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Manuscript title: Long-standing themes and new developments in offsite construction: the case of UK housing

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Abstract

This paper reviews the evolution of offsite construction methods in UK housing over the past 15 years and puts this in an international context. Long-standing themes include targets for construction productivity, challenges of labour shortages and skills, desire to learn across sectors and a need to develop new business models. Newer developments include research and development funding through the UK government’s ‘transforming construction’ initiative, higher pre-manufactured value and increased digitisation. The paper concludes with recommendations for practice, policy and research.

Keywords: public policy
1. Introduction

The World Economic Forum says greater use of standardised prefabricated modular components has the potential to boost productivity in the construction industry (WEF, 2016). There are also a range of international initiatives to foster the adoption of offsite construction.

In the UK, an agenda to transform the industry by bringing together the manufacturing, construction, digital and energy sectors was set out in the UK government’s 2018 construction sector deal (HM Government, 2018), which was published in response to its industrial strategy a year earlier (HM Government, 2017). This agenda, which is being progressed through a number of investments in a transforming construction programme (through Innovate UK), seeks to develop new processes and standards, including modular components for manufacturing buildings offsite.

Such initiatives are not new. The history of offsite construction in the UK can be traced back decades (Taylor, 2009) and the challenge of building UK capacity for offsite manufacturing was set out in a Housing Forum review 15 years ago (Venables et al., 2004). This paper revisits that review and discusses the subsequent evolution of both international research and UK policy.

2. Literature review

The evolution of UK policy and practice on the use of offsite construction in housebuilding was analysed primarily through review of government policy documents over the period 2004–2019, drawing on the websites of UK government...
departments and associated policy-forming organisations, such as the Construction Leadership Council (CLC).

The information available on the UK Parliament website through 2018/2019 inquiries into offsite manufacturing for construction (House of Lords, 2018) and modern methods of construction (House of Commons, 2019) were also reviewed, as were relevant reports by management and industry consultants.

Relevant UK and international research papers were identified in the Scopus database and mapped using bibliometric analysis. The literature was searched and collected using selected keywords shown in Table 1. The search was set to ‘all fields’ for the period January 2004 to April 2019, and the research subjects were ‘engineering’ and ‘business, management, and accounting’. There were 1963 results, with 1778 results remaining after a screening process to filter the unrelated literature.

3. Innovation policies and practices

Features of UK offsite housebuilding, as described by Venables et al., (2004) in the Housing Forum report, are set out in Table 2.

Co-authors of the 2004 report had spent many years studying industrialised housebuilding in Japan, discussing its similarities and differences from car production and the potential for cross-industry learning (Gann, 1996); and drawing implications for UK housebuilding (Barlow and Ozaki, 2005, Barlow et al., 2003). They were interested in lean manufacturing principles in the car industry, and their uptake by Japanese housebuilders, which were often part of the same corporate groups. Today,
there is renewed interest in the comparison with Japan, with a recent 2019 UK expert mission to Japan.

Several recent housing projects in the UK have used volumetric offsite manufacturing. Examples are the George Street development in Croydon by HTA Architects and Vision Modular Systems, which involves two towers, one of which is 44 storeys (135 m); and the Gateshead Innovation Village that is building and comparing different forms of modular building. CLC has produced a smart construction dashboard of key performance indicators for housebuilding (CLC, 2018c) to improve productivity, capacity, quality and whole-life performance.

The UK government’s 2018 sector deal states, ‘The government will work with housing clients, developers and their supply chains, to ensure that the Industrial Strategy Challenge Fund supports the development and commercialisation of technologies and digital building designs that can help deliver the government’s 2015 commitment to deliver 1·5 million homes by 2022.’ (HM Government, 2018: p. 13).

It explicitly builds on the Farmer Review (2016), which argued that the industry does not have the capacity to provide an adequate supply of affordable new-build housing to the market using only traditional methods of construction. Thus housing remains an important sector, though the UK government research and development investment is focused on non-residential buildings (such as schools and colleges) and infrastructure (such as transport), as five government departments (including education and transport) have committed to a presumption in favour of offsite construction in their procurement.
A selection of the reports and policies over the last 15 years are mapped in a timeline in Figure 1 and summarised in Table 3 to show the evolution of policy making. Such longstanding themes and new developments are considered here in relation to the characteristic features of the innovation system in UK offsite housebuilding identified in Table 2.

- Capacity: questions of market demand and production capacity that are salient in Venables et al., (2004) are also the focus of significant ongoing work on demand aggregation, and demand/supply matching (CLC, 2017). There has been a shift in the mix of offsite manufacturing over the last 15 years, from building element (framing, panel and cladding) solutions to more complete volumetric solutions, with an associated increase in pre-manufactured value. Of respondents in the survey discussed in Venables et al., (2004: p. 17), most were using framing systems (32 respondents), with others using cladding systems (19) panel systems (20) building services (11) and volumetric modules (10). There are now ambitious benchmarks and targets for pre-manufactured value (CLC, 2018a: p.10). NHBC Foundation (2018: p.5) describes how ‘among these developers, a large proportion (69%) were delivering housing using advanced modern methods of construction (mainly volumetric or panelised systems)’, where volumetric has high pre-manufactured value (MHCLG, 2019).

- Labour and skills: labour shortage is a major challenge in both 2004 and recent years. Venables et al., (2004) reported that lack of skilled labour slows
down the rate of expansion of the offsite manufacturing industry, while recommending multiple shift working on the production line to increase output of manufacturing facilities. The CLC skills workstream, together with the Construction Industry Training Board (CITB) has an action plan on skills (CLC, 2018b), where more than half of survey respondents in a recent survey believe the shortage of skilled labour is a great problem (RICS, 2018).

- Learning across sectors: this is a long-standing theme in improvement agendas, and work that promotes offsite construction. As noted in Venables et al., (2004), and shown in Table 2, such comparison has been encouraged by government policy then (as it had been in the 1960s). The concept of cross-sectoral learning is to learn from production processes in manufacturing industries (e.g. car or aerospace manufacturing industries) and to apply their mature technology (e.g. lean manufacturing) in offsite modular construction (Gann, 1996). In recent UK policy, the potential to learn from other sectors is again raised by Farmer (2016). This interest is also a motivation in the UK industry strategy, sector deal (HM Government, 2018) and transforming construction programme, which have the ambition to innovate by bringing together the construction, manufacturing, digital and energy sectors.

- Business models: a range of different business models were identified by Venables et al., (2004), with stakeholders having contrasting business models, and the set-up of facilities by individual companies or joint ventures as a crucial step. In more recent times, building information modelling (BIM) in
housing has not been as extensive as it has been in mandated government projects, and yet it is critical to allow efficient offsite housing delivery at scale. The CLC workstream recommends targeting efforts to companies with business models and objectives that align with the benefits of smart construction. For some housing developers, ‘smart construction does not fit their existing organisational and business model (site management, supply chain, cash flow) – where housing completions are typically slowed to match the rates to maintain desired sales prices’ (CLC, 2017: p. 6).

- International interaction: in 2004 Venables et al., (2004) had a particular focus on UK capacity and so did not discuss export markets, but did mention imports. More recent policy making has emphasised an opportunity for UK modular construction generally to increase growth of global construction markets, contributing towards the Construction 2025 target of 50% increase in exports (HM Government, 2013). There is also recent inward investment, for example a Japanese housebuilder, Sekisui House, announced a partnership with Urban Splash in May 2019, with funding from the UK’s home building fund administered by Homes England.

There has been a step change in digitalisation from 2004 to 2019. In Venables et al., (2004) there was no mention of ‘digital’ or ‘computer’. There is an emphasis on development and application of new technology in modular construction to improve the building quality and deal with the skilled labour shortage (p. 19), but the nature of this technology was not specified.
More recent policy reports emphasise, 'smart construction and digital design' (e.g. HM Government, 2013: p.8) and BIM level 2 has been mandated in government projects since 2016. However, the adoption of BIM in housebuilding was uncertain due to the new business model and large investment required (Farmer, 2016: p.36). Recent work has brought together agendas on the use of digital and modular construction through platform approaches (e.g. Bryden Wood, 2018), and there is growing interest in the potential for BIM to support offsite construction (e.g. Vernikos et al., 2014).

Offsite housebuilding in Venables et al., (2004) was framed in relation to targets for improving construction productivity, first set out in the Strategic Forum for Construction (2002) report, that aimed for 20% of projects being achieved with integrated teams and supply chain by the end of 2004 and 50% by the end of 2007 (Venables et al., 2004). Similarly, recent policy on offsite housebuilding is framed in relation to the current targets, towards 2025. These are for 33% lower costs, 50% faster delivery; 50% lower emissions and 50% improved exports (HM Government, 2013: p.5).

A new development has been a new framework for multi-occupancy higher-risk residential buildings (HRRBs) that are 10 storeys or more in height (Hackitt, 2018). Related recommendations propose a radical transformation of the sector, with a systems approach to understanding risks and responsibilities in delivery. There is also substantial recent work to develop standards to support warranties and
insurance in the sector, with the government providing support through Buildoffsite property assurance scheme (DHCLG, 2016).

4. International research

There is a growing international research literature on innovation in offsite housebuilding, with strong contributions from Hong Kong, Australia, Canada and Europe (particularly Sweden). Within this literature, five major networks are discussed below, based on the co-author cluster graph shown in Figure 2.

i. Offsite construction automation, production simulation and visualisation: this cluster covers new solutions being developed through design automation, onsite-production simulation and visualisation (Olearczyk et al., 2009, Moghadam et al., 2012, Liao and Teo, 2019). From 2013 research includes plant selection, especially craneage, and related onsite optimisation (Olearczyk et al., 2012, Olearczyk et al., 2014, Han et al., 2018). Decision-making support and optimisation for offsite construction have been examined in relation to scheduling (Moghadam et al., 2011, Liu et al., 2014, Liu et al., 2015), risk management (Vernay et al., 2013), resource management (Moghadam and Al-Hussein, 2013) and productivity optimisation (Afifi et al., 2016).

ii. National offsite construction strategies: this is a relatively small cluster of studies that explore offsite construction industry strategies. These studies have focused on a critical review of national strategies, both in Nigeria (Rahimian et al., 2017) and Europe, including the UK (Nadim and Goulding, 2009, Nadim and Goulding, 2010, Nadim and Goulding, 2011, Goulding et al., 2015).
iii. Decision-making, business and industry strategies and technology adoption: research in this much larger cluster across the UK, Hong Kong, Australia, China and Malaysia spans from decision-making support approaches (Pan et al., 2008, Wu et al., 2019) and technologies (Shou et al., 2017, Niu et al., 2017) to business models (Pan and Arif, 2011, Pan and Goodier, 2012) and industry strategies (Pan et al., 2007, Pan et al., 2012, Pan and Hon, 2018, Tan et al., 2019). This work also has interest in sustainability in prefabrication in relation to green building technologies (Chan et al., 2018), low-carbon-dioxide emissions (Teng et al., 2018) as well as automated and robotic construction (Pan et al., 2018). These studies have also investigated the factors (Akmam Syed Zakaria et al., 2018) and the barriers (Xia et al., 2014) that may affect the adoption of offsite contruction.

iv. Production and supply chain optimisation: there a modest cluster of research with this focus, with work exploring strategies for industrialised construction (Blismas and Wakefield, 2009) and new approaches to optimise production and supply chain management in offsite building projects (Arashpour et al., 2016, Arashpour et al., 2017). One of the approaches suggested is to utilise agile and lean concepts (Pasquire et al., 2006, Court et al., 2009, Mostafa et al., 2018). In Sweden, buyer–supplier relationships were also investigated through case studies to propose new purchasing strategies for industrialised housing (Pasquire et al., 2011, Bildsten, 2014, Bildsten and Manley, 2015). Agile and lean concepts have also been applied to industrialised timber housing construction (Sardén and Stehn, 2006, Höök and Stehn, 2008). In China, the sustainability and efficiency...
within the supply chain have been evaluated against the industrialisation of offsite construction (Liu and Zhang, 2018, Liang et al., 2017).

v. Platform-based product design and production approaches: this cluster include studies in the Scandinavian context (Jensen et al., 2013, Jansson et al., 2018, Johnsson, 2013, Veenstra et al., 2006) that have examined how to integrate the platform-based product design approach into industrialised construction, and proposed platform strategies to address the need for both standardisation and customisation.

New developments in the literature include the rising interest in digitisation, sustainability, skill sets for industrialised construction and stakeholder management. For example, in cluster iii, there is recent work on technology adoption related to the internet of things, BIM and robot and automation; leveraging the performance of information management and decision making in offsite construction (Niu et al., 2017, Tan et al., 2019); and stakeholder management (Teng et al., 2017, Jiao et al., 2018, Xue et al., 2018).

The themes in the literature also connect with policy developments in the UK. For example, there are shared interests in platform strategies and mass customisation across cluster v, and recent UK reports (Bryden Wood, 2017, Bryden Wood, 2018) as well as the UK Infrastructure and Projects Authority’s recent consultation for a platform approach to design for manufacture and assembly (P-DfMA).
5. Discussion and conclusions

Taking the case of UK housing, this review finds long-standing themes over the last 15 years that include the targets for construction productivity, challenges of labour shortages and skills, desire to learn across sectors, and a need to develop new business models. The adoption of offsite methods has been the focus of research and advocacy over many years, and the benefits of offsite construction are well known (e.g. White and Mather, 2018).

The housing industry has different market dynamics, involving a more distributed set of actors in procurement and different companies in delivery, than other parts of construction. Such market dynamics are potentially due to the different change-driving levels from public procurement, given that the UK government procures much more infrastructure than housing (IPA, 2018: p.12). While at times treated as out of scope, housing is often referred to in reports on construction (e.g. Wolstenholme, 2009) and is important to the scale-up of offsite methods.

The growing international research literature on offsite housing, with particularly intense research activities in Hong Kong, Australia, Canada and Europe, suggests increasing research interest in digitisation, sustainability, skillsets for industrialised construction and stakeholder management, and active research in areas that relate to the UK policy developments, such as platform strategies and mass customisation. There are significant clusters around offsite construction automation, production simulation and visualisation; national offsite construction strategies; decision-making,
business and industry strategies and technology adoption; production and supply chain optimisation and platform-based product design and production approaches.

Taken together, this review of UK housebuilding policy and practice evolution and of the international research literatures, suggest ways that technological advancements can help the industry evolve. To overcome challenges described in the longstanding themes, practitioners can use research on platform-based and data-driven approaches and tools for supply-chain integration and optimisation. To deepen understanding of the levers and barriers for change, there are useful comparators to be drawn.

For example, in the UK, mega projects have accelerated the innovation process by creating a coordinated critical mass of demand (e.g. in the London Crossrail project’s Innovate 18 programme, Pelton et al., 2018) and there may be a useful comparison with the transport sector. There is also a renewed need for rigorous comparisons internationally, to understand the differences in context, role of the buyer and nature of government intervention. Examples include differences between modular housebuilding in Hong Kong (e.g. Shan et al., 2019) and the UK, and between platform strategies in USA (e.g. Amazon’s Plant Prefab) and the UK.

Future research will be vital in supporting a shift towards knowledge-intensive offsite production. Potential new directions for research include extending work on emergent technologies, platform strategies and mass customisation, and also on the innovation process itself and the business models that will support transformation.
Acknowledgements

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References


Table 1. The keywords for bibliometric review

<table>
<thead>
<tr>
<th>Key words</th>
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<tr>
<td>‘off site construction’ OR ‘offsite construction’ OR ‘offsite modular construction’ OR ‘industrialised building’ OR ‘industrialised construction’ OR ‘prefabricated construction’ OR ‘prefabricated building’ OR ‘industrialised construction’ OR ‘industrialised building’ OR ‘modular construction’ OR ‘modular building’ OR ‘house module’ OR ‘building module’ OR ‘housing module’ OR ‘industrialised housing’ OR ‘industrialised house building’ OR ‘industrialised housing’ OR ‘industrialised house building’ OR ‘prefabricated prefinished volumetric construction’ OR ‘industrialised building system’ OR ‘modular integrated construction’ OR ‘design for manufacture and assembly’ OR ‘modern methods of construction’ AND ‘innovation’</td>
</tr>
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Table 2. Features of UK offsite housebuilding as described by Venables et al., (2004)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
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<tbody>
<tr>
<td>Capacity</td>
<td>Market demand and production capacity drove the review, where the context was ‘the intense pressure within the housing market, especially in south-east England, and a government and industry concern to improve the performance of the construction industry.’ (p. 18)</td>
</tr>
<tr>
<td>Labour and skills</td>
<td>Low production capacity and lack of skilled labour were found to slow down the rate of expansion. One recommendation was to apply multiple shift, rather than single shift, working on production lines (p. 23).</td>
</tr>
<tr>
<td>Learning across sectors</td>
<td>Learning from manufacturing: ‘In a similar manner to efforts in the 1960s, the house-building industry has again come under pressure from government to adopt concepts and techniques from other manufacturing industries.’ (p. 20)</td>
</tr>
<tr>
<td>Business models</td>
<td>Differing business models identified across speculative development, registered social landlords, manufacturing and assembly (p.28-29). Within this: ‘A number of companies are either expanding their own facilities or engaging in joint ventures with other firms to set up new production facilities’ (p. 28).</td>
</tr>
<tr>
<td>International interaction</td>
<td>Considered in relation to imports only: ‘a number of overseas firms that currently produce OSM components for their domestic market and who are monitoring developments in the UK to identify a suitable time to enter the market’ (p.26).</td>
</tr>
</tbody>
</table>
Table 3. Selected recent UK policies and reports over the last 15 years

<table>
<thead>
<tr>
<th>Date</th>
<th>Report / policy</th>
<th>Publisher</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2005</td>
<td>Improving Public Services through better construction</td>
<td>The National Audit Office</td>
<td>NAO (2005a)</td>
</tr>
<tr>
<td>11.2005</td>
<td>Using modern methods of construction to build homes more quickly and efficiently</td>
<td>The National Audit Office</td>
<td>NAO (2005b)</td>
</tr>
<tr>
<td>Year</td>
<td>Title</td>
<td>Author/Institution</td>
<td>Date</td>
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<td>-----------------------------------------------------------------------</td>
<td>--------------------------------------------------------</td>
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</tr>
<tr>
<td>2.2017</td>
<td>Fixing our broken housing market</td>
<td>Department for Housing, Communities and Local Government</td>
<td>DHCLG (2016)</td>
</tr>
<tr>
<td>2018</td>
<td>Innovation Workstream</td>
<td>Construction Leadership Council</td>
<td>CLC (2018a)</td>
</tr>
</tbody>
</table>
Figure 1. Timeline of selected reports and policies
Figure 2. Author clustering in papers about offsite construction and innovation system using keywords in Table 1 – there are 37, 33, 185, 105 and 33 papers in clusters i, ii, iii, iv and v respectively.