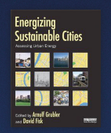
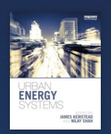
Other Centre related publications featured in this review:


GEA (2012)
*Global Energy Assessment – Toward a Sustainable Future.*
Cambridge, UK and New York, NY, USA, Cambridge University Press, and the International Institute for Applied Systems Analysis, Laxenburg, Austria.




Grubler, A. & Fisk, D. (2012)
*Energizing Sustainable Cities: Assessing Urban Energy.*
USA, Routledge




Keirstead, J. & Shah, N (2013)
*Urban Energy Systems: An Integrated Approach.*
Oxon, Routledge

For all enquiries relating to the Laing O'Rourke Centre for Systems Engineering and Innovation please contact the Laing O'Rourke Centre Administrator:

**Alexandra Williams**
Centre Administrator
Room 437, Skempton Building
Imperial College London
South Kensington Campus
London SW7 2AZ
United Kingdom

**Tel:** +44(0)207 594 5995

**alexandra.williams@imperial.ac.uk**



Imperial College London

LAING O'ROURKE

# Laing O'Rourke Centre for Systems Engineering and Innovation

## Contents

**Professor Jeff Magee**
Dean of the Faculty
of Engineering

**Professor David Fisk**
Laing O'Rourke Professor
of Systems Engineering
and Centre Director

**Professor Nick Buenfeld**
Head of the Department
of Civil and Environmental
Engineering

# Foreword

The Centre for Systems Engineering and Innovation was created following an agreement between Laing O'Rourke and Imperial College London signed in October 2010 and is hosted within the Department of Civil and Environmental Engineering.

As engineering projects become ever more complex, the need for systems thinking in their inception and delivery has become a prerequisite for a successful outcome. This is Imperial's shared vision with Laing O'Rourke. The prime mission of the Centre is to bring the techniques of modern systems engineering to modern building services, but its influence is planned to be much wider.

From *Creating Systems That Work (2007)* a Royal Academy of Engineering report, which envisaged a systems engineer as someone with a T-shaped skill set with proven skills in one field of engineering, but knowledge of the systems approaches across others. The Centre's MSc aims to develop engineers with this profile.

The MSc in Systems Engineering and Innovation takes young engineers with proven track records and exposes them to systems problems and solutions across a wide range of engineering disciplines. For a long while systems engineering has focussed on the efficient organisation of the assembly of components of large systems.

With the growing power of computation, systems engineering can now model and optimise the performance over time of large networked systems. Current research into optimising urban energy systems at Imperial is a case in point.

The future of urban energy systems also formed the subject of the Centre's First Distinguished Lecture. Most recently systems engineering techniques have extended to the performance of vast networks that are populated by near autonomous components and subsystems, such as telecommunication networks. The world of systems engineering is becoming ever more challenging.

Systems issues pervade the research of the Department of Civil and Environmental Engineering from structures to transport planning. The Faculty of Engineering at Imperial is the most highly rated in the UK and has a worldwide reputation for quality. It provides staff from eight different Departments to deliver the Centre's multi-disciplinary teaching and research. Systems engineering not only tackles current issues, but empowers society to be even more ambitious in what it seeks to do. The Centre's ambition is to enable engineering firms like Laing O'Rourke to deliver that promise.

This document covers the period from the Centre's inception up until March 2013. It highlights the new MSc Course, the research sponsored by the Centre and its increasing outreach activities.

**April, 2013**


## Acknowledgements

The Centre would like to thank **Mr Andy Rutt MBE** for his efforts in administering all Centre related activities. Andy left the Centre during spring 2012 to return to his former passion in the military. The Centre wishes Andy well in his future endeavours.


## 1.1 Centre timeline October 2010 – March 2013

**2010**

**October**

Laing O'Rourke and Imperial College London sign a joint donation agreement.

**2011**

**February**

The Imperial Graduate School approve the new MSc in Systems Engineering and Innovation part-time programme.

**October**

First cohort of MSc Systems Engineering and Innovation students join Imperial.

**December**

By December 2011, two PhD studentship holders commence study at Imperial.

**2012**

**January**

Charles Ogilvie of SERCO Energy delivers the first paper in the Laing O'Rourke Centre Lecture Series.

**April**

The Centre hosts the CIBSE/ ASHRAE International Technical Conference *Buildings Systems and Services for the 21st Century.*

**May**

Professor David Fisk is elected as President for the Chartered Institute of Building Services Engineers (CIBSE).

Ray O'Rourke KBE, Chairman of Laing O'Rourke, is awarded an Honorary Doctorate of Science for his outstanding contribution to engineering and to the UK construction industry. The award is presented during Imperial's Postgraduate Graduation Ceremony held at the Royal Albert Hall.

**June**

The Centre launches its *Working Paper Series*.

**September**

Adjunct Professor Gavin Davies of the Laing O'Rourke Engineering Excellence Group addresses staff at the Department of Civil and Environmental Engineering Staff Assembly.

**October**

Second cohort of MSc in Systems Engineering and Innovation students join Imperial.

**December**

Professor Ochieng and Dr Angeloudis, both lecturers and dissertation supervisors on the Centre's MSc programme, win a grant to help deliver better construction methods for nuclear power plants.

**2013**

**January**

Professor Fisk presents a paper on *Benchmarking – Gaming or Winning?* at the winter meeting of the American Society of Heating Refrigeration Air-Conditioning Engineers (ASHRAE) held in Dallas.

**February**

PhD Scholars, Marianna Micallef and Sarah Noyé present their research projects at the Laing O'Rourke Doctoral Conference 2013 in Dartford.

The Centre hosts its inaugural annual distinguished lecture delivered by Professor Arnulf Grubler who presents findings from the Cities in the International Institute for Applied Systems Analysis (IIASA) 2050 Global Energy Assessment.

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# MSc in Systems Engineering and Innovation: Introduction

Dr Christian Onof,
MSc Course Director

The Centre is responsible for delivering the MSc programme in Systems Engineering and Innovation which is designed to develop the next generation of technology champions in modern complex engineering systems. The course welcomes students who have already demonstrated competence and leadership in their field and who wish to extend their knowledge of systems, the broader application of systems thinking, and apply their learning successfully into the real world.

## 2.1 Meet the students

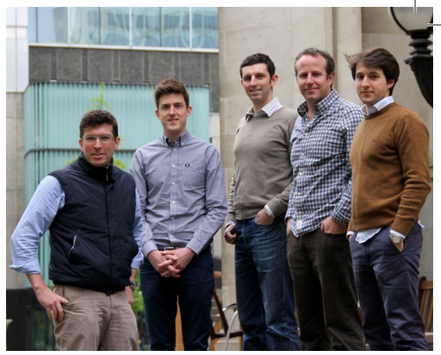

**Diego Aranda-Pérez** is an industrial engineering graduate from Univeridad Pontificia Comillas – Madrid. In his MSc, Diego will measure thermal inertia in buildings using temperature sensors. Existing control systems for heating, ventilation and air conditioning usually ignore thermal inertia which leaves room for significant improvements in terms of energy savings and managing demand. To include thermal inertia in control systems means adding substantial complexity to existing models: they require more information about the geometrical and physical characteristics of the building and involve longer computation times. Systems engineering is the best approach to deal with this complexity.

> "In just the first few months of the course, I have already changed my approach to problem solving.
>
> The difference between innovation and invention is the use of what you discover."
>
> Diego Aranda-Pérez

**Are you inspired to become a next generation systems engineer?**

Full details regarding the MSc programme can be found on **page 24**



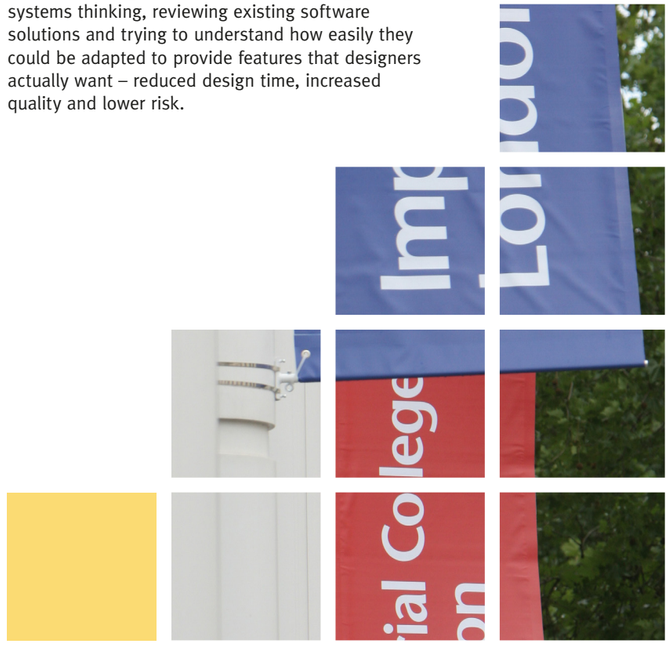


**Cohort 2 from left:** Daragh Campbell, Douglas Baldock, Andrew Ellwood, Matthew Brown and Diego Aranda-Pérez.


**Douglas Baldock** is a building services consultant at Hoare Lea in London. Cities are major consumers of energy, through heating, cooling, electrical power, and transportation services. Urban energy models which use optimisation techniques are widely used to plan new energy infrastructure for cities and large neighbourhoods. However the same challenges of system integration also exist within large building complexes, such as hospitals or university campuses. In his MSc Douglas is exploring the feasibility of using urban optimisation models in these smaller projects. He will develop a business plan that could be presented to investors interested in growing the market share for this software.

> "Complexity has become inherent in building systems design and the industry needs to adapt from both a technical and business perspective. This course gives students the knowledge and skills in both disciplines."
>
> Douglas Baldock


**Matthew Brown** is a senior design engineer with broad experience across all disciplines in data centres, critical infrastructure industries and more recently renewables. In his MSc Matthew is investigating the lack of software within the design industry that aids systems thinking at the initial concept stage. Most software solutions currently available are for specific calculations, such as flow rates, cable sizes or protection. He will research the need for a design tool that would encourage systems thinking, reviewing existing software solutions and trying to understand how easily they could be adapted to provide features that designers actually want – reduced design time, increased quality and lower risk.

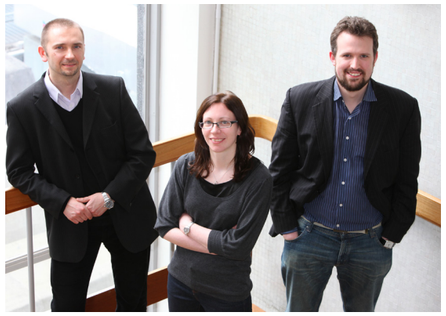


# 2.1 Meet the students


> "When the possibility of attending the MSc in Systems Engineering and Innovation at Imperial arose, it was an opportunity that I couldn't miss. The prospect of putting what I am learning into action in the workplace is very exciting."
>
> Daragh Campbell

**Daragh Campbell** has more than 15 years' experience in the construction industry, from delivering pharmaceutical and biotech facilities in Ireland to data centre projects in the UK. Data centres provide the platform for so many industries and represent a unique load on the power grid because they have little tolerance for load management. Data centres currently use decentralised power solely for back-up generation, usually in the form of diesel generators. In his MSc, Daragh is considering how fuel cells could best be integrated into the data centre industry not just as back-up power but also independent power generation.


> "The teaching is of a very high standard and the reputation of the College means that it attracts high quality guest speakers."
>
> Rhona Malcolm



**Cohort 1 from left:** Irek Starzyk, Rhona Malcolm and Michael Enstone.

**Rhona Malcolm** is a senior engineer at Crown House Technologies (part of the Laing O'Rourke group) based at Heathrow Terminal 2A where she is responsible for delivery of the electrical infrastructure. In her MSc, Rhona is studying the feasibility of using cloud computing to make energy models available to local authorities. Local authorities need to decide how to meet their future energy challenges while working with increasingly tight budgets. Cloud computing provides a potentially cost-effective way for local authorities to access energy modelling software. From a systems perspective local authorities can introduce a new energy policy which may inadvertently have a negative impact on other parts of the city infrastructure. Modelling and considering the city as a system can help them make better decisions.






**Irek Starzyk** is a mechanical design engineer at Crown House Technologies (part of the Laing O'Rourke group) working on Heathrow Terminal 2A project. In his MSc, Irek is exploring ways to use technologies like virtual and augmented reality to improve design and collaboration within the construction industry. These technologies are already used in the manufacturing, aerospace and healthcare industries and could be a useful tool during design, construction, maintenance and demolition of buildings. His research is carried out at the Design London Innovation Technology Centre at the Royal School of Art which houses a 3D stereoscopic visualisation system, allowing for an immersive experience and the visualisation of life size objects in real-time.

> "The course has made me realise that the success of an engineering project can depend on the right approach to the system requirements, their risks and how the risk is managed."
>
> Irek Starzyk


**Andrew Ellwood** has eight years' experience in manufacturing plant and machinery installation projects. In his MSc Andrew is researching ways to improve the use of tower cranes and pre-manufactured modular elements in building construction. The aim of the research is to reduce the costs of large infrastructure projects by reducing man-hours spent on site while also improving accident and quality assurance statistics. Andrew's long-term goal is to move into the energy/utilities sector and he believes the MSc (and the specific module on energy policy) will equip him with the underpinning knowledge to achieve his ambitions.


**Michael Enstone** is a building services engineer for AECOM with varied project experience, from combined cooling, heat and power installation to the refurbishment of listed buildings. During his MSc Michael has developed a smartphone application to improve the information provided by photographs taken on site. Academic literature has similar ideas; however these often require additional equipment or processes. A systems way of thinking led Michael to use existing smartphone cameras to collect richer information that can enhance site monitoring. When photos are taken on site the orientation and location of the phone is recorded and can be used to categorise photos in a database.

> "The MSc in Systems Engineering and Innovation is superbly taught by high calibre lecturers and visiting captains of industry. The pace of work is both manageable and enjoyable. The modular attendance allows students to maintain a busy career life whilst consolidating learning through offline assignments."
>
> Andrew Ellwood

> "I was offered the chance to participate in this MSc through work and I thought this was a unique opportunity to gain an understanding of an alternative way to approach projects."
>
> Michael Enstone

# 3 Innovation

## Imperial West – view from the top

### Building the next generation of engineers

Professor David Gann is the Vice President for Development and Innovation at Imperial College London and has worked closely with the Centre since its inception.

He sees the Laing O'Rourke Centre for Systems Engineering and Innovation, and its MSc programme, as very much part of an Imperial way of doing things.

**Professor David Gann**

**Imperial West view at dusk**
Artist's impression

**Imperial West Building**
Artist's impression



"The Laing O'Rourke Centre is targeting an area of pressing need and growing importance," says David. "We know that the active components of buildings, what we call the mechanical and electrical systems, are becoming more sophisticated and complex." They are being driven harder to do multiple jobs, whether in hospitals, schools or houses, and they are consuming a bigger part of the budget, both in capital spend and in operating costs.

"It's important that we get this right," says David, and fully understand the interplay between the active elements and the passive fabric and structures of a building, including their environmental impact.

Looking at the performance of buildings and infrastructure from a systems viewpoint means teaching people the engineering skills to understand how all of those elements work together in the long term and can be delivered in a cost effective way in the short term.

One challenge is how often the active elements of a building are recycled and refitted. In many structures, including hospitals and schools, these elements will have a shorter lifetime than the passive structure. In a big scientific building with wet labs you have to reconfigure the way you are working, and upgrade your building services, even more often.

"The Francis Crick Institute, St Pancras, London is a very good example of a high-end scientific building with a lot of services," says David, and a project which the Centre's MSc students have an opportunity to be exposed to. The Francis Crick Institute is a unique partnership between six scientific organisations, including Imperial. Laing O'Rourke is leading the construction of The Francis Crick Institute, and completion is expected by 2015. When finished, it will be one of Europe's largest biomedical centres, housing some 1,250 scientists.

The laboratories are designed to be adaptable to change and to foster collaboration between fields, and also to minimise their environmental impact. The external shell of the building will take two years to complete, but another two years will be spent fitting out the interior, including specialist scientific and computing equipment.

Imperial College London is involved in another high-profile scientific construction project – the expansion to a new campus at Imperial West in White City. "The most exciting thing happening in Europe," according to David. The first phase of this new 150-million research and translation hub is scheduled for completion by 2016. The seven-acre site will house research laboratories alongside commercial offices and social spaces designed to encourage collaboration and foster translation of research into business ideas.

Technically demanding projects like The Francis Crick Institute, St Pancras and Imperial West create opportunities for the Centre's students. "We need to create the talent in the construction industry to build the high-end, high-quality infrastructure that keeps British science on the front foot," says David. As Laing O'Rourke becomes an engineering enterprise, which is its own vision, it needs engineers that can do the systems that make these high-end facilities and new hospitals work.

When hundreds of scientists and engineers start working at Imperial West in 2016, David hopes they will tackle problems in several key areas. There will be links with technology start-ups, some of whom are already on site. There are major research areas where Imperial is already strong but can contribute even more – ranging from health and well-being to energy and the environment. "Big science itself needs big facilities," notes David. "Scientific instruments are often the precursor to innovation." He argues you couldn't have had self-cleaning glass from UK company Pilkington – glass which is hydrophilic and photocatalytic – without the electron tunnelling microscope. Pilkington was one of the first manufacturers to put an electron tunnelling microscope in its factories.

Finally, designing smart cities of the future will rely on world class engineers of the sort that Imperial has a reputation for producing. London now has a Smart London board, a panel of experts chaired by David, aimed at making London work more efficiently by making its infrastructure better. Smart London is about how the whole city functions as a result of the complex interplay between its 'systems', not unlike the systems of a high-tech building. London is home to several of the world's top universities, including Imperial, and they are fundamental to the vision of a Smart London, according to David "This is a fantastic place to have a corporate linked Centre for postgraduate teaching and research on systems."

**Sarah Tomlin** is a freelance writer based in London.

# 4

## PhD Research

## 4.1 Laing O'Rourke Centre

The Centre provides a natural interface between Laing O'Rourke and the specialist expertise at Imperial. World class research enriches the quality of our teaching, provides a vital learning environment for students and advances the welfare of society. It is therefore natural that the Centre hosts research as part of its activities. Some of its associates are involved in industrial research and research funded by the Governments Technology Strategy Board. Under the Centre's founding agreement, Laing O'Rourke also support PhD research in areas of common interest.

The two PhD projects underway at the centre tackle two different areas of construction industry interest. But both address a wider emerging concern about component performance beyond the original design concept to the rough world of reality. A construction industry committed to delivering what it promises first time requires a growing knowledge base. This is an exciting and challenging area for academic research.

**Professor David Fisk, Centre Director**

**Dr Robert Vollum**

### Creating Underground Space: Innovation in water-resistant design, construction and performance

**Marianna Micallef**

Imperial supervisors:
**Professor Bassam Izzuddin, Dr Robert Vollum**

Laing O'Rourke supervisor:
**Dr John Stehle**

This project concerns the improved design of reinforcement for controlling early age thermal and shrinkage cracking in concrete structures such as deep basements and water tanks. The research impacts upon cost effectiveness, quality, buildability, safety, durability and sustainability through improved performance and the minimisation of steel consumption. One outcome of the PhD will be the training of a young engineer to be an expert in the design of watertight concrete and numerical modelling.

### Wireless sensor networks for building system commissioning

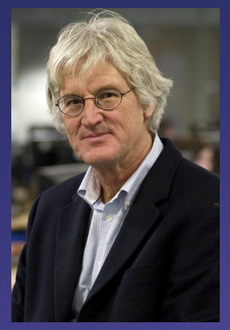
**Sarah Noyé**

Imperial supervisors:
**Professor David Fisk, Dr Robin North**

Laing O'Rourke supervisors:
**Dr Gavin Davies and Malcolm Moorby**

With buildings consuming 44% of total UK energy there is increasing pressure to improve whole-life building energy efficiency, and a corresponding market opportunity. In other areas, increasing information has been used to reduce consumption. In the transport sector, examples include the use of continuous monitoring and feedback to drivers and fleet managers to reduce fuel use, or real-time monitoring to support efficient traffic management. In this PhD we are working with Crown House Technologies (part of Laing O'Rourke) to develop and deploy wireless technologies for seasonal commissioning, and to investigate ways to reduce building energy consumption. Above all, we have an opportunity to undertake real, practical field trials on state-of-the-art buildings and to deliver tangible benefits.

**Dr Robin North**



As engineering projects become ever more complex, the need for systems thinking in their inception and delivery has become a prerequisite for a successful outcome. The prime mission of the Centre is to bring the techniques of modern systems engineering to modern building services, but its influence is planned to be much wider.

**Professor Jeff Magee**
Dean of the Faculty of Engineering

**Image:**
Faculty Building

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## 4.2
## Marianna Micallef

> “I had a false impression that academia and the construction industry are two distinct and non-overlapping institutions.”

**Marianna Micallef** graduated as an architect and civil engineer from the University of Malta in 2006. She also has an MSc in Advanced Structural Engineering from Imperial College London. Her PhD studies at the Laing O’Rourke Centre focus on the design and performance of water-resistant reinforced concrete (RC) structures. In particular, she studies concrete cracking in RC walls with edge restraints. The goal is to control crack widths, and hence water leakage in walls with various edge restraints by varying the reinforcement arrangements and wall restraints.

When restrained, concrete cracks during setting and cooling because of its low tensile strength. Steel reinforcement is used to control the width and spacing of cracks, so as to improve concrete durability and prevent leakage. This is especially important in the design of water-resistant and underground RC structures.

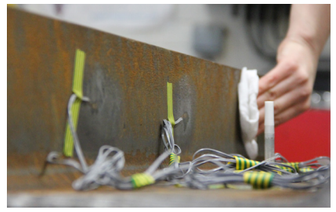
> “I look at this doctoral degree as a learning curve and a way to develop ideas where self-discipline and self-motivation play an important part of the study.”

Past research has focused on predicting crack spacings and widths in RC designs. From an engineering perspective, the design assumptions and principles in Eurocode 2 (EC2) differ from those used in BS8007, which was the previous UK building code.

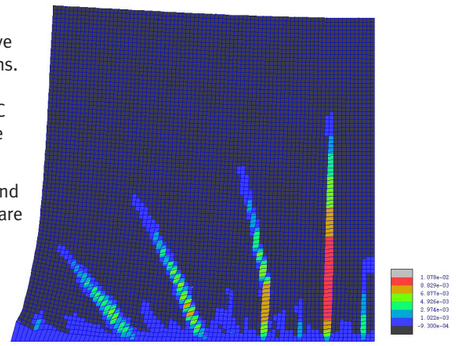
This PhD research was motivated by the observation that EC2 can require significantly more reinforcement than BS8007 to control crack widths, with economic and practical implications. For some designs, so much reinforcement is needed that it is difficult to get concrete around it.

The objective of this research is to increase the confidence with which engineers can predict crack widths and to ultimately improve the EC2 method for designing reinforcement to control crack widths. It is envisaged that the research will lead to less onerous reinforcement requirements for crack control in edge-restrained RC sections, which in turn will lead to more economical and buildable structures.

Preliminary studies have shown the need for experimental work and further numerical modelling both of which are underway. Studies are expected to be completed by the end of 2014 or early 2015.



**Experimental work** – instrument installation to restraints



**Numerical modelling**
– typical total strain plots



## 4.3
## Sarah Noyé

**Sarah Noyé** is a first year PhD student at the Laing O’Rourke Centre. She previously obtained an MSc in engineering at the French *grande école* Mines de Nancy. Sarah’s PhD research at Imperial focuses on how to reduce the gap between as-designed and as-operating energy consumption through improved data collection during building commissioning to ultimately reduce building energy consumption.

> “Through their funding, Laing O’Rourke is giving me the opportunity to study at one of the top European universities in civil engineering. I find the partnership with Laing O’Rourke challenging and motivating as I can directly relate my research to the industry.”

Building systems, such as air conditioning, heating, cooling, and ventilation, are crucial for our everyday comfort as we spend 80% of our modern life inside and they are crucial for our future as they represent more than 50% of building energy consumption. Innovative technologies are needed to better control energy consumption without sacrificing comfort.

Humanity faces new energy challenges from shrinking fossil fuel resources, and the building sector represents about a third of the total energy consumption of developed countries. Efforts have been made to encourage new buildings to consume less energy, but they mainly influence the design phase of the construction process. In practice, most new buildings do not operate as well as would be expected from their design. Commissioning is a quality control process that can ensure good realisation of the initial design.

Historically, the purpose of commissioning has been to ensure the safety and comfort of building users, but energy efficiency is rising in importance. Tests before building hand-over are not sufficient to ensure energy efficiency, as they do not account for variations in weather and occupancy. Extra tests need to be carried out during the first year of operation of the building. Sarah’s research seeks to introduce a post-occupancy commissioning process to address the lack of data that hampers such efforts. The introduction of Wireless Sensor Network (WSN) technology enables relatively cheap sensing methods. Sarah’s research uses WSN to provide continuous and simultaneous monitoring of systems for extended periods at reasonable cost. The goal is to evaluate the initial performance of the heating, ventilating and air conditioning systems under different operating conditions, to diagnose problems and to ultimately reduce energy consumption.

**NI Wireless Sensor Nodes**

> “This century will face a major environmental crisis. I left high school with the only certitude that I wanted to dedicate my career to cope with this issue. I believe that engineers have a big role to play there. They have to provide the technical innovations that will lead to a more renewable energy mix as well as improved efficiency of our energy usage.
>
> As the building sector represents 40% of energy consumption in developed countries, it seem to me that saving energy in buildings is an important problem to tackle for a more sustainable future.”

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## Outreach 5.1
## Distinguished lecture series

The Annual Distinguished Lecture series aims to promote systems engineering research to audiences from industry, government, academia and members of the public. The Centre held its inaugural distinguished lecture on 11 February 2013, delivered by Professor Arnulf Grubler, of the International Institute of Applied Systems Analysis (IIASA) and Professor in the Field of Energy and Technology, Yale University. Within IIASA's recent Global Energy Assessment that looked out to 2050, Professor Grubler led the urban energy study which viewed the developed and developing worlds at the impressive level of scholarship for which IIASA is renowned.

**Professor Arnulf Grubler**

View the lecture **'The future of urban energy systems – a global energy assessment'** at www.imperial.ac.uk/lorsystemscentre/seminars

"It was a great pleasure to give the Centre's first Distinguished Lecture presentation on urban energy systems. IIASA has had a fruitful collaboration with Imperial College London in this new and exciting area as part of the 2012 Global Energy Assessment.

The future growth of the world's population will be in urban settlements. While some of this will be through the expansion of existing megacity structures, most growth seems likely to be in many smaller urban areas. This has been the persistent pattern of past urbanisation over more than a century and reflects how the population eventually shares itself between cities of different sizes.

Future cities, especially fast growing ones, will need to be energy efficient to remain competitive. They must have secure energy supplies to function as an effective system. Perhaps the biggest challenge of all is that they must make a contribution to dramatic reductions in greenhouse gas emissions. To understand how this can be achieved requires careful systems analysis and data gathering. The capital investments required are huge and need to be robust.

Seeing a city's consumption of energy as a single system rather than as disparate consumption streams is a relatively new concept in urban theory. A systems approach reveals opportunities for reduction in energy use as a result of interactions between streams.

The systems analysis that was conducted for the Global Energy Assessment suggests that a full urban energy system integration could yield reductions in energy consumption and greenhouse gas emissions as high as 50% (IIASA, 2012). The future challenge for integration is as much in the fragmentary social systems of cities as it is in their physical systems. I look forward to continual co-operation between IIASA and the Centre for Systems Engineering and Innovation."

**Professor Arnulf Grubler**



## Outreach 5.2 Research highlight
## Nuclear power plants: developments in construction

**Dr Panagiotis Angeloudis** and **Professor Washington Ochieng** are both lecturers on the Centre's MSc in Systems Engineering and Innovation programme. Students benefit from exposure to these academics and their research.

The research team led by Dr Angeloudis working in partnership with engineering firms Laing O'Rourke, ARUP and BRE has been successful in establishing a 3 year project with £1.7 million funding from the government and industry. The aim of the project is to optimise the design, manufacture and assembly of components for nuclear power plants as part of a wider Government strategy to boost activity in the construction sector and to make the UK a global leader in nuclear power plant construction.

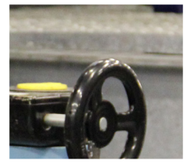
Many of the UK's nuclear plants are aging and due to be decommissioned. The Government recognises that this represents a great opportunity for industry and academia to work together and reassess how these facilities are designed and constructed. Any innovations in this area could give the UK construction sector a competitive edge.

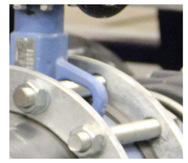
Key research areas in this project are the structural performance of preassembled components, their reliability, and innovations in their manufacture and assembly. The Imperial team will focus on the difficulties in handling larger-than-usual construction components while taking advantage of their prefabricated nature. For example, the number, size and location of tower cranes to be used during construction will have direct consequences on the overall layout of the construction site and the speed of assembly. The algorithms developed will seek to balance overall transport and handling costs against the rate of construction, while ensuring safety and other operational constraints.

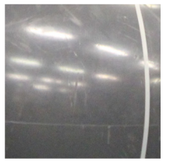
Imperial is a world leader in developing innovation for automating cargo handling. We will transfer these skills to inform the design and assembly of prefabricated components in nuclear construction. This will enable the industry to rethink and streamline the entire design and assembly process. Faster and cheaper construction should ultimately mean lower energy costs for customers and lower risk and disruption during assembly. A recent case study showed that the use of preassembled components in large scale civil engineering construction projects has the potential to reduce construction site $CO_2$ emissions by 50%, water consumption by 30% and construction waste by more than 50%. In addition, this project will seek to provide the necessary evidence to regulatory authorities on the performance of preassembled components through analysis and physical testing.

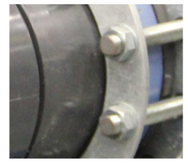
**Dr Panagiotis Angeloudis**

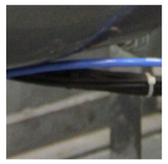
**Professor Washington Ochieng**

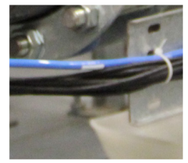












## Outreach 5.3
## Cyber Security and Building Services

The *Working Paper Series* for the Laing O'Rourke Centre provides a platform to debate current issues in systems engineering. The papers can be contributed by academics, or even by PhD and MSc students associated with the Centre. For example, a paper on the use of cloud computing was co-written by MSc student Rhona Malcolm and Dr James Keirstead.

For the full collection of Working Papers see:
www.imperial.ac.uk/lorsystemscentre/workingpapers

**Professor David Fisk**, Director of the Centre, summarises his working paper on cyber security below:

Cyber security is usually seen as a threat to the integrity of enterprise data. What makes cyber-attack so attractive to the attacker is its anonymity and low risk of capture. The cyber-attack on the Iranian nuclear programme widened the debate to include the threat of malicious attacks on supervisory control and data acquisition systems. Even then the implications for modern building management systems (BMS), seems to have gone unnoticed.

BMS pose interesting cyber security problems. They are long lived and so many run on software platforms that are no longer 'supported' by the original manufacturer. This means that the security vulnerabilities in new platforms will not be present in older BMS systems, but that a targeted attack on an older system is likely to find more unpatched vulnerabilities.

Reviewing all the ways that an aggressor can get access to BMS, e.g. Wi-Fi or internet links, the inevitable conclusion is that, despite its best efforts, the computing industry can never deliver total security to a networked system. This is in part because of the ever increasing speed of computation. The implication for system design is that, the system itself should have a full back-up mode available to provide skeletal provision should the digital system become infected.

Why would anyone attack the BMS when companies have so many other high profile targets? The BMS is vulnerable in part because its unimportance means it is likely to be weakly protected. That is the paradox of cyber security.

**Professor David Fisk**

Laing O'Rourke Professor of Systems Engineering and Centre Director



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## Outreach 5.4
## Drop-in clinics

As part of its outreach activities, the Laing O'Rourke Centre has held five drop-in clinics where meetings occur between Imperial researchers and Laing O'Rourke staff. "The dialogue has proved very valuable to Laing O'Rourke. The construction industry tends to focus on research and development of new techniques and processes for example, in relation to asset performance or product development of live projects. However, industry doesn't have all of the good ideas by any stretch of the imagination and our collaboration with Imperial is very helpful" says Dr Gavin Davies, Director at the Engineering Excellence Group at Laing O'Rourke and Adjunct Professor at Imperial.

To date, the topics of the drop-in clinics have been varied – ranging from research collaboration between industry and academia, to supporting undergraduate students with their third year projects, and sessions on recruitment advice for graduates. Gavin says "So far there has been a great mix of content from across the various disciplines hosted by the Department of Civil and Environmental Engineering including topics from the water sector and advances in concrete engineering."

According to Gavin, one of the big challenges is changing industry's perception of academic research. "Many companies struggle to engage with the level of return from long-term research, especially in the construction sector which is not used to investing in long-term projects," says Gavin. Most R&D projects are medium-term developments, which can take a small number of years to get to market rather than a small number of months. "Laing O'Rourke are absolutely fine with this", he says.

"Another advantage of working with academia is the opportunity to develop credibility and confidence in new solutions. Developing technical, engineering and financial credibility helps to de-risk innovation, which is very important for our customers", says Gavin.

Laing O'Rourke are keen to ensure that the relationship between the company and Imperial remains *dynamic*, with the Laing O'Rourke Centre not only acting as the hub at Imperial for future R&D in construction but also as a valuable 'meeting of minds' between academia and industry. "Out of all of the academic institutions, we have found Imperial to be very business focused. This is very positive from our perspective" says Gavin. "Laing O'Rourke value the multidisciplinary approach, "we see great value in the relationship viewed as a whole being greater than the sum of its parts" adds Gavin. "The desire to partner and to develop something that benefits both parties is a great thing". It is with this vision that the cross-faculty Centre at Imperial continues to develop further with future drop-in clinics planned across the College.

**Alexandra Williams**
Centre Administrator

**Dr Gavin Davies**

Mechanical Engineering Discipline Lead, Laing O'Rourke Engineering Excellence Group

## Outreach 5.5
# Undergraduate outreach

Outreach is integral to the Centre's objectives and it is viewed as an essential tool during the recruitment of our future generation of engineers. The Centre often acts as the locus for on-going graduate development for the College's undergraduate engineering students. It is during the key stages in the curriculum that the Centre coordinates and facilitates educational and recruitment opportunities for undergraduates across the Faculty of Engineering.

To date nearly 250 first year undergraduate MEng students from the Department of Civil and Environmental Engineering have received exposure to *live* construction in the form of site visits to one of many Laing O'Rourke projects ranging from *Crossrail* to the innovative *The Leadenhall Building* project. Early exposure to engineering challenges within the construction industry is very important for Imperial students. The interaction received during opportunities such as these help our students to develop a broad knowledge base from the outset of their studies.

To establish a continuum of contact with the industry, the Centre assists with the promotion of the Laing O'Rourke *Scholarship* programme and coordinates various associated activities. The programme can offer extensive support to prospective graduate employees for up to four years during their studies. Scholars may also have the opportunity to participate in a summer placement for up to eight weeks during their summer break.

Other key recruitment co-ordinated by the Centre on behalf of Laing O'Rourke include the annual *Recruiter in Residence* event, usually held at the start of the new academic year. This activity has now run for several years. Finally, the Centre is involved with the annual *Meet the Industry* evening which offers a further platform for various future graduate opportunities at Laing O'Rourke.

Graduate recruitment remains at the forefront of Laing O'Rourke's educational strategy. The Centre is currently exploring other undergraduate promotional opportunities across the Faculty of Engineering.

**Alexandra Williams**
Centre Administrator





**Ding Zhou – Research Student**
Ding's research involves investigating making cement mortar containing recycled glass.

# 6

## Summary and overview

## 6.1 Key highlights Oct 2010 – Mar 2013

**Professor David Fisk,**
Centre Director

The Centre for Systems Engineering and Innovation set out to *bring systems engineering to the built environment*. We have seen steady growth in many arenas including undergraduate involvement with Laing O'Rourke, the launch of the part-time MSc programme, the inauguration of the *Laing O'Rourke Lecture Series*, the *Working Paper Series* – showcasing current research themes pertinent to systems engineering – from *Cyber Security to Urban Cloud Modelling Systems*.

With world class research at the centre of Imperial's mission, the Centre hosts two superb PhD Laing O'Rourke Scholars whose projects are exploring exciting developments. With urban energy systems hot on the agenda, the Centre was fortunate to secure Professor Grubler of IIASA as its first Annual Distinguished Lecturer. The Centre had worked with Professor Grubler as part of the IIASA 2012 *Global Energy Assessment*, which led to the *Energizing Sustainable Cities* book published by Earthscan this year.

## 6.2 Looking ahead

Further exciting outreach activities are planned for the year ahead, with plans to develop the undergraduate and postgraduate remits of the Centre. The first *Laing O'Rourke Fourth Year Undergraduate Prize for Best Final Year Project Presentation* will be awarded at the October 2013 Graduation Ceremony. We expect the MSc programme to be approved for Chartered Engineer accreditation by the first MSc graduation in 2014.

We will be taking our research to the fore. Routledge will be publishing the book on *Urban Energy Systems* edited by Professor Shah and Dr Keirstead, with contributions from many other Imperial colleagues including Dr Sivakumar and myself. I will be speaking at the New York Times Conference *Energy for tomorrow – building sustainable cities*. One of our PhD Scholars, Ms Sarah Noyé presented her paper on *Smart systems commissioning for energy efficient buildings* at the CIBSE International Technical Symposium during spring 2013. Continuing with the Laing O'Rourke Lecture Series, eminent colleagues in their field are due to deliver further open lectures which include Professor Geoff Levermore of MACE, who is scheduled to talk on *Climate change, the IPCC, uncertainty and the built environment*. Also contributing to the series, Professor Keith Clarke CBE, former Chief Executive of WS Atkins Plc will deliver his lecture reflecting on organisational systems titled – *More desks or a bigger table – options for organising cock-ups!* The Centre looks forward to the coming year.

# Summary and overview
## 6.3 MSc Programme overview

The MSc programme is delivered part-time over two years or full-time over one year of which the academic year is split into three terms: autumn, spring and summer. Part-time students spend two weeks each term whilst full-time students spend four weeks each term at Imperial for intensive teaching. Inter-sessional progress assignments are usually undertaken via distance learning. During the progression of the MSc, students will also complete a dissertation on a new innovative technology, and in conjunction with the Business School devise a strategy to manage the successful application of the innovation.

| **2013-2015** | **Course Dates for two year programme** (Two weeks, usually in the following months) | | | **Exam** (1 Day) |
|---|---|---|---|---|
| 2013/14 | October 2013 | January 2014 | May 2014 | June 2014 |
| 2014/15 | October 2014 | January 2015 | May 2015 | June 2015 |
| **2013-2015** | **Course Dates for one year programme** (Four weeks, usually in the following months) | | | **Exam** (2 Days) |
| 2013/14 | October 2013 | January 2014 | May 2014 | June 2014 |

### Each week will typically include in its programme:

- Lectures and seminars
- Workshops
- Presentations
- Group projects
- Individual meetings with supervisors

### Entry requirements

- A minimum of an Upper Second Class Honours degree (or overseas equivalent) in an engineering or scientific subject would normally be required for entry to the programme, in addition to industrial experience and/usually working towards Chartered Engineer status.
- Industrial experience demonstrating outstanding leadership and innovation potential in their field.

### Learning outcomes

- 'Systems' as a much bigger idea than screwing parts together that fit. The student should now see systems thinking as something that pervades the understanding of everything that can be done in a complex world.
- The ability to recognise that global energy systems while changing rapidly have an underlying rationale that has deep implications for the selection of long life M&E building services.
- Confidence in the ability to demonstrate self-direction, originality and lack of risk aversion in tackling radically new engineering systems and concepts in M&E building services.
- Ability to evaluate critically the implications of new services application in areas such as networks, fuel cell and nuclear technology.
- Distinguishing between novelty and innovation and with that understanding, being able to lead an organisation to the forefront in systems innovation.
- The independent learning ability required for continuing professional development in systems and networks.

### Course themes

- Systems approaches in engineering: introduction and foundations.
- Using a systems approach to analyse technologies and innovation.
- Applying systems analysis to energy supply policy.
- Data network systems models.
- Process engineering design optimisation of large systems.
- Systems approaches to safety reliability and resilience.
- Whole systems design to decarbonise energy systems.
- Power transmission and storage: integrating systems into energy supply.
- Innovation and entrepreneurship.




### Assessment

- Two 1,000 word reports.
- Two 2,000 word essays.
- One 3-hour examination at the end of June in Year 1 (part-time programme).
- One 3-hour examination at the end of June in Year 2 (part-time programme).
- Two 3-hour examinations during June in Year 1 (full-time programme).
- A 20,000 word dissertation which commences at the end of the first term.

Students also undertake progress reports in the form of assignments or group work during the course of the programme. For part-time students, inter-sessional assignments and assessments one and two listed above are taken via distance learning mode under the guidance of the programme lecturers.

### Fees

Full details of programme fees can be found at **http://www3.imperial.ac.uk/lorsystemscentre/msc/fees**

### Applications

Applications for the 2013-15 part-time programme, reference **H26524** and full-time programme, reference **H265** should be made online **http://www3.imperial.ac.uk/registry/admissions/howtoapplypg**

For all enquiries please contact the Centre Administrator for advice on your suitability. Early application is advisable.