

TOWARDS THE INTEGRATION OF SUSTAINABLE INFRASTRUCTURE INTO THE EXISTING BUILT ENVIRONMENT

Branka Dimitrijević¹, Glasgow Caledonian University, Glasgow, United Kingdom

The construction sector in the United Kingdom is dominated by small and medium size enterprises (SMEs) which have less than 250 employees and usually do not have research capacities to develop a range of low carbon innovations applicable in the construction sector. Various European and national funding programmes have addressed this problem by providing funding for research collaboration between universities and SMEs. The paper provides a selection of the outputs of academic/industry research, undertaken by seven Scottish universities through the project CIC Start Online from September 2009 until February 2013, related to low carbon planning, building design, technologies, construction, refurbishment and performance. The studies either contributed to the further development of existing products or processes, or tested new products or processes, often developed for a specific project with a potential for application in future projects. Online dissemination of the project outcomes has assisted in attracting membership across Scotland, the United Kingdom and internationally.

Along with the low carbon building products and technologies, new low carbon infrastructure is being planned and developed in order to provide connections and services for energy generation from renewables, energy storage and decentralised distribution, water management (harvesting, saving and reuse), waste management (reduction, reuse and to-energy), transport (electric vehicles, cycling and walking) and information communication technology (ICT) for monitoring and managing infrastructure systems. The second part of the paper outlines how innovations for integration of sustainable infrastructure into the existing built environment will be supported through the follow-on joint project of nine Scottish universities, named Mainstreaming Innovation.

Key words: sustainable infrastructure, innovations, reduction of carbon emissions.

INTRODUCTION

CIC Start Online project was planned to respond to several key policies and guides on sustainable building design and construction published at that time when the project was prepared and during its delivery. *The Government Economic Strategy* (Scottish Government, 2007) highlighted the importance of creating and maintaining a sustainable built environment. The *Climate Change (Scotland) Act 2009* (Scottish Government, 2009), whose aim is to reduce carbon emissions in Scotland by 80% by 2050, was another key policy to which the project responded. The report *Developing Scotland's low carbon built environment* (Kelly, 2010), highlighted that the

affordability of research for SMEs, the lack of tested innovative solutions and guidelines on how to apply them in practice were perceived as barriers to the adoption of innovations. To address the above barriers, CIC Start Online organised a quarterly competition for feasibility studies and academic consultancies on sustainable building design and refurbishment undertaken for the benefit of Scottish SMEs from October 2010 until January 2012. Over 80 joint academic/industry applications were assessed by the independent assessment panel, 70 approved and over 60 completed. The outputs of several studies whose innovative products, processes and design solutions addressed low carbon planning, building design, technologies, construction, refurbishment and performance are presented in the chapter *"Innovations for sustainable building design and refurbishment supported*

through CIC start online".

From the focus on building design and refurbishment, academic/industry collaboration for developing innovations for a more sustainable built environment in Scotland has moved towards the integration of energy efficient existing and new buildings with new, more sustainable infrastructure systems for energy generation from renewables on site, energy storage and decentralised distribution, better water management (harvesting, saving, recycling), more sustainable waste management (reduction, reuse, to-energy), ICT/BMS systems for monitoring and management of

This paper was presented at the 2nd International Scientific Conference „REGIONAL DEVELOPMENT, SPATIAL PLANNING AND STRATEGIC GOVERNANCE – RESPAG“, Belgrade, 22nd-25th May 2013, organised by the Institute of Architecture and Urban & Spatial Planning of Serbia.

¹ Cowcaddens Road, Glasgow, G4 0BA, Scotland, UK
Branka.Dimitrijevic@gcu.ac.uk

infrastructures, including increased integration of “green infrastructure” – landscaping and biodiversity – which can mitigate the effects of changing climate. The widening of the scope for innovations is backed by some early and more recent visions of sustainable development, briefly outlined below.

Landscape and biodiversity

Sustainable infrastructure cannot be truly sustainable if it is not integrated into the natural and built environment with due care for landscaping, biodiversity and quality of design. Natural landscaping and biodiversity within the built environment have their own intrinsic value as living systems of our planet, acknowledged by the fourth principle of the Rio Declaration on Environment and Development (United Nations, 1992) in contrast to the homocentric worldview that had dominated throughout the industrial revolution which has contributed to the rise in carbon emissions. As climate change can cause extreme weather events such as prolonged and stormy rainfall or long periods without rain causing drafts that affect plants, animals and people, mitigation of the effects of extreme weather on the natural and built environment becomes increasingly important. Innovative approaches towards mitigating effects of prolonged rainfall include sustainable urban drainage which can be designed to enhance natural landscape within the built environment and can increase biodiversity (Building for the Future, 2007).

Energy and Information Communication Technology (ICT)

Energy 2020: A strategy for competitive, sustainable and secure energy (European Commission, 2010) set out initial policy decisions that will be needed to meet the 2020 energy objectives. The strategy underlines the need to rebalance energy actions in favour of a demand-driven policy, empowering consumers and decoupling economic growth from energy use. In particular, the transport and construction industries must pursue an active energy savings policy and diversify towards non-polluting energy sources. The new energy strategy focuses on five priorities: (1) achieving an energy efficient Europe, (2) building a pan-European integrated energy market, (3) empowering consumers and achieving the highest level of safety and security, (4) extending Europe's leadership in energy technology and innovation and (5) strengthening the external dimension of the EU energy market. This will be achieved through energy efficiency measures, from generation to point of use and development of infrastructure to ensure a secure

supply for Europe and reduce fuel poverty.

In 2011, the economist Jeremy Rifkin, published a vision for “the third industrial revolution” that would include (1) a shift to renewable energy; (2) transformation of the building stock into micro-power plants to generate energy from renewables on site; (3) deploying hydrogen and other energy storage technologies in buildings and throughout the infrastructure to store intermittent energies; (4) using Internet technology to transform the power grid into an energy-sharing intergrid; and (5) transitioning the transport fleet to electric plug-in and fuel cell vehicles that can buy and sell electricity on an interactive power grid (Rifkin, 2011).

Rifkin's vision was earlier presented and discussed with businesses in the USA and with the EU governments, and has influenced further thinking about new infrastructure and technological concepts such as the use of information communication technologies (ICT), organic-lightemitting-diodes (OLED) and 3D printing that will change how buildings look and operate within the context of distributed information, distributed energy generation and distributed manufacturing which has been envisaged by Rifkin (Johnston, 2013). Johnston (2013) describes how Rifkin's vision is currently translated into practice and what can be expected in the near future. The way energy is generated and distributed will change – locally produced DC power from a solar panel will be used by a local DC powered device. Many aspects of Smart Grid will be based in buildings, including integration of distributed energy resources, demand response, energy-efficiency measures, electric-vehicle battery integration, thermal storage HVAC systems and provision of time of use pricing signals. ICT could lead the way as it already uses 60W Universal Power over Ethernet (UPoE), 100W Universal Serial Bus (USB) 3.0 and 380V DC power supplies for data centres, and with Cisco's estimate of 33 million devices powered by their 3rd generation UPoE system, UPoE could become a ubiquitous solution in the commercial environment. Smart DC solutions are also beginning to move into different sectors within the built environment, most predominately LED lighting in which the US is taking a lead in the development of standards for DC networks in buildings and has pulled in key players in the lighting, power distribution and ICT sectors. The next few decades could bring a further integration of the virtual and real world by giving any real thing an IP address and connecting it to an “internet of things”, which could lead to the convergence of previously defined verticals in the building sector, particularly building management systems (BMS) and power distribution systems

under a new name of integrated energy management. Furthermore, the convergence of Smart DC and energy management systems will open up many more opportunities for innovation such as the creation of a true Digital Energy Network in which Smart DC could evolve from intelligent fault monitoring towards the complete decentralisation of power control, where distributed “power routers” forward packets of power to IP addressable end-devices. The above description indicates changes that will happen in the existing and new buildings regarding energy generation, storage and distribution.

Transport

Along with changes in buildings, electricity powered transportation fleet will be introduced. Electric vehicles will become a part of the energy storage system, very often linked to the buildings in which their owners live or work. Symbiotic relationship between buildings and vehicles will require new solutions in the design of buildings and energy services. As the network of charging points for electric vehicles will expand beyond built up areas, the impact of this infrastructure and complementary services, similar to those developed for other types of vehicles along the roads will have spatial impacts that have to be assessed, leading towards the development of related planning and design guidelines. The consideration of location and design of charging points for vehicles is appearing as a new task for planners and designers in Scotland as Scottish Government has announced in February 2013 plans for free installation of home charging points throughout Scotland, public charging outlets within at least every 50 miles on trunk roads and an integrated network joining up electric vehicles with public transport (Scottish Government, 2013). Currently, charging of electric vehicles in Scotland is free to stimulate demand.

Water

In European Union, the Directive 2000/60/EC established a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which (a) prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems; (b) promotes sustainable water use based on a long-term protection of available water resources; (c) aims at enhanced protection and improvement of the aquatic environment through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges,

emissions and losses of the priority hazardous substances; (d) ensures the progressive reduction of pollution of groundwater and prevents its further pollution, and (e) contributes to mitigating the effects of floods and droughts. In the United Kingdom guidance for sustainable water management through water harvesting, saving and recycling in daily activities (Environment Agency, 2007, 2010, 2011; DEFRA, 2011), in businesses and industry (Waterwise, 2010a; Zero Waste Scotland, 2012), and water industry as a whole (Waterwise 2010b) have been updated in the last few years to address the potential effects of climate change on availability of water. In Scotland, the law on the management of Scotland's water resources has been updated (Scottish Government, 2012a) to introduce new duties relating to the government vision of Scotland as a Hydro Nation and set a legislative framework that will underpin other non-legislative activity.

Waste

EU's Waste Framework Directive (Directive 2008/98/EC), dealing with prevention, preparing for reuse, recycling, other recovery (notably energy recovery) and disposal, has initiated publication of related guidance in the UK (WRAP, n.d.) as well as legislation and action plans in Scotland (Scottish Government, 2012b; Zero Waste Scotland, 2010). The new Resource Efficient Scotland advice and support service, established on 1st April 2013, replaces Scottish Government business and public sector advice services currently delivered by Zero Waste Scotland, Carbon Trust and Energy Saving Trust. Advice on energy, water, materials and waste can be accessed from a single service which will provide free support, training and access to funding to help organisations implement resource efficiency measures. Resource Efficient Scotland will also commission research and development, fund commercialisation of innovative technologies and facilitate collective industry agreements.

The above legislative and operational context, and the outlined visions of the changing built environment in forthcoming decades stimulate development of innovative solutions that will be supported by the project Mainstreaming Innovation, described in the chapter "*Support for innovations for integration of sustainable infrastructure into the existing built environment*".

INNOVATIONS FOR SUSTAINABLE BUILDING DESIGN AND REFURBISHMENT SUPPORTED THROUGH CIC START ONLINE

The range of innovations supported through the project and other outputs can be classified in

six subgroups presented below. Development and application of an innovative product or a process initiates the assessment of the context in which they are applied to enable optimum performance and achieve the most cost effective solution. These considerations often lead to innovative approaches in planning, building design and management, thus creating a web of related innovations.

Planning

The resilience of buildings, neighbourhoods and cities in the context of climate change as well as their adaptability to the changing users' needs were the themes of the second online conference organised by the project. Avoidance, resistance and recovery in relation to the potential increase of flooding (Roaf, 2011) and managing urban heat island (Emmanuel and Kruger, 2011) due to climate change were the topics of two videos. The theory of self-organising built environments as a response to carbon levels (Moore, 2011) provided an insight into alternative approaches to the reduction of carbon emissions. Benefits of establishing energy co-operatives were presented by Borthwick and Muneer (2011). Accessibility of urban spaces for everyone was explored in the video by White and Grant (2011). Planning issues addressed through the project studies include the influence of microclimate on building design (Kumar and Emmanuel, 2010) and the regeneration of a rural estate (Sharpe and Bridgestock, 2012). Sometimes, planning aspects were addressed to enhance the performance of an innovative building service system, e.g. in the feasibility study about the development of a hybrid solar thermal mass (HSTM) system for the application in new housing by Noguchi *et al.* (2010). The study led to the alterations to an existing masterplan to enhance the HSTM system's performance as well as communal functions (Barr *et al.*, 2010). Through the analyses of the site and the discussions with housing representatives, some problems in the existing plan were highlighted and key guidelines for the alternative design proposal drawn up.

Building Design

Principles and processes related to sustainable building design and applied in several Scottish architectural practices were explored and presented in a conference video (Grierson and Moultrie, 2011) and summarised in an article (Grierson, 2011), showing a diversity of approaches both in terms of practice policy and design output. The same was evident at the Scotland's Housing Expo 2010 from which several examples of sustainable housing

design were presented in a conference video produced by the project (Brennan, 2011).

A range of energy simulation tools has been developed to date to assist the design of more sustainable buildings. Their capabilities, from modelling operational energy use to predicting overall carbon consumption and resource impacts, are explained in a conference video by Clarke (2010). The article by a Scottish software developer, published in the project's quarterly online magazine, explores the capability of simulation software to intervene in all stage of the design process (Wheatley, 2010), while the article by Isaacs *et al.* (2011) presented the advances in a recently developed simulation tool to analyse impacts of different design and planning options on sustainability within a 3D model.

Simulation tools were used in one feasibility study to benchmark performance between different building construction systems, but also to examine the meaning and implications of the term 'zero carbon' and the role of renewables both on and off site as a method of reaching such a goal (McEwan and Roaf, 2010). In another study the aim was to prototype a simple options appraisal tool to help make specific decisions such as payback periods for insulation and the use of blinds to avoid overheating (Counsell *et al.*, 2012). As the adaptation of existing simulation tools for architectural education is critical in embedding iterative practice in sustainable design practice, this was the focus of the study by Uduku and Roderick (2012) that enquired how an existing simulation package could be adapted to become an effective undergraduate teaching tool through simplifying and clarifying key processes such as daylight analysis and building energy demand.

Other studies demonstrated the use of different software for modelling and exploring design options such as Autodesk Ecotect and CADline Cymap (Stinson and Bros-Williamson, 2012), BIM (Motawa and Corrigan, 2012), ESP-r (Jack *et al.*, 2010; Mitchell and Ritchie, 2012), EDEM tool for energy, carbon and cost assessment (Tuohy *et al.*, 2010) and IES Virtual Environment (McEwan and Roaf, 2010).

Technologies

A decision making tool has been developed by Girard *et al.* (2011) to assist the optimisation of economic, environmental and energy savings in buildings. The tool enables the early assessment of on-site energy available for a building in the context of its location and provides a rapid identification of the most appropriate and cost effective way of achieving

lowest carbon emissions. Whether and how the knowledge and tools are applied in practice was the theme of a study which investigated the adoption of low-carbon technologies in Scottish housing associations (Moore *et al.*, 2010).

The potential for improving the performance of new technologies by combining different innovations, e.g. achieving higher ground source heat pump coefficient of performance (COP) through the use of roof-top thermal solar collectors, was explored in a study by Muneer and McCauley (2012). This potential was also examined in the study on the energy impact of different strategies of integrating PV and thermal heat recovery systems (Noguchi, 2011; Noguchi *et al.*, 2011a). Retrofit of existing housing with photovoltaic (PV) panels was explored in several studies (Bros-Williamson, 2011b; Noguchi *et al.*, 2011b; Stinson and Bros-Williamson, 2012b). The potential of the use of solar powered technologies to reduce fuel poverty in one feasibility study has led to the development of 'Solar photovoltaic design guide for Scotland' by Irshad and Muneer (2012).

Construction

Novel building insulation products from recycled textile and other materials were tested by Baker and Newlands (2013). Investigating new markets for recycled plasterboard was the focus of the study by Hunter and Pahl (2013).

As off-site construction methods enable good quality control and easier integration of new technologies within building components, their development and application were addressed, e.g. in the study by Noguchi and Dhamne (2012a) that explored the potential for integration of PV/thermal roof modules for prefabricated housing. The use of cross laminated Scottish-grown timber in high density affordable housing was the theme of the feasibility study undertaken by Wilson (2013). Thermal properties of a closed timber systems were modelled by Barr and Sanders (2011, 2012).

The potential for the application of off-site systems in housing has been demonstrated in a range of projects at Scotland's Housing Expo 2010 (Barrett, 2010; BurrIDGE, 2010; Keith, 2011) and at the Housing Innovation Showcase 2012 (Banks, 2012). Other articles in the project's online magazine presented the use of timber Brettstapel system in a school (Liddell, 2010) and in a home (Halliday, 2012), a mixed use building constructed of cross laminated timber (Miles and McQuillan, 2012) and manufacturing of off-site timber systems in Scotland (Newlands, 2012).

Refurbishment

Sustainable refurbishment was the theme of the first online conference organised by the project. The one-hour videos addressed a range of issues that have to be considered, e.g. improving energy efficiency in traditional buildings (Baker *et al.*, 2010), the use of solar PV and hot water panels for buildings (Muneer and Bowmaker, 2010), the potential for solar refurbishment of Scotland (Roaf *et al.*, 2010), upgrading Glasgow's social housing stock (Porteous *et al.*, 2010), the problem of rural SME contractors and sustainable technologies (Moore, 2010), retrofit and renewables in traditional rural buildings (Brennan, 2010) and the use of simulation-based design tools for decision making (Clarke, 2010).

Several studies were subsequently developed to assist decision making for refurbishment projects, including a strategy for improving energy and carbon performance of tenements (Tuohy *et al.*, 2010), a tool for assessing cost effectiveness of carbon reduction in tenement buildings (Jack *et al.*, 2010) and an energy efficiency retrofit cost-benefit calculator (Jenkins *et al.*, 2012; Simpson *et al.*, 2012). Improvement of building fabric to increase energy efficiency before considering the use of new technologies for energy generation from renewables was also included in a study on existing housing (Bros-Williamson, 2011a) and in older historic properties (Bros-Williamson, 2011c; Mitchell and Ritchie, 2012, 2103). As many traditional buildings in Scotland have external walls built of stone with lath and plaster in the interior, tests were undertaken to assess whether thermal insulation can be inserted between stone and lath (Bennadji and Levie, 2012).

Refurbishment of traditional pre-1919 buildings to Passivhaus (or Passive House) standard was examined in a study on an 18th century traditional Scottish house (Bros-Williamson, 2012a) and on tenement buildings (Sharpe *et al.*, 2013).

Performance

Information on the performance of new technologies and design solutions is crucial to reassure building owners, clients, designers and contractors that they are choosing building materials, components, technologies and design solutions that meet the required performance, and are easy to maintain and durable. As designers wish to learn from their projects and improve on their performance, a study on embedding post-occupancy evaluation (POE) into practice was undertaken for an architectural practice to enable

benchmarking of new designs against previous projects (Nugent *et al.*, 2010). Regarding early examination of performance, Motawa and Corrigan (2012) explored a sustainable BIM-driven POE for buildings. The cost of embedding POE in practice was examined in a study by Shearer *et al.* (2012) and summarised in an article by Newlands (2013).

The performance of a balanced mechanical ventilation with heat recovery system as an extractor of roof-integrated PV heated air in housing was examined by Noguchi and Dhamne (2012b). The theoretical and actual performances of a ground source heat pump after its installation within a heritage building were compared by Sharpe and Shearer (2012). Thermal and condensation analysis of a typical solid wall following a refurbishment intervention was examined by Bros-Williamson (2012b). Noguchi and Raidu (2012) explored physical and metaphysical impacts of a roof mounted wind turbine in housing context.

POE assisted in identifying causes of the problems with performance in a refurbished heritage building (Sharpe and Shearer, 2012a, 2012b). Findings from POE of housing projects, presented at the online conference by Sharpe (2011), indicated the impact of occupants' behaviour on the quality of indoor air. The study by Musau and Deveci (2013) assessed the environment and energy impact of occupant behaviour in housing. The problem of indoor air quality when air-tightness of buildings is increased was discussed in an article in the quarterly online magazine (Shearer, 2011) and was the theme of the live conference 'Build Tight, Ventilate Right' (filmed and available as a DVD package from CIC Start Online).

SUPPORT FOR INNOVATIONS FOR INTEGRATION OF SUSTAINABLE INFRASTRUCTURE INTO THE EXISTING BUILT ENVIRONMENT

Following the success of the CIC Start Online project, which was completed at the end of February 2013, the consortium of the universities involved in the project prepared a proposal for the follow-up project whose scope will be wider and the consortium will consist of nine Scottish universities. The project has secured funding from Scottish Government from the start of April 2013 until the end of March 2014. The project summary is provided below.

The one-year project, named "Mainstreaming Innovation", aims to (a) reduce carbon emissions through research and application of integrated sustainable infrastructure in the existing built environment that could be

replicated on existing and new building estates (e.g. housing, education, healthcare and other building estates); (b) adapt to changing climate by strengthening the resilience of buildings and infrastructure, and by reducing fuel poverty; (c) mitigate the impacts of changing climate by influencing the development of skills and capacities for planning, designing, procuring, managing and maintaining low carbon built environment; (d) ensure security of supply of energy and resources by maximizing the use of local low carbon resources and independence of supply systems; and (e) develop methods of ensuring that innovations are presented to building owners/clients, industry and colleges.

The project will support development, testing and application of innovative low carbon technologies for improving (1) landscaping and biodiversity, (2) energy efficiency in existing buildings, (3) energy generation from renewables, storage and decentralised systems, (4) water harvesting, saving, recycling and flood prevention, (5) waste reduction, reuse and waste-to energy, (6) low and zero carbon transport and (7) ICT/BMS systems for monitoring, reporting and management of low carbon infrastructure.

New technological solutions that combine different low carbon innovations to make better use of resources, close energy loops, achieve better efficiencies, reduce the need for maintenance and minimise the costs will be encouraged. Innovations will be tested on selected existing estates for healthcare, education and housing. At least seven studies are planned per estate, 21 in total. The applications for feasibility studies will be reviewed by an independent Advisory Panel and submitted for funding to Scottish Funding Council through Interface and to Technology Strategy Board.

The project outputs will be presented at demonstration events in colleges whose curriculum includes courses related to the innovations. The outputs of all the studies will also be disseminated at seminars which will be filmed and transmitted online and saved as video recordings. The project will publish monthly E-News and a quarterly online magazine with articles on the context (legislation and policies), support (financial initiatives and other forms of support), research and best practice.

CONCLUSIONS

As an independent Assessment Panel, established to assess application submitted to CIC Start Online, approved only the

applications whose outcomes would provide a direct benefit to a business that has applied jointly with academics, the innovations developed through the project were industry driven and indicated areas in which the industry needed assistance. The studies either contributed to the further development of existing products or processes, or tested new products or processes, often developed for a specific project with a potential for application in future projects. The outcomes of the studies were presented at seminars, transmitted online as interactive webinars in real time and then made available as video recordings on demand at the project website to the project members. Online dissemination of the project outcomes has assisted in attracting membership across Scotland, the United Kingdom and internationally. By the end of February 2013, the project had over 2,200 from over 1,500 organisations, of which over 910 members were from over 700 Scottish SMEs. The project has attracted over 200 international members from 53 countries. Since the CIC Start Online videos became available on YouTube, there have been over 25,508 viewings. An important legacy of the project is the searchable knowledge base of all project outputs, available on the project website which will remain accessible to everyone.

At the end of 2010, the project partners agreed to prepare a proposal for a new project and undertook research on the EU, UK and Scottish policies related to sustainable infrastructures. The research was funded by Scottish Government and will be published on the project website. The project will collaborate with Glasgow Housing Association, Health Facilities Scotland and universities' estates to test feasibility of innovations on the existing estates. Industry advice will be provided free from Skanska, an international building contractor operating in Scotland. The project will aim to identify innovations that can be put forward to Technology Strategy Board (TSB) for funding for feasibility studies for integration of sustainable infrastructure through the programme 'Buildings better connected' in 2013. TSB will follow this call with another collaborative research and development competition, planned for January 2014, which will offer £4.5m funding. TSB indicated that most of the UK government's £330bn investment over the next decade is targeted at large infrastructure projects and that there is an opportunity to capitalise on this by developing local infrastructure that is inter-connected with larger-scale infrastructure, but which responds to customers' need for flexibility and convenience. The TSB announcement also

includes a potential vision of the future as offered by Rifkin (2011); which was endorsed by the EU and included in the UK energy policy.

The project Mainstreaming Innovation aims to assist Scottish SMEs on the path to that future by including not only Rifkin's vision of the new energy, ICT and transportation infrastructure, but also the infrastructure for sustainable management of water, waste, land and biodiversity. The project will be led by Glasgow Caledonian University in collaboration with Edinburgh Napier University, Robert Gordon University, the Glasgow School of Art, Heriot-Watt University, University of Edinburgh, University of Aberdeen, University of Abertay Dundee, and University of Strathclyde Glasgow.

ACKNOWLEDGMENTS

The CIC Start Online project was funded by European Regional Development Fund and Scottish Government through SEEKIT programme and Scottish Funding Council. Scottish Enterprise provided funding for academic consultancy. The project Mainstreaming Innovation is funded by Scottish Government.

References

- Note: All CIC Start Online outputs listed in the References can be accessed at www.cicstart.org.
- Baker, P., Curtis, R., Heath, N., Cant, A. (2010) Improving energy efficiency in traditional buildings. *CIC Start Online conference Sustainable Refurbishment*, video 1.
- Baker, P., Newlands, B. (2013) Developing 'Homegrown' Natural Fibre Insulation Products. *CIC Start Online Academic Consultancy AC01 and Webinar 18*.
- Banks, B. (2012) Fife Housing Innovation Showcase. *CIC Start Online Innovation Review*, 11:76-81.
- Barr, E., Grassie, T., Noguchi, M. (2010) Hybrid Solar Thermal Mass System for Housing. *CIC Start Online Webinar 1*.
- Barr, J., Sanders, C. (2011) Thermal Analysis of the J.Pod Construction System. *CIC Start Online Academic Consultancy AC16*.
- Barr, J., Sanders, C. (2012) J.Pod Timber System. *CIC Start Online Innovation Review*, 11:46-57.
- Barret, R. (2010) A Scottish Passive 'Hoose'. *CIC Start Online Innovation Review*, 3:31-38.
- Bennadji, A., Levie, M. C. (2012) Testing of a method for insulation of masonry and lath walls in existing domestic Scottish construction. *CIC Start Online Feasibility Study FS24 and Webinar 13*.

- Borthwick, S., Muneer, T. (2011) Energy co-operatives as a means of achieving sustainability. *CIC Start Online conference Resilience of Buildings, Neighbourhoods and Cities*, video 8.
- Brennan, J. (2010) Retrofit and renewables in traditional rural buildings. *CIC Start Online conference Sustainable Refurbishment*, video 6.
- Brennan, J. (2011) Learning from Scotland's Housing Expo. *CIC Start Online conference Resilience of Buildings, Neighbourhoods and Cities*, video 2.
- Bros-Williamson, J. (2011a) Feasibility study into energy efficiency improvements in tenements in Bellshill, Glasgow. *CIC Start Online Feasibility Study FS29 and Webinar 14*.
- Bros-Williamson, J. (2011b) Solar PV feasibility study for homes in the city of Edinburgh (Malcolm Homes). *CIC Start Online Feasibility Study FS31 and Webinar 22*.
- Bros-Williamson, J. (2011c) Synergy of Fabric and Energy conservation in older historic properties. *Academic Consultancy AC07 and Webinar 12*.
- Bros-Williamson, J. (2012a) Benefits and options for retrofit of an 18th century traditional Scottish house using the Passive House standard. *CIC Start Online Feasibility Study FS32 and Webinar 20*.
- Bros-Williamson, J. (2012b) Thermal and condensation analysis of a typical solid wall following a refurbishment intervention. *CIC Start Online Feasibility Study FS58 and Webinar 37*.
- Building for the Future (2007) *Sustainable Construction for Professionals – Conserving Water in Further Education Colleges*. Oxford.
- Burridge, A., and J. (2010) The Flower House at Scotland's Housing Expo 2010. *CIC Start Online Innovation Review*, 5:28-43.
- Clarke, J. (2010) Simulation-based design tools: real time energy systems performance information. *CIC Start Online conference Sustainable Refurbishment*, video 7.
- Counsell J, Murphy G, Pert A, Counsell S (2012) Options Appraisal Tool for Architects (OATA). *CIC Start Online Feasibility Study FS-59*.
- DEFRA (2011) *Water for life*. The Stationery Office, Norwich.
- Directive 2000/60/EC of the European Parliament and of the Council 23 October 2000 establishing a framework for Community action in the field of water policy. *Official Journal of the European Communities*. <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:327:0001:0072:en:PDF>, (accessed on 14/01/2013).
- Directive 2008/98/EC of the European Parliament and of the Council on Waste and repealing certain directives. *Official Journal of the European Communities*. <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF>, (accessed on 14/01/2013)
- Emmanuel, R., Kruger, E. (2011) Urban Heat Island: Managing local climate change to enhance resilience of cities. *CIC Start Online conference Resilience of Buildings, Neighbourhoods and Cities*, video 6.
- Environment Agency (2007) *Conserving Water in Buildings*. Environment Agency, Bristol.
- Environment Agency (2010) *Harvesting Rainwater for Domestic Uses – An information guide*. Environment Agency, Bristol.
- Environment Agency (2011) *Greywater for Domestic Users – an information guide*. Environment Agency, Bristol.
- European Commission (2010) *Energy 2020: A strategy for competitive, sustainable and secure energy*. Brussels.
- Girard, A., Irshad, W., Muneer, T. (2011) Optimization of economic, environmental and energy savings in buildings. *CIC Start Online Feasibility Study FS26 and Webinar 11*.
- Grierson, D. (2011) Architectural Design Principles and Processes for Sustainability. *CIC Start Online Innovation Review*, 9:51-58.
- Grierson, D., Moultrie, C. (2011) Principles and Processes Related to Sustainable Building Design. *CIC Start Online conference Resilience of Buildings, Neighbourhoods and Cities*, video 1.
- Halliday, S. (2012) Plummerswood Active House. In *CIC Start Online Innovation Review*, 12:70-79.
- Hunter, C., Pahl, O. (2013) Investigating New Markets for Recycled Plasterboard. *CIC Start Online Feasibility Study FS25*.
- Irshad, W., Muneer, T. (2012) Solar photovoltaic design guide for Scotland. *CIC Start Online Feasibility Study FS50 and Webinar 25*.
- Isaacs, J., Falconer, R., Gilmour, D., Blackwood, D. (2011) Interactive simulation and visualisation platform. *CIC Start Online Innovation Review*, 9:46-48.
- Jack, D., Cockroft, J., Hand, J. (2010) Tenement Flat Carbon Reduction Shopping List. *CIC Start Online Feasibility Study FS06 and Webinar 4*.
- Jenkins, D., Barnham, B., Hay, S., Simpson, S., Ingram, V. (2012) Development of an Energy efficiency retrofit cost- benefit calculator. *CIC Start Online Academic Consultancy AC13 and Webinar 16*.
- Johnston, J. (2013) Smart DC: the Internet Revolution comes to Buildings. *CIC Start Online Innovation Review*, 14:24-33.
- Kelly, D. J. (2010) *Developing Scotland's low carbon built environment*. Scottish Enterprise, Glasgow. <http://www.evaluationonline.org.uk/evaluations/Browse.do?ui=browse&action=show&id=383&taxonomy=BUI>, (accessed on 14/01/2013)
- Keith, D. (2011) The Modular House - Plot 15 – Scotland's Housing Expo. *CIC Start Online Innovation Review*, 6:30-41.
- Kumar, B., Emmanuel, R. (2010) Independent verification of a climate based worldwide building energy index. *CIC Start Online Academic Consultancy AC04 and Webinar 8*.
- Liddell, H. (2010) Acharacle Primary School, Ardnamurchan. *CIC Start Online Innovation Review*, 4:30-34.
- McEwan, D., Roaf, S. (2010) Assessment and Application of Zero Carbon Building in Scotland. *CIC Start Online Feasibility Study FS08 and Webinar 10*.
- Miles, S., McQuillan, J. (2012) Cross Laminated Timber Construction in Scotland. *CIC Start Online Innovation Review*, 9:21-27.
- Mitchell, G., Ritchie, P. (2012) Developing robust details for roof upgrade. *CIC Start Online Feasibility Study FS54*.
- Mitchell, G., Ritchie, P. (2013) Developing Robust Solutions for Roof Upgrades. *CIC Start Online Innovation Review*, 14:54-65.
- Motawa, I., Corrigan, W. (2012) Sustainable BIM-driven post-occupancy evaluation for buildings. *CIC Start Online Feasibility Study FS49 and Webinar 29*.
- Moore, D. R. (2010) The problem of rural SME contractors and sustainable technologies. *CIC Start Online conference Sustainable Refurbishment*, video 5.
- Moore, D. (2011) The theory of self-organising built environments as a response to carbon levels. *CIC Start Online conference Resilience of Buildings, Neighbourhoods and Cities*, video 5.
- Moore, D. R., McDonald, S., Abdel-Wahab, M. (2010) An Investigation of the Adoption of Low-Carbon Technologies by Scottish Housing Associations. *CIC Start Online Feasibility Study FS15 and Webinar 6*.
- Muneer, T., Bowmaker, H. J. (2010) Use of solar PV and hot water for buildings. *CIC Start Online conference Sustainable Refurbishment*, video 2.
- Muneer, T., McCauley, L. (2012) Achieving Higher Heat Pump COP through the use of roof-top thermal solar collectors. *CIC Start Online Feasibility Study MS43 and Webinar 23*.
- Musau, F., Deveci, G. (2013) Assessing the environment and energy impact of occupant behaviour. *CIC Start Online Feasibility Study FS22*.
- Newlands, B. (2012) The Art of Building. *CIC Start Online Innovation Review*, 9:28-38.
- Newlands, B., Shearer, D., McNeil, T. (2013) Embedding Post Occupation Evaluation into Practice. *CIC Start Online Innovation Review*, 14:34-42.

- Noguchi, M. (2011) Industry Aspirations for Building Integrated Photovoltaic Thermal Heat Recovery Systems. *CIC Start Online Innovation Review*, 8:24-31.
- Noguchi, M., Dhamne, K. (2012a) BIPV/T modular roof development for zero-energy prefabricated housing production. *CIC Start Online Feasibility Study FS40*.
- Noguchi, M., Dhamne, K. (2012b) Examining the performance of a balanced mechanical ventilation with heat recovery system as an extractor of roof-integrated PV heated air applied to Scottish zero-energy affordable housing. *CIC Start Online Feasibility Study FS46*.
- Noguchi, M., Raidu, B. (2012) Physical and metaphysical impacts of a roof mounted wind turbine. *CIC Start Online Feasibility Study FS48*.
- Noguchi, M., Grassie, T., Ringaila, A. (2010) A Hybrid Solar Thermal Mass System Development for the application to Tenants First Housing Co-operative's zero-carbon affordable homes. *CIC Start Online Feasibility Study FS01 and Webinar 1*.
- Noguchi, M., Musau, F., Udagawa, M., Higuchi, Y., Larsson, S., Ringaila, A. (2011a) Assessing the energy impact of different strategies of integrating PV/thermal heat recovery systems in Scottish homes. *CIC Start Online Feasibility Study FS17*.
- Noguchi, M., Nirmal, S., Irshad, W., Muneer, T. (2011b) A 10kWp Photovoltaic facility for Fairfield Housing Co-operative. *CIC Start Online Feasibility Study FS35 and Webinar 19*.
- Nugent, K., Clarke, J., Bradley, F. (2010) Embedding simplified post occupancy evaluation within the design process. *CIC Start Online Feasibility Study FS04 and Webinar 3*.
- Porteous, C., Sharpe, T., Menon, R. (2010) Upgrading Glasgow's Social Housing Stock - reflections on 1990's demonstrations and 21st Century reality. *CIC Start Online conference Sustainable Refurbishment*, video 4.
- Rifkin, J. (2011) *The Third Industrial Revolution*. Palgrave Macmillan, New York.
- Roaf, S. (2011) Flooding resilience: avoidance, resistance and recovery. *CIC Start Online conference Resilience of Buildings, Neighbourhoods and Cities*, video 3.
- Roaf, S., McLennan, C., Goudsmidt, G., Heath, N., Cant, A. (2010) The Solar Refurbishment of Scotland. *CIC Start Online conference Sustainable Refurbishment*, video 3.
- Scottish Government (2007) The Government Economic Strategy. <http://www.scotland.gov.uk/Publications/2007/11/12115041/0>, (accessed on 14/01/2013).
- Scottish Government (2009) Climate Change (Scotland) Act 2009. <http://www.legislation.gov.uk/asp/2009/12/contents>, (accessed on 14/01/2013).
- Scottish Government (2012a) *Water Resources (Scotland) Bill*. Edinburgh.
- Scottish Government (2012b) The Waste (Scotland) Regulations 2012. <http://www.legislation.gov.uk/sds/2012/9780111016657/contents>, (accessed on 14/01/2013).
- Scottish Government (2013) Electric Vehicles in pole position. <http://www.scotland.gov.uk/News/Releases/2013/02/electric-vehicles06022013>, (accessed on 6/02/2013).
- Sharpe, T. (2011) Resilience to Occupancy: Findings from recent Post Occupancy Evaluation projects. *CIC Start Online conference Resilience of Buildings, Neighbourhoods and Cities*, video 4.
- Sharpe, T., Bridgestock, M. (2012) Glencanisp Masterplan for the Assynt Foundation. *CIC Start Online Feasibility Study FS47*.
- Sharpe, T., Shearer, D. (2012a) 9-11 Gilmour's close - comparing theoretical performance against actual performance. *CIC Start Online Academic Consultancy AC06*.
- Sharpe, T., Shearer, D. (2012b) Post Occupancy Evaluation of adaptive restoration and performance enhancement of Gilmour's Close, Edinburgh. *CIC Start Online Innovation Review*, 12:51-59.
- Sharpe, T., Bridgestock, M., Gilbert, J. (2013) PassivTen: Refurbishment of tenement properties in East End of Glasgow to Passivhaus standard. *CIC Start Online Feasibility Study FS39*.
- Shearer, D. (2011) Seal Tight, Ventilate Right. *CIC Start Online Innovation Review*, 8:32034.
- Shearer, D., Newlands, B., McNeil, T. (2012) Embedding Post Occupancy Evaluation into Practice. *CIC Start Online Feasibility Study FS56*.
- Simpson, S., Jenkins, D., Hay, S., Heath, N. (2012) Development of an energy efficiency retrofit cost-benefit calculator - phase two. *CIC Start Online Academic Consultancy AC21 and Webinar 24*.
- Stinson, J., Bros-Williamson, J. (2012a) The sustainability and energy efficiency of three new build dwellings in Aberdour, Fife. *CIC Start Online Feasibility Study FS60 and Webinar 35*.
- Stinson, J., Bros-Williamson, J. (2012b) Solar PV feasibility study for homes in the city of Edinburgh (Port of Leith Housing Association). *CIC Start Online Feasibility Study FS34 and Webinar 22*.
- Tuohy, P., Cockroft, J., Dougall, M. (2010) Improving Energy and Carbon Performance of Housing - A Glasgow Case Study Garrioch Road Tenement Flats. *CIC Start Online Feasibility Study FS07 and Webinar 2*.
- Uduku, O., Roderick, Y. (2012) Environmental Design Teaching Model. *CIC Start Online Academic Consultancy 10 and Webinar 15*.
- United Nations (1992) Rio Declaration on Environment and Development. <http://www.un.org/documents/ga/conf/151/aconf15126-1annex1.htm>, (accessed on 21/10/2012).
- Waterwise (2010a) *Mainstreaming water efficiency in the UK: helping to meet the challenges of climate change through wasting less water*. Waterwise, London.
- Waterwise (2010b) *Water efficiency and the water companies: A 2010 review*. Waterwise, London.
- Wheatley, C. (2010) Taking Analysis Out of the Architects' Back Room. *CIC Start Online Innovation Review*, 2:26-29.
- White, R., Grant, M. (2011) Towards a Visible City for Visually Impaired Users. *CIC Start Online conference Resilience of Buildings, Neighbourhoods and Cities*, video 7.
- Wilson, P. (2013) The use of cross laminated timber in high density affordable housing and the potential to manufacture this engineered timber product in the Dumfries and Galloway region. *CIC Start Online Feasibility Study FS52 and Webinar 36*.
- WRAP (n.d.) *Achieving good practice Waste Minimisation and Management: Guidance for construction clients, design teams and contractors*. WRAP, Banbury.
- Zero Waste Scotland (2010) *Zero Waste Scotland Delivery Plan 2011-15*. http://www.wrap.org.uk/sites/files/wrap/ZWS_DeliveryPlan2011.pdf, (accessed on 21/11/2012).
- Zero Waste Scotland (2012) *Implementing a Water Minimisation Programme - A complete guide for organisations in Scotland*. Zero Waste Scotland, Stirling.

Received February 2013; accepted May 2013