

Institution: Edinburgh Napier University		
Unit of Assessment: Unit of Assessment 13 – Architecture, Built Environment and Planning		
Title of case study: Enabling New Industry Practice in Offsite Timber Construction		
Period when the underpinning research was undertaken: 2002 - 2018		
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:
Robert Hairstans	Professor	2002 - present
Period when the claimed impact occurred: 2014 - 2019		
Is this case study continued from a case study submitted in 2014? N		
<p>1. Summary of the impact (indicative maximum 100 words)</p> <p>Edinburgh Napier University (ENU) has led pioneering research into industrialised timber and offsite construction solutions. Research has developed multiple innovative industry products, including timber design engineering software accessed monthly by over 10,000 engineers via the global software and hardware company Trimble.</p> <p>New construction technologies have also been developed with industry partners, which has led to significant knowledge exchange with 200 industry and public sector stakeholders. Impact from these exchanges has led to a number of award-winning projects, including Structural Awards, Scotland's tallest timber building, and the first ever Gold level sustainability performance. In 2015 the research was recognised by the award of the Queen's Anniversary Prize for timber engineering and sustainable construction.</p>		
<p>2. Underpinning research (indicative maximum 500 words)</p> <p>Approximately half of all non-renewable resources that mankind consumes are used in construction, an industry that is also high in energy consumption and carbon emissions. These considerations have led to a stagnation in productivity via traditional methods within the industry. A recent national report, subtitled <i>Modernize or Die</i>, highlighted the need for an immediate technological revolution to mitigate this stagnation, which has led to global drive towards offsite construction (factory produced building systems) to build energy-efficient, affordable homes. Offsite timber construction (building systems formed from wood in an industrialised setting) is renewable, energy efficient, and can sequester carbon. To mainstream the benefits of offsite timber construction there is need for greater regulatory compliance, supply chain integration and digitisation in order to overcome barriers within traditional business models and procurement practices.</p> <p>Professor Hairstans has led research at ENU on industrialised timber systems since 2002. Initially employed as a Knowledge Transfer Partnership (KTP) associate with Oregon Timber Frame, the 2-year long KTP investigated more efficient forms of timber platform frame production and construction. Research determined a revised methodology for timber platform frame construction, constructing truss rafter roofs at ground level to be lifted into position by crane. Redesigned systems and parametric analysis also ensured optimal performance, energy efficiency (thermal conductivity and airtightness) and structural regulatory conformity, including harmonisation with the Eurocode 5: Design of timber structures (EC5) [O1, P1]. Eurocodes are European standards which facilitate standardisation in order to reduce obstacles to trade, improve transparency of design, and facilitate the specification and adoption of new engineered products and systems.</p> <p>Following the KTP, Professor Hairstans established an industry multi-stakeholder research partnership with Oregon Timber Frame, Cullen-Illinois Tool Works and ETA Fixings, linked to the</p>		

BSI B/525/5 'structural timber' committee who were providing harmonisation guidance for UK structural engineers. Research sought to determine hybridised forms of conforming with EC5 racking performance requirements. The research utilised analytical modelling and structural test work to determine the critical junctions for optimisation. The research scope and stakeholder networks were then expanded to investigate the structural optimisation of industrialised timber systems more broadly. The work identified that research findings needed to be embedded in industry standard software to facilitate uptake via the standard work flow of engineers in practice. Correspondingly, a relationship with Trimble was established [O2, O3, P1].

Professor Hairstans also led research to integrate UK timber resource into offsite and engineered products, including mass timber systems with an emphasis on Cross Laminated Timber (CLT). CLT is a solid timber slab formed from parallel and perpendicular lay-ups of dimensional timber that is capable of longer load span structural arrangements. Research investigated mechanical performance and dimensional stability by means of product testing and pilot manufacture, as well as market feasibility and regulatory conformity [O5]. Professor Hairstans formed industry networks, and the discovered structural performance attributes were applied on showcase projects establishing supply chain integration requirements, utilising both home-grown and imported timber to stimulate market demand [P5]. Follow-on in-situ and post-occupancy evaluation then validated the technical compatibility and efficiency of the derived solutions [P3].

Research on industrialised timber products created new data sets from pilot manufacture and structural test work, structural calculation methods via analytical modelling and industry led spin-off projects via supply chain integration and network creation [P4, P5, P6]. The industry spin-offs projects have included massive timber systems [P5], mass customisable roofing solutions and volumetric forms of offsite construction for low carbon affordable housing. Research also explored the potential utilisation of Accoya wood, an acetylated timber for long term durability, in alternative structural applications via controlled and in-situ structural measurements [P6]. The technical research findings were digitally enabled in order to maximise utilisation and ensure compatibility with future industry software applications and the implementation of building information modelling (the latter in collaboration with Dr Panagiotis Patlakas of Birmingham City University) [O4, P2]. Additional funding was secured to increase the uptake of industrialised timber construction and improve the productivity of the sector via offsite skills creation. This led to a hypothesis for creating an offsite industry cluster, derived in collaboration with Professor Ryan E. Smith (Director of the School of Design and Construction, Washington State University) [O6].

3. References to the research (indicative maximum of six references)
O1, O4, O5 and O6 have been published following rigorous peer review.

- [O1] Hairstans, R. & Kermani, A. and Lawson R. (2004) "Crane erection of timber-trussed rafter roofs" *Institution of Civil Engineers - Journal of Engineering Sustainability*, Vol 157, Issue ES2, ISSN 1478 4629, Pg -89-98 <https://doi.org/10.1680/ensu.2004.157.2.89>
- [O2] Design Guide (2007) Manual for the design of timber building to Eurocode 5 Contributing author. Guidance for the design of structures of single-storey and medium-rise multi-storey buildings using common forms of structural timberwork to be in accordance with Eurocode 5. *TRADA Technology*, ISBN 978 0 901297 <https://archive.org/details/ManualForTheDesignOfTimberBuildingStructuresToEurocode5/page/n381/mode/2up>
- [O3] Hairstans, R. (2010 and 2019) "Off-site and industrialised timber construction – delivering quality and efficiency", 2nd edition, *TRADA Technology*, ISBN 978-1-909594-81-4. Can be supplied by HEI on request.
- [O4] Patlakas, P., Menendez, J. & Hairstans, R. (2015) "The Potential, Requirements, and Limitations of BIM for Offsite Timber Construction" *International Journal of 3-D Information Modelling*, Vol 4, Issue 1, ISSN 2156-1710, Pg 54 – 70 <https://doi.org/10.4018/IJ3DIM.2015010104>

- [O5] - Crawford, D., **Hairstans, R.**, Smith, S. & Papastavrou, P. (2015) "Viability of cross-laminated timber from UK resources", *Institution of Civil Engineers - Construction Materials*, Vol 168, Issue 3, ISSN 1747-650X, Pg 110 – 120 <https://doi.org/10.1680/coma.14.00064>
- [O6] - **Hairstans, R.**, & Smith, R. E. (2017). Offsite HUB (Scotland): establishing a collaborative regional framework for knowledge exchange in the UK. *Architectural Engineering and Design Management*, 13, 1-18. <https://doi.org/10.1080/17452007.2017.1314858>

Key research grants:

- [P1] (2002 – 10) Oregon Timber Frame (**TOTAL £195,000**) - Knowledge Transfer Partnership, Innovate UK (£120,000) & Development of a Hybrid Racking Panel, Scottish Enterprise (£75,000), Professor Hairstans (PI).
- [P2] (2010 – 12) Engineering and Physical Sciences Research Council (**TOTAL £125,000**) Structural Optimisation of Timber Offsite Modern Methods of Construction. Professor Hairstans (PI).
- [P3] (2010 – 13) European Regional Development Fund (**TOTAL £550,000**) - Low Carbon Building Technology Gateway (LCBTG), Sean Smith (PI), Professor Hairstans lead on 'Offsite Construction' and low carbon technologies, ERDF (£250,000) and Wood Products Innovation Gateway WPIG), ERDF (£300,00), Peter Wilson (PI), Professor Hairstans lead on 'Industrialised Timber Technologies' and timber supply chain.
- [P4] (2011 - 13) Industry Led Commercial Projects (**£119,830 TOTAL**): Commercial Development of Tekla Tedds software applications (19,050); Stage 1 & 2 OSB3 testing and analysis, Coillte Group (£56,430); Assessment of Accoya Structural Performance, Accsys Technology (£32,000); SmartPly testing for structural connection performance, Coillte Group (£12,350), Professor Hairstans (PI).
- [P5] (2012 – 2013) Massive Timber Research and Commercialisation (**£136,039 TOTAL**) Solid Timber Work Package, Scottish Enterprise (£23,750); Commercialisation of Solid Timber Production, CCG(OSM) (£30,426); 2014 – 15 UK CLT: Pilot manufacture, structural testing and demonstration project, Scottish Enterprise (£33,940); 2014 – 15 UK CLT - Generic detailing, Scottish Enterprise (£18,938); 2014 – 15 MAKAR dowel-lam, Scottish Funding Council (£28,985), Professor Hairstans (PI).
- [P6] (2016 – 18) Scottish Funding Council (SFC) via Construction Scotland Innovation Centre (CSIC) (**£240,897 TOTAL**): Link Housing Association, Volumetric Construction (£61,137); Donaldson Timber Engineering, Modular Roofing System (£132,834); CCG(Scotland) Ltd, Scottish Funding Council via Construction Scotland Innovation Centre (£46,926), Professor Hairstans (PI).

4. Details of the impact (indicative maximum 750 words)

The research has increased productivity and improved working practices for major UK house builders whilst ensuring the conformity with new regulatory requirements (building performance and structure). Findings have also impacted the supply chain, accelerating the adoption of industrialised timber technologies and adding value to UK-sourced timber. Wide-reaching and strategic networks have been formed to ensure implementation, including a co-operative of industrialised timber fabricators in Scotland. Research findings have also been digitised and widely disseminated via a strategic partnership with global software enterprise Trimble, to significantly influence professional practice and maximise international uptake.

IMPACT ON UK HOUSE BUILDING

The utilisation of timber frame construction in the UK has almost doubled between 2002-2019 from 15% to 28.4%, equating to approximately 50,000 houses per annum. As a result of the ENU and Oregon Timber Frame (UK) KTP, major UK developers Barratt, Taylor Wimpey, and Persimmon et al (representative of 80% of the market) now utilise the safer and more efficient crane erect method of construction as standard [C1]. Oregon have expanded from 1,250 (2014) to 2,980 (2019) units per annum, increasing their number of employees in this period from 96 to 185. In 2019, Oregon were acquired by the UK's largest house builder Barratt as a result of their research and innovation led approach for optimised performance.

IMPACT ON PROFESSIONAL PRACTICE

The KTP, hybrid racking research and follow on EPSRC funding led to design guidance which has informed the PD6693 UK racking performance standard, facilitating the harmonisation of Eurocode 5 into UK practice. This supported the development of new technical and engineering construction calculations for structural Eurocode 5 racking performance and connection details (critical wall, floor and roof junctions) that have been digitally enabled. The establishment of a working partnership with Trimble, a leading global USD3.10 billion (Financial Year 2018 revenue) built environment software and hardware organisation has allowed ENU researchers to automate code compliance applications and disseminate their structural engineering platform 'TEDDS' [C2]. This has more than 10,000 global active users per month, with the primary markets being the UK and Ireland (50%), USA, Singapore, Malaysia, Australia and Canada. 19.2% of the monthly utilisation is of the Eurocode 5 calculations, and 10.3% is of the timber connection calculations, facilitating the specification of industrialised timber systems whilst improving the efficiency of engineers during the design process [C2]. ENU has now forged a strategic partnership with Trimble, establishing the 2nd UK and 10th international Trimble Technology Lab, which has expanded the University's leadership in training and research in 3D building design, digital fabrication and the sustainable built environment [C3].

IMPACT ON TIMBER SUPPLY CHAIN

Research into industrialised timber technologies pioneered new practical applications. Accoya Wood (a timber product modified for durability via an acetylation processes) was innovatively used for ground beams for new build and retrofit applications and follow-on conformity with General German Building Approval for Structural timber by DiBT [C4]. Mass timber products were developed and utilised along with ENU input in the multiple award winning 2014 Commonwealth Games Athletes Village and Fife Housing Innovation Showcase, built for the Kingdom Housing Association [C5].

Applied research on Cross Laminated Timber (CLT) by the ENU team resulted in CCG (a lead manufacturer of industrialised timber systems in Scotland) announcing the purchase of a GBP4.15million plant to produce up to 10,000m³ of CLT per annum. This would sequester 6.76 million kgCO₂ from the atmosphere in the built environment [C6]. CCG continued to develop CLT utilisation with ENU support, resulting in Scotland's tallest timber building, and the award of the Structural Timber Awards 2018. ENU provided evidence for building performance conformity and a follow-on evaluation for validation for this project [C6]. Research has culminated in live projects to showcase findings and has generated additional knowledge via feedback loops. The Link Alva project is a GBP5.3 million construction contract of 48 homes to achieve "first ever" Gold Level of Sustainability (2018) for social rent. It is supported by a grant of GBP3.077 million from the Scottish Government's Greener Homes Initiative scheme for ENU research intervention to enable regulatory conformity [C7].

LOCAL AND INTERNATIONAL IMPACT

Research resulted in an expanded portfolio of over 200 local, national and international industrial partners. Network groups (including mass timber, timber engineering, dowel-lam, advance manufacturing, and timber frame) were established by ENU involving 147 membership organisations, including architectural and structural engineering practices, sawmills, supply chain organisations and construction firms.

These have facilitated industry led strategic research programmes on a variety of novel timber technologies. Industry partner specific research has resulted in over 50 industry led innovation projects, culminating in the 2015 Queen's Anniversary Prize [C8]. The work has also accelerated the growth of the Scottish timber offsite construction from GBP125 million (2012) to GBP300 million (2019), including the formation of Offsite Solutions Scotland, a collaborative cluster of leading industrialised timber manufacturers backed by Scottish Government [C9]. Growth is predicted to reach GBP343 million by 2023 [C10]. ENU is the academic lead providing research and innovation support to underpin this growth, and Scotland is now recognised internationally as being at the forefront of industrialised timber technologies. The work has supported the country of increasing its capability of responding to the UK

Government's presumption in favour of offsite manufacture, whilst addressing the need for more regenerative forms of construction that utilise renewable natural capital.

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

- **[C1]** Letter from Oregon timber frame stating market use and clients between 2014-2019 using ENU KTP research outputs.
- **[C2]** Letter from Trimble stating historical research partnership culminating in the establishment of a Trimble Technology Lab at ENU.
- **[C3]** Trimble Technology Lab press release.
<https://www.napier.ac.uk/about-us/news/trimble-technology-lab>
- **[C4]** Utilisation by Accsys Technology for the design guidance used for structural applications (Dunsmore House).
<https://www.accoya.com/uk/project/dunsmore-house-structural-accoya-beams-replace-concrete-foundations/>
- 'Howden Hall Road' the 2016 Wood Protection Awards project of the year.
<https://www.hbdonline.co.uk/news/scottish-accoya-project-scoops-wood-award/>
- **[C5]** Featured industry TRADA case study - The Future Affordable House type.
<https://www.trada.co.uk/case-studies/future-affordable-dunfermline-fife/>
- **[C6]** Article in the Herald regarding Glasgow construction firm CCG investing in Cross Laminated Timber Production.
http://www.heraldscotland.com/business_hq/entrepreneur/13215685.Company_has_ambition_on_Titanic_scale/
- Webpage on CCG website outlining research support from ENU to construct the largest mass timber building in Scotland.
<http://c-c-g.co.uk/project/ellerslie-road-glasgow/>
- **[C7]** Webpage on Link Housing website outlining £5.3 million construction of 48 homes for social rent, supported by ENU research.
<https://linkhousing.org.uk/news-resources/latest-news/link-and-paragon-complete-new-development-for-social-rent-in-alva/>
- **[C8]** Award to ENU of 2015 Queen's Anniversary Prize for its work in timber engineering, sustainable construction and wood science. <https://www.napier.ac.uk/about-us/our-schools/school-of-engineering-and-the-built-environment/institute-for-sustainable-construction/queens-anniversary-prize#:~:text=Queens%20Anniversary%20Prize%20In%202015%20Edinburgh%20Napier%20University,in%20timber%20engineering%2C%20sustainable%20construction%20and%20wood%20science.>
- **[C9]** Article on Scottish Housing News outlining launch of Offsite Solutions Scotland with Scottish Government backing.
<https://www.scottishhousingnews.com/article/industry-experts-join-housing-minister-promote-offsite-manufacturing>
- **[C10]** Research report detailing a Scottish Government funded review demonstrating the ambition for scale.
<https://www.cs-ic.org/media/3848/offsite-project-final-report-23-01-2020.pdf>