathered, in which specimens were exposed to accelerated ageing procedures; and one natural weathering. The accelerated ageing techniques were defined by ISO 12543 for investigating exposure to high humidity and high temperature.

All weathering procedures were found to reduce the post-fracture performance of the laminates, when compared to newly manufactured specimens. This work highlights the importance for research into the post-fracture performance of weathered full-scale laminates



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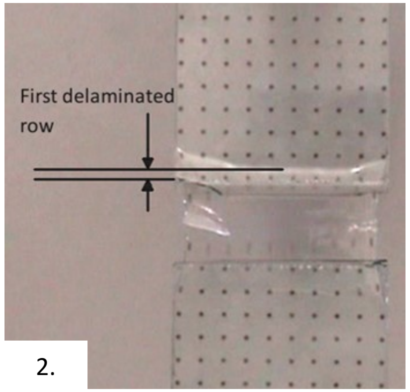

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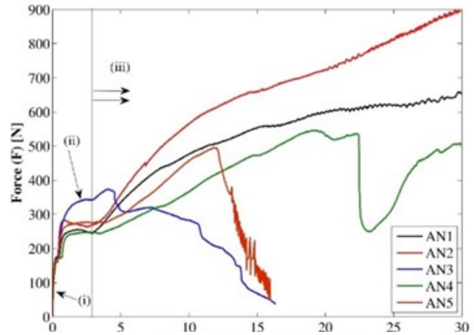

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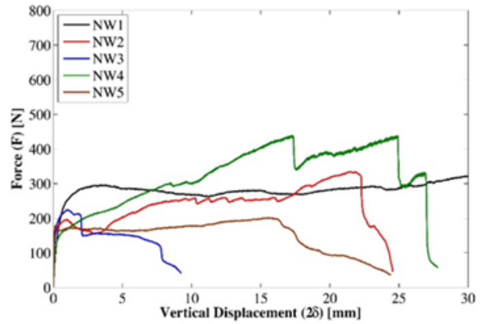


1. Schematic of TCT test rig; 2.Delamination after TCT test; 3. Force displacement response of the newly manufactured specimens; 4. Force displacement response for specimens subject to natural weathering

Kenneth Zammit

Kenneth.Zammit@burohappold.com

Kenneth developed his early career in structural engineering, which drew him towards the multiphysics aspects of façade engineering. After completing an MSc in Facade Engineering at the University of Bath, Kenneth joined the façade engineering team at Whitbybird where he developed his facade detailing skills working closely with specialist contractors. He subsequently started the facade engineering team at Thornton Tomasetti in London, growing the team into a group of six engineers. He joined the gFT research group in 2007 to undertake a part time PhD program. Kenneth is now a group director of Facade Engineering at Buro Happold, where he leads a team of 30 facade engineers in London. Kenneth is committed to advancing the state of knowledge in structural glass and wind engineering and has authored and presented numerous papers on these topics. He also sits on the CWCT technical group which is responsible for the development of technical standards for facades in the UK.

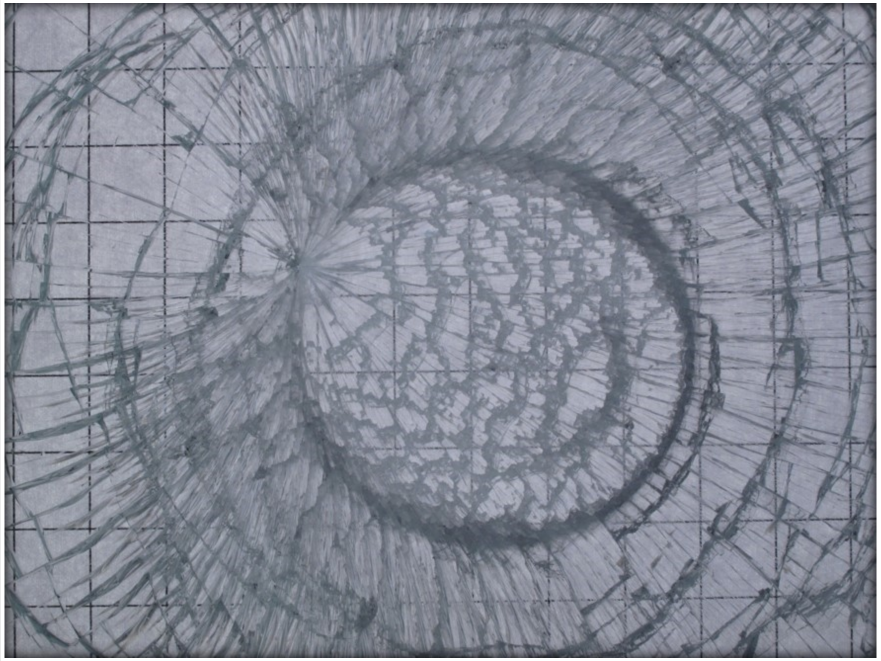
Funded By:

EPSRC
Engineering and Physical Sciences Research Council

Wind Engineering of Glass Facades

With façade costs in excess of £2,000/m2, and glass being one of the most prevalent cladding materials, efficiency and safety in design are of crucial importance. Despite its great durability, the material suffers from stress corrosion, meaning that glass strength is sensitive to both environmental conditions and load duration. Glass design, normally controlled by wind loading, is therefore sensitive not only to peaks of wind pressure, but also to its complete wind loading history. This structural and fluid flow challenge is compounded by the complexity of layered glass products in use, as well as the intricacy of façade geometries, mostly developed for environmental reasons. Existing glass design methods do not cover all of these aspects and make simplifying assumptions, resulting in a significant loss of accuracy.

This research develops a method to integrate developments in glass fracture mechanics, insulated glazing and laminated glass modelling and wind engineering. The technique builds on the results of testing to destruction of 200 specimens of new and naturally weathered glass, automated calculation methods for insulated glazing units and visco-elastic modelling of laminated glass and large scale wind tunnel testing. Using this information, it is possible to quantify the probability of failure of glass plates when subject to the multiple storms endured during the cladding design life, with an unprecedented level of accuracy. Using wind tunnel data, directional wind speed variations, as well as meteorological data on wind direction and frequency of storm intensity, efficiencies of 30% over existing design methods were shown to be achieved.



1. Fracture pattern of glass specimen subjected to co-axial double ring test

Corinna Datsiou

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Corinna Datsiou joined the gFT research group in June 2013. She received her Diploma in Civil Engineering, specializing in Structural Engineering, from the Aristotle University of Thessaloniki, Greece in 2012. Before starting her PhD, she worked as a research assistant for a few months at the Laboratory of Construction and Building Materials of the Aristotle University of Thessaloniki. Her recently completed PhD project focused on the stability and performance of cold bent glass plates and the mechanical durability of glass. Her research was funded by EPSRC, Eckersley O'Callaghan and the Onassis Foundation.

Funded By:

EPSRC Engineering and Physical Sciences Research Council

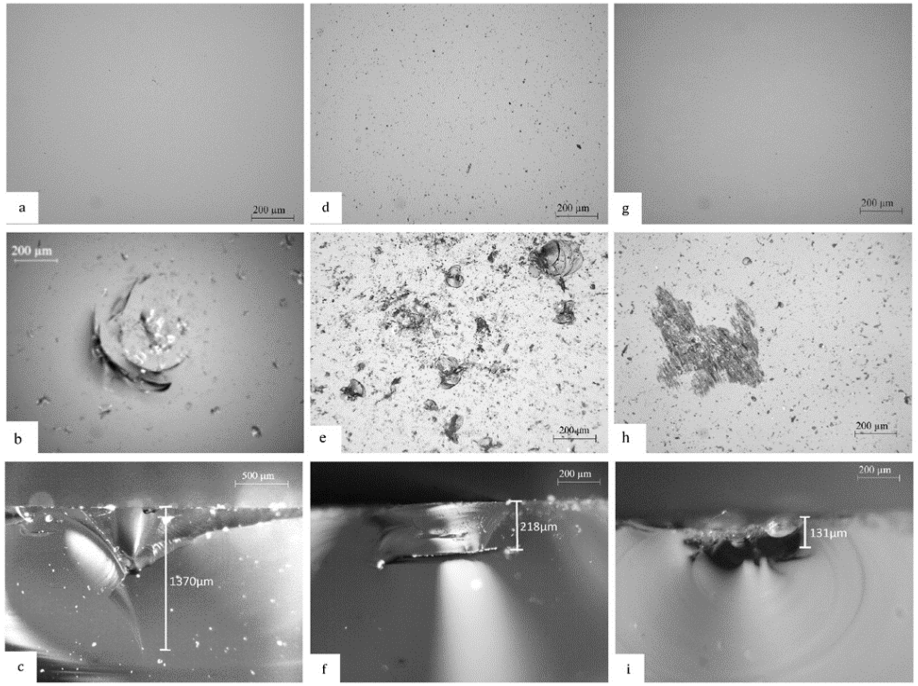
EOC

Onassis Foundation

The strength of aged glass

Glass is known for its excellent durability, but the strength of glass is very sensitive to the characteristics of its surface, which is known to accumulate damage during its service life. There is however, a lack of strength data on weathered or aged glass, particularly on thermally or chemically toughened glass.

In this presentation, the author's previous results on the artificial ageing of glass are condensed in a user friendly assessment procedure that allows the selection of suitable parameters for the artificial ageing of glass. Based on this procedure, a carefully calibrated sand trickling test is used to produce surface damage equivalent to erosive action of 20 years of natural weathering on different types of glass: soda-lime-silica annealed, soda-lime-silica fully toughened and alumino-silicate chemically toughened. The soda-lime-silica glass specimens are tested destructively in their as-received and artificially aged form in a conventional coaxial double ring set-up, while the alumino-silicate chemically toughened specimens are tested in an improved coaxial double ring set-up. The strength data are analysed statistically and the design strengths for each glass type are obtained. Fractrography is subsequently used to identify and measure the critical flaw size on each specimen.



The results show that all glasses suffer a loss in strength after artificial ageing, with fully toughened glass providing the best post-aged performance. However, it is also found that the degree of toughening / residual surface stress in the glass affects the erosion resistance.

1. Micrographs of (a-c) annealed glass; (d-f) fully toughened glass and; (g-i) chemically toughened glass: as-received surface, artificially aged surface and maximum critical flaw (top to bottom).

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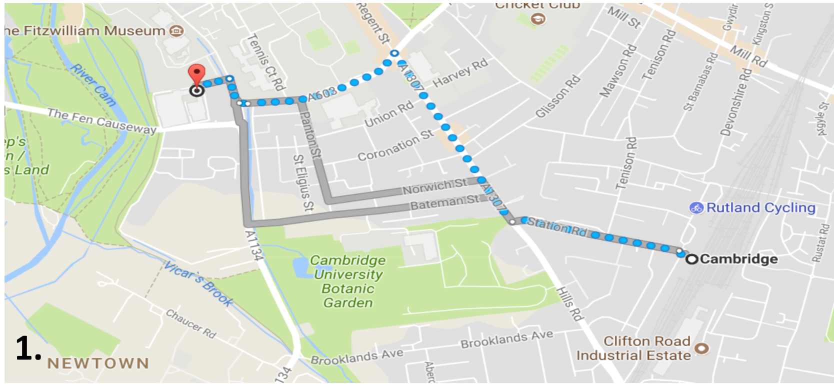
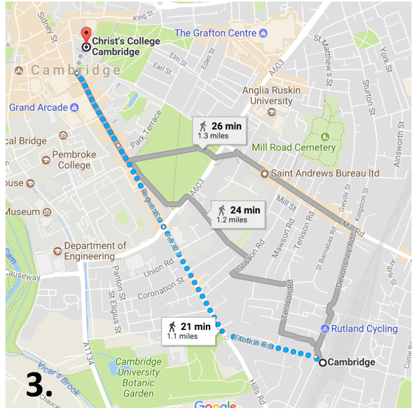
EVENING DINNER

Dinner will be held at Christ's College, Cambridge. Starting with drinks at 18:30, followed by dinner in the formal hall at 19:00. On arrival please report to the Porters' Lodge, where you will be directed to the drinks.

Walking distances:
1. Train Station to Dept of Eng (19 min)
2. Dept of Eng. to Christ's (15 min)
3. Christ's to Train Station (23 min)





Menu

Grilled Goat Cheese with Rocket and Herb Salad
Indonesian Salad (VE)
(Artisan Bread with Olive Oil & Balsamic Vinegar)
******
Supreme of Gressingham Duck in Plum and Brandy Sauce
Aubergine & Fig Moussaka with Apricots and Prunes (VG)
Lentil & Vegetable Cottage Pie (VE)
******
Chocolate Cheesecake with Vanilla Ice Cream
Fresh Fruit Platter with Raspberry Sorbet, Coulis & Honeycomb Crumb

FEEDBACK

Thank you for attending Engineering Skins 2017.
We would be grateful if you could take the time to complete this feedback form.

Please share your opinion on the direction of the research and/or of the individual presentations

We would also welcome your thoughts on the running of the day:

Organisation and Structure of the day: poor 1 2 3 4 5 excellent

Catering and Location: poor 1 2 3 4 5 excellent

Quality of the presentations: poor 1 2 3 4 5 excellent

If you have any further comments, please provide them below:

Request for further information:

Would you like any further information on the research projects? e.g. electronic copies of publications
If so please state what information you require and provide your contact details.

NOTES