Foreword

It is with great pleasure that I welcome you to the 2016 BRE Trust Research Conference, taking place in my home town of Birmingham. This year we are celebrating the 10 year anniversary of the BRE Trust Centres of Excellence programme, which was launched to stimulate growth of the UK’s research and teaching capabilities in support of the built environment.

During the last 10 years we have extended our strategic partnerships from the original 4 founding Centres at Bath, Cardiff, Edinburgh and Strathclyde to also include Loughborough, Hertfordshire and University College London (UCL). The impact of these relationships goes from strength to strength, evidenced by the impressive results of these UK Institutes in the 2014 Research Excellence Framework.

These Centres now support a collective capability of more than 100+ academic and research staff, 300 studentships active or completed and a research portfolio of over £60m active or delivered during this time. This equates to more than 10 times the return on investment for the Trust.

During this time we have also formed a growing number of strategic partnerships with the overseas universities at Brasilia and Tsinghua, extending both the technical breadth of research and also the potential impact that the outputs of their research work will have via the associated Innovation Parks that underpin these relationships.

And the network continues. BRE has active links with over 25 universities worldwide which has also recently been extended by our merger with Constructing Excellence and their own university partnerships. I am delighted that so many of our partners are joining us at this conference as we commit our ongoing support to significantly extend the impact we create together for the benefit of the wider built environment in the next decade and beyond.

Dr Deborah Pullen MBE FCIOB FIMMM CEng
Group Research Director, BRE

Proceeding agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Presentation subjects</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:30</td>
<td>Welcome and introduction</td>
<td>Dr Deborah Pullen, BRE</td>
</tr>
<tr>
<td></td>
<td>Birmingham’s regeneration story</td>
<td>Craig Rowbottom, Birmingham City Council</td>
</tr>
<tr>
<td></td>
<td>BRE Centre for Integrated and Sustainable Communities</td>
<td>Professor Raquel Naves Blumenschien, University of Brasilia</td>
</tr>
<tr>
<td></td>
<td>Building life cycle assessment</td>
<td>Carlos Rodriguez Campos, University of Strathclyde</td>
</tr>
<tr>
<td></td>
<td>Evaluating and further developing the new sustainability standard for masterplanning</td>
<td>Lewis Sullivan, UCL</td>
</tr>
<tr>
<td>11:15</td>
<td>Refreshments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Environmental standards in China</td>
<td>Professor Li, Tsinghua University</td>
</tr>
<tr>
<td></td>
<td>Maximising and managing innovation</td>
<td>Adam Golden, Costain &amp; Constructing Excellence</td>
</tr>
<tr>
<td></td>
<td>Smart systems for smart buildings</td>
<td>Al-Azhar Lalani &amp; Emilio Mistretta, University of Hertfordshire</td>
</tr>
<tr>
<td></td>
<td>Doped TiO2 nanostructured photocatalytic coating for MDF and lime based substrates</td>
<td>Andrea Gianniccolo, University of Bath</td>
</tr>
<tr>
<td></td>
<td>Making collaborative research a success: lessons from Loughborough</td>
<td>Dr Christina Hopfe, University of Loughborough</td>
</tr>
<tr>
<td>13:15</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The regeneration of Broad Street and Brindley Place</td>
<td>Simon Dingle, Carillion PLC</td>
</tr>
<tr>
<td></td>
<td>Self-healing geotechnical structures via microbial action</td>
<td>Stefani Batshoevera, Cardiff University</td>
</tr>
<tr>
<td></td>
<td>Capture of volatile organic compounds by natural building materials</td>
<td>Carla DaSilva, University of Bath</td>
</tr>
<tr>
<td></td>
<td>Hybrid coupled modelling of heat and smoke movement through complex buildings</td>
<td>Ben Ralph, University of Edinburgh</td>
</tr>
<tr>
<td>15:35</td>
<td>Refreshments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Semantic web of things approach to smart city challenges</td>
<td>Shaun Howell, Cardiff University</td>
</tr>
<tr>
<td></td>
<td>Firefighting interventions in basements and my BRE Trust impact</td>
<td>Dr Agustin Majdalani, University of Edinburgh</td>
</tr>
<tr>
<td>16:50</td>
<td>Finish</td>
<td></td>
</tr>
</tbody>
</table>
### Contents

- Flood resilience: improving building drying times  
- Thin-shell textile-reinforced concrete floors for sustainable buildings  
- Photocatalytic doped TiO₂ and TiO₂ hybrids based coatings for lime and wood substrates  
- Capture of volatile organic compounds by natural building materials  
- Whole-timber structural systems  
- District heating and cooling optimization and enhancement  
- Semantic web of things for advanced applications in smart city systems  
- Self-healing geotechnical structures via microbial action  
- Total life cycle and near-real time sustainability assessment approach: an application to the urban environment  
- Real-time and semantic energy management across buildings in a district configuration  
- Ignition of solid fuels exposed to transient incident heat fluxes  
- Intelligent Egress  
- Hybrid modelling for the examination of heat and smoke spread in complex buildings  
- Embedding circular economy in the building sector  
- Investigating the performance gap in relation to overheating in the UK domestic sector  
- Measuring community resilience to natural hazards in low income countries  
- Bringing big data into building energy modelling  
- Traceability in the construction supply chain  
- Simplified life cycle assessment method for domestic buildings, a user-friendly tool  
- Modelling indoor environmental quality in low energy housing  
- Dynamic exergy analysis for the built environment  
- Social innovation systems for building resilient communities  
- Modelling of energy demand variation and uncertainty in small-scale domestic energy systems  
- Development strategies for future cities to ensure energy resilience  
- The value and use of urban health indicators in city built environment policy and decision-making  
- Master-planning with (and without) BREEAM communities: case studies from the UK  
- Sustainable neighbourhood design: examining the role of evaluation in neighbourhood masterplanning  
- Towards informal planning – mapping the evolution of spontaneous settlements  
- Facts about Birmingham
Flood resilience: Improving building drying times

Fiona Gleed, Peter Walker, Juliana Holley, Andrew Heath, Michael Lawrence
BRE Centre of Excellence for Innovative Construction Materials, University of Bath

Summary
The UK has experienced a series of significant flooding events in the last twenty years and these are predicted to increase in both frequency and severity due to climate change. Reviews carried out in the wake of flooding, most notably by Sir Michael Pitt following flooding in 2007 (Pitt, 2008) have highlighted the requirement to improve resilience, with drying of buildings identified as a factor in extended recovery times.

This study seeks to develop a better understanding of the behaviour of masonry wall structures, identifying experimental and analytical methods to explore moisture absorption, migration and desorption during a cycle of flooding and subsequent drying.

In the UK, 1.8 million people live in homes that are likely to flood at least once in 75 years (Sayers et al, 2015). Flooding can come from a number of sources, including rain, rivers, the sea, ground water or accidental discharge from pipes. Flood resistance measures such as air brick covers and door boards could prevent some homes being flooded but uptake is low particularly where householders have not previously experienced flooding (Owusu et al, 2015).

Constituent material properties
Bricks, blocks and mortar are porous materials and can be characterised by the combined property of sorptivity (Hall and Hoff, 2002). Comparisons will be made between different types of brick, block and mortar, including consideration of the interface between mortar and masonry units, using gravimetric methods, gas absorption tests and microscopic inspection of polished cross sections.

References
Bonfield, P. (2016). The property flood resilience action plan. DEFRA.
Thin-shell textile-reinforced concrete floors for sustainable buildings

Will Hawkins, John Orr, Paul Shepherd and Tim Ibell
BRE Centre of Excellence for Innovative Construction Materials, University of Bath

Summary

As the operational efficiency of new buildings steadily improves, the total lifecycle energy comes to be dominated by the embodied energy of the construction materials. The building structure itself is the largest single contributor to this, of which the majority is typically contained within the floors for multi-storey buildings. Taking inspiration from the famous shell builders of the 20th century, this project brings together modern developments in computational design, material technology and construction methods to explore the feasibility of a widespread application of concrete shells as floors in multi-storey buildings, in order to create a low embodied energy alternative to traditional reinforced concrete flat slabs. A novel structural system is proposed which features a thin, durable, textile-reinforced concrete shell combined with a lightweight concrete fill and tensile ties. Results from a computational investigation indicate that considerable savings in both weight and embodied energy can be achieved whilst maintaining the large spans and floor to floor heights of typical modern concrete-framed buildings. Further work will involve the construction and testing of an experimental prototype, and the continued development of a practical computational design and analysis framework.

Analysis and results

In the proposed system, a thin, curved TRC shell spans between column supports to create a vaulted ceiling (Figure 1). In order to create a usable floor surface, a self-leveling fill of lightweight, low-strength concrete is then applied (using the shell as formwork). By integrating the services within the structural zone, the total depth is similar to an equivalent flat slab.

The performance of shells is geometrically sensitive, giving rise to several important conclusions associated with the design:

- The prestress of the ties and their vertical position should be ‘tuned’ to maximise the efficient operation of the shell. In service, the most important design driver is therefore the expected range of loading between the maximum and minimum design scenarios
- Non-uniform and concentrated floor loading scenarios dictate the required section strength in some regions of the shell
- Differential settlement of columns should also be assessed and analysed as this introduces bending moments
- The designer can influence the behaviour of the shell through the definition of the surface geometry

Figure 1: Proposed shell flooring system

Future work

A number of alternative formwork systems, and their corresponding effect on geometry and performance, will be developed and analysed in future work. A programme of physical testing has also been devised in order to explore construction methods, determine the structural behaviour and verify the predictions of the analysis model. This will culminate in the testing of quarter-scale shells created using the various formwork methods. A proposed test set-up is shown in Figure 3.
Photocatalytic doped TiO₂ and TiO₂ hybrids based coatings for lime and wood substrates

PhD student: Andrea Giampiccolo, Supervisors: Richard J. Ball, Martin P. Ansell
BRE Centre for Innovative Construction Materials, Department of Architecture and Civil Engineering, University of Bath, BATH, BA2 7AY

Background

Indoor air quality and the effect of pollutants on the environment and human health is of increasing interest to the academic community and importance to society. In particular many items commonly found in the home and workplace release volatile organic compounds (VOCs) into the atmosphere. Polymer based materials, fibres, paints, coatings, varnishes and carpets tend to have particularly high release rates due to their manufacturing process. The photocatalytic activity of titanium dioxide (TiO₂) is well known and shows great promise as a suitable photo-catalyst for decomposition of pollutants and subsequently improving the quality of the indoor environment. This research focuses on the synthesis and characterization of doped TiO₂ and TiO₂ hybrids photocatalytic powders. Where pure TiO₂ exploit his photocatalytic activity using UV light the process of doping with pure and doped TiO₂ synthesised in laboratory using sol-gel methods were successfully used to produce nanostructures in a straightforward and inexpensive way. Comparing different synthesis there is a consistency in dimension of the particle size as shown in the SEM and FE-SEM image presented.

Research program

Preparation of pure and doped TiO₂ through a sol-gel method is centred on the hydrolysis and polymerization of a metal-organic precursor to form a colloidal suspension. The excess of solvent was removed after completion of the reaction and the resulting powders were treated thermally to obtain the anatase polymorph. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were used to investigate the morphology and crystal structure particles. The crystalline structure of the nanoparticles was confirmed using Raman spectroscopy and X-ray diffraction. The photo-catalytic activity was measured using complementary methods.

Representative lime and wood substrates were coated with different paint formulations. These paints are a water-alcohol solution containing either the commercial nanoparticles Kronoclean 7000, p25 or laboratory synthesized doped TiO₂ nanoparticles. The photocatalytic activity at the liquid solid interface was assessed by observing the degradation of a methylene blue (MB) solution, containing the nanoparticles following an adaptation of ISO 15678:2010 standard. The degradation was followed using a UV spectrophotometer and comparing the value of absorbance of the solution with deionised water. All the powder samples were dissolved in 100 ml of MB solution and after waiting a period of 15 min to reach equilibrium samples were extracted using a syringe with a nanosized filter unit and analysed in the UV spectrophotometer.

Ink intelligent tests show that all the coatings prepared are all active in the degradation the organic dye contained in the ink. Also during this tests sol-gel prepared particles are more performant than commercial Kronoclean 7000, Co-doped TiO₂ pure TiO₂ and blank irradiated during this tests sol-gel prepared particles are more performant that commercial P25 if not better than commercial Kronoclean 7000.

PC activity of powders and coatings

Methylene blue degradation photocatalytic test

The photocatalytic activity of the commercial Kronoclean 7000 and Co-doped TiO₂ samples were more performant compared to the commercial P25 if not better than commercial Kronoclean 7000.

Project outcomes/conclusion

Synthesis, characterization and coatings preparation

Sol-gel synthesis methods were successfully used to produce nanostructures in a straightforward and inexpensive way. Comparing different synthesis there is a consistency in dimension and distribution of the particle size as shown in the SEM and FE-SEM image presented.

Methylene blue degradation photocatalytic test

Methylene blue test shows that doping TiO₂ with Cobalt actually improved the performance using visible light when compared to commercial particles. Also pure TiO₂ has performance comparable to the commercial P25 if not better than commercial Kronoclean 7000.

References

Capture of volatile organic compounds by natural building materials

Carla F. da Silva¹, Martin P. Ansell¹, Andy Dengel² and Richard J. Ball¹
¹BRE CICM, Department of Architecture and Civil Engineering, University of Bath, Bath, UK
²Fire and Building Technology Group, BRE, Watford, UK

Table 1: Impact of TVOC concentration human health (from Mølhave 1997)

<table>
<thead>
<tr>
<th>TVOC concentration (μg/m³)</th>
<th>Health impact</th>
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<tbody>
<tr>
<td>&lt; 200</td>
<td>No irritation or discomfort expected</td>
</tr>
<tr>
<td>200 - 3000</td>
<td>Imitation or discomfort may be possible</td>
</tr>
<tr>
<td>3000 - 25000</td>
<td>Discomfort expected and headache possible</td>
</tr>
<tr>
<td>&gt; 25000</td>
<td>Toxic range where other neurotoxic effects may occur</td>
</tr>
</tbody>
</table>

Figure 1: Sources of gas pollutants to the indoor air

When exposed to a polluted environment, building materials can adsorb airborne pollutants compounds and subsequently re-emit them sometime later, depending on physical and chemical conditions including humidity, temperature, concentration etc. This phenomenon is known as the sink effect and can significantly affect the concentrations of VOCs in indoor environments. Several mathematical models are being developed and studied to estimate the impact of the sink effect on the concentration of VOCs in indoor environments

Table: Impact of TVOC concentration human health (from Molhave 1997)

To reduce the problems caused by poor IAQ, the Seventh Framework Programme for Research and Technological Development project ECO-SEE aims to develop new eco-materials and components for the purpose of creating both healthier and more energy-efficient buildings. This will be achieved through hygrothermal (heat and moisture) regulation and the removal of airborne chemical pollutants using both passive capture and photocatalysis. The adoption of natural materials in this project will reduce the embedded energy and associated carbon dioxide emissions from manufacture of the construction materials and components. This PhD project is supporting the aims and objectives of the ECO-SEE project.

References


Research programme

The main tasks include:

- Chemical and physical characterisation of building materials
- Measurements of the emissions rates of VOCs and formaldehyde from the materials
- Materials surface characterisation – properties that will have an effect on adsorption and desorption of VOCs and formaldehyde such as surface area, porosity and pore size
- Exposure of the building materials to a controlled source of polluted air in order to evaluate the adsorption/desorption capacity of the materials. Tests carried out in lab-scale environmental chambers (2-litre nominal volume) and in a real-size room chamber (30 m³ chamber with door and window)
- Both emissions rates and adsorption/desorption tests were performed at the BRE laboratory facilities in Garston.

Project outcomes/conclusions so far

- VOCs with different physicochemical properties showed different adsorption properties which depended on the material being evaluated. In general VOC molecules with higher polarity were more easily adsorbed on to the material's surface
- New materials with an enhanced capacity to adsorb VOCs and formaldehyde are currently under development

Publications/research output

Whole-timber structural systems

PhD Student: Aurimas Bukauskas
Supervisors: Paul Shepherd, Pete Walker, Bhavna Sharma
Sponsors: BRE, University of Bath, US-UK Fulbright Commission
BRE Centre for Innovative Construction Materials, University of Bath EPSRC Centre for Doctoral Training in Decarbonisation of the Built Environment

Summary

Forests worldwide face a disproportionate demand for a narrow range of timber species, ages, and growth shapes. This is because sawn timber production favours predominantly high-stiffness, straight, and medium-to-large diameter trees. This imbalanced consumption results in management strategies which produce low-diversity, overstocked forests which are vulnerable to fire, the rapid spread of diseases and pests, and with limited ability to adapt to climate-change related weather events and climatic shifts. Unsawn timbers, used as structural elements in their whole, round form – “whole-timber” – have demonstrated to be a high-value alternative to sawn timber which can make use of much more diverse range of tree typologies than conventional dimensioned lumber. The use of whole-timber in structures increases the marketable value of a broad range of tree types, allowing for more flexible forest management strategies which can prioritise forest resilience and ecological stability.

A series of innovative whole-timber structures in the United States, United Kingdom, and New Zealand have demonstrated that whole-timber is a highly effective and efficient structural material. The primary challenge preventing wider adoption of whole-timber as a structural material is the unique design process required to design, optimise, and build structures using non-standardised round timber. This research will develop design tools and digital fabrication methods which will address the unique challenges of whole-timber design. These tools will allow architects and engineers to design efficient, expressive large-scale structures in whole-timber.

Project motivation

In 2000, the United States Forest Service estimated that approximately 56 million acres of national forests were at increased risk of forest fire, disease, and pest incursion due to an excessive build-up of small-diameter trees (Forest Products Laboratory 2000). Because these trees are of little value to conventional sawn timber producers, forest managers cannot cover the costs of the preventive harvesting of small-diameter trees which is required to ensure the resilience of these forests. Finding value-added uses for small-diameter trees which can offset the costs of sustainable forest management is therefore an ongoing primary research focus at the US Forest Products Laboratory. Similar situations face most forested regions in the world – in all cases, finding high-value applications for a more diverse range of timber ages, species, and growth shapes can help to support more flexible and sustainable forestry management strategies.

Wolfe (2000) identified round-timber structural poles, “whole-timber”, as a potential high-value structural application for small-diameter material. Wolfe showed that round timbers can be rated to significantly higher bending capacities than the largest conventional dimensioned lumber elements which can be sawn from them. This is for two reasons. Firstly, saving a timber into dimensioned elements is subtractive – the resulting sawn elements are limited by the size of inscribed rectangles on the smaller end of any log. This effect is particularly pronounced for trees of less than 250 mm in diameter, as this approaches the minimum standard sizes of dimensioned timbers. The effect is even more significant for trees with even small amounts of curvature. Second, the strength of timber is highly orthotropic in the direction of its grain, which curves around knots and other internal imperfections. Saving breaks the continuity of these curving fibres and introduces local weaknesses into the resulting timber, reducing its stiffness and ultimate capacity significantly, and often unpredictably.

Thus, for trees of small diameter, with curvature, or with significant internal imperfections, “whole-timber” is a much more efficient structural use of timber. Its broader adoption as a structural material in large-scale structures has the potential to significantly reduce resource pressure on forests by making a broader range of trees marketable, thus allowing for more resilience-oriented forest management strategies.

Research programme

This research will focus on the development of software tools to aid architects and engineers in the form-finding and structural optimisation of large-scale whole-timber structures. The project will involve a dialogue with practicing architects and engineers in the field of whole-timber construction and timber engineering more broadly. This exchange will involve early input from designers, as well as feedback and testing of tools in the field.

Project outcomes

The concrete outcome of this project will be a software tool, designed to integrate easily with existing computer-aided design and structural analysis software which will allow architects and engineers to address the design challenges unique to whole-timber. More broadly, this project aims to clarify the design challenges unique to whole-timber construction, and to establish a research programme which can address these challenges in the future to increase the adoption of whole-timber as a primary structural material.

References


The “Big Shed” prefabrication workshop at the Architectural Association School of Architecture’s woodland campus, Hooke Park, completed in 2012, uses small-diameter larch timbers as primary structural elements.

The “Woodchip Barn” at the Architectural Association School of Architecture’s woodland campus, Hooke Park, completed in 2016, uses forked beech trees (a low-value forest product) as its primary structure.
District heating and cooling optimization and enhancement

Summary

District heating and cooling (DHC) systems are attracting increased interest for their low carbon potential. However, most DHC systems are not operating at the expected performance level. Optimization and Enhancement of DHC networks to reduce (a) fossil fuel consumption, CO2 emission, and heat losses across the network, while (b) increasing return on investment form key challenges faced by decision makers in the fast developing energy landscape.

Background

District Heating and cooling (DHC) is a system that delivers hot water and cold water derived from a central plant to buildings via extensive underground pipe network. Although DHC has attracted increased attention in recent years reflected by higher adoption rates, there are still problems to overcome to trigger large-scale acceptance.

Research programme

The objective was to optimize the whole system to minimize energy consumption and CO2 emission. This will be discussed from following aspects:

Optimization from generation
In DHC networks, heat and cold are usually generated from central plants using large generation units with higher efficiency and more advanced air pollution control methods. Integration of sustainable energies, combined cooling heating and power generating units and energy storage technology are vital methods to improve the efficiency, economy and reduce emission from the network. Meanwhile, it is essential to guarantee that the amount of energy produced is able to satisfy heat demand while not causing waste for over-generation. Smart meters working together with weather forecasts is a good solution to predict energy consumption of each building which can be applied to control heat and cold generation in the energy center.

Optimization from distribution
In order to understand heat losses in the distribution system, a Simulink model was developed to study the distribution network of a small DH system as shown in Fig. 1 and Fig. 2. Heat loss during the weekday daytime is around 1~2% of the distributed heat. However, the heat loss during night is about 8~12%, depending on the amount of heat delivered and ambient temperature. The model can also be applied to select the best pipe configuration, including size and insulation materials at the decision making stage to minimize operation cost. It can also be applied for the prediction of heat losses based on history data, so that energy provider can be aware in advance how much heat should be produced when heat losses are involved to avoid over generation and under generation. Better insulation of the pipes or advanced pipes with lower thermal conductivity and lower distribution temperature can enhance the effectiveness of the system.

Optimization from transmission
Heat substation is a heat transfer interface between the distribution network and the building pipe circuits, usually including the following parts: heat exchanger, energy meter and control valve. A higher performance heat exchanger can absorb more energy from the distribution medium, namely more energy transfer per unit volume, which directly impacts on the effectiveness of the network heat transfer capacity. To ensure the thermal comfort of the consumers and guarantee that heat can be supplied to them promptly, an installation of by-pass between the supply and return pipes is necessary.

Optimization from users
Residential houses, hospitals, schools and commercial buildings are common terminal users of DHC systems. Several issues with regard to building energy conservation, energy price and residents awareness of energy saving directly or indirectly affect energy consumption and thereby the efficiency of the entire DHC system. Optimization from the heat users will result in less energy consumption, which facilitates the advancement of future 100% renewable DHC and low energy DHC network.

Research output

The research has been published in The 4th IEEE International conference on Smart Energy Grid Engineering (2016, Canada) and more results will be addressed in two forthcoming journal papers.

Yu Li, Yacine Rezgui
BRE centre for sustainable engineering, Cardiff
Semantic web of things for advanced applications in smart city systems

Shaun Howell
BRE Trust Centre for Sustainable Engineering, Cardiff University

Summary
The convergence of the Internet of Things, artificial intelligence, big data, and information modelling would be transformative for built environments. This work offers a benchmark for bringing together in smart city systems by addressing a key barrier: application layer interoperability. A web platform is proposed which builds on experience in research projects across the energy and water domains, to greatly simplify application development through resource discoverability and semantic interoperability. This supports a step change for smart cities through Semantic Web of Things systems which empower advanced applications by merging a lightweight IoT approach with domain semantic standards in an extensible and scalable manner.

Background
Cities are facing increasing pressure to improve efficiencies across systems, with constrained resources to facilitate change. Technologies which can improve operational performances of these systems with low capital expenditure therefore offer attractive options. This has led to a rapidly growing market for the Internet of Things (IoT), with a forecasted market impact of $4-11 trillion by 2025[1]. However, IoT requires pervasive interoperability in order to unlock 40-60% of its value[2], and so standards such as HyperCat[3] are addressing this for dynamic IoT data sources. At the same time, semantic models are being developed for exchanging static data, such as in Building Information Modelling[4], the European INSPIRE directive[5], and CityGML[6]. Further, artificial intelligence (AI) could leverage these data for transformative operational benefits, and is addressing this for dynamic IoT data sources. At the same time, 2025[1]. However, IoT requires pervasive interoperability in order to unlock 40-60% of its value by 2025[1]. However, IoT requires pervasive interoperability in order to unlock 40-60% of its value[2], and so standards such as HyperCat[3] are addressing this for dynamic IoT data sources. Technologies which can improve operational performances of these systems with low capital expenditure therefore offer attractive options. This has led to a rapidly growing market for the Internet of Things (IoT), with a forecasted market impact of $4-11 trillion by 2025[1]. However, IoT requires pervasive interoperability in order to unlock 40-60% of its value[2], and so standards such as HyperCat[3] are addressing this for dynamic IoT data sources. At the same time, semantic models are being developed for exchanging static data, such as in Building Information Modelling[4], the European INSPIRE directive[5], and CityGML[6]. Further, artificial intelligence (AI) could leverage these data for transformative operational benefits, and is addressing this for dynamic IoT data sources. At the same time, 2025[1]. However, IoT requires pervasive interoperability in order to unlock 40-60% of its value[2], and so standards such as HyperCat[3] are addressing this for dynamic IoT data sources. Technologies which can improve operational performances of these systems with low capital expenditure therefore offer attractive options. This has led to a rapidly growing market for the Internet of Things (IoT), with a forecasted market impact of $4-11 trillion by 2025[1]. However, IoT requires pervasive interoperability in order to unlock 40-60% of its value[2], and so standards such as HyperCat[3] are addressing this for dynamic IoT data sources. At the same time, semantic models are being developed for exchanging static data, such as in Building Information Modelling[4], the European INSPIRE directive[5], and CityGML[6]. Further, artificial intelligence (AI) could leverage these data for transformative operational benefits, and is addressing this for dynamic IoT data sources.

This study hypothesised that integrating leading edge IoT, semantic modelling, and AI technologies, can offer significant value to decision makers. The work involved a three stage process of i) theoretical study, ii) action research alongside experts, and iii) developing a reference implementation. Most of the work was building and testing ontologies and semantic web middleware which achieved the described integration, then analysing the value of this across pilot sites in the energy and water domains. The outcomes of these experimental learning cycles were unified and generalised where suitable in the final stage.

Research programme
Energy domain experimental cycles
The study engaged with three energy projects which each used semantics, IoT, and AI via different mechanisms, which produced a broad evidence base. The first project regarded a retrofit knowledge-based building energy management system. This integrated an optimised rule base with a graphical interface and real time sensor data through a triple store which described the building and its occupants. The scope was then extended to multiple buildings in another project, which integrated distributed energy resources with a multi-agent system and a demand prediction web service, through a domain ontology. Finally, the approach was explored on a polygeneration grid, where the operation of an energy hub was improved by integrating a simulation model, multi-agent system and optimisation engine, through a knowledge base of the district.

Water domain experimental cycle
The approach was tested in the water sector to deepen the evidence base and produce more generalisable insights. Work was conducted through a research project which web-enabled sensors and integrated AI and optimisation techniques with data from across the network, static network descriptions, and smart home systems, through a semantic intelligence approach, shown in Fig. 2. The work focussed on scoping, developing, and testing a domain ontology and accompanying ontology-driven middleware platform. The domain ontology extended the W3C semantic sensor network ontology[7], and was aligned with emerging and standard industrial models. The ontology served as a language for describing the physical, cyber-physical, and socio-technical aspects of the water network. Accompanying software then leveraged this by reusing GIS data, EPANET models, sensor metadata, and telemetry data, for a knowledge-based approach to water management.

Towards a unified smart city approach
The learning and artefacts from the separate projects were brought together in a reference implementation which could serve as a benchmark for future work and offer value outside of energy and water systems. This stage involved two aspects: knowledge meta-modelling and software development. The first stage produced a smart city ontology, grounded in the separate projects’ work and the BSI smart city concept model[8]. The software aimed to embody the lessons learnt across the projects, to derive real value from integrating IoT, semantic modelling, and AI technologies. This involved balancing the need for explicit semantics with scalability and accessibility, and has similarities to the W3C ‘Web of Things’ vision.

Project outputs
The study served as a proof of concept, formalised substantial learnings for practitioners, provided a reference implementation which could serve as a benchmark extension of the state of the art, and offered valuable domain ontologies. This has resulted in 16 publications, international policy impact, EC deliverables, and ongoing work towards new standards. The key results include:
- Impact scenarios describing where and how the integration of IoT, semantics and AI could offer value
- Energy and water ontologies, and a smart city ontology which provides extensibility into other industries
- A semantically-enabled middleware platform which supports resource discovery and rich, scalable interoperability
- Forward looking recommendations about Semantic Web of Things systems, from various stakeholder perspectives

Selected publications


References
[9] BSI, ‘Smart city concept model-guide to establishing a model for data interoperability.’
Self-healing geotechnical structures via microbial action

Stefani Botusharova, Dr Michael Harbottle, Dr Diane Gardner
Materials For Life (M4L) project at Cardiff University

Summary

Microbially induced calcium carbonate precipitation (MICP) has been widely used in geotechnical engineering research for developing a more sustainable alternative to chemical grouting for ground stabilisation. This PhD project aimed at taking this mechanism a step further and use it to introduce self-healing abilities in geotechnical structures (e.g. embankments, earth dams, tunnels) for preventing damage and alleviating costly and difficult maintenance procedures to such structures.

Background

Marine and soil bacteria have long been known to facilitate chemical reactions, which result in the precipitation of inorganic minerals in the subsurface (e.g. Yellowstone limestone deposits). One such bacteria is Sporosarcina ureae-a common soil aerobic, spore-forming organism, which contains the urease enzyme. Urease adds the hydrolysis of urea and in the presence of calcium ions in solution, the following chemical reaction occurs:

\[
\text{CO(NH}_2\text{H}_2 + 2\text{H}_2\text{O} \xrightarrow{\text{urease}} 2\text{NH}_4\text{H} + \text{CO}_2 + \text{Ca}^{2+} \rightarrow \text{CaCO}_3
\]

The metabolic products of the biological process are ammonium and carbonate, which result in an elevated pH in the surrounding environment and precipitation of calcium carbonate crystals on the surface of the bacterial cell (Fig. 1). This principle has been widely used to date in research for developing an alternative, more sustainable and efficient grouting method (DeJong et al. 2006) as current chemical grouting technologies for ground stabilisation have been shown to be polluting in some cases. Bacterial precipitation of calcium carbonate has also been extensively used in research for self-healing concrete and cementitious materials. However, little attention has been given so far to developing self-healing properties in geotechnical structures (e.g. embankments, earth dams, tunnels) for preventing damage and alleviating costly and difficult maintenance procedures to such structures.

Research programme

Self-healing cycle in aqueous solution

The basics of the self-healing cycle were examined in experiments in aqueous solution. The ability of Sp. ureae to produce spores was investigated in a mineral medium which does not support growth; spores were microscopically observed to be present in cultures after approximately 16 hours of incubation. To examine if the bacteria was able to complete multiple healing cycles, regeneration experiment was performed. It consisted of deteriorating spore-containing crystals of calcium carbonate and then inoculating them in fresh growth media to determine if spores would regenerate. The long-term response of spores was also examined.

Self-healing of soil

The ability of these bacteria to cement a mass of sand, sporulate once nutrients become scarce (due to the entombment in the crystal) and come back to life when the crystal breaks down (e.g. a shear plane or crack in soil) was also examined. The healing of the soil and the physical testing were performed in a specifically designed for the purpose apparatus (shown in Fig. 2). The apparatus allowed aseptically pumping nutrients for the bacteria and physical testing in an unconfined compression machine. The physical damage was then attempted to be “re-healed” by re-introducing nutrients to the specimens again.

Figure 1: Bacterial calcium carbonate precipitation (bacterial cells can be seen in close-up picture)

Figure 2: Sand column apparatus and unconfined compression testing of the samples

Conclusions

Results from the experimental work indicate that:

- Bacterial spores encapsulated in calcite were able to regenerate after the crystal “tomb” was broken down and they were exposed to nutrients
- After regenerating, the bacteria produced secondary precipitation of CaCO3
- Spores have been shown to survive 6 months and be able to regenerate and form calcite
- Bacteria was able to produce significant amounts of calcite within a mass of soil, however, regeneration and re-healing of the soil are still to be examined

References

Total life cycle and near-real time sustainability assessment approach: an application to the urban environment

Corentin Kuster, Prof. Yacine Rezgui, Dr. Monjur Mourshed
BRE Trust Centre for Sustainable Engineering, Cardiff University

Summary

There is currently a large variety of frameworks that aim to assess sustainability at the building and urban level. Although the models are pretty complete, result of years of research and expert consultation; they are mainly developed for design purposes. The research aims to develop a new framework that can assess a neighbourhood sustainability at every stages of its life cycle, in near real-time and regardless of its location.

The past decade has seen a great evolution in the design and management of the cities. The new paradigm that the environmental protection led to the development of numerous tools and practices at any scale (Ameen, Mourshed, and Li, 2015). Thus, sustainability assessment frameworks have emerged; first in order to assess the quality of individual buildings then extended to the neighbourhood or an urban area.

Those frameworks are most commonly based on a set of key indicators. Quantitative or qualitative, the indicators allow the evaluation of environmental, social and economic criteria, themselves part of main themes that represent the overall urban system. Some of the most known frameworks worldwide are BREEAM-Communities, LEED-ND, CASBEE-UD, Ecoquartier, DGNB-UD etc (Sullivan, Rydin, and Buchanan, 2014).

Although these frameworks are really complete, taken into account a broad variety of indicators that well represent the key performance indicators interconnections, this approach is enhanced by the integration of information and communication technologies, the recent improvement in data storage and services and the use of artificial intelligences.

Research programme

First, the current urban sustainability assessment frameworks have been reviewed in order to identify the gaps and issues that exist. It appeared that a large majority of those frameworks was focusing on design, providing guidance for a good development or retrofit. Relatively few tools provide the means for stakeholders or people to manage better the neighbourhood while in operation. The idea is to use newly developed ICTs to give people a dynamic insight of their neighbourhood and help them to act accordingly.

However, such implementation does not go without any challenges. Indeed, the actions taken during the operation phase require a quick decision making, forcing a more accurate assessment, based on data collected in real time. Thus, several new aspects must be considered while developing such framework such as data collection and availability, the influence of outdated data on the indicator assessment, the relevance of some indicators within a real time model, the actions taken following the assessment and their impacts (high, low, short term, long term), the development of new assessment means (ontologies, artificial neural network forecasts, simulation) etc.

These issues are currently being investigated via an expert consultation using the DELPHI approach. The Delphi method involves several rounds of questionnaire where each round is more precise and narrow until reaching a consensus. The first round is the selection of relevant indicators for a real time and operation framework. Then, in the second round, the questions are refined on the meaning of "real time", the associated actions, and the possibility for local adaptation of every indicators and the potential issues for implementation.

In parallel, different other aspects are investigated such as the place of forecasting model in such approach and in decision support systems in general, the importance of big data and the concerns toward current technologies and reliability, the use of an ontology to represent the key performance indicators interconnections and calculations and as a mean to improve local and temporal adaptability, a study of cognitive theories on data visualisation and dashboard design.

Project outcomes/conclusion

The implementation of the framework has already been envisaged via the creation the platform CUSP. CUSP stands for Cardiff Urban Sustainability Platform and is currently being developed within the BRE Trust Centre for Sustainable Engineering at Cardiff University. The Figure 1 presents the main features of the future platform.

The data are collected from various sources such as meters, survey or statistical data. They are implemented into the ontology and other data processing that aims to give meaning to the different elements. The data processing includes clusterization, aggregation and disaggregation, scenario prediction and optimisation methods. These elements are underlying a 3D interface visible by the user. Finally, dashboard will display the main outcomes such as the key performance indicators based on the framework definition, the real time information, scenario predictions, alerts, recommendations, reports etc. CUSP gives the perfect opportunity for the new framework to be tested and validated for the pilot sites of Ebbs Vale, and Cardiff University campus later on.

References


Real-time and semantic energy management across buildings in a district configuration

Jonathan Reynolds
BRE Trust Centre for Sustainable Engineering, Cardiff University

Summary

Buildings are large consumers of energy in developed countries. To address this it is necessary for a new generation of building control methods to be developed to reduce this consumption whilst maintaining occupant comfort. However, future changes in our energy production architecture mean that this problem needs to be tackled at a district level in order to take advantage of load sharing, demand response and local renewable generation. This PhD project aims to develop and trial a number of control methods applied at a building and district level. These will utilise artificial intelligence techniques such as artificial neural networks and genetic algorithms as well as take advantage of modern developments in high performance, cloud computing power.

Background

Combating the influence of climate change is one of the world’s most vital challenges and will continue to be for many decades in the future. Given that 40% of energy consumption in the EU occurs in buildings, this is an important sector to target to achieve large energy reductions. These targets sit in the wider context of seismic shifts in the architecture of energy production and consumption. Countries are increasingly focussed on moving away from centralised, large, fossil fuel power plants towards smaller, local, renewable energy production. This is leading to the concept of community based energy systems or microgrids. The concept of the microgrid is an independent local energy grid potentially including generation units, storage capacity and smart adaptable loads in a single or multiple buildings, possibly using the existing central grid as backup. However the introduction of new, stochastic energy supply can lead to instability in the system and presents new control problems. To overcome this the concept of demand response, DR, is essential to pre-emptively shift consumer load away from times when energy production will be low.

Research programme

District level control

Much of the current research on energy control in buildings is focussed at a building or even a zone level. But to achieve the vision of truly smart microgrid, control frameworks at a district level need to be developed. Combining buildings in a district configuration could allow greater flexibility in energy sharing and could provide a greater source of load flexibility to be able to collectively participate in DR events set by the central grid. However district level control could take a number of forms. One approach is to create an internal energy market between the buildings that encourages DR through price variation. Another is completely centralised control where each building management system, BMS, would simply act as a data collection tool and provide the actuation for a higher level, cloud based centralised controller. Another option would be a DR controller where initially each individual building would optimise their own daily schedule. These profiles would be aggregated at district level where the district controller would be responsible for flattening the overall district load profile. To achieve this research needs to be carried out into semantic modelling and interoperability within a district. The potential use of higher order cloud based analytics needs to be investigated and the security and privacy questions raised by this control need to be solved.

District modelling

In order to develop the energy management strategy, district modelling is essential (figure 1). We have used a Faro 3D laser scanner to scan a small district in Ebbw vale. From a collection of scans a point cloud can be generated. This can then be used as a template to create as built BIM models as well as energy models. These models are then integrated into our Computational Urban Sustainability Platform, CUSP. This aims to engage the public in energy consumption whilst maintaining occupant comfort. At a district level it will aim to maximise the consumption of local renewable energy and minimise reliance of the grid. A number of different control architectures will be tested based on EU project pilot site data. We will aim to determine the best control architecture for different types of districts.

Input Data
- Weather
- Occupancy
- Time and Date

Optimised Schedule

GA Optimiser

ANNA Building Model

Optimised

Building

Actuation

Sensor Data

Figure 2: Potential optimisation strategy
Ignition of solid fuels exposed to transient incident heat fluxes

Simón Santamaria
Supervisor: Dr. Rory Hadden
BRE Centre for Excellence in Fire Safety Engineering

Summary
Understanding ignition is the key to defining the fire risk associated with a material. This PhD builds on current ignition theory and focuses on the study of the thermal evolution of the solid when exposed to a source of radiant heating. By incorporating a general analysis of the transient energy balance, the heat transfer through the material and the chemical reactions (pyrolysis and gas phase combustion) can be more accurately understood. The fundamental study seeks to understand the interaction between the gas and solid phase phenomena and improve current descriptions of the flammability of solid materials.

Background
The classical theory of ignition[1] incorporates the main driving parameters into a unified model, based on the energy balance in the solid phase, the temperature-dependent chemical reactions (pyrolysis, oxidation and combustion) and the mass and energy conservation equations. This theory incorporates the main driving physical parameters and allows predictions of critical indicators, such as: time to ignition or critical surface temperature for ignition. Application of the theory requires some experimental work and consequently these variables depend to some extent on the experimental set-up used to measure them e.g. mixing of the pyrolysis products and the flow condition at the surface of the sample. It follows that ignition depends on the rate of generation of pyrolyzates, which is a process defined by the energy flux (including the heat losses from the sample) and the flow environment.

A common approach has been to keep the IRHF constant over time. This simplifies the analytical approach and also creates a logical transition between imposing a boundary condition and evaluating the material’s response. That is, the material is exposed to several constant IRHFs and then values such as time to ignition or critical heat flux are determined. This series of experiments are then used to categorize the material and define flammability criteria.

Theoretical framework
The theoretical framework for this project is based on a generalization of the classical theory of ignition. The new formulation focuses on the transient energy balance and the rates of generation of pyrolysis products and the flow condition at the surface of the sample. The IRHF assumption is eliminated, allowing for a more accurate prediction of ignition. The new formulation is applied to transient IRHFs and providing a comprehensive formulation of ignition under such conditions.

Research programme
The PhD is a three year, experimental programme aimed at understanding the limitations of current ignition theory when applied to transient IRHFs and providing a comprehensive formulation of ignition under such conditions. The radative environment during a fire depends on the flame properties, geometry and orientation of the surfaces. Consequently, materials placed within the fire environment will not be heated uniformly. By analysing the thermal evolution, temperature gradient and rate of generation of pyrolyzates under transient IRHFs, ignition theory can be further generalized to progress from the constant IRHF assumption. Furthermore, this fundamental understanding will also be used to investigate the fundamental heat transfer and fluid mechanic processes which control ignition of solids.

Research output
The fundamental understanding of ignition and flame spread is the cornerstone for a correct assessment of the fire risk and a safe and efficient application of performance-based design criteria. By deepening our understanding of this phenomenon we will increase our ability to accurately analyse and efficiently predict fire behaviour.

Outcomes of this project will include journal and conference papers in the years to come.

References
Intelligent Egress

Liam Ingram* and Stephen Welch
BRE Centre of Excellence in Fire Safety Engineering, University of Edinburgh

Summary

Intelligent egress proposes a novel approach to handling evacuations during fire related emergencies in the built environment. It is widely recognised that evacuees often rely on their original route of ingress to escape, or simply follow others, which in turn can lead to violation of basic design assumptions and hence, inefficient evacuations\(^1\). However, modern buildings are rich in sensors which can potentially be utilised to improve the safety and efficiency of egress. Data from these sensors may be exploited to monitor the fire development, smoke spread and occupant location. It is envisioned that an “intelligent egress” system would exploit these live measurements to generate dynamic route planning information that would be conveyed to the occupants in order to encourage them to adopt safer and more efficient escape routes. In order to achieve effective guidance, some element of prediction of the future evolution of the scenario is required, encompassing the fire hazard development and human behaviour aspects, such as queueing and bottlenecks, with the instructions reviewed and updated as required.

Background

The foundation of the intelligent system is the fire-egress risk model: CRISP\(^2\). CRISP is a two layer fire zone model with a detailed representation of human behaviour, originally run in Monte-Carlo fashion for risk analysis. It is capable of simulating fire development, smoke movement, various fire suppression systems, as well as the occupants’ interaction with the event. In earlier work, a linking to sensor measurements related to the fire was implemented, to establish a prototype steered fire modelling tool, K-CRISP\(^3\). The potential for predicting fire evolution was demonstrated in a live multi-compartment fire test in the FireGrid project\(^4\). A methodology to include within the model the influence of way finding, encompassing visual and audio cues, is also required and CRISP was further extended to include a simple occupant response model. Real life and computational experiments comparing evacuation time, with and without visual or audio aids were implemented and expected behaviours were reproduced\(^5\).

Research programme

The newly developed dynamic route planning system, which is coupled with the egress model, represents the built environment with a network of nodes and edges. A list of fast paths for each modelled building is determined and suitably stored. Upon the occurrence of an event requiring evacuation, the route planning system receives “live” sensor information from the CRISP simulation (Figure 1 and 2) regarding the fire hazard and location of occupants.

The stored path information is retrieved for each populated node, with paths utilising nodes with a detected hazard of a certain severity being omitted where possible. A number of solutions (Path sets – a “safe” path from each populated node to a safe node) are generated and tested for safety and efficiency. The most successful discovered solution is selected and the appropriate way-finding information is communicated to the CRISP simulated occupants.

This process is repeated at regular time intervals with updated sensor data. The route recommendations may be altered, giving the essential dynamic aspect to the system. Occupants are constantly monitored throughout the scenario, allowing predictions relating to their future movement speed to be considered. Moreover, the general movement speed in certain areas can be used to identify previously unknown egress hindrances, hence increasing the solutions’ relevance to the actual event.

The aim of this project is to demonstrate the advantages of an intelligent egress system by comparing guided and un-guided evacuations across a range of simulated environments. It is hoped that this will encourage full scale trials.

References


Hybrid modelling for the examination of heat and smoke spread in complex buildings

Benjamin Ralph
BRE Centre of Excellence in Fire Safety Engineering, University of Edinburgh

Summary

The majority of fire fatalities occur outside of the room of fire origin and are due to the effects of smoke inhalation. Two way fire-building interaction is an important factor in a fire's growth and spread. Due to computational limitations fire safety engineers are typically required to curtail the examined building domain to a small number of enclosures. Phenomena important for fire life safety and fire spread may be ignored in the fire engineering analysis. This project aims to provide a framework whereby the total building system can be explicitly modelled within industry-accepted timesframes by employing hybrid modelling: the coupling of computationally less expensive models to more expensive models with higher fidelity. Boundary conditions can be extended and more of the far field can form part of the fire safety analysis.

Background

Over 50% of fire fatalities in the US, UK and Australia occur outside the room of fire origin\textsuperscript{(1)-(3)}. Over 65% of fire fatalities in the UK are due to smoke inhalation\textsuperscript{(4)}. The total building system is an important factor which affects the growth and development of a fire and the transport of smoke\textsuperscript{(5)}. Due to computational limitations, the typical fire safety modelling paradigm ignores the total building system. This problem is compounded as buildings are getting taller\textsuperscript{(6)}, more complex\textsuperscript{(7)} and more reliant upon performance based design to meet society's expectations of life safety\textsuperscript{(8)}.

Cutting-edge modelling methods use computational fluid dynamic (CFD) models (also called field models) to examine the growth of fire and the flow of hot smoke and gases. These models (e.g. Fire Dynamics Simulator (FDS), OpenFOAM) solve discretised conservation equations to predict criteria such as temperature, species concentration, visibility and velocity. The high number of calculations means that field models are computationally expensive. Designers must curtail the extent of the domain analysed and important phenomena may be ignored. We want to extend the boundary conditions to include additional floors, stairs, heating ventilation and cooling (HVAC) systems, shafts and remote areas whilst maintaining acceptable computation time.

To solve this problem, hybrid modelling can be utilised. Hybrid modelling is the coupling of less computationally expensive models (e.g. semi-empirical zone models, 1D network models) to a field model to enable a total building system to be accounted for in the calculation. Smoke spread to and ventilation changes in remote areas can be explicitly examined.

Network model transient transport

The new 1D mass transport subroutine is an explicit Runge-Kutta conservation of species and energy using a finite difference Euler method with a Godunov upwinding scheme. The analytical form of the conservation equations solved are:

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho \mathbf{u})}{\partial x} = 0$$

(1)

Where $\rho$ is the density, $\mathbf{u}$ is the conserved variable, $t$ is time, $u$ is the velocity and $x$ is the 1D length. The ducts are discretized into cells. The following numerical discretization (pure upwinding) is used:

$$\frac{\rho_i^{n+1} - \rho_i^n}{\Delta t} = \frac{1}{2} \left( \frac{\rho_i^{n+1} - \rho_i^{n-1}}{\Delta x} \right)$$

(2)

Where $n$ is the current time step, $i$ is the current cell, $\Delta t$ is the time step, $\Delta x$ is the cell dimension and titles represents cell centre values. The Courant-Friedrichs-Lewy (CFL) condition for the Godunov scheme is:

$$\Delta t \leq \frac{\Delta x}{u_i}$$

(3)

To maintain the CFL condition, the subroutine takes sub-steps of the FDS time step via the least integer of the FDS time step divided by the CFL time step. A fuller description, with numerical verification, is provided in the FDS documentation.

Heat transfer in the hybrid model

Heat transfer between the coupled models is required to accurately output gas phase temperature. The network model will be represented in the field domain as hollow Langrangian particles. Radiative and convective heat transfer in the network model and between the field model and the network model will be computed using known and existing code in FDS. Extensive coupling between the sub-models is required as FDS gas phase variables will affect the convective heat transfer coefficient.

Validation and investigatory experimentation

A series of experiments will be carried out to both validate the model and to investigate total building fire system-inteaction phenomena.

Instrumentation will include thermocouples, velocity meters, gas analysers. The medium sized experimental set up will incorporate enclosures separated by duct/corridors and a form of mechanical ventilation system.

Project outcome/Conclusions

- Fire and smoke spread throughout a building is an important factor in fire fatalities
- Total building system/fire interaction is central to fire growth and spread
- These phenomena may be ignored in the typical modelling paradigm due to computational limitations

Figure 1: Typical implementation of a field model (FDS); showing numerical grid, temperature slice (top) and velocity vectors (bottom)

Figure 2: Hybrid coupled modelling concept

Network model transient transport

The new 1D mass transport subroutine is an explicit Runge-Kutta conservation of species and energy using a finite difference Euler method with a Godunov upwinding scheme. The analytical form of the conservation equations solved are:

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- These phenomena may be ignored in the typical modelling paradigm due to computational limitations

Figure 3: Sketch of potential experimental set up

- Coupled hybrid modelling can analyse the total building system and keep computational time reasonable
- Network transient transport has been implemented into FDS's continuous integration cycle

References

Embedding circular economy in the building sector

Katherine Adams*, Mohamed Osmani*, Tony Thorpe* and Gilli Hobbs+
*School of Civil and Building Engineering, Loughborough University
+ Building Futures Group, BRE

Summary

The aim of the project is to develop a framework for embedding circular economy throughout a building’s lifecycle. The framework will be applied at two levels, firstly at a high level focusing on the strategic opportunities across a building’s lifecycle stages and secondly, at a detailed level for implementing a circular economy during the fit-out phase for commercial building. A thorough understanding of the principles of the circular economy and how these can be applied at each stage of a building’s lifecycle will underpin this framework, along with the critical success factors for adoption. These factors are likely to include issues such as procurement, information exchanges, supply chain collaboration and business models.

Background

The term ‘circular economy’ is becoming increasingly commonplace with Governments and organisations developing strategies and policies such as the EU’s Circular Economy Package with a goal of boosting global competitiveness, fostering sustainable economic growth and generating new jobs. Common elements of the circular economy include sustainable resource use by achieving the effective flow of materials, enabling high value material circular loops, through reuse, repair, recycling, and remanufacturing, and moving away from the generation of waste, with the aim to ensure that material resources retain their inherent value for as long as possible (Figure 1). The drivers behind the circular economy include an increasing demand for resources resulting from a growing population and growing prosperity, rising scarcity and price volatility of resources, and the provision of high value secondary raw materials. Our current model of consumption is largely linear

Research programme

The aim of this research is to create a framework for embedding a circular economy across a building’s lifecycle. The research consists of the following objectives:

1. Examine the current circular economy drivers, barriers and enablers in the building sector
2. Determine the principles of circular economy and how they can be applied at each stage of a building’s lifecycle
3. Establish the critical success factors required for the adoption of the principles across the lifecycle
4. Create a high level strategic circular economy framework across a building’s lifecycle stages
5. Develop a detailed framework for implementing a circular economy during the fit-out phase for commercial buildings
6. Validate the effectiveness of the framework

Project outcome/conclusions

The project will develop a systematic method of embedding circular economy throughout a building’s lifecycle taking into account the roles of the supply chain, resulting in a strategic level framework. The detailed level framework for commercial fit-out will provide a vehicle for implementation of circular economy, focusing on the critical success factors and how these can be adopted.

References


Figure 1: An illustrative example of the circular economy (Stegeman 2015)
Investigating the performance gap in relation to overheating in the UK domestic sector

Loughborough University*, BRE**

Summary

Current methodologies that address the issue of overheating are associated with numerous limitations such as failing to consider the uncertainty that emerges from various contributing factors. Hence, their effectiveness is debatable. This PhD project aims to propose a systematic approach to increase the confidence of predicting overheating in residential buildings and by doing so, to reduce the associated performance gap.

Background

Despite the fact that many countries have adopted very stringent building energy performance regulations and have set ambitious targets regarding CO2 emissions, it has been observed that very little work or evidence exists in relation to overheating. The most important factors that can influence the likelihood of a home to overheat include: solar gains, warm exterior air, the Urban Heat Island (UHI) effect, noise, orientation, insulation, type and amount of glazing, thermal mass, ventilation, occupant behaviour and internal gains. These factors can be attributed to four categories: Climate, Occupants and Internal Gains, Fabric, and Site Context. Existing methodologies for assessing overheating are limited in two ways: they fail to take into account all the contributing factors and for the factors that they include, they don’t consider at all the uncertainty that emulates from them.

Research programme

Predicting overheating is a complex task which consists of the following stages:

- Analyse the indoor environment conditions of the building
- Establish comfort or health criteria according to which the propensity of overheating will be evaluated
- Investigate whether this uncertainty can be quantified to bridge the performance gap and, if so, how this can be achieved

These objectives will be fulfilled through the following:

- Literature review (objective 1, 2 & 3)
- Dynamic thermal modeling (objective 2 & 4)
- Analysis of monitored data (objective 3 & 4)
- Sensitivity/Uncertainty Analysis (SA/UA) (objective 2 & 4)
- Dynamic simulations conducted in Energy Plus to reveal the gap between predictions and measurements in relation to indoor air temperatures.

The anticipated outcome of this research is the development of a prototype that will couple building performance simulation (BPS) tools with observations and measurements made in real case studies.

References


Project outcomes/conclusions

The anticipated outcome of the research is the development of a prototype that will couple building performance simulation (BPS) tools with observations and measurements made in real case studies.

Two papers are in preparation for the Building Simulation 2017 conference.

Figure 1: Main factors contributing to overheating

This PhD programme focuses on the first stage. More specifically, the main objectives include:

- Investigate the impact of factors that can have an immediate effect on overheating (e.g. thermal mass)
- Illustrate how these factors are simulated and identify the inherent uncertainty
- Investigate the gaps and limitations of current methodologies that address the issue of overheating (Appendix P of SAP methodology, CIBSE TM52:2013 etc.)
- Investigate whether this uncertainty can be quantified to bridge the performance gap and if so, how this can be achieved
Measuring community resilience to natural hazards in low income countries

Madeleine Edgeworth (Supervised by Lee Bosher, Robby Soetanto, Stephen Garvin)
BRE Centre for Resilience, Loughborough University, BRE Trust

Summary

Community Resilience is an ability of a group of people connected by quality of human relationship and geographical location to cope with the natural hazards that they are exposed to. The term gained popularity in the disaster management sector a few decades ago as a positive connotation to the term vulnerability to drive efforts to build communities’ abilities to cope with such events. There are copious amounts of literature defining and discussing the term conceptually and over 50 tools have been developed to assess it. However, the concept was not qualitatively derived as applied to people in a disaster management context but was instead borrowed from the disciplines of ecology and mechanics (where it described ecosystems and steel beams respectively) and applied to people. Thus, within disaster management it has less empirically derived characteristics and little research has focused on the indicators and variables for its assessment. In a world where likelihood of disasters and their impacts is increasing as natural hazards increase, urban areas grow and poverty levels remain almost static, there is a need for community resilience levels to be increased and thus better understood. This gives rise to the question “how can we most effectively understand a community’s resilience to natural hazards so that resilience building efforts are most impactful?”. This PhD project aims to better define the antecedents and characteristics of community resilience to natural hazards and to create a refined list of variables to assess community resilience within a defined context. This will be achieved through a literature review and primary data collection from communities exposed to natural hazards in coastal areas of India and the Philippines.

Research programme

This research will use a literature review and interviews with stakeholders assessing and building community resilience to illustrate the existing conceptualisation of community resilience to natural hazards and prioritised indicators and their associated variables. This framework and its variables will then be applied to assess communities’ resilience to natural hazards in India and the Philippines through interviews, questionnaires and observation. A large number of variables will be assessed, including a range of types of variable for one specific indicator i.e. from Nominal, Ordinal, Interval and Ratio measurement scales. Data will be analysed to link variables measured to coping ability. This research will use two forms of research design: 1. A longitudinal research design will be adopted, whereby the analysed data for the communities in India will be compared to data collected 15 years ago to ascertain changes in resilience, highlighting change in risk perception overtime and potentially effectiveness of community resilience building efforts in the communities. 2. A cross-sectional study will be carried out using an iterative analysis process to refine the list of variables after each community assessment to those which are critical to indicate community coping or resilience levels. This will then be repeated in a second country to determine to what extent the context must be defined for the refined list of variables to remain applicable and to what extent the coping mechanisms demonstrated by communities can be generalised.

In low-income countries there are communities that have been exposed to extensive hazards that have developed their own traditional coping mechanisms to minimise any negative impact to them. However, many are still impacted and those subject to intensive hazards are often less prepared for such events – this is thought to be due to decreased risk perception with increased time from the hazard event. To minimise the potentially devastating effects of these natural hazards when they strike it is imperative that non-governmental organisations (NGOs), international non-governmental organisations (INGOs) and private organisations build these communities’ resilience to such natural hazards and do so in a way which is long lasting. These stakeholders have developed policies, frameworks and assessment tools to assess community resilience, however, many still don’t have a clear working definition and those that are assessing it (traditionally through vulnerability and capacity assessments (VCAs)) don’t always design the most effective solutions or solutions that are based on the assessment findings.

Background

Increasingly frequent extreme weather events are among the greatest threats to poverty reduction and shared prosperity, rolling back years of development gains and plunging millions of people into poverty. The damage caused by large disasters can also outweigh development assistance and represent a permanent loss of development momentum (Independent Evaluation Group, 2006). The Sustainable Development Goals (UN, 2015) and Sendai Framework for Action (UNISDR, 2015) are global drivers for building community resilience to natural hazards in low-income countries.

Intended project outputs, outcomes and impacts

This research has the following intended outputs:
- Mapping of existing community resilience assessment tools
- A refined list of variables to assess community resilience in a defined context
- A defined scope to which the refined variables of community resilience to natural hazards identified are applicable to
- A list of coping mechanisms to natural hazards in rural communities in coastal regions in India
- A conceptual framework of community resilience from a disaster management perspective

Relevant outputs and findings will be shared through discussions, presentations, lectures and journal papers with the following groups in hope of achieving the outcomes and impacts listed:
- Community members who are assessed as part of this research, so that they better understand their own community resilience to the natural hazards they’re exposed to and to implement their own solutions to minimise the negative impact of natural hazards
- Stakeholders including NGOs, INGOs and private organisations assessing and building community resilience in the types of communities defined within the scope to better understand community resilience, the indicators and variables to assess it and effective coping mechanisms to implement. It is hoped that these stakeholders can then adapt their assessment tools to include the refined list of variables where appropriate to their working context, to understand better how these link to the communities’ coping abilities and how this informs programme design so that they implement more effective and long-lasting solutions

Organisations influencing those building community resilience including donors, to adapt their policies as well as specific calls for proposals
- Organisations developing assessment tools for the use of organisations building resilience, including the BRE’s tool for “Quantifying Sustainability in the Aftermath of Natural Disasters” (QSAND), to adapt the indicators and variables and specific coping mechanisms based on the refined list (depending on the context)
- Universities training and educating people on disaster management and the built environment including land use planning in India and the Philippines so that their teaching materials include examples of effective coping mechanisms and how to most efficiently and effectively assess community resilience using the refined list of variables, so that those working to plan and develop communities within these countries in the future take can make informed judgements to consider and build community resilience to natural hazards.

References

Available at: http://www.un.org/sustainabledevelopment/sustainable-development-goals/
Bringing big data into building energy modelling

Zhang Yu (Steven)* Supervisors: Kevin Lomas*, Simon Taylor*, Paul Chung* and Jose Ortiz*
School of Civil and Building Engineering, Loughborough University* Department of Computer Science, Loughborough University* Housing & Energy Group, BRE*

Summary

Big data, Internet of Things (IoT), distributed energy generation, smart meters, district heating and cooling are among the identified 12 specific technologies likely to affect UK cities in the future. More and more open and big data are becoming available on building energy consumption and on socio-demographic characteristics of people, many of these are geographically referenced. For data protection reasons, these data are aggregated to small geographical area, eg. output areas. This PhD project will learn from geodemographic classification methods, by studying building energy consumption statistics with various sociodemographic information at LSOA/OA/postcode levels, with data mining techniques (classification, regression, machine learning etc.), in order to seek new knowledge related to peoples’ energy use behaviour. The feasibility of applying existing geodemographic classification methodology and tools in building a bespoke open-source building energy classification will also be investigated. Such classification may be reproduced at other level of detail, for example, at city level with finer geographical resolution, for better targeting and monitoring on local area.

Background

The built environment and the people within it form a complex interactive system, influencing each other. While it is necessary to consume energy in the built environment to maintain a comfortable indoor environment, the existing way of unsustainable consumption of energy and resources may lead to serious adverse impact on human beings, and energy consumption in buildings need to be reduced and transformed to low carbon technologies. With the increased level of computational capacity and data availability, energy consumption in buildings are being studied with big data at increased level of computational capacity and data availability, which may contribute to better characterization of domestic building energy consumption at small census output area level, and in turn enable the targeting for building energy improvement measures, while providing a tool for the study of energy consumption pattern.

Small area classification study

It is proposed to study the geodemographic characteristic with relation to domestic energy consumption. The UK government carries out national census every 10 years to get information about everyone in the country, which is considered as one of the most comprehensive source of information for details of family composition, health, employment and other socio-economic characteristics. Census data are published in output areas (OAs), which can be grouped into super output areas, ie. Lower Super Output Area (LSOA) and Middle Layer Super Output Area (MSOA). There is upper and lower boundary for the amount population and households in each area, to ensure no information on individual may be identified and also to ensure data quality, while aim to ensure consistency of area over time.

In the meanwhile, open data is bringing us access to multiple sources of data, being measured, recorded and published at constantly reducing time periods and for real scenarios, including sub-national level and local level. With these energy data, especially data at the LSOA level, various study has been carried out to model domestic energy consumption to visualize the variation of energy demand, to benchmark energy consumption, to study the energy efficiency uptake, however, constrained by the information provided in census data, only limited amount of the available information on socio-demographic were compared to the information provided in census data, only limited amount of the available information on socio-demographic were considered and presented in these study. It is known that there is a large variation of building energy consumption among household with different socio-demographic factors at the national level, sub-national level and household level, but, the socio-demographic characteristics of LSOA is in relation to the energy consumption has not been fully investigated yet. While there are classifications for how well buildings perform in terms of energy consumption, there seems to be no dedicated classification tools to determine what type of energy user are living in the building stocks (eg. high energy consumer, moderate energy consumer, low energy consumer), at least, have not been found at LSOA level.

Likely outcome

It is envisaged, with the continuous support and supervision from strong supervision team at both Loughborough University and BRE, to publish a Bespoke version of OAC type classification for domestic building energy study. If the building energy consumption could be classified, either according to the physical performance, or according to the real performance, or according to some other indicators (representing people’s demand, or other unmeasurable factors that may be linked with location), it may encourage future building energy study to be carried out. Also, as the LSOA/LSOA has a unique position in policy implementation, in national statistic release, in avoiding potential ethical issue, and in the capacity of integrating to the upper level or drilling down to the lower level, it is a sensible way to start bring big data into building energy modelling.

References


Traceability in the construction supply chain

Assel Katenbayeva*, Jacqui Glass*, Aaron Anvuur*, Shamir Ghumra** and Miles Watkins**
School of Civil and Building Engineering, Loughborough University, LE11 3TU*
BRE Group, Watford, Herts, WD25 9XX**

Summary
Traceability is a key component for verifying and ensuring sustainability claims associated with sourcing, production and transformation of the product as it moves along supply chain. This PhD project focuses on traceability in the context of sustainability particularly for the construction sector.

Traceability for sustainability
The topic of sustainability has extended its scope from focusing on individual companies in the past to considering the entire network of supply chains at present. Modern long and highly fragmented supply chains impose social and environmental risks. From the other side, they have a great potential to spread sustainable business practices around the globe.

A key component for verifying and assuring sustainability claims associated with supply chains is traceability (UN Global Compact & BSR, 2014). Traceability refers to the “ability to trace the history, application or location of an object” (BSI Standards Publication, 2015, p.20).

The concept of traceability is closely linked to transparency and responsible sourcing. In order to disclose information related to suppliers, this information must be traced. Therefore, traceability is an essential condition for supply chain transparency. On the other hand, transparency is important to enable traceability. Thus, when tracing a product, a company needs to connect with its suppliers and obtain information about the product; it means suppliers need to be transparent when revealing information to the company.

At the same time, traceability serves as means through which responsible sourcing within an organisation’s supply chain is demonstrated and ensured. Hence, traceability enables companies to account for their environmentally and socially responsible practices, as associated with products and supply chains. In this way, traceability can influence customer choice and play an important role in providing an incentive for sustainable production and ethical business behaviour.

Traceability in the construction sector
Yet in contrast to other sectors, such as food industry, fashion, forestry and pharmaceutics, traceability issues are still at an emerging stage in the construction sector. At present, there is minimal academic literature on traceability with just a few studies noting traceability in relation to responsible sourcing of construction materials.

Traceability requirements in the sector appear to be addressed exclusively in the standard BES 6001 (BRE Global Ltd, 2014) on responsible sourcing of materials (mainly construction materials but also others), developed by Building Research Establishment (BRE) in the UK. However, the standard does not provide suggestions on how to actually implement traceability programmes, which is a major shortcoming, but it should be recognised that guidelines also do not exist in other sectors either. In addition, the lack of academic literature on traceability within construction supply chain might lead to a poor understanding of the concept of traceability.

Research objectives
This PhD research aims to:
1. Develop a theoretical framework for traceability within the construction supply chain
2. Develop a process model for implementing traceability within the construction supply chain

Following objectives will enable to developing a theoretical framework:
– Understand the conceptual meaning of the term traceability in supply chain
– Analyse how the concept of traceability is addressed in the construction sector
– Assess construction companies’ attitude and awareness towards traceability programmes
– Identify potential benefits and challenges associated with implementing traceability programmes within the construction industry

To develop an implementation model it will be necessary to:
– Develop a strategy to implement traceability in the construction supply chain
– Test and validate effectiveness of the strategy

Potentially, research outcomes will help to identify implications and recommendations for changes in standards and practices.

References
Simplified life cycle assessment method for domestic buildings, a user-friendly tool

Carlos R Campos+ University of Strathclyde +

Summary

The overall purpose of this research study is to contribute to reducing the negative effect of domestic building construction to the environment. The specific objective is to study holistically the entire building process, including all the stages of the Life Cycle Assessment (LCA) from design, through construction, operation and demolition until the end-of-life for a complete and user-friendly LCA scheme. This will facilitate the development of a new methodology for assessing the environmental performance of existing and new domestic buildings in the UK, in particular a new decision-making tool. The methodology proposed aims to overcome the existing low link between the environmental assessment tools and real life monitoring figures.

Background

Life Cycle Assessment has been used to study the environmental impacts of different products and systems since the early '70s. Although there are several tools to study the energy efficiency and environmental impacts of buildings the most common ones are complex software. With these software packages is possible to evaluate the different forms of construction even at the design stage in order to choose the most sustainable option. Despite having access to their content, it is not as easy to implement as it should be in the domestic sector where a complete LCA including social and economic factors should be generated in order to get close-to-reality environmental information.

Some of the stages of buildings are not deeply researched and not properly addressed by LCA software tools at the present time. Improving certain stages in a building's life cycle is directly related with the design stage in order to choose the most sustainable option. Despite having access to their content, it is not as easy to implement as it should be in the domestic sector where a complete LCA including social and economic factors should be generated in order to get close-to-reality environmental information.

Research programme

The project consists of:

- Investigating the current software and schemes available related to LCA of buildings.
- Producing a simplified method and user-friendly tool for calculating LCA of domestic buildings.
- Validation of the tool with case studies.

The methodology is in line with the current ISO 14000 family and EN 15978 Building Standards and it has been developed with Matlab Software 2016. The LCA stages that have been considered are the following:

- Manufacturing
- Construction
- Replacements
- Op. Energy
- Decommissioning
- Waste processing

Therefore it is worth researching and developing new methods in order to reduce this energy consumption and CO2 emissions within the built environment and specially the domestic sector.

This methodology refers to the building's fabric Life Cycle and takes into account current industry figures for demolition, disposal and recyclability of a wide range of construction materials used in the most typical buildings projects in the UK.

A case study was performed with a 4-in-block domestic building taken from the BRE Innovation park located in Ravenscraig, Glasgow, UK. This typology, which is one of the most frequent typologies (there are 265,000 approx. in Scotland), is one of the worst performing both thermally and acoustically. Within this case study different retrofit scenarios are evaluated.

Figure 1: Glasgow’s Four Peripheral States (CES Ltd, 1985)

Project outcomes/conclusions

It is seen, after more than 20 LCA related software were studied, that there is a general lack of deep End-of-life and beyond impacts analysis. There are very important stages even if they are quite far in time for new buildings. These impacts could be reduced in almost 50% if taken into consideration from the very early stages of the building life cycle process.

There is a clear interaction between design, energy utilization and CO2 emissions during all LCA stages in a building’s life that clearly affects to the social and economic factors of a project considering the life span of a building and its users. For example, if less is invested in the construction phase (e.g. specification of poor insulation), the investment needed for heating and maintenance will increase.

The almost 18% of the housing stock in the UK belongs to social housing schemes, which are often coinciding with low incomes families.

This project is under performance but very early prediction of results show that without taking into account operational impact (LCA sub-stage BE), the end-of-life of the building life cycle could be responsible of up to 35% of the embodied carbon (KgCO2e) and 39% of the embodied energy (MJ). More results will be revealed once the study will be finished.

References


Figure 2: BRE Ravenscraig Innovation Park “Retrofit Building”

Summary

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References


Figure 2: BRE Ravenscraig Innovation Park “Retrofit Building”
Modelling indoor environmental quality in low energy housing

Maria del Carmen Bocanegra-Yanez1, Paul Strachan1
1ESRU, University of Strathclyde, Glasgow

Summary

As a consequence of the push towards low carbon buildings with high levels of insulation and air tightness, there are concerns that the risk of overheating and poor indoor air quality (IAQ) increases. The aim of this PhD project is to assess the impact that pollutant sources, occupancy profiles and ventilation strategies have on thermal comfort and IAQ in low-energy houses using the detailed thermal simulation program, ESP-r.

Background

To reduce building energy consumption and carbon emissions, Building Regulations and Standards require more insulated and air-tight buildings, which may lead to a poor quality indoor environment when not designed appropriately. An example can be found in the Dormont Park Passivhaus Development in Scotland, UK (Figure 1) where significant overheating was recorded, even during winter periods. However, the overheating frequency calculated by the Passive House Planning Package (PHPP) was only 0.2% (MEARU 2015). A possible reason for this is that PHPP, as well as other simplified tools, models the entire house as one single zone, where the air is well mixed and the internal heat gains are constant and evenly distributed within the building, which is unrealistic. In addition to overheating, poor IAQ in low energy buildings is a concern, not only as a result of reduced ventilation rates, but also due to the increased number of materials used in modern building construction. These materials, together with cleaning products and occupants’ activities, emit pollutants to the indoor environment and can lead to health problems if the ventilation is insufficient. The detailed modelling and simulation can be used to design appropriate ventilation systems by predicting the risk of overheating and poor IAQ at different locations in the building at different times. The objective of this study is to assess the impact that different pollutant models, occupancy profiles and ventilation strategies have on the distribution of thermal comfort levels and IAQ in low energy houses through a case study using the detailed thermal simulation program, ESP-r. CO2 is commonly used as a proxy for IAQ, but a novelty of this research is the integrated analysis of pollutant distribution for other pollutants, specifically formaldehyde.

Research programme

A model was created (Figure 2) of the Dormont Park houses based on the available constructional information, monitored data of the external and internal conditions over a 2-year period, plus detailed occupant diaries. A calibration methodology and acceptance criteria were defined, addressing the current absence of specific guidelines for model calibration based on the indoor environment.

Detailed contaminant emission models have not yet been implemented in detailed thermal simulation programs. Therefore, once the results were in acceptable agreement with measured data, a review of current literature on indoor pollutants was undertaken and a transient power law model was implemented in ESP-r to model formaldehyde emissions.

Different scenarios were then defined including mechanical ventilation with heat recovery (MVHR) with and without summer bypass, natural and hybrid ventilation, with different control strategies based on indoor temperature, CO2 or both. Finally, the different scenarios were compared based on indoor environmental quality (thermal comfort and IAQ).

Detailed building modelling and simulation can be used to design appropriate ventilation systems by predicting the risk of overheating and poor IAQ at different locations in the building at different times. The objective of this study is to assess the impact that different pollutant models, occupancy profiles and ventilation strategies have on the distribution of thermal comfort levels and IAQ in low energy houses through a case study using the detailed thermal simulation program, ESP-r. CO2 is commonly used as a proxy for IAQ, but a novelty of this research is the integrated analysis of pollutant distribution for other pollutants, specifically formaldehyde.

Project outcomes/conclusions

The main conclusion arising from the scenario analysis is that, contrary to the usual assumption of an even distribution of indoor environmental conditions, there can be significant variations in the internal distribution. Important factors are the use of appliances in different rooms within the building at different times, occupants’ activities, the ventilation strategy used and the openings between rooms. Finally, formaldehyde emissions from carpets and kitchen cabinets do not seem to be a risk for the health of the inhabitants in any ventilation scenario for the sources assumed in this modelling study.

Further work will include the implementation of more complicated emission models of formaldehyde (dependent on temperature and relative humidity) as well as other pollutants, for example, PM2.5. Low energy houses in different climates will also be studied.

The research should lead to recommendations for the design of appropriate ventilation systems and a better understanding of variations in the indoor environment.

References


**Dynamic exergy analysis for the built environment**

Valentina Bonetti, Joseph Clarke
ESRU, Energy Systems Research Unit. University of Strathclyde, Glasgow

**Summary**

Exergy is a state function that combines energy and entropy by means of a reference environment. By merging the first and the second law of thermodynamics, exergy quantifies energy quality, expressing the maximum potential work that an energy flux or quantity of matter can accomplish when brought into equilibrium with the defined reference environment. Although exergy assessments are widely used for optimising processes in various engineering fields, their application to the built environment is controversial and restricted to a research scene, especially when it comes to dynamic analysis. This research contributes to the discussion around the theoretical framework of dynamic exergy analysis of buildings, its reference definition and meanings through the development of a dynamic simulation tool within the ESP-r software.

The importance of sustainable, resilient and comfortable buildings, in terms of impact on environment and health, is very well known. Building design strategies nowadays work towards energy conservation to reduce the dependency on fossil fuels and the environmental impact while maintaining indoor comfort. But high-efficiency buildings are still high-cost and often not resilient. Alternative approaches use exergy, a thermodynamic state function that combines energy and entropy (generally understood as a way to estimate the maximum work potential of a system). Exergy is significant as it allows for a more comprehensive understanding of the interactions between buildings and their surroundings.

The first step of this research mixes, through a pragmatic methodology, practical experiences from low-budget construction sites with concepts from the relatively new discipline of non-equilibrium thermodynamics, and proposes an alternative energy design approach based on the second law of thermodynamics. This approach aims to better understand the interactions between buildings and their surroundings, as well as to provide a deeper insight on favourable energy interactions between the building and its surroundings, and a design guidance to exploit the site potential. The hypothesis deriving from this multidisciplinary investigation is that buildings, as living ecosystems, evolve by improving their ability to perceive and capture increasing portions of the surrounding energy available on site and increasing the exergy drop through them. Exergy assessments guide the design process towards the maximum exploitation of the site potential within the energy and economic budget constraints.

**Research programme**

The first step of this research mixes, through a pragmatic methodology, practical experiences from low-budget construction sites with concepts from the relatively new discipline of non-equilibrium thermodynamics, and proposes an alternative energy design approach based on the second law of thermodynamics. This approach aims to better understand the interactions between buildings and their surroundings, as well as to provide a deeper insight on favourable energy interactions between the building and its surroundings, and a design guidance to exploit the site potential.

**Current state of the art**

Exergy could provide a deeper insight on favourable energy interactions between the building and its surroundings, and a design guidance to exploit the site potential. However, the dynamic nature of building performance requires dynamic calculations, rather complex and not commonly applied yet, since classical exergy assessments are conducted on a steady-state basis. Major obstacles for dynamic exergy analysis are a controversial definition of the reference state and the lack of simulation tools.

**Simulation of the building envelope**

The building envelope is considered the core of exergy analysis and the starting point of any assessment for the built environment. The dynamic exergy analysis of the building envelope (based on the dynamic software ESP-r with an user-defined reference state, which can be fixed or time dependent) is therefore the development of an open-source tool for the dynamic exergy analysis of the building envelope (publication). The second step of this research is therefore the development of an open-source tool for the dynamic exergy analysis of the building envelope, based on the dynamic software ESP-r, with an user-defined reference state, which can be fixed or time dependent. The exergy stored in each construction node and the conductive, convective and radiative energy fluxes are calculated with Shukuya’s formulas, using the energy results obtained from ESP-r for hourly time steps as an input. The output is represented by values of exergy storage and conductive fluxes for the inner nodes of each construction element, and conductive and radiative energy fluxes for surface nodes. Visual representations (2D and 3D, as in Figure 2) allow comparisons of the impact of reference state and design choices. At this stage, the tool does not provide any concise ranking index and is therefore intended for use by people with exergy simulation expertise; the main aims are to contribute to a robust theoretical framework for building exergy analysis by facilitating the reference-state controversial discussion and to develop the first module of an open-source dynamic exergy simulation tool.

**Project outcomes/conclusions**

The dynamic exergy analysis of the built environment still presents controversial aspects and is rarely performed. The main aims of this work are to release the core of an open-source dynamic exergy simulation tool, facilitate the debate around the reference-state selection and define useful exergy indices, towards a new paradigm for sustainable and resilient low-cost building design.
Social innovation systems for building resilient communities

Donagh Horgan
Department of Architecture, University of Strathclyde

Summary
As practitioners we can sometimes take a very narrow view of sustainability – what it means for the built environment and where it can provide guidelines for more efficient fabric, systems, or behaviours. However, in the context of building strong resilient communities, sustainability is as much about how we plan and develop holistic social infrastructures comprising complicated interdependent structures, and their delicate social-ecosystem consisting of human and organisational stakeholders.

Approach
Having trained and practiced as an architect across a number of geographies I am acutely aware of the need for the profession to open up and accept new knowledge from fast-paced and flexible applications such as technology, sustainable business and user-centred design thinking. Modern technology systems are developed following an agile process – with low upfront investment costs, where solutions are constantly prototyped and tested with user communities before being refined and delivered at scale. Prior to the Great Recession in 2008, I left architectural practice to take up a masters study in Service Design innovation, which has transformed my skillset, allowing me to apply an (architectural) design process to conceive of solutions for a whole new set of non-spatial problems. My consultancy since then has sat at the intersection of design, technology and social change working with mainly public sector agencies on social innovation and organisational transformation. My decision to pursue a PhD is to bring this new knowledge and ways of working back into architecture and embed these tools in the skillset of the sustainable placemaker.

The recession produced a lull in building, which inspired many practitioners to re-evaluate the contribution of the profession of architecture to society. A lack of resources, for building, for investment and seedling growth has made us reconsider and assign greater value to our collective resources. The evident and growing inequality that exists within our communities has necessitated a reflection on how we design and plan sustainable buildings. Never before has there been such a pressing need to examine and reimagine our methodology and approaches in granular detail. Prevailing thought around sustainable cradle-to-cradle life cycles for products and building materials is beginning to collide with open and engaged practices in consultation, allowing us to collectively envisage sustainable and resilient mutually cooperative neighbourhoods. Architects, planners and environmental professionals alike are beginning to take another look at the pillars of thinking laid out over half a century ago by the likes of Mumford and Jane Jacobs. Rapid advances in technology – making much easier how we connect people, policy and performance now affords us the opportunity to test new ways of working, planning partnership and collaboration. My research, by practice, will see me setting up experiments and design-led engagement exercises to test and refine social innovation methodologies for building resilient communities.

Methodology
Over the next few years I have set out a pathway – connecting to new knowledge bases in technology, social science and policy planning – to research, analyse and propose models of social innovation that can inform a future-proofed architectural practice. This will involve identifying and mapping a number of case-studies, scenarios and situations where a set of multidisciplinary stakeholders are working to develop resilient communities. My area of research will study a variety of examples at three distinct scales – networks, frameworks and architectures – intentionally referring to concepts from software and technology development and reformatting them back into components of architectural (and broader) systems.

Focussed on a participatory approach to problem solving core to my research will be my practice – leading to the critical appraisal of a set of planning scenarios and governance models. I will view case studies through the prism of ensuring sustainable pathways to resilience, picking out the challenges and opportunities to complex yet open, multi-stakeholder projects. My work has honed my skills in design methodology, workshop facilitation, stakeholder engagement and analysis. I have a proven background working with a range of cross-sector organisations on user-centred service design, proposition development and business transformation. I also have a unique experience working across a number of thematic areas both in research and practice, these include IoT and Smart Cities; Community planning, service design and social infrastructure models such as co-housing, Policy, transformation and framework design; and agile technology development and design management.

Connecting themes and case studies
Social innovation invariably derives from a need, be it a community at breaking point through inequality, demographic changes, lack of opportunities and brain drain or a host of shocks caused by our modern economic reality and the context of climate change. Common across my practice, and areas of interest is a core belief that truly sustainable models for social innovation are based around how communities gain resilience through their independence – by co-producing their social infrastructure and setting truly local seeds for enterprise and development.

I will focus on a set of local and international scenarios, beginning at the network scale, where communities of practices have formed to drive sustainable social innovation in a challenging context.

Dublin, Ireland – Ballymun and others: My practice in Dublin focuses on a programme I have designed with Innovation Dublin, to meet unmet need of the community through strategic design thinking. Ballymun has recently undergone a billion-euro physical regeneration yet the accompanying social regeneration is sorely lacking. My work looks at what social infrastructures must be connected to unlock the transformational nature of a brand new built environment. Projects have included activating vacant space through the establishment of a Social Innovation Hub, maker spaces and more.

Christchurch, New Zealand: In 2017 I will travel to New Zealand to map out networks of resilience in the context of the devastating earthquake some years ago. Projects include Gap Fillers and special policy zones.

Recife, Brazil: As some of my practice in Brazil I have identified the case study of Porto Digital, a distributed technology urban regeneration area of the old port in Recife, Pernambuco. Subsequent case studies may include countries akin to Iceland, cities like Detroit and Boston and metropolitan regions such as Glasgow and others.

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PhD Supervisors – Prof. Branka Dimitrijevic and Dr. Igor Calzada
Representational Images available on request.
Modelling of energy demand variation and uncertainty in small-scale domestic energy systems

Graeme Flett and Nick Kelly, BRE Centre for Excellence in Energy Utilisation, University of Strathclyde

Summary

Domestic energy demand is significantly influenced by occupancy patterns, socio-economic characteristics, and individual household behaviours. A highly differentiated, probabilistic, bottom-up model for occupancy, and electrical and hot-water consumption has been developed to assess the variation and uncertainty in demand prediction for small-scale energy systems. The model output has highlighted the need to predict demand probabilistically to ensure robust performance of largely grid-independent systems under all potential operating scenarios.

Background

Future UK domestic energy scenarios predict an increase in community-scale microgrids with varying levels of independence. This shifts the focus of analysis from national to local scales. For systems of less than 1000 households, the types of households and area socio-economics have an increasing influence on demand characteristics. For even smaller systems, where individual household behaviours become increasingly significant, variations in energy-use behaviour result in greater uncertainty for demand prediction. This uncertainty has been estimated to be at least a factor of two for individual households(1) but little work has been done to either confirm this or quantify the impact at different scales.

Existing demand models have been primarily focused on deterministic prediction of average use at low time resolution. Models of this type, such as BREDEM, are suitable for housing stock analysis but limited for detailed analysis at the small-scale. Existing domestic occupancy models are primarily based on Markov-Chain (MC) methods using time-use survey data for calibration. A review concluded that this approach remains the most effective but that several enhancements were possible. An updated MC-based method was developed to improve duration prediction, capturing of occupant interactions, and occupant differentiation by age, employment status, and household type.

Research output

Demand factors

A review of the demand influencing factors identified in previous research concluded that the following were the primary determinants for electrical demand in order of increasing direct influence: location, house type/size/tenure, household composition/age, employment status, income, floor area, appliance ownership, appliance energy ratings, occupant energy-use behaviour, occupancy duration and timing, appliance use frequency. For hot water the list is similar. All but the final three factors are either known or are predicted probabilistically from survey data.

Occupancy modelling

Prediction of active occupancy duration and timing was deemed a critical input for any demand model that aims to capture household-level variation. Existing domestic occupancy models are primarily based on Markov-Chain (MC) methods using time-use survey data for calibration. A review concluded that this approach remains the most effective but that several enhancements were possible. An updated MC-based method was developed to improve duration prediction, capturing of occupant interactions, and occupant differentiation by age, employment status, and household type.

Demand modelling

Appliance-level demand data from the UK Householder Electricity Survey (HES) conducted in 201011 has allowed critical analysis of existing demand prediction methods. The review determined that the typical use of both time-use survey activities and per-timestep appliance use probability calculation methods poorly replicated the demand data.

An improved event-based method was therefore developed using the HES data for the main occupant-initiated appliances to determine separately: average appliance use frequency per household, daily use factored for occupancy, and the timing of each use based on start time probability distributions. The model also includes a variety of use frequency multipliers to account for variations between and within each household type, and based on differences in income, occupancy timing, and energy-use behaviours. A similar approach has been used for hot water demand, with use volume ranges treated in the same manner as individual electrical appliances.

Model applications and limitations

The aim of the highly probabilistic, 1-minute resolution model was to capture the range of electrical and hot water demand levels per-household. Validation has shown that this is achieved for average electrical (see Figure 1) and hot water demand. Review of the time-dependent demand profiles generated concluded that the behaviour of c.85-90% of households was captured with good accuracy within the probabilistic output, with the remaining households having highly distinctive behaviours. For communities of over 20 households all overall demand behaviours were replicated.

Conclusions

Analysis of both demand data and the model output showed that area socio-economic factors can account for a c.16% variation in average demand for identical house types in the lowest and highest area deprivation deciles. The model also confirmed that on average the demand uncertainty for individual households is in excess of a factor of two, with the uncertainty far exceeding this for outliers. This uncertainty translates to a typical average demand uncertainty of c.10-15% for 100-household systems and overall probabilistic variation with system scale as shown in Figure 2. More detailed supply and demand matching analysis determined that similar variation in factors such as solar panel output utilisation and grid make-up importing can be expected as a result of the residual uncertainty.

The main contribution of this work has been the development of improved methods for high resolution occupancy and energy demand modelling for a comprehensive range of households. It has also been shown that this type of differentiated and probabilistic model can be used to understand the variation and uncertainty in predicted demand and the impact on small-scale energy system performance.

References

**Development strategies for future cities to ensure energy resilience**

Ciaran Higgins – PhD Proposal

University of Strathclyde

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**Summary**

Energy systems modelling typically varies in complexity and accuracy with geographical extent. At district level, detailed geospatial models are often created to closely represent the energy system in order to understand to a high degree of accuracy the energy flows likely to be experienced. As we move up to city-scale, however, the models created tend to be less representative of the physical system and tools such as Excel or Matlab are used to describe the system. However, if we are to gain a true understanding of our physical energy systems at the city-scale, the flows of energy across them and the potential problem areas, it is essential that we model them to a consistent degree of accuracy across the whole city.

To achieve this a GIS-based hierarchical energy modelling approach is proposed – written in Python – that will perform detailed energy systems analysis at the district level, which will in turn be propagated to the city-level ('top-level') with the districts represented using abstract models. The project will seek to develop a methodology that identifies the most appropriate district extents, based on factors such as: the nature of the built environment; the infrastructure supporting the area (i.e. the extent of the network in any given area); and ‘softer’ considerations such as political ward boundaries or Datazones.

An automated flow will be developed that parses the electrical network to identify the abstraction points that will define the extent of each ‘district’, which will in turn be used to auto-generate the abstract for each.

The project will also seek to determine the impact of the use of abstracts on factors including, but not limited to: speed of simulation; accuracy of results; and compatibility across a different energy vectors.

The project will model in detail the built environment using industry-standard tools, and the impact on the electrical network assessed. A number of different energy scenarios will be represented to create a wide range of test results and the accuracy of using the abstract-based simulation against the fully flat simulation compared against all possible permutations.

Furthermore, the data required to perform the detailed district-level simulations in GIS will be investigated, and a list of essential and preferable datasets compiled. The impact of including or omitting specific datasets on the overall quality of results will be assessed.

Techniques used in the electronics industry will be applied to the energy modelling with a particular focus on how different libraries – used in electronics to model process variations and different operating regimes – can be applied to energy modelling to simulate different scenarios, e.g. climate change, differing energy delivery systems, etc. This will allow the energy system to be assessed for a number of different future scenarios in order to discover their resilience.

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**Research programme**

**GIS model development**

A model will be created in GIS that best represents the energy system across Glasgow city centre. The datasets available for use in the model will be assessed against a range of criteria including, but not limited to:

- Availability (to either academia, public bodies or the wider public)
- Cost
- Accuracy
- Currency
- Frequency of update

The ease with which each dataset can be used as input to external tools – such as ESP+®; HOMER, etc. – will be assessed and an overall flow created within GIS that takes the raw datasets on input and, via Python-based scripts, performs a series of automated manipulations that allows the energy flows across the city to be calculate.

The nature of database structure that is the most efficient/expandable/wide-ranging (in terms of functionality) will also be investigated – for example, GIS versus PostGIS. The impact of each database structure on the commands available for data manipulation/analysis will also be assessed and the appropriate balance of speed versus accuracy identified.

**Electrical network analysis: propagation of energy values**

Upon creation of the initial GIS energy model, the impact of the calculated energy demand on the electrical network – the dataset for which will be provided by SP Energy Networks – will be assessed. The ease with which this data can be propagated across the electrical network from individual properties up to primary substation level and beyond will be assessed, and the results compared with monitored data available for primary substations to ensure results are within an acceptable tolerance.

**Abstract development**

Using the fully populated electrical network, algorithms will be developed that will identify the most appropriate point in the electrical network for abstraction. The topology of the electrical network will be the primary factor that defines the abstraction point, but other factors will also be considered including, but not limited to:

- The nature of the built environment in particular parts of the city
- The infrastructure supporting the area (i.e. the extent of the network in any given area)

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**Possible commonality of extent with other infrastructures (for example, road network, district heating networks, etc)**

- ‘Softer’ considerations such as political ward boundaries or Datazones

**Simulation comparison: abstract versus full-flat**

Having both the fully detailed and abstract models for each district, the effectiveness of using each when modelling the energy flows at city level will be compared. Using identical input data and geographical extent, the models will be compared with respect to the following factors:

- Simulation time
- Accuracy of results
- Ease of analysis

**Library scaling**

- The possibility of scaling each input library to account for different scenarios – future climate change, for example – will be investigated and the impact on simulations tested. Scaling will be applied to the input data, any manipulated data and the abstracts created and the difference in results using the detailed (‘flat’) and abstracted flows compared.

**Applicability to other infrastructures**

- The applicability of the flow developed to create abstracts based on the electrical network will be tested against other utilities, with the hope that additional functionality can be developed that considers all local infrastructure for multi-vector analysis.

**Progress to date**

1. GIS function (plugin) created that analyses an electrical network and parses it to bring data from endpoints back to common node at secondary substation level. This is based on previous work done through Derryhrye Ltd.
2. Paper written to analyse datasets available for city-wide energy modelling
3. System architecture under development that will assess:
   a. Datasets needed on input
   b. Manipulation of datasets required
   c. The platforms upon which to run simulations: cloud versus local; Linux versus Windows; etc
   d. Speed of operation (wrt above platforms and flow created)
   e. Algorithms requiring development to produce required output
The value and use of urban health indicators in city built environment policy and decision-making

Helen Pineo1,2, Nicole Zimmermann1, Paul Wilkinson3, Michael Davies1
1Institute of Environmental Design and Engineering, Bartlett School of Environment, Energy and Resources, University College London 2Building Establishment 1Department of Social and Environmental Health Research, London School of Hygiene and Tropical Medicine

Summary

Health and wellbeing is becoming an increasingly important policy objective for city planning, transport and housing departments. Researchers produce substantial evidence about the built environment's impact on health. Yet there is a lack of knowledge about how and whether this evidence informs municipal policy and decision-making. Many urban health practitioners have been developed to help policy-makers understand and monitor the local health impact of the urban environment. Indicators are created using evidence-based relationships between physical environment features and health outcomes. This research seeks to understand the value and use of urban health indicators by city built environment policy and decision-makers. It tries to understand whether and when they are a route through which research evidence may inform policy.

Overview

Professionals and academics agree that health and wellbeing is not well integrated into policies in city services such as urban planning, regeneration and housing. Observers offer potential explanations such as: poor evidence of causality between built environment features and health outcomes; different professional norms across health and environment professionals; and the complexity of urban health systems. Urban health indicators (UHIs) are summary measures which describe the impact of the urban environment on health outcomes. When informed by local data, indicators may be a useful form of evidence to inform local government policy and decision-makers. Researchers suggest that indicators can also support engagement with non-specialists about complex topics and help monitor policy impact over time. In the fields of planning and health, academics have also proposed indicators as a key policy tool to help monitor policy impact over time. In the fields of planning and health, academics have also proposed indicators as a key policy tool to help monitor policy impact over time.

This research involves a mixed-methods approach of quantitative and qualitative data collection and analysis. The systematic review identifies both quantitative data about UHI tools and qualitative data about their use by policy and decision-makers. Both datasets will inform the in-depth qualitative research into two case studies of policy-makers. This will then inform the development of a systems model of indicator use in the policy process.

Systematic review

Systematic literature reviews are a form of secondary research which comprehensively review the existing evidence about the effectiveness of a particular intervention. This systematic review aims to identify the nature and characteristics of UHI tools and their use by municipal built environment policy and decision-makers. There are two parts to the review. The first part involves a census and taxonomy of UHI tools. The second part analyses qualitative data about the use of UHI tools in built environment policy and decision-making contexts. The review also investigates how these tools aim to account for complexity in urban health and whether this impacts their value to users. The findings from this review will inform the second stage of this research.

Qualitative analysis

Two case studies have been selected to investigate the use of UHI tools by municipal policy and decision-makers. The San Francisco Indicators Project (USA) was created by the city's Department of Public Health to inform planning and housing policy in the city. Semi-structured interviews with city planning and public health officers were conducted in April 2016. The Community Indicators Victoria system (Australia) provides data on urban health indicators across Victoria. Its creators have been working with local built environment policy-makers to promote use of the indicators. Semi-structured interviews will take place in early 2017.

System dynamics analysis

Data from the semi-structured interviews will be analysed and used to develop a model of indicator use in the policy process using system dynamics. System dynamics is a method based in complexity science and systems thinking which supports better understanding of complex problems. A causal map will be developed and tested through a workshop format with the case study interviewees.

Project outcomes/conclusions

Analysis of both demand data and the model output showed that this is a part-time PhD project which commenced in September 2015. Findings from the scoping review for the systematic review were presented at the International Conference on Urban Health (ICUH) in San Francisco in April 2016.11

Publications/research output

In addition to the abstract and presentation at ICUH, a protocol for the systematic review is currently under peer review following submission to the Systematic Reviews journal.12 Additional research publications are planned to disseminate the results of the systematic review and the development of a causal diagram for indicator use in policy-making. A non-academic publication about the research is planned for early 2017 in the Town and Country Planning Journal.

References

**Master-planning with (and without) BREEAM communities: case studies from the UK**

Lewis Sullivan*, Prof Yvonne Rydin+, Dr Jessica Ferm+
*Centre for Urban Sustainability and Resilience, University College London
+The Bartlett School of Planning, University College London

### Summary

This research analyses the attempts by BREEAM Communities and associated actors to intervene in the master-planning processes of six urban developments in the UK.

### Introduction

BREEAM Communities is a tool for assessing and certifying the sustainability of new neighbourhoods, and is one of several such frameworks published in the past decade (Joss 2012). These tools do not only assess and certify sustainability, but potentially organise, inform, validate, frame, and otherwise participate in the work of developing a ‘sustainable’ urban master-plan (Goh & Rowlinson 2013; Sullivan 2014). In the case of their building-level counterparts, these interventions seem to result in more sustainable outcomes (Schweber 2013; Goh & Rowlinson 2013; Holmes & Hudson 2002). Whether this is the case at the neighbourhood scale is not yet well understood.

BREEAM Communities was first published in 2008 and then re-published in 2012 and has been employed on numerous projects in the UK and Europe, and more recently further afield. The research methodology was influenced primarily by work in the field of science and technology studies (STS; e.g., Callon & Law 2005; Larsenther 2015; Rydin 2012; Sullivan L. Neighbourhood Sustainability Frameworks: A Literature Review. USAR Working Paper Series. UCL, 2015. BREEAM Communities as a socio-technical tool: Lessons from a comparative Anglo-Swedish study and future directions for research. Nordic Environmental Social Science (NESS) conference; 2015).

### Research outline

The research methodology was influenced primarily by work in the field of science and technology studies (STS; e.g., Callon & Law 2005; Larsenther 2015; Rydin 2012; Asdal 2008), in particular the concepts of qualculation – a term drawing attention to the spectrum of quantitative and qualitative decision making – and translation – the processes of forming a network of actors. This facilitated a conceptualisation of BREEAM Communities as both a physical artefact and an assemblage of (varyingly mutable) knowledge-claims and qualitative requirements, in a network together with an ensemble of Assessors, spreadsheets, external standards, emails, and so on. In turn, this allowed the author to focus on how BREEAM Communities is integrated into urban developments, how it influences decision making around sustainability, and how those changes are stabilised and persist to later development stages.

To this end, six case studies of developments in the UK were assembled. These case studies are based on interviews, document reviews, and observations from meetings and site-visits. Interview questions have been directed towards: 1) BREEAM Communities’ embeddedness and agency in the network of actors that constitute an urban development, 2) the mobility and mutability of inscribed knowledge-claims when translated into specific development instances, 3) participation in negotiation, qualification and other events throughout the development process, and 4) the stabilization of those interventions.

Data from these case studies is currently being analysed using ATLAS.ti, a piece of qualitative data analysis software. Case studies are analysed both internally and comparatively. The validity and generalisability of the findings are to be tested in a series of workshops planned for 2017.

### Emerging themes

A series of stub walls will be constructed, using different combinations of brick and block, in the flood tank at the HIVE testing facility. Water level will be raised to approximately 600mm, the limit at which structural renovation is anticipated for flooded buildings, and maintained overnight before draining (Figure 2). Moisture movement within the wall and reduction of moisture content with time will be monitored using impendence testing, wooden plugs and localised samples. A subsequent set of walls will be used to compare the behaviour of walls with cavity insulation. These will be selected to reflect new build practice as there is limited remaining scope to retrofit existing building stock.

### Project outcomes

The aim of this study has been to investigate how BREEAM Communities acts and is acted upon within an urban development; how it influences decision making and calculations; and how that influence is stabilised. At this stage, analysis has not been concluded though emerging themes include:

- **Contingency**
  - The standard allows for flexibility but also renders it potentially vulnerable to manipulation or poor management. The extent and mechanisms for this is explored.

- **Qualification**
  - The ways in which BREEAM Communities’ participates in judgements and calculations varies considerably: from criteria directly framing design decisions to more diffuse and subtle changes in emphasis of documentation and design meetings.

- **Stabilisation**
  - The local authority, Assessor, and existing legal and regulatory actors (e.g., section 106 agreements) appear to play a key role in how BREEAM Communities’ influence is stabilised.

### Research outputs


### References

Goh, C.S. & Rowlinson, S., 2013. THE ROLES OF SUSTAINABILITY ASSESSMENT SYSTEMS IN DELIVERING SUSTAINABLE.
Larsenther, S., 2015. Calculation and local climate initiatives – can numbers close the climate controversy? In NESS.
Sustainable neighbourhood design: examining the role of evaluation in neighbourhood masterplanning

Rosalie Callway, Prof. Tim Dixon, Dr. Dragana Nikolic
University of Reading, BRE, EPSRC

Summary
Sustainable neighbourhood standards, such as BREEAM Communities, have been examined by various researchers. There is more limited research contrasting the assumptions of these standards with core concepts in urban design practice. This research positions BREEAM Communities within the narratives surrounding the strategic practice of masterplanning. A number of challenges and opportunities are identified that may affect the standard's application in the future.

Background
BREEAM Communities is a UK-based standard that aims to promote the 'sustainable development' of new and regenerated neighbourhoods. It is one of an increasing number of standards and tools which aim to respond to a number of global threats facing an increasingly urbanised society (Ioss et al. 2015). The following summary outlines early findings from a review of the standard.

Rationale and method
BREEAM Communities can be understood as multi-criteria evaluative framework, in that it outlines 41 issues than can be applied to assess the sustainability performance of a proposed development. The standard's technical structure and its adoption by the construction sector. Firstly, regarding its technical structure, there are a number of design-related concerns and inconsistencies. For example, the scheme assumes all issues are commensurable, i.e. a lost score in one area e.g. green infrastructure, can be traded with credits elsewhere e.g. street safety (Munda & Nardo 2005). This raises questions about how and by who such trade-offs are decided. The standard strongly advocates stakeholder and community engagement in masterplanning. It is inconsistent about how far this should go however, especially in defining priorities. Another technical concern relates to where complex interactions are missed. For example, investment in landscaping may benefit environmental quality and raise real estate values. Yet this may displace people on lower incomes who cannot afford higher prices, so-called 'environmental gentrification' (Dale et al. 2009). Unlike other BREEAM standards it does not require ex-post evaluation necessary to validate the certification.

Secondly, various external factors are likely to influence BREEAM Communities application in the construction sector. This includes the issue that many developments may be a smaller scale than BRE considers viable to assess. Market conditions may affect the number of larger-scale developments taking place (Lorenz and Lützkendorf 2008). Masterplanned neighbourhoods can take decades to deliver, with changing actors and dynamic decision-making processes, impacting the ownership of evaluations. The regulatory context is also important, only three English councils currently require BREEAM Communities within planning application processes (Gastlegh, Bristol & Swindon).

Early findings
The literature review was used to formulate a textual analysis of the mandatory issues in BREEAM Communities and contrasted with the ‘prerequisite’ issues from the US equivalent, LEED. Neighbourhood Development (Figure 1). A point score was applied if the standard refers to urban design attributes that have been associated to particular sustainability benefits, e.g. sites designed with natural surveillance have been associated to the social benefit of neighbourhood safety (Boyko & Cooper 2012). The analysis suggests that the BREEAM Communities mandatory issues refer to a wider breadth of design attributes as compared to LEED NO. Both schemes contain fewer references to attributes associated with social and technical sustainability benefits, potentially pointing to areas for standard enhancement (Callway et al. 2016).

BREEAM Communities comes up against some criticism (as well as praise) from both academics and practitioners in relation to two broad areas: the standard’s technical structure and its adoption by the construction sector. Firstly, regarding its technical structure, there are a number of design-related concerns and inconsistencies. For example, the scheme assumes all issues are commensurable, i.e. a lost score in one area e.g. green infrastructure, can be traded with credits elsewhere e.g. street safety (Munda & Nardo 2005). This raises questions about how and by who such trade-offs are decided. The standard strongly advocates stakeholder and community engagement in masterplanning. It is inconsistent about how far this should go however, especially in defining priorities. Another technical concern relates to where complex interactions are missed. For example, investment in landscaping may benefit environmental quality and raise real estate values. Yet this may displace people on lower incomes who cannot afford higher prices, so-called ‘environmental gentrification’ (Dale et al. 2009). Unlike other BREEAM standards it does not require ex-post evaluation necessary to validate the certification.

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Conclusion
BRE argues that the standard is structured to fit with ‘typical’ masterplanning processes. Such processes are likely to vary considerably in ‘real world’ practice however. The next stage of this research is undertaking empirical examination of six UK masterplanned sites, considering the practitioners, practices and the enactment of those practices (Egels-Zandén and Rosén 2015), to better understand these processes and how BREEAM Communities is perceived to interact with them (Fig 2).

References
Towards informal planning – mapping the evolution of spontaneous settlements

Maddalena Iovene*, Sergio Porta*, Ombretta Romice*, Andrés Mejía Acosta+, Graciela Del Carmen Fernández De Córdova Gutiérrez*  
*Urban Design Studies Unit (UDSU), Department of Architecture, University Strathclyde, Glasgow  
+Kings college, International Development Institute, London  
Centro de Investigacion de la Arquitectura y la Ciudad (CIAC), Departamento de Arquitectura, PUCP, Lima

Summary

Spontaneous and unplanned human settlements scattered around the globe, have often proven to be promoters of important values and fundamental environments for the less-off, otherwise a real vehicle to social and human change (Turner, 1976). They have been considered as a tool for economic progress and community empowerment that allowed for sparkling and solid ties to grow and heterogeneous urban spaces to develop. Consequently, the aim of the current research is to shed light on the internal structure of an informal settlement in Lima, capital city of Peru (South America) and its evolution in time. In order to allow for generalizations and classifications of urban models and settlement patterns and to identify some characteristics of urban change that can be recognised at a global level. The evolution in time of the settlement’s internal structure will be analysed from a physical (morphology) and non-physical (governance, society) point of view.

Background

We now live in a world made of cities. This global demographic transition (Watson, 2009, p. 160) from rural to urban environments has its peak in 2008 when, for the first time in history, more than 50% of the world’s population lived in cities (ibid). These figures had its peak in 2008 when, for the first time in history, more than half of the world’s population lived in cities (ibid). These figures had its peak in 2008 when, for the first time in history, more than half of the world’s population lived in cities (ibid). These figures had its peak in 2008 when, for the first time in history, more than half of the world’s population lived in cities (ibid).

Global South (Desa, 2014). As a matter of fact, cities in the so-called developing world will account for 95% of urban expansion over the next two decades (UNHSP, 2003).

Need for morphological analysis

Scholars, development practitioners and international aid agencies have tried at length to group and classify informal settlements in order to generate theories that could be of help to further analysis and to gain a better understanding of which guidelines are to be used in order to develop sustainable implementation programmes. However, the state of the art of informal settlement analysis presents a twofold gap of knowledge: neither development (Caniggia & Goethert, 1978; Hamdi, 2010) nor informal settlements studies (Hernández, Kellett, & Allen, 2010) nor urban morphology research (Caniggia & Maffei, 2008; K. Kropf, 2009; J. W. Whitehand, 2001) have yet addressed the physical form of informal settlements.

To date, there is still need for theoretical models that are both comprehensive and inclusive, which is able to grasp the complexity and the powerful dynamics of the city-making process and the urban fabric (Ludeña, 2006) of cities. For this reason and faithful to our goal to address both the process and the product alike, preliminary to the setting up of a conceptual framework is a proper investigation of the urban environment, by acknowledging the existence of multiple components, not only physical, that influence and shape. So, the question we need to answer is ‘what does the urban environment consist of?’

Project outcomes/conclusions

According to some preliminary observations, it has been possible to identify some ‘universal patterns’ of urban change (however with some fundamental differences); thus confirming that however spontaneous and informal, these settlements do have a structure, which is not random and chaotic but rather follows some global rules of evolution.

Furthermore, we believe the possibility of defining typologies of informal settlements on the basis of their internal structure (both physical and governative) could be extremely helpful in allowing planning models to generate from local and traditional patterns and fight against Western solutions to Third World cities (Watson, 2009).
Facts about Birmingham

1. Birmingham means home (ham) of the people (ing) of the tribal leader Birm or Beorma.
2. Birmingham is the youngest city in Europe, with under 25’s accounting for nearly 40% of its population. A significant contribution to this comes from Birmingham’s 5 universities hosting 73,750 students every year.
3. Nearly a third of Birmingham’s residents are of minority ethnic origin, bringing a rich cultural mix to the city.
4. There are 30 other Birminghams around the world and one crater on the moon called Birmingham!
5. Birmingham’s international Partner Cities include Chicago (USA), Frankfurt (Germany), Johannesburg (South Africa), Leipzig (Germany), Lyon (France) and Milan (Italy).
6. Clean sweep!… Council street cleaners regularly sweep 1,300 miles of road and empty 4,000 litter bins – helping to make Birmingham officially the UK’s cleanest large city.
7. Thanks to its innovative 18th century Industrialists building a canal network to aid trading networks, the city has more miles of canals than Venice with 56 kilometres of waterways.
8. With over 8,000 acres of open space and 6 million trees, Birmingham is one of the greenest cities in the UK. Sutton Park is one of the largest urban parks in Europe outside of a capital city and covers an area of 2,400 acres.
9. Birmingham has more Michelin-starred restaurants than any other UK city outside London, with Purnells, Simpsons, Turners, Adam’s, & Carters flying the flag for the city’s fine dining.
10. Balti cuisine is synonymous with Birmingham – over 100 balti houses, many of which can be found in the city’s famous Balti Triangle, attract over 20,000 visitors each week.
11. Classic kitchen cupboard staples like Bird’s Custard, Cadbury chocolate, Bourneville Drinking Chocolate, HP Sauce and Typhoo tea, all started life in the city.
12. Birmingham Hippodrome is the busiest and most popular theatre in the UK with over 520,000 visitors taking their seats at performances every year.
13. For over 250 years Birmingham’s Jewellery Quarter has been a national epicentre for jewellery design – producing an estimated 40% of the UK’s jewellery.
14. Famous brummies include Lenny Henry, J R Tolkien, Jasper Carrott, Wizard, Duran Duran, ELO, Toyah Wilcox, Julie Walters, Black Sabbath, Jamelia, Trevor Eve, Martin Shaw, Richard Hammond, Bill Oddie, Dizzee Rascal, Frank Skinner, Ian Lavender, UB40 and Orlando Bloom’s great great great grand mother…
15. Birmingham’s Bullring has hosted markets since the 12th century and spans an area of over 60 football pitches.
16. The architecturally remarkable Selfridges building is decorated with 15,000 spun aluminium discs.
17. Birmingham’s Frankfurt Christmas Market is the biggest of its kind in the UK with nearly 200 stalls living the city centre, welcoming over 5.5 million visitors each year.
18. Football referee whistles were invented and first manufactured in Birmingham. It’s also where the original FA Cup was made.
19. New Street is the busiest interchange station in the UK with a train leaving the station every 37 seconds, supporting 52 million passengers every year.
20. Celluloid was invented in 1862, by Alexander Parkes; the first plastic was known as Parkensine.
21. The first of the famous Odeon chain of cinemas first opened in Perry Barr, Birmingham in 1930.
22. John Watt invented the steam engine, the letter copying machine and a unit of power.
24. Electro-plating was invented in Birmingham by John Wright in 1840.
25. The Pneumatic tyre was invented in Birmingham by John Dunlop in 1888.
26. Joseph Chamberlain (1836-1914) is recognised as the founder of municipal government.
27. Alec Issigonis designed the world famous ‘Mini’, which started production in 1959 at Longbridge, Birmingham.
28. X-Ray photography for medical purposes was pioneered by Major John Hall Edwards; he took the first x-ray in Birmingham in 1896.
29. The Peaky Blinders were a real ‘razor gang’ living in Small Heath, Birmingham in the early 1900s.
BRE Group
Bucknalls Lane,
Watford,
WD25 9XX
T +44 (0)333 321 8811
E enquiries@bre.co.uk
W www.bre.co.uk

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