

Institution: Queen's University Belfast		
Unit of Assessment: 12		
Title of case study: Queen's research enabling industry to deliver innovative low carbon construction materials		
Period when the underpinning research was undertaken: 2007 - 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Su Taylor,	Prof. of Structural Eng.	2008- present
Marios Soutsos,	Prof. of Structures/Materials	2012- present
Mohammed Sonebi,	Senior Lecturer in Civil Eng.	2005- present
Daniel McPolin,	Senior Lecturer in Civil Eng.	2008- present
Sreejith Nanukuttan	Senior Lecturer in Civil Eng.	2008- present
Period when the claimed impact occurred: 2013-2020		
Is this case study continued from a case study submitted in 2014? N		
<p>1. Summary of the impact Construction materials research at Queen's University Belfast targeting resource efficiency, performance prediction and rheology have enabled construction material suppliers to embed innovation, improve their offering/products, develop best practice, and reduce the carbon footprint of the products by 15-40%. As a consequence, they were able to capture a larger market share whilst generating a total savings/new income of GBP5,960,000. The underpinning research and subsequent impact were achieved through 5 EU/RCUK funded projects and 8 KTP projects with 8 industrial partners.</p>		
<p>2. Underpinning research</p> <p>Concrete products and the construction industry provide GBP2,400,000,000 of commercial income for Northern Ireland. [text removed for publication]. Whilst this commerce is critical for the economic development of the region, the related environmental emissions and resource depletion had to be minimised and this has been the focus of QUB research since early 2000. The breadth of the research undertaken in the three core areas is highlighted below along with notable outputs.</p> <p>1 Resource efficiency In traditional concrete made with Portland cement, the cement, which occupies only 15-20% of the mass of concrete, contributes to 83% of its embodied carbon. 2012 onwards, Soutsos, Nanukuttan and Kwasny have published articles on the viability of 100% Portland cement replacement under the banner of <u>low impact binder technology</u>. A protocol for the selection of new sources of clay to be used as binding material [R1], provides best practice guidance and was developed for and published jointly with banahUK. <u>Cementitious construction boards</u> – Magnesium oxychloride boards are used as sheeting/cladding material in construction due to its superior fire resistance and lower carbon footprint. Since 2018, QUB researchers led by McPolin have been working with Resistant, a leading supplier of magnesium oxychloride boards, to create a moisture resistant version of the board for external application [R2]. <u>Insulation and bio-based materials</u> – Insulation materials used for achieving energy efficiency in buildings have a significantly large associated embodied carbon. Research at QUB, led by Sonebi paved the way in developing low impact bio-based materials from agri-waste sources. The work has resulted in a RILEM recommendation which is the only industrial best practice technical document for bio-based materials [R3].</p> <p>2 Performance prediction Predicting the <u>real-time strength</u> development of concrete allows the precast concrete industry to adopt lean manufacturing techniques and embed innovation with confidence. Temperature</p>		

Impact case study (REF3)

monitoring and the use of maturity functions for integrating the heat evolved into real-time strength development is established in various articles and projects by Soutsos, Sonebi and Taylor. A notable article from this collection is [R4] which outlines the work conducted by QUB at Creagh concrete involving both light weight aggregates and self-compacting concrete for making structural panels.

Predicting the long term performance of concrete structures in marine or de-icing environments enables effective asset management to reduce maintenance. Continuing the research strategy outlined in the Environmental Statement in REF2014, article [R5] by Nanukuttan, Basheer, and others sets out the establishment of PERMIT, a non-destructive test and a methodology for estimating the remaining service life of structures. This resulted in income for QUB spinout Amphora NDT Ltd through instrument sales and consultancy. PERMIT features as the only NDT chloride test in the RILEM state-of-the-art report on Performance-based specification for concrete.

3 Rheology

Modern concrete structural elements host an array of electrical, heating/cooling and utilities components as well as steel reinforcement. Making concrete flow around these obstacles is critical for the success of the precast industry. Research led by Sonebi on self-compacting flowable concrete [R4, R6] using high levels of cementitious additions and other by-products provides cost reduction, energy savings, noise reduction and improvement in the working environment for staff, whilst achieving the desired surface finish.

3. References to the research

Resource Efficiency

R1. McIntosh, J. A., Lawther, S. E. M., Kwasny, J., **Soutsos, M. N.**, Cleland, D. **Nanukuttan, S.**, Selection and characterisation of geological materials for use as geopolymers precursors”, *Advances in Applied Ceramics*, Vol. 114, 7, 2015, pp. 378-385. <https://www.tandfonline.com/doi/abs/10.1179/1743676115Y.0000000055>

R2. Aiken, T.A., **Russell, M.**, **McPolin, D.** and Bagnall, L., Magnesium oxychloride boards: understanding a novel building material, *Materials and Structures*, Vol. 53, No. 118, 2020. <https://doi.org/10.1617/s11527-020-01547-z>

R3. Amziane, S., Collet, F., Lawrence, M., Magniont, C., Picandet, V., **Sonebi, M.**, Recommendation of the RILEM TC 236-BBM: Characterisation testing of hemp shiv to determine the initial water content, water absorption, dry density, particle size distribution and thermal conductivity, *Materials and Structures*, 2017, 50:167, <https://link.springer.com/article/10.1617/s11527-017-1029-3>

Performance prediction

R4. Kwasny, J., **Sonebi, M.**, **Taylor, S.**, Bai, Y., Owens, K, and Doherty, W., Influence of the type of coarse lightweight aggregate on properties of Semi-Lightweight Self-Consolidating Concrete, *ASCE Journal of Materials in Civil Engineering*, vol. 24, no. 12, 2012, pp. 1474-1483. <https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29MT.1943-5533.0000527>

R5. **Nanukuttan, S. V.**, **Basheer, P. A. M.**, McCarter, W. J., Tang, L., Holmes, N., Chrisp, T. M., Starrs, G., Magee, B., The performance of concrete exposed to marine environments: predictive modelling and use of laboratory/on site test methods, *Construction and Building Materials*, vol. 93, 2015, pp. 831-840. <https://www.sciencedirect.com/science/article/abs/pii/S0950061815005802>

Rheology

R6. **Sonebi, M.**, Grünwald, S., Walraven, J., Filling Ability and Passing Ability of Self-Consolidating Concrete, *ACI Materials Journal*, Vol. 104, No. 2, 2007, pp. 162-170. www.concrete.org/publications/internationalconcreteabstractsportal.aspx?m=details&id=18579

4. Details of the impact

Our portfolio of research aimed at low impact binders and reducing the virgin raw material demand has helped stakeholders offer new products, reduce the environmental impact of

existing products and increase their market share/revenue. Details of which are quantified in Table 1 and elaborated in the statements below.

Table 1 Selected industrial partners who benefitted from our research on the themes identified in Section 1 and details of impact.

Company	Theme	Underpinning research	Savings/income per annum (total for the period)	Reach of impact
Creagh Concrete ²⁰⁰⁷⁻²¹	Perf. Prediction, Res. Efficiency & Rheology	[R1, R4, R6]	GBP400,000 per year (2013-20, GBP3,200,000) [S2]	UK/Ireland
Moore Concrete ^{2014-21,}	Perf. prediction & Rheology	[R4, R6]	GBP100,000 per year (2014-20, GBP700,000) [S4]	UK/Ireland National Award – Concrete Society.
Bullivant ²⁰¹⁵⁻¹⁸ Taranto	Res. efficiency & Rheology	[R6]	(2015-18, GBP300,000) [S5]	UK/Ireland/New Zealand KTP Awards- UK
[text removed for publication]				
Resistant ²⁰¹⁸⁻²¹	Res. Efficiency & Perf. prediction	[R2]	(2018-20, GBP1,000,000) [S10]	UK
[text removed for publication]				

^{Superscript} indicates the years of collaboration; Total savings for 2013-20 period is GBP5,960,000.

banahUK worked with Soutsos and Nanukuttan to accelerate the development of a viable geopolymer binder as a 100% Portland cement replacement for structural applications. Performance of this binder under extreme environments (chlorides, sulphates, fire and acidic) was studied and necessary microstructure modifications were proposed. Guidelines for the selection of the raw materials and sustainability of the supply chain for scaling up [R1], pricing structure and cost benefit analysis were all established through joint research projects.

“This (above) work was invaluable in providing the required information to banahUK for presentation to potential clients and ultimately fed into the development of the British Standard Publication - PAS 8820:2016.”

Source: Testimonial by R&D Manager of banahUK [S1].

Creagh concrete is one of the largest precast concrete suppliers in the UK with over 1,000 direct employees and GBP110,000,000 annual turnover. Following on from the Innovate UK project and article [R4], Creagh adopted self-compacting concrete containing high levels of supplementary cementitious materials and fillers, across the majority of its precast structural panels, which enabled them to achieve a low noise factory and fair faced products with sophisticated inserts.

“The net result of 12 years of collaboration is that Creagh today offers concrete products that are:

- 40% more environmentally friendly*;
- 70% of all products utilises self-compacting concrete*;

*compared to 2007 production figures.

- Creagh has completed the factory trials for innovative cementless binders, for ultra low impact concretes.

.... Overall, by embedding these innovative ideas, Creagh has been able to generate an additional income of GBP4,700,000 over the last 12 years.”

Sources: Testimonial by Director of Creagh Concrete [S2]; videos of demonstrator buildings in Northern Ireland and Spain [S3].

Moore Concrete was able “to reduce the cost of selected precast concrete products by at least 25% with a direct savings of £102,000/pa” due to energy savings and raw material reduction. The continued development of SCC (self-compacting concrete) has enabled the company to tender for contracts with strict dimensional tolerances, highly demanding time schedules, and high durability requirements. Other benefits:

- Improved production or operational efficiency by 35%
- Market share of existing products increased by 25%”

Source: Managing Director of Moore Concrete [S4].

Bullivant Taranto

“The partnership also resulted in the development of a novel vaulted floor system and new patented pile connection which led to increased turnover (25%), profit and new client base”

- “Cost of production reduced by 25%, energy reduction by 30% + and reduction in cement/ replacement with waste materials which lowered CO₂ emissions.
- Increased market shares with regards to precast piling (40%), including the expanding renewables market such as Carrowleagh Windfarm.”

Source: Managing Director of Bullivant Taranto [S5]

Dr. Sonebi’s research on self-compacting concrete [R6] contributed to the development of **BS EN 12350 Parts 8-12**, [S6]. His significant contributions to this field are detailed in the testimonial provided by RILEM President [S7].

Sonebi and Taylor coordinated the EU Eirocrete project funded under **FP-7IAAPP** and developed a low energy, durable, self-compacting concrete, pre-stressed with basalt fibre reinforced polymer bars for use in civil infrastructure. This project aligned with the need for future sustainable infrastructure with reference to EU strategy for reducing greenhouse gas emissions.

In 2007, QUB team led by Basheer and Nanukuttan developed PERMIT, an NDT for determining ionic diffusivity in concrete. This was brought to market by Queen’s spinout **Amphora NDT** and to date have sold more than 75 instruments worldwide generating >GBP450,000 for NI economy (GBP168,000 for this impact period). The article [R5] sets out guidelines on how to use PERMIT and other tests to determine the remaining service life of structures. PERMIT features as the only *in situ* non-destructive test for quantifying the rate of chloride ingress in the RILEM state-of-the-art report on Performance Specification of Concrete [S8].

“Amphora was able to apply this philosophy to determine the remaining life of existing piles at Arrowhead Quay, London for Laing O’Rourke. This work directly led to the piles being reused and the NHBC granting approval for the prestigious 50 and 55 storey Wardian London project, valued at £428m. In addition to the obvious cost savings from the addition of excess piles (estimated to be in excess of £50m), the project also had a large social impact by reducing construction time by an estimated 6 months.”

Source: Managing Director of Amphora NDT [S9].

Research led by McPolin “allowed us (**Resistant**) to scientifically understand the product using myriad of analytic and assessment techniques through the rigorous testing”.

In the absence of standards, Dr. McPolin’s “involvement in the PAS 670 Steering Committee will give us (**Resistant**) the best possible chance to establish performance criterion for MgO boards”.

“through the KTP term we have managed to grow our sales significantly”... “I could confidently say it has been circa £1 million pounds of sales growth due to the KTP scheme”

Source: Managing Director of Resistant [S10].

The testimonials by the industry leaders identify how the research developed at QUB have helped them to embed technology, achieve cost/carbon savings, offer new products, increase revenue, and increase their market share.

5. Sources to corroborate the impact (indicative maximum of 10 references)

S1. Director of R&D, BanahUK

S2. Director of Creagh Concrete Products Ltd

S3. Video evidence 1 - Demonstrator building by Creagh Concrete as part RE4 research project involving QUB- <https://www.youtube.com/watch?v=6qhicAkfqrQ>

Video evidence 2 – Demonstrator building at Madrid, Spain built as part of RE4 project involving QUB. Creagh manufactured the pre-cast Wall Panels, Columns and Beams and provided assembly instructions. Concrete contained up to 65% recycled materials from construction and demolition waste
<https://www.creaghconcrete.co.uk/news/2019/september/re4-project-modifies-construction-process>

Source to corroborate evidence same as **S2**.

S4. Managing Director, Moore Concrete

S5. Managing Director, Bullivant Taranto

News article – Bullivant Taranto - R&D helps business save GBP100,000 and attract customers <https://www.gov.uk/government/case-studies/taranto-rd-helps-business-save-100000-and-attract-customers>

S6. Evidence British Standard (EN) **12350:2010** Parts 8, 9, 10, 11 and 12, Testing fresh concrete: Self-compacting concrete. [text removed for publication]
<https://shop.bsigroup.com/ProductDetail?pid=000000000030360088>

S7. Testimonial by RILEM President - identifying the significant contributions Dr. Mohammed Sonebi's has made to Self-Compacting Concrete & Bio-Based Aggregates research and best practice.

S8. Evidence - RILEM state-of-the-art on Performance-based specification for concrete. Permit and Service life modelling is detailed in section 8.10 (in Chapter 8, pages 190 -194) and section 11.6 (of Chapter 11, pages 279-285).
(https://www.rilem.net/global/gene/link.php?news_link=2015142902_0428-rilem-tc-psc-230-star-final-document-for-web-protege.pdf&fg=1).

S9. Managing Director, Amphora NDT

S10. Managing Director, Resistant