Institution: The University of Edinburgh & Heriot-Watt University (the Alliance)

Unit of Assessment: 16 Architecture, Built Environment and Planning

Title of case study: 5: Rethinking concrete formwork for a new era of sustainable construction

1. Summary of the impact

This Alliance project demonstrated, through the exploration of flexible formwork techniques, that it is possible to use concrete in a much more diverse, sustainable and quality-controlled way than in 20th century architecture, achieving a 25-35% reduction in the carbon footprint of concrete constructions. It has engendered an attitudinal change within the global construction industry, with one US industry professional saying "*Prior to this research, concrete was often perceived of as a harsh, aggressive material. Experimentation with fabric forming has shown that it doesn't have to be so*". The research has led to two Knowledge Transfer Partnerships, an award-winning Chelsea Flower Show entry and the proprietary application of the technology in other forms of construction. It has also stimulated partnership working with government and schools; collaboration described as the "*Curriculum for Excellence at its best*".

2. Underpinning research

The Alliance's investigation into Fabric Formed Concrete (FFC) is one of a global network of FFC research projects involving close collaboration with the Universities of London (UK) and Manitoba (Canada). It began in 2004 as a research-led teaching programme; an innovative methodology within University-based architectural research. The aim was to explore the viability of using flexible formwork for concrete, facilitating the development of forms that are difficult to achieve using conventional, rigid methods and allowing less skilled workers to achieve better quality results with a reduced environmental impact. With outputs including a prize-winning book, the first of its kind in the subject area, and Pedreschi's supervision of the first PhD thesis in the subject area, the Alliance's research sits within the growing body of innovation studies on 'disruptive technologies' – those that may revolutionise existing ways of doing things.

The principal researcher is Prof Remo Pedreschi (1989-present). Since 2005, Pedreschi has undertaken 18 Fabric Formed Concrete studies in which, with trainee architects in a workshop environment, he has developed, designed and constructed concrete architectural components, such as walls, columns, beams and shells, using fabric formwork. The process involves experimentation – through repeated prototyping and development – leading to full-scale construction, with progress and outcomes reflected upon and documented at each stage. Collaborators within the Alliance include Prof Fiona McLachlan (1988-present), while those beyond the Alliance include Alan Chandler (University of East London) and Mark West (University of Manitoba).

The iterative nature of the Alliance research, comparative to other FFC studies, has resulted in a nuanced understanding of the technology, particularly its sustainable credentials. Key findings are that fabric formwork improves the quality of, and reduces visible defects in, concrete constructions; makes concrete forms (such as beams etc.) more structurally efficient; can achieve a 25-35% reduction in the carbon footprint of concrete constructions; simplifies the construction process; and allows for a wider range of forms, including those with complex geometries. Emerging themes have been studied in greater depth of technical detail as part of PhD and Masters dissertations in a joint programme, Structural Engineering with Architecture. Projects testing the technology in real situations include the first 'real world' application of FFC in UK construction, Whitburn Social Housing development in West Lothian (2007), while the research has also been the catalyst for two Knowledge Transfer Partnerships: one with Watson Stonecraft and Fischer GmbH to investigate applying the technology to the light stone cladding of buildings (2006 to 2008); and one with ACS Stainless Steel.

3. References to the research

Publications

Chandler, A. & Pedreschi, R. (Eds) (2007) *Fabric Formwork* London: RIBA Publishing (ISBN: 978-1-85946-284-3). This 96-page book, the first in the subject area, received a Special Commendation in the 2008 Royal Institute of British Architects (RIBA) President's Awards for Research.

Brennan, J., Pedreschi, R., Walker, P. & Ansell, M. (2013) The potential of advanced textiles for fabric formwork. *Proceedings of the Institution of Civil Engineers, Construction Materials* 166, Issue CM4, 229–237 http://dx.doi.org/10.1680/coma.12.00052

Pedreschi, R., McLachlan, F., & Lee, S. (2008). Fabric Cast Concrete. In Dhir, R. K., Newlands, M. D., Dyer, T. D., & Tang, M. C. (Eds.), *Designing Concrete for the Visual Environment.* (pp. 61-72). Watford: BRE Press, ISBN 13-978-1-84806-040-1

Pedreschi, R. (2011). The use of fabrics as formworks for concrete structures and elements. In Oñate, E., Kröplin, B. & Bletzinger, K.-U. (Eds) *Textile Composites and Inflatable Structures V: Structural membranes 2011* (pp. 421-431). Barcelona: International Center for Numerical Methods in Engineering (CIMNE) (ISBN 978-84-89925-58-8)
http://congress.cimne.com/membranes2011/frontal/doc/Membranes_2011_ebook.pdf

Pedreschi, R. (2013). Fabric formed concrete structures and architectural elements. In Cruz, P. J. (Ed.), *Structures and Architecture.* (pp. 1-8). CRC press (ISBN: 978-0-415661959). See http://www.crcpress.com/product/isbn/9780415661959

Funding

Funding for the research has involved material contributions from suppliers and a series of small grants from: the Concrete Centre (£5,000, 2006); Alliance Knowledge Exchange funding (£6,000, 2006-2009); the Centre for the Built Environment, a pan-Scottish organisation based at Glasgow Caledonian University (£4,500, 2008); John McAslan + Partners architects (£5,000 for the Castleview Primary School project, 2009-2010); and Fenchurch Advisory Partners (£2,500 for the Fenchurch Garden project at the Royal Horticultural Society (RHS) Chelsea Flower Show, 2009).

4. Details of the impact

Concrete is the most ubiquitous of all building materials, available and used globally, with cement (its active ingredient) consumed in excess of 2000 million tonnes annually. However, despite its extensive use, it has developed significant negative associations, for example, with high carbon emissions. Pedreschi has successfully communicated his research directly to the concrete industry in order to help it challenge outside perceptions, as confirmed by the [text removed for publication] The Concrete Society in Scotland (see 5.1, below), who has said…
"*the fact that work of this nature and calibre is being done here, in Scotland, has helped us, as an industry, improve the image and reputation of concrete as a material, so much so that we are currently preparing for a major exhibition on concrete, with Architecture and Design Scotland, which focuses on sustainability and innovation as key themes and have a number of schools* [across central Scotland] *seeking to work with concrete as a truly cross curriculum medium*".
The research has also changed attitudes within the wider construction industry, as described by construction industry professional, [text removed for publication] USA; see 5.2), who has said…
"*Prior to this research, concrete was often perceived of as a harsh, aggressive material. Experimentation with fabric forming has shown that it doesn't have to be so; that it's possible to create more interesting, organic forms, with a richer texture than before, and with reduced environmental impact*".

In November 2008, the book *Fabric Formwork* received a Special Commendation in the Royal Institute of British Architects (RIBA) President's Awards for Research (see 5.3). The president said "*It represents a very exciting series of initiatives… and shows us how the genesis of an idea with an architecture school can influence practising architects and find its way through to completed*

projects". In 2009, the multi-award-winning garden designer, [text removed for publication], approached the Alliance to produce Fabric Formed Concrete elements for his 2009 Chelsea Flower Show entry, having read an article on the possibilities of the technology and undertaken research into innovators in the field. [text removed for publication] said of the Edinburgh team "*the shapes and textures that they are experimenting with are beautiful and the possibilities for a garden structure almost infinite*".

For [text removed for publication] Chelsea entry, The Fenchurch Garden, the team designed, constructed and delivered 19 'tree root' shaped concrete panels, each up to 2.5 metres in height and weighing 700kg, within a five-week timeframe. The panels were described as "*exceptional, inspiring and innovative*" by the Chelsea judges and the garden went on to win the 2009 RHS Silver Gilt Medal and Most Creative Design Award and to be widely publicised by the *BBC*, *The Guardian*, *The Daily Telegraph* and *Garden Design Journal*. *The Enduring Gardener* blogged… "*The gardens that really appeal to me are the ones that confound my prejudices* [and] *make me reconsider a particular material. The Fenchurch Garden made me look at concrete in an entirely new way*" (see 5.4). Alliance researchers are now discussing a second project with [text removed for publication], again for the Chelsea Flower Show.

Industry recognition led to architects, John McAslan + Partners, funding a project to enhance the exterior of Castleview Primary School in Edinburgh, based on the system developed in the University's Knowledge Transfer Partnership with Watson Stonecraft. Over a three-week period in 2009, Pedreschi, trainee architects and the school's P6 pupils collaboratively designed and constructed a series of Fabric Formed Concrete wall panels in the University workshops. In 2010, the panels were installed on the school site by Stone Engineering and later incorporated into the Craigmillar Heritage Trail. The project was supported by the local community, several small businesses and the City of Edinburgh Council and has been described thus [text removed for publication]:
"*In order to eradicate the poverty of ambition in Scotland, it is vital for schools to be involved in partnership working. Castleview Primary School is situated in an area of regeneration in Craigmillar Edinburgh. For some of our pupils, they were the first members of their family to have been inside a university and they are now aware that with hard work and perseverance they could access a university education. The result of our collaboration, the Castleview Wall, featured in the Craigmillar Historical Trail and made children aware that they could create their own history for their community. Castleview's partnership working has been acknowledged as "sector leading" during a recent HMIE inspection* [which saw the school, which had previously faced closure, transformed into one of the most highly rated in the country] *and was a City of Edinburgh award winner. The Wall Project exemplifies Curriculum for Excellence at its best*" (see 5.5).

The Castleview wall was launched in June 2010 at an event addressed by the children and attended by [text removed for publication] (see 5.6). He said "*I am delighted to see the great work done by the children and am deeply grateful for the input from Remo and the University. It is of lasting benefit to the school and of everlasting benefit to the particular children involved*". The MSP has since become proactive in initiating collaboration between the University and pupils at Portobello High School. They have been involved in workshops to develop materials and modules for teaching construction under the new Curriculum for Excellence and, together with digital technology experts, a generic 80-credit Masters level module on Disruptive Technology.

The international impact of the project builds on success in the European Concrete Design competition, *Plastic Opacity*, and in the US-led *Concrete Thinking for a Sustainable World* competition (2008). Links have been made with the Canadian Concrete Association and the Federal Center of Technological Education (CEFET) in Belo Horizonte, Brazil. The University of Edinburgh is a founding member of the International Society of Fabric Forming, with Remo Pedreschi delivering the keynote speech at its second international conference in Bath (June 2012). At this event, the team also held a workshop for global industry professionals, artists and academics using Fabric Formed Concrete panels in a prototype framing system.

Latterly, the research has facilitated closer collaboration between the concrete and textile industries. Two knowledge sharing workshops have been held, including *Textiles in the Environment and Construction*, funded by Scottish Enterprise, in June 2011. The Alliance has started a 'proof of concept' project with J&D Wilkie, as well as established links with other Scottish manufacturers of 'technical textiles'; global growth rates for which are approximately 4% per year greater than for home and apparel textiles. [text removed for publication] J&D Wilkie has said "*Remo's enthusiasm for all things concrete is infectious and... we have become more actively involved in developing some of our technical textiles for specific use in concrete applications. The market holds interesting possibilities for us and we would not have found it nor developed products for it without* [the Alliance's] *input*" (see 5.7).

5. Sources to corroborate the impact

5.1 A factual statement from [text removed for publication] The Concrete Society in Scotland has been made available in support of this case study.

5.2 Authorised quote from e-mail correspondence. Contact details for further corroboration from [text removed for publication] ArroDesign have been provided separately.

5.3 A copy of the certificate corroborating the Special Commendation of Fabric Formwork in the RIBA President's Awards for Research 2008, as well as the President's testimony, is available, on request, in pdf format.

5.4 Media coverage of The Fenchurch Garden project includes the following feature on the *BBC* website… http://www.bbc.co.uk/chelsea/small_gardens/elysium.shtml
… and an article in *The Guardian* dated 19 May 2009…
http://www.guardian.co.uk/lifeandstyle/2009/may/19/chelsea-flower-show-winners
… and an article in *The Daily Telegraph* dated 17 May 2009…
http://www.telegraph.co.uk/gardening/chelseaflowershow/5329004/Chelsea-Flower-Show-2009-small-gardens-big-ideas.html
… and a blog entry by *The Enduring Gardener*…
http://blog.theenduringgardener.com/ideas-to-steal-from-chelsea/

5.5 A factual statement from [text removed for publication] Castleview Primary School has been made available in support of this case study. The School's inspection performance is corroborated in The Edinburgh Evening News…
http://www.edinburghnews.scotsman.com/news/education/castleview-primary-hailed-after-climbing-ranks-1-3096760

5.6 Contact details for further corroboration from [text removed for publication] have been provided separately. See also a quote from this source in…
http://www.ed.ac.uk/polopoly_fs/1.44226%21fileManager/KE_Newsletter_Summer2010.pdf

5.7 A factual statement from [text removed for publication] J&D Wilkie has been made available in support of this case study.