ENGINEERED SKINS 2016

1st September - University of Cambridge - LR6

Proceedings

Recent Developments in Glass and Façade
Engineering Research at the University of Cambridge

gFT glass & façade technology research group

UNIVERSITY OF CAMBRIDGE

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Programme - 1st September 2016

Faculty of Engineering

09:30	Coffee & Registration	
10:15	Welcome Address	*Prof. David Cardwell*
10:30	Keynote: Smart materials for energy-efficient glazed façades	*Andreas Schueler, EPFL*
11:20	Coffee Break	
11:40	Simulation based performance prediction of adaptive façades	*Fabio Favoino*
12:00	Adaptive facades in the built environment	*Hanxiao Cui*
12:20	Bio inspired strategies for energy efficient facades	*Mark Allen*
12:35	Lunch	
13:35	Keynote: FRP Building Envelopes: Challenges and Solutions	*Mark Hobbs , PCT*
14:25	GFRP-glass sandwich panels: structural and thermal analyses	*Dr Carlos Pascual Agulló & Alessandra Luna Navarro*
14:50	FRP-Based High-Performance Building Envelopes	*Isabelle Paparo*
15:10	Fatigue analysis of a GRC to metal anchorage under wind load excitation	*Dr Marco Doná*
15:30	Early-stage design for manufacture of façades	*Jacopo Montali*
15:50	Coffee Break	
16:10	Artificial ageing of glass with sand abrasion	*Corinna Datsiou*
16:30	Shear strength of laminated glass	*Dr Mauro Overend*
16:50	Discussion: Complexity in Façades	*Pr. Chris Burgoyne, UoC & Andrew Watts, Newtecnic*
17:50	Closing remarks	*Dr Mauro Overend*
18:30	Dinner at St Catharine's College (optional)	

UNIVERSITY OF CAMBRIDGE

gFT glass & façade technology research group

Dear Guest,

Welcome to the 7th 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.

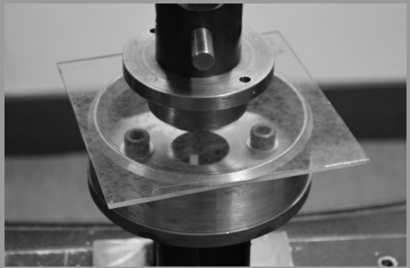
We would like to thank British Glass, Dow Corning, Interpane, Seele and Tuchschmid for sponsoring this event. We would also like to thank the numerous funding bodies and industrial partners who are contributing to our research activities. These are acknowledged in the relevant project descriptions in 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.

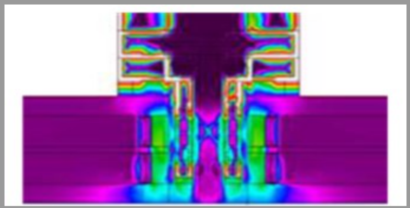
I hope you enjoy the day and that you find our research stimulating and useful.

Dr. Mauro Overend
Research Group Coordinator

Micrograph of critical flaw in glass.

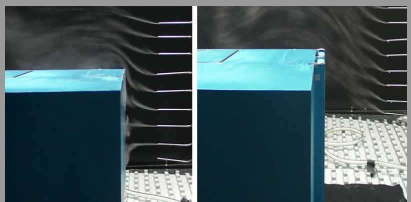


Coaxial double ring tests on glass.



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 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.

Dr. Mauro Overend

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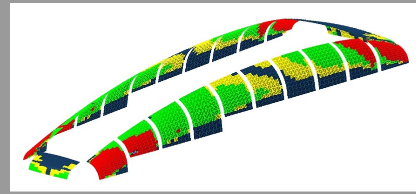
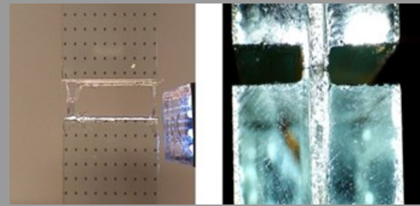
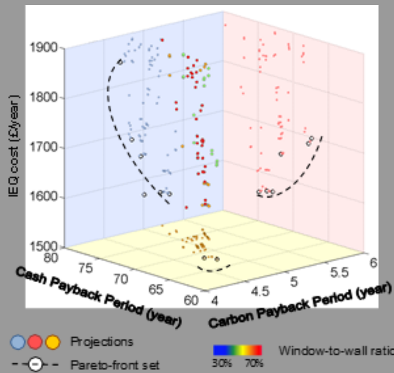
Mauro is a senior lecturer in Building Engineering Design at the Department of Engineering, University of Cambridge and he is Fellow of Christ' s College. Mauro is a chartered engineer with several years of consulting engineering experience in the fields of structural engineering and façade engineering. He currently 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 60 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 2011 Guthrie-Brown medal by the Institution of Structural Engineers and the 2013 IABSE Prize by the International Association of Bridge and Structural Engineers.



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



Trough-crack tension test for laminated glass.



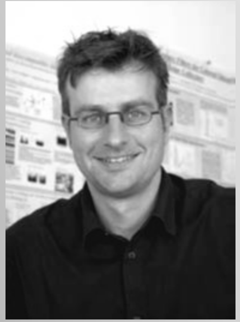
Multi-objective design optimisation of façade design.

Optimisation of adaptive glazing thermos-optical properties.

KEYNOTE SPEAKERS

Prof. David Cardwell — Welcome address

David Cardwell is Professor of Superconducting Engineering and Co-Director of the KACST-Cambridge Research Centre. He is also Head of the Engineering Department. Under Prof. Cardwell's leadership the Bulk Superconductor research group at Cambridge works on the processing and applications of bulk high temperature superconductors, which can be used to generate very high magnetic fields. He has authored over 330 technical papers and patents. Professor Cardwell has been a Fellow of Fitzwilliam College since 1993. He is actively involved in the recruitment of overseas undergraduates for the sciences, particularly from the Far East.



Andreas Schüler

EPFL

After studies of Physics at the Universities of Freiburg i.Br., Ann Arbor (Michigan USA) and Basel, Dr. Andreas Schüler started up a research group devoted to nanotechnology for solar energy conversion at Ecole Polytechnique Fédérale de Lausanne EPFL. Dr. Schüler delivers lectures, and supervised PhD and Master students at EPFL. His current research topics include nanostructured coatings for selective solar absorbers, thermochromic solar collectors, electrochromic glazing, and photovoltaic applications. Dr. Schüler won the Solar Energy Journal Best Technical Paper Award in 2007 and 2013.

Smart materials for energy-efficient glazed façades

This presentation gives an overview on some of our recent developments in the field of energy-efficient glazed facades.

Coloured solar glazing with high energetic transmission gives new possibilities for architectural integration of active solar energy systems (photovoltaic and thermal). The coloured reflection is produced by thin film multilayer interference, likewise avoiding useless absorption within the material and maximizing the conversion efficiency of the solar panel. The architect can choose the colour of the opaque part of the building façade in a wide range, while the energetic efficiency of the solar panel is maintained at a high level.

So far, the solar heat gain coefficient of most windows installed today shows only a moderate angular dependence and thus only exhibits rather small variations between summer and winter. Novel micro-structured glazing with a strong angle-selective energy transmission can be used to reduce the energy consumption for both heating in winter and cooling in summer. By redirecting a part of the incident solar radiation, an enhanced use of daylight will also be possible, allowing deeper penetration of light into the depth of the room.

Innovative nanocomposite thin film materials might improve the properties of electrochromic smart windows. Next generation switchable glazing shall exhibit faster optical switching, stronger contrast between clear and colored state, improved homogeneity and energy efficiency of switching, as well as superior durability.

Novel microwave-transparent low-e coatings for energy saving windows might considerably facilitate wireless communication (mobile phones, internet of things). Such coatings have been originally developed for mobile communication in trains, and might also have a possible impact on the building sector.

Starting from the first idea, we have been accompanying these innovative technologies at every stage of their maturity, and some are market-ready today.

Mark Hobbs

PCT

Mark Hobbs interest in lightweight materials and marine structures originally lead him to a position at Gurit where he worked as a structural engineer on a wide range of FRP structures, initially mainly in the marine market. During this time he achieved one of his childhood dreams of working on an Americas Cup yacht, and following this he became increasingly involved in the use of advanced FRP in architectural structures, with responsibility for concept design and technical approval for a number of world leading FRP structures.

In 2015 Mark joined Premier Composite Technologies as Head of Structural Engineering. He currently leads a team of 11 structural engineers working on large scale advanced FRP structures, and enjoys continuing to find new challenges for these exciting materials.

FRP Building Envelopes: Challenges and Solutions

Use of advanced fibre reinforced polymer (FRP) to form building envelopes can bring a number of benefits. Light weight efficient panels can be produced which allow large panel spans, reducing secondary structure and allowing rapid installation. Panels can provide multiple functions including external finish, forming the weathertight building envelope and incorporating insulation and services. Moulded FRP panels open up the possibility of complex shapes. Pre-fabricated parts built off-site reduces time on site and waste.

Although the use of advanced FRP is commonplace in other industries there are a number of challenges in the civil and architectural markets which have tended to limit the use of FRP. Many of these can be overcome or mitigated by understanding the materials and using them appropriately.

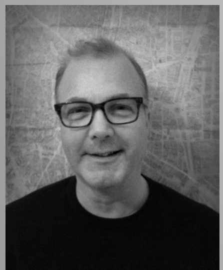
This talk will demonstrate how challenges have been overcome on a number of recent projects which have made extensive use of FRP as part of the building envelope, including large scale projects such as the 607m tall Makkah Clock Tower which includes 60,000m² of FRP façade panels and the Haramain High Speed Railway Station in Medinah which has a 26,400m² FRP roof, as well as smaller projects including the Glass Lantern at the Apple Zorlu store in Turkey, which has a 100m² carbon fibre roof supported on four panes of structural glass.

Chris Burgoyne

University of Cambridge

Chris Burgoyne graduated from St John's College, Cambridge. After taking a Master's degree at Imperial College and working in industry he returned to Imperial for a PhD. He was appointed to a Lectureship in the Concrete Structures section at Imperia, which led to a change of emphasis towards the behaviour of prestressed concrete structures. Since prestressing tendons are the most heavily stressed of all structural elements, they were natural candidates for the application of very high strength fibres. This has led to long-term studies of the strength, creep and durability properties of these fibres, as well as studies of their application to concrete structures, bridges and offshore. He maintains a continuing interest in general prestressed structures and also in the structural mechanics of bone. Chris was appointed Reader in Concrete Structures in 1999 and Professor in 2015. He is a Fellow of the Institution of Structural Engineers and a Member of the Institution of Civil Engineers.

Andrew Watts



Newtecnic

Andrew is a building engineer and an architect who specialises in the engineering design of facades and their interface with structural and environmental design. Andrew leads Newtecnic, building engineers, whose research from first principles allows the company to generate its own technologies for the complete building envelope. Newtecnic's involvement from concept to fabrication, including engineering design for structure, facades and the internal environment. Andrew is a Fellow of the Institution of Civil Engineers, and the Institution of Engineering Designers and a member of the Royal Institute of British Architects. He is the author of the Modern Construction Series of textbooks.

Complexity in Façades

Contemporary building envelopes generally consist of multi-layer systems, where each layer addresses a specific performance aspect such as structural integrity, thermal performance and architectural finish. This approach can lead to an inefficient use of materials, particularly in buildings with complex geometry. This trend of spiralling complexity was raised by Prof Chris Burgoyne in last year's Engineered Skins Symposium. This year Andrew Watts (Newtecnic) explains how emerging technologies are developed and deployed to produce a new integrated and efficient building envelop for buildings with complex geometry.

The technical performance of facades for public buildings comprises a mix of requirements with different aims. The control of daylight, sunlight, thermal transmission, structural design and weather tightness can lead to a complex set of facade assemblies in the facade design. This mix of requirements can result in the facade being designed as a series of layers, where each layer performs a specific sub-set of functions within the complete facade assembly. Alternatively, the different performance requirements can be partially combined within a facade build-up of reduced thickness in a monolithic construction.

The concept of the layered facade and the monolithic facade can be accommodated with supporting structure that avoids duplication of primary and secondary structure. For layered facades, the separation of inner and outer facade layers does not necessarily require secondary structure to support the outer skin. If the supporting wall follows the geometry of the outer facade panels, and the facade panels can be made to suit a supporting structure, then a single structural layer can be used where two layers would previously have been required. For monolithic facade assemblies, facade panels can fit around primary structure without the need to be positioned independently of that structure.

For current technologies, assemblies for facades are typically separated in a 'loose-fit' arrangement. The weather-tight layers, the supporting structure and the environmental control, such as solar shading, are positioned in separate layers.

In emerging technologies, elements are combined to improve efficiency by reducing the number and weight of components, with the aim of reducing cost. New priorities of combined primitives of assembly generate new technologies. Newtecnic generates its own emerging technology. This presentation will show five projects where technology for the facades is developed by Newtecnic: a museum in Istanbul, a theatre de Rabat, a metro station in Riyadh, a retail mall in Riyadh and a TV tower in Istanbul. In each project, a brief presentation will show how the development of each facade technology is driven by specific design objectives rather than the application of pre-determined technology.

gFT RESEARCH GROUP ABSTRACTS

Fabio Favoino

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Fabio Favoino joined the gFT research group in January 2013. He graduated (BSc and MSc) in Building Engineering at the Technical University of Torino, Italy in 2010, that included a 6 months student exchange period at TU Delft. After then he joined the TEBE research group, at the Energy Department of Technical University of Torino as a research assistant, working on the experimental evaluation of energy performance of dynamic building envelopes. His PhD project is about the energy and comfort performance prediction of adaptive building envelope systems. He is co-author and active member of the Cost Action TU1403—Adaptive Façade Network. His research is supervised by Dr Mauro Overend and is funded by EPSRC and Wintech Ltd.

Funded by:

EPSRC

Engineering and Physical Sciences Research Council

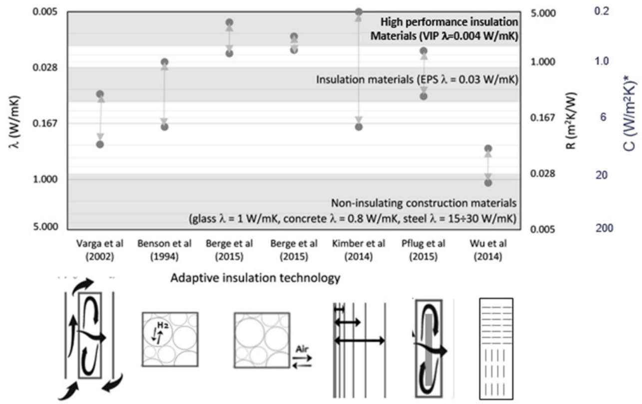
WINTECH

Simulation of adaptive facades: adaptive insulation for office buildings

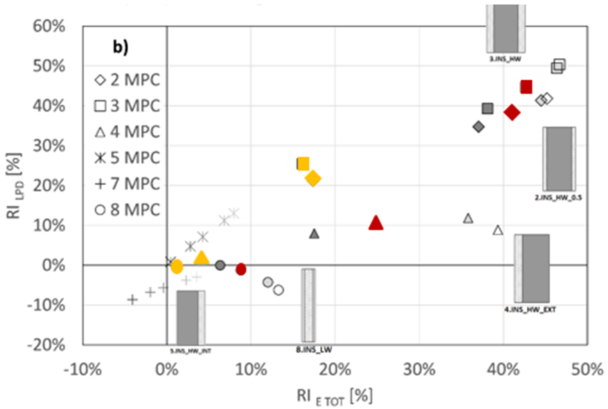
Fabio Favoino`s research focuses on the environmental performance of building integrated adaptive facades. During his PhD he developed an innovative computational tool to simulating the performance of adaptive facades. In this presentation the overall framework of his research work is outlined, in order to present his latest case study, about the design and control optimisation of adaptive insulation systems.

The increasing insulation levels imposed by building regulations result in heating energy savings, but tend to increase cooling energy use and/or reduce thermal comfort. Adaptive insulation could provide an opportunity to reduce building energy use while improving the environmental quality, but there is a lack of information about its performance when integrated into the building envelope. This case study aims to evaluate and optimise the performance of different adaptive insulation configurations for office buildings in a temperate climate. Alternative adaptive insulation configurations and control strategies for opaque walls are evaluated by means of building performance simulation. An innovative optimisation/simulation strategy is adopted to optimise design and control aspects. The results are evaluated in terms of primary energy saving potential and global thermal comfort.

The study shows that if properly designed and controlled, adaptive insulation, has significant potential in decreasing energy use in buildings while simultaneously improving global thermal comfort. When optimally controlled the adaptive insulation can achieve up to nearly 50% energy saving and thermal comfort improvement compared to its static reference solution. Significant improvements could be achieved with technologies that are readily available.



1. Typologies and insulation ranges of adaptive insulation technologies



2. Total energy savings and improved thermal comfort vs reference static insulation, for different adaptive insulation technologies.

Hanxiao Cui

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Hanxiao joined the gFT group in 2014 and earned an 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. In his spare time, he is an avid tennis player and cyclist.

Supported By:

CHINA SCHOLARSHIP COUNCIL

Adaptive facades in the built environment

Adaptation is one of the widest spread phenomena in natural world. It had been first observed in biological systems as a responsive behaviour that makes an organism better suited to a changing environment, and later was applied for the design of mechanical control systems in order to mitigate the risks associated with uncertainties.

The research on adaptive facade is motivated by two facts. First, facades are operated in an environment with substantial uncertainty, such as weather conditions and occupant behaviour, leading to a performance gap between expectation and actual operation. Second, the design lifetime of a building facade is considerably longer than the time scale of technological improvements, resulting in risks of technological obsolescence.

Adaptiveness is recognised as a critical ability to improve facade performance in an uncertain and constantly changing environment. However, the challenges on the research of adaptive facades are threefold: 1) the lack of concrete definition on the concept of adaptiveness, 2) the evaluation methods to compare the performance of an adaptive facade system in an uncertain environment, and 3) a systematic review a variety of existing adaptive facade technologies.

To define adaptiveness in the built environment, I reviewed the research on adaptation in biology, system design and control theory and summarised two defining attributes of adaptiveness: responsiveness and purposefulness. This working definition will be the first step to understand the logical principles of adaptation and eventually develop a functional adaptive facade in the future.

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.

Bio-inspired strategies for energy efficient facades.

For many years, both engineers and architects have been fascinated by the prospect of learning from nature and emulating it in their designs. But, how successfully do "buildings inspired by nature" actually mimic nature? How successfully do they combine functional properties with aesthetic expressions? And, how do they holistically address human-building interaction?

The presentation will begin by examining some buildings inspired by nature and discuss their achievements and the lessons that can be learnt. The ultimate goal: create a catalogue of mechanisms found in nature for the control of lighting, temperature and ventilation. Some of the most intriguing ones, potentially applicable to the facades of the future, will be revealed.

To close, a model of one of the most promising mechanisms, a species of termite mound that maintain a constant temperature within their nest will be presented. For this novel mechanism, ventilation is driven by diurnal flow fluctuations and exchange of gases through porous walls is used.

Overall I hope this talk inspires you to look for the answers in nature next time you face an engineering problem.

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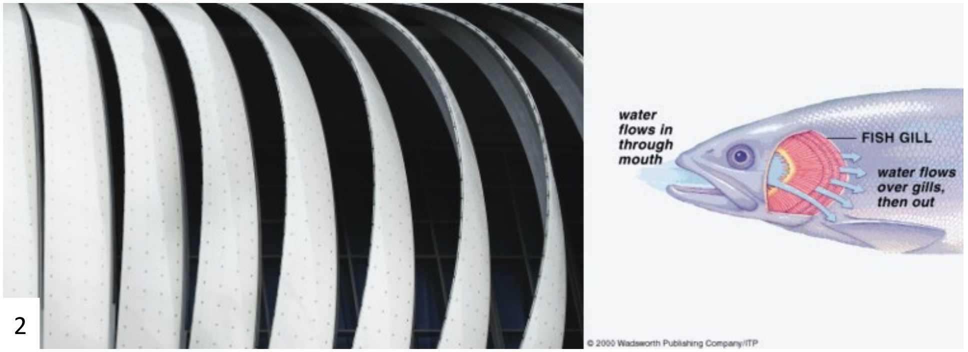

2

1. The Eastgate Centre in Zimbabwe is seen as a biomimicry icon, inspired by local termite mounds . 2. One Ocean in South Korea uses moveable lamellas to control air flow in the building, inspired by the gills of fish.

Carlos Pascual Agulló

cp570@cam.ac.uk

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 daylighting 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.

Funded By: EPSRC Engineering and Physical Sciences Research Council

Alessandra Luna Navarro

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Alessandra graduated in 2013 in Building Engineering and Architecture from La Sapienza University of Rome as best of class. After she gained chartered status as a civil engineer and worked for two years in Industry. At present, she is concluding her MPhil in Energy technologies at the Department of Engineering in Cambridge with a dissertation on energy performance in GFRP-glass façades. She will start her PhD at Cambridge in October 2016.

GFRP-glass sandwich panels: structural and thermal analyses

During the last decade several researches have demonstrated the feasibility of adhesively-bonded GFRP-glass sandwich panels for façade applications, by means of physical experiments. This sandwich configuration (Fig. 1a) has important benefits compared to traditional facades: it provides a thin, structurally stiff and thermally performant building envelopes with low embodied energy. However no analytical tools exist to-date for the structural design of this type of sandwich panels. Similarly, no detailed investigation of the thermal performance of these panels has been performed.

Current research in the gFT research group has produced new analytical models for predicting deflections, strains and stresses in adhesively bonded sandwich panels with thick glass face sheets, a shear-flexible FRP core and adhesive layers. The models have been validated numerically and shows good agreement with experimental results obtained in short-span sandwich beams. The structural adhesive employed for the connection allowed for a high degree of shear transfer resulting in composite actions between face sheets and core of around 90%. A numerical model based on Computational Fluid Dynamic (CFD) has been developed in order to evaluate the convection, conductive and radiative heat transfer through the sandwich system (Fig. 1b) and the results have been validated by experiments performed in a hot-box (Fig. 1c). In the frame region of the GFRP-glass systems, modelled U-values were approximately 50% lower than in equivalent aluminium-glass systems showing the potential of GFRP to reduce thermal bridges. A Building Energy Simulation (BES) has been also completed in order to assess the energy savings for thermal comfort achievable by using this novel technology instead of traditional glass façades.

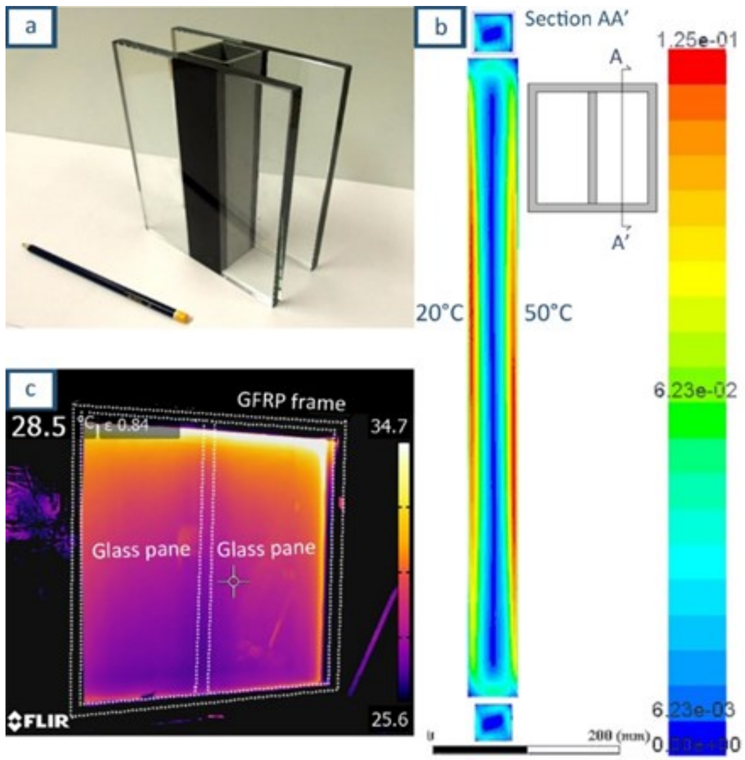

Figure 1: (a) Adhesively-bonded GFRP-glass specimen; (b) numerical modelling of the thermal behaviour of GFRP-glass sandwich panel and; (c) thermal experiment of GFRP-glass sandwich panel in hot-box.

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.

Funded By:

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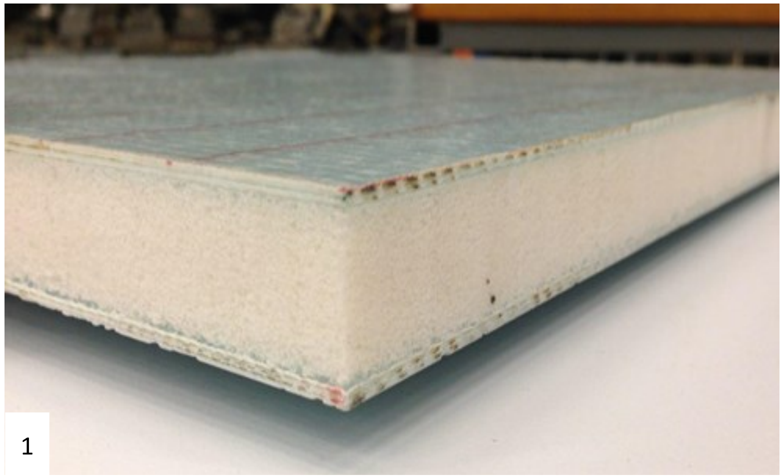
FRIEDRICH EBERT STIFTUNG

FRP-Based High-Performance Building Envelopes

Geometrically complex building envelopes are typical 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 driving design parameter of sandwich structures is their stiffness, as deflection criteria often govern their design. The mechanical performance of sandwich structures relies on the perfect bond between face sheets and core. It is therefore essential to assess the short and long-term bond-line behaviour at the face sheets - 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 freeze-thaw cycles; the degradation of the sandwich panels will be evaluated after 1 and 2 months of ageing. In addition to the temperature loading, the specimen is subjected to a constant load (15% or 35% of $P_{max,fail}$). This loading aims to represent real world applications such as cladding and should favour the creep deformation of the foam core. The testing program assesses the influence of the humidity within the sandwich panel on its structural performance, when subjected to freeze-thaw cycles.



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1. GFRP –Sandwich panel. 2. Artificial ageing box for freeze-thaw cycles.

Marco Doná

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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.

Funded By:

EPSRC
Engineering and Physical Sciences Research Council

Innovate UK

newtecnic
facade design + engineering + technology

Fatigue analysis of a GRC to metal anchorage under wind load excitation

Since its discovery almost 60 years ago, Glass Reinforced Concrete (GRC) has seen a growing number of applications in the construction industry. One of its main uses is for cladding elements in façades, where the durability and strength of GRC allow the construction of relatively thin panels that do not require additional reinforcing bars. GRC also has the great advantage to be manufactured in any shape, and is therefore particularly appealing for free-form building envelopes.

As façade elements, GRC is subjected to transient applied loads. Wind load, seismic load and thermal expansion fluctuate over the service life of the façade. Some of the typical load scenario are alternating or pulsating tension loads as well as reversing bending moments. Indeed, one of the critical aspects in the design of a GRC façade is the connection of the panels to the supporting structure. It is at these fasteners locations that stress concentrations are generated, thereby increasing the risk of failures. These stress concentrations that fluctuate over the service-life raise the need for a fatigue-based design approach.

In this presentation a fatigue test plan will be presented and discussed based on a real case study of an anchorage connector for GRC panels. The link between the random nature of the wind load and the definition of the corresponding stress levels and number of cycles for the fatigue test will be discussed, as well as the number of sample required to produce statistically significant design values.

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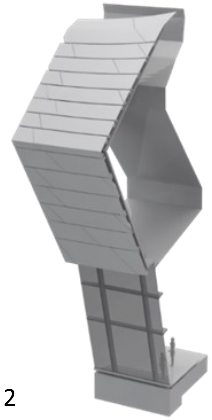

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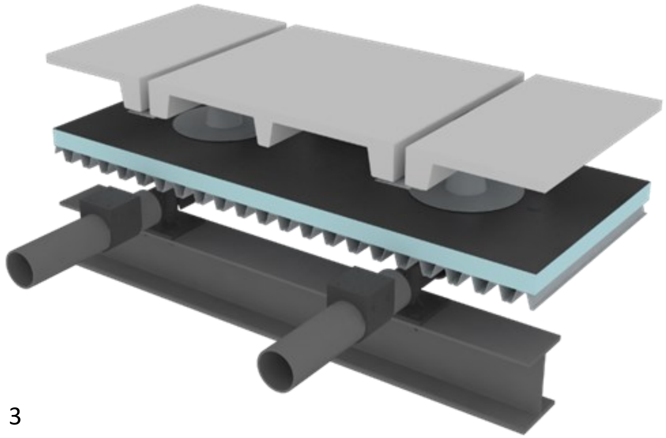

3

1. X-ray view of the building. 2. External 3D view of typical bay. 3. Assembled 3D view of typical bay.

Jacopo Montali

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Jacopo Montali joined the gFT research group in October 2014. After his graduation in Civil Engineering at the University of Parma in 2009, he worked as an free-lance engineer for 2 years. In 2011, he attended a high specialization course at Venice University of Architecture IUAV in Energy and Sustainability and then he worked in Torino as a consultant engineer on façade systems, building energy modelling and LEED certification for 3 years. He is a LEED AP: O+M since June 2013. His research on optimised façades for manufacturing and assembly is supervised by Dr. Overend and funded by EPSRC and Laing O'Rourke.

Funded By:

EPSRC
Engineering and Physical Sciences Research Council

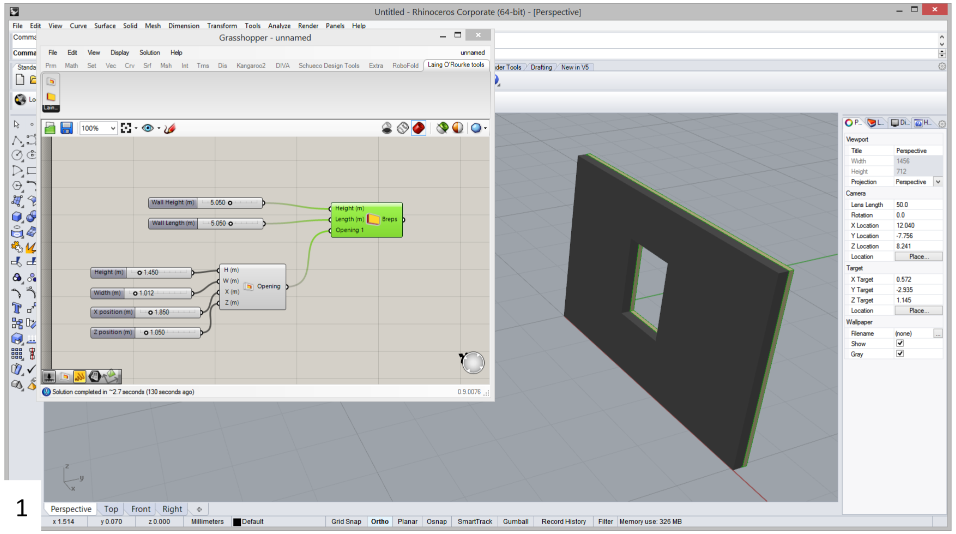
LAING O'ROURKE

Early-stage design for manufacture of façades

The growing housing demand in the UK market, along with the need for increased efficiency in the delivery process of buildings, require innovative solutions to deliver high performance, customised and affordable buildings. Prefabrication is a potential solution to achieve higher quality standards and shorter delivery times, although careful planning is required: this aspect sharply contrasts with the way buildings are traditionally designed, with supply chain changing on a project-by-project basis and design teams following a linear approach with increased levels of complexity.

In this context, building façades play a fundamental role: they have to concurrently provide a different number of performances while respecting constraints in terms of cost, manufacturability, standard compliance and aesthetic appearance. For these reasons, façade design is one of the most interdisciplinary engineering disciplines: every actor involved along the design and manufacturing process has to work collaboratively to deliver a complex product.

The aim of this research work is to provide a digital, knowledge-based tool to support the design process of specific façade systems, based on manufacturing capabilities of the system supplier / façade builder. The tool will be used by architects and façade consultants during the early stages of the decision making process. It will also introduce new opportunities for a more conscious, well-constrained, multi-objective optimisation and it will reconsider the current paradigm in the construction industry, in which "each design is a prototype". The research will impact façade design in terms of reduction of errors, lead times while increasing design variability; it will also develop a human readable knowledge repository for knowledge reuse in future projects.



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1.Experimental version of the digital KBE tool supporting façade design of a precast, single-leaf, façade concrete panel.

Kyriaki Corinna Datsiou

kd365@cam.ac.uk

Kyriaki 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 Building Materials of the Aristotle University of Thessaloniki. Her PhD project is on the design and performance of cold bent glass and the mechanical durability of glass and is supervised by Dr Overend. Her research was awarded 3rd prize at the 2015 IStructE Young Researcher's Conference and she is funded by EPSRC and Eckersley O'Callaghan.

Funded By:

EPSRC
Engineering and Physical Sciences Research Council

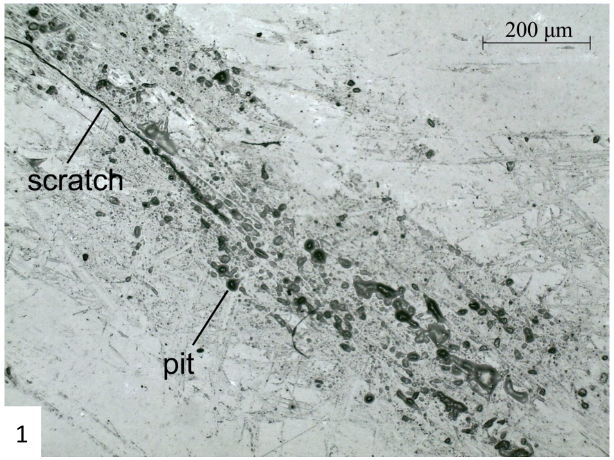
EOC

Artificial ageing of glass with sand abrasion

The strength of glass is governed by the condition of its surface; surface flaws accumulate due to weathering actions during the service life of glass and are expected to lead to strength degradation. When quantified, strength reduction can even reach 75-85% of the strength of glass in its as-received state. Therefore, the long term assessment of the strength of glass is crucial in order to ensure its safe use in structural applications. Artificial ageing methods are often employed to assess the long term performance of materials, but a reliable method for the artificial ageing of glass has yet to be established.

This presentation will focus on the experimental testing that has been undertaken in order to investigate the weathering effect on the surface of naturally aged glass and to also assess the effectiveness of a falling abrasive method as a potential artificial ageing method for glass. This method involves the use of an abrasive medium (silica sand & riverside gravel) that is allowed to trickle on the glass specimen from a controlled drop height and therefore, induce a random flaw population on its surface. The influence of each artificial ageing parameter of this process on the strength of glass was investigated in turn.

Optical microscopy and coaxial double ring tests were used to evaluate the naturally aged and artificially aged glass. Good agreement was achieved for glass strengths at different probabilities of failure between the artificially and naturally aged glass for specific combinations of artificial ageing parameters. An assessment procedure for the strength of novel glass was finally proposed; this procedure can reproduce the level of damage found in naturally aged glass in as-received glass.



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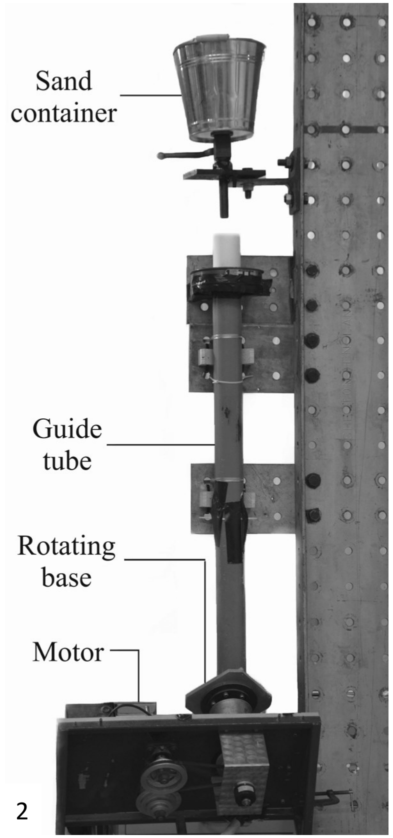

2

1. Surface of 20 year old naturally aged glass. 2. Artificial ageing rig for the falling abrasive method.

Mauro Overend

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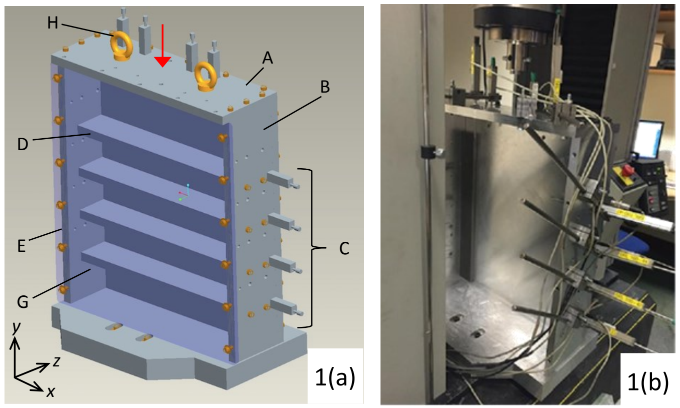
Mauro is a senior lecturer in Building Engineering Design at the Department of Engineering, University of Cambridge and he is Fellow of Christ' s College. He is a chartered engineer with several years of consulting engineering experience in the fields of structural engineering and façade engineering. 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 60 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 2011 Guthrie-Brown medal by the Institution of Structural Engineers and the 2013 IABSE Prize by the International Association of Bridge and Structural Engineers. In 2015 he was appointed by the European Commission to the project team tasked with drafting the glass Eurocode.

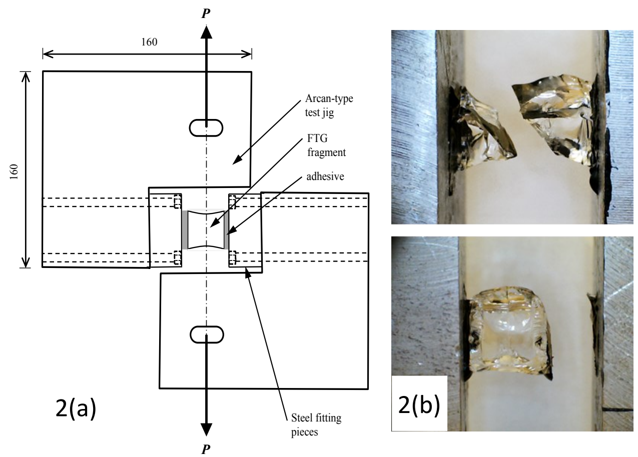
Shear strength of laminated glass

Longitudinal shear failure of glass has been observed in several lab-based experiments ranging from glass "plucking" failures in high strength adhesive joints to longitudinal shearing of glass layers in laminated glass units. But to date this failure phenomenon has been merely reported as an experimental observation and has not been fully explained or investigated directly.

In this study we investigate the longitudinal shear strength in triple-laminated glass. The shear failure consists of longitudinal splitting along the glass phase of large format triple laminated glass panels and is triggered by the fragmentation of the core glass sheet, in the absence of any further external loads. This could lead to the complete detachment of one outer glass sheets from the fragmented core and would therefore be deemed as unsafe mode of failure.

A mechanics-based hypothesis is put forward in this report that explains this new mode of failure. The hypothesis is tested and the salient mechanical characteristics of in-plane splitting failure were characterized by means of physical experiments, numerical (FE) analysis and theoretical work. In particular, the volumetric expansion of fully toughened glass and the shear strength of glass were quantified. This data was used to validate a simple analytical method for determining: (a) The Action and; (b) The resistance. The analytical method was subsequently used to illustrate how design graphs could be constructed in order to set safe limits (e.g. maximum dimensions of laminated glass) to prevent this mode of failure.





1. Shear stress test set-up (a) Schematic view of the test rig; (b) View of the test chamber mounted in test machine.

2. Fragment shear strength test (a) Arcan test frame; (b) fragment failure modes.

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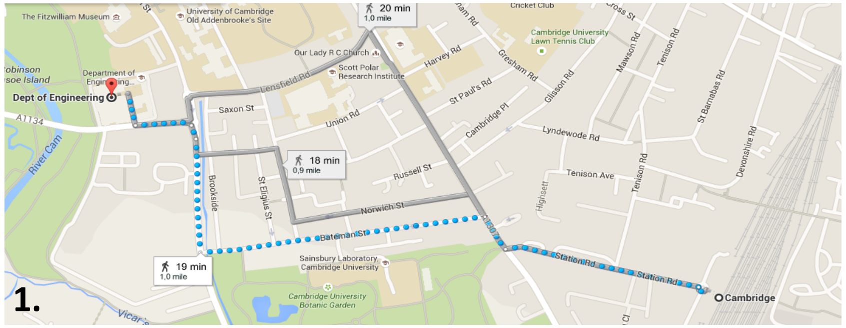
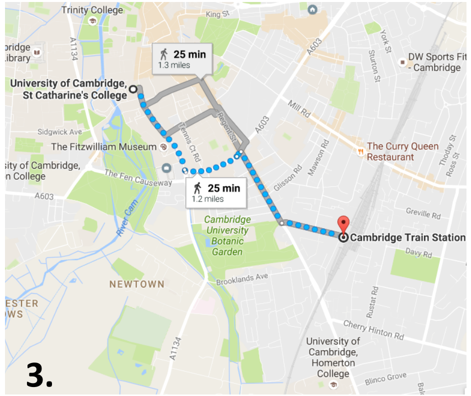
EVENING DINNER

Dinner will be held at St Catharine's College, Cambridge. Starting with drinks at 18:30, followed by dinner in the senior combination room 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 (20 min)
2. Dept of Eng. to Catharine's (8 min)
3. St Catharine's to Train Station (25 min)



Menu

Pan fried sea trout with peas

Or

Summer garden salad (v)

~

Loin of lamb with vegetables

and red wine sauce

Or

Grilled courgette stuffed with tomato,

basil & goat's cheese (v)

~

Chocolate & raspberry tart

FEEDBACK

Thank you for attending Engineering Skins 2016.
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.