Cambridge Centre for Housing & Planning Research

Places for People

Deploying modular housing in the UK: exploring the benefits and risks for the housebuilding industry

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July 2021

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1. Executive summary

The housing crisis in the UK has been widely acknowledged: home-building rates are just half of the 300,000 required annually and are insufficient to meet accumulated need (HM Government 2018a). The failure to meet these supply levels is partly explained by the challenges that the industry is facing, such as low productivity, labour shortages, lack of collaboration and failure to embrace new technologies (Burgess et al. 2018). Modern methods of construction (MMC), manufacturing methods that harness digital techniques, Building Information Modelling (BIM) and offsite manufacture (House of Lords 2018) have all been widely promoted as solutions to industry challenges, with a particular emphasis on the potential of offsite manufacturing for residential housing.

As stated in the Industrial Strategy, the goal is to 'build new homes in weeks – and even days – rather than months; that can deliver new buildings at a third of the cost; that can provide affordable, energy efficient homes' (HM Government 2018a: 3). This report considers the opportunities and challenges of making greater use of offsite or modular built homes to meet the UK's housing needs.

The report identifies numerous potential benefits of a shift to offsite housing construction, including the greater speed of onsite operations; higher fabrication quality; safer working conditions; improved material efficiency and reduced waste; less noise and disruption for residents and neighbours; lower labour requirements; and reduced need for onsite reworking. Building offsite, combined with increased use of BIM, may also make it easier to provide the 'golden thread' of information needed for effective management and maintenance of housing (Burgess et al. 2020).

However, there are also a number of risks associated with offsite housing construction which, along with challenges, have led to a low uptake of these innovations in the housing sector. The cost of investment required to adopt modular housing development models is high, and this is a barrier to their uptake (Burgess at al. 2020). A key challenge inhibiting the shift to new business models in housing delivery is the lack of a demand pipeline large and stable enough to ensure the market absorption of new homes and to maintain the financial viability of offsite housing factories.

The skills required for offsite housing construction are not the same as those used in traditional construction, and the current skills gap in the UK poses a further barrier to greater use of modular build techniques. One of the constraints on the uptake of new technologies in construction is the lack of evidence to confirm the benefits of the use of offsite and modular techniques. Lenders and insurers can be risk averse to financing developers and

contractors applying innovative approaches as they are seen as high risk compared to conventional approaches used in the housing sector. Furthermore, as a result of lingering negative perceptions of post-war 'prefab' buildings, housing customers in the UK still have a strong cultural preference for traditionally built 'bricks and mortar' homes.

Resistance to change among individuals and management at the organisational level in the housebuilding sector can present another constraint for the use of modular and offsite construction techniques. The lack of regulation governing the use of innovative technologies in construction presents another challenge for the industry. The current operational environment in the construction sector has been designed for traditional housing, and there can be logistical challenges in the use of modular units relating to storage, transport to site and onsite fit.

After outlining both the opportunities and the challenges, the report concludes with the following policy suggestions which could boost the supply of modular homes:

- The greater deployment of modular housing could be facilitated through further financial commitments (e.g., government grants, tax breaks and subsidies aligned with modular approaches) and planning policy incentives from the government (such as 'fast-tracking' of planning permission for modular housing development).

- Given the anticipated greater scale and increased speed of production of modular-manufactured homes compared with homes built using traditional approaches, a stable pipeline of demand is needed to ensure the market absorption of new homes and to maintain the financial viability of offsite factories. This could be achieved through the promotion of investment in the private rented sector (e.g., Build to Rent), or through utilising public land supply to help ensure access to sufficient suitable sites for modular housing development. It could also be achieved through greater housing provider collaboration in modular procurement.

- A clear and coherent set of standards and regulations (including technical issues, quality, and health and safety) for the industry is needed to mitigate risks and provide certainty and confidence for clients and contractors who decide to use modular approaches, offsite manufacturing and MMC, as well as for consumers. Modular homes need the same warranty provisions as traditionally constructed homes in order to create confidence amongst consumers, lenders and insurers.

- The deployment of modular housing requires different skills compared to those needed for traditional building methods. To ensure the industry's labour force is

equipped with the necessary skills (such as digital literacy, use of new software and knowledge in offsite manufacture), retraining schemes and education programmes need to be delivered in collaboration with national and local government, education providers, industry bodies (e.g., the Construction Leadership Council) and the housebuilding industry.

- Local authorities should ensure that the recommendations of central government are supported at the local level. This could be achieved by incentivising modular manufacture methods in local planning policy or by promoting local education and skills training to develop a suitably skilled workforce.

- In addition to upskilling schemes and training at the organisational level in the industry, it is recommended that housebuilders and developers identify and support individuals or teams to lead and champion their innovation journey through incremental adoption and use of modular methods, offsite manufacturing and MMC, and to combine this with their digital innovation strategy. Such leaders should boost employee confidence in the vision, the implementation strategy, and the expected outcomes from the transition to greater use of digital innovation and modular housebuilding.

- The industry needs to provide strong backing to innovation champions among housebuilders and developers who actively use modular and offsite approaches and MMC, in order to boost their efforts and promote the benefits of innovation.

- Systematic data capture and evidence collection by housebuilders and developers around the use of modular and offsite methods are needed to create a strong evidence base of the benefits of offsite housing construction and MMC. This would help to combat customers' mistrust, overcome risk aversion, and boost confidence among lenders, and provide benchmarking for new housebuilders entering the modular housing production sector.

- Construction in general, and housebuilding in particular, will play a vital role in the UK's post-COVID recovery. More can be done within the construction and housebuilding sector to develop a vision of how the uptake of modular methods, offsite manufacturing and MMC will be part of this recovery, and could also help to tackle regional inequalities and address the 'levelling-up agenda'. This will require collection of data on where components are both manufactured and used, in order that the geographies of production can be understood and used to inform decision-making about sustainable and responsible procurement.

- Housebuilders and developers could do more to engage with customers in the design process, and with end users, to gather post-occupancy data. Feeding this data back into house design will bolster the aim of increasing resident satisfaction and improving building performance.

- To overcome the problem of interoperability between different components manufactured offsite, which can create onsite fit issues and other additional work, standardisation of the components, e.g., having a 'kit of parts' to be used across the industry by different manufacturers, is recommended. Suitable collaboration platforms in the construction sector (such as through the Construction Innovation Hub) could play a role in the development of standards, tools, designs, and regulation methods and support a sustainable marketplace for modular and offsite manufacturing.

- To share learning about deploying modular housing, initiatives to promote collaboration need to be pursued both within the housebuilding industry, e.g., the Building Better group (NHF 2020) and the wider construction sector. This would provide structures for effective communication and exchange of experience, synthesise learning, and help to build networks and collaboration opportunities.

2. Modular homes in the UK

2.1. What is modular housing?

Definitions

There are various terms used in relation to modern methods of construction (MMC), offsite construction or offsite manufacturing, and modular housing, which can cause misunderstandings and clashes between different information sources. Indeed, terms that commonly relate to the same construction approach in different sources might be labelled as MMC, offsite, modular housing, prefabricated housing, etc. This report draws on the definition presented in the House of Commons report (2019a: 14) and, under the banner of MMC, includes 'forms of offsite manufacture for construction, including modular and panellised systems, and timber or steel framed homes' with an emphasis on the role of digitalisation in modern construction and the precision finishing that digital technology can help to deliver.

MMC embraces a wide range of offsite and onsite manufacturing techniques which provide an alternative to traditional construction methods (NHBC 2018). The Modern Methods of Construction (MMC) definition framework was developed by a specialist sub-group of the MHCLG MMC cross industry working group (MHCLG 2019a). The intention is for the framework to regularise and refine the term 'MMC' by defining the broad spectrum of innovative construction techniques being applied in the residential market. The framework also supports the industry's ability to evaluate the different ways available of increasing the 'Pre-Manufactured Value' (PMV) of its residential built assets (ibid).

The framework includes a range of approaches which spans offsite, near site and onsite pre-manufacturing, process improvements and technology applications (MHCLG Joint Industry Working Group on MMC 2019). The term 'pre-manufacturing' encompasses processes executed away from final workface, including in remote factories, near site or onsite 'pop up' factories (ibid). The definition framework identifies the following seven MMC categories:

Category 1 – Pre-Manufacturing - 3D primary structural systems
Category 2 – Pre-Manufacturing - 2D primary structural systems
Category 3 – Pre-Manufacturing - Non systemised structural components
Category 4 – Pre-Manufacturing - Additive Manufacturing
Category 5 – Pre-Manufacturing – Non-structural assemblies and sub-assemblies
Category 6 – Traditional building product led site labour reduction/productivity improvements
Category 7 – Site process led labour reduction/productivity improvements

Offsite manufacture for construction is a manufacturing-based approach which involves the production of components of buildings (e.g., foundations, roof cassettes, walls, floors, kitchen, and bathroom units) or whole (modular) units of a building, in a factory for installation on site (Burgess et al. 2020). Offsite manufacture for construction is increasingly associated with greater use of digital technologies at different stages of the construction process. Techniques such as BIM, Geographic Information Systems (GIS) and 3D printing allow virtual access to complex information about a building's specific components and installation requirements, meaning that problems in the manufacturing process can be identified and addressed early in the construction process (Burgess et al. 2018).

De'Ath and Farmer (2020), who have already made numerous recommendations designed to stimulate and galvanise the demand for modular homebuilding, many of which are echoed in this report, support the use of all seven categories MMC, but give most attention to the Category 1, volumetric segment. This 'is deliberate in that it is the single MMC approach most aligned to creating true additionality of capacity in the market and it also has the highest level of pre-manufactured value that can be re-distributed within the economy to achieve wider economic policy objectives including new supply chain creation and "levelling up"' (De'Ath and Farmer 2020: 11). They go on to explain that 'volumetric or Category 1 MMC modular means the construction of fully finished modules, or structural boxes, that include fitted kitchens and bathrooms. These are bought to site and assembled either with or without external fabric materials…. this method enables 70%+ of the home's construction value to be manufactured, this is also termed its Pre-Manufactured Value [PMV] and compares to traditional build's PMV of circa 40%' (De'Ath and Farmer (2020: 11).

History

Modular housing is often viewed in a negative light by consumers, builders, investors and insurers alike based on an enduring image of low-quality post-World War II prefabricated housing (prefabs), These units were widely perceived as being of poor quality and design, and were not built to last (NHBC 2016). There were many cases of these 'factory-made' houses being found to have defects, and some collapsed, causing risk to life and increased homelessness (NHBC 2020).

Despite these shortcomings, prefabricated housing is understood to contain some durable features, and to represent progressive engineering techniques. World War I and World War II both resulted in a serious shortage of skilled labour and essential materials and required changes to industrial capacity. A significant number of prefabricated techniques were deployed for housebuilding after World War I, and more than 20 steel-framed housing systems were produced in efforts to alleviate the housing shortage. The use of non-

traditional construction methods and new materials were used to produce homes at low cost and to overcome shortages of skilled labour and traditional materials throughout the inter-war period. New materials and construction methods were introduced to make use of the existing manufacturing capacity and find alternatives in times of scarcity of labour and traditional materials (NHBC 2019). Large-scale housebuilding campaigns followed World War II to provide much needed homes, and these led to a shift towards industrial housebuilding and high-rise construction techniques, frequently focusing on the redevelopment of city centres (NHBC 2020).

The rapid construction of new prefab homes in the post-war period helped to replace houses damaged in the war as well as to help meet government targets to clear slums and create separate homes for every family. In the immediate post-war period, timber supplies were primarily allocated for pit propping, leading to the use of steel and aluminium for prefab construction. Between 1946 and 1949, over 150,000 prefabs were designed, produced and erected across the UK (NHBC 2020). Systems developed in the immediate post-war period allowed houses to be constructed from cast-in-situ concrete, maximising the use of unskilled labour. This had lasting effects on techniques used in the industry and, by the 1970s, light concrete blocks had become a mainstay of conventional housebuilding. Although traditionally built homes remained predominant in the decades following World War II, innovations adopted in the post-war period clearly helped to meet the immediate and temporary housing need (NHBC 2019).

By the 1990s and 2000s, many housing providers had turned to a new typology to address the scarcity of affordable urban housing: compact flats for key workers in the public sector (NHBC 2020). Light steel frame 'volumetric' construction allowed developers to construct and connect small repeating units of floor area. However, volumetric construction faced a key obstacle, in that quality, performance and maintenance benefits outweighed their increased capital costs, but panellised light steel structures continued to develop. Timber, one of the oldest construction materials in the world, with its lightweight features and ease of transportation, was also used in new construction technologies (RICS 2018). Softwoods used in composite components and timber-insulated structural panels represent opportunities for panellised and volumetric prefabrication, and since timber frames were introduced into the UK in the 1960s, this became a common form of MMC for housing construction - it currently accounts for nearly a fifth of overall output (NHBC 2019).

Promoted by the government, factory-made housing historically delivered on quantity, with less emphasis on the quality of houses themselves or their integration into local character and wider urban infrastructure (NHBC 2020). Multiple accidents involving prefabrication signalled the end of their mass use and redirected the housebuilding industry back to

traditional construction methods (Burgess et al. 2020). In particular, the collapse of the Ronan Point tower block in 1968 undermined public confidence in high-rise concrete buildings, leading to the end of the use of prefabricated concrete for prefabricated high and medium rise residential developments. Similarly, the Grenfell Tower fire created concerns for using structural timber technologies even for medium-rise buildings.

As a recent report by the NHBC Foundation illustrated (NHBC 2020), different periods in the history of modular housing have stimulated the development of multiple technologies, including: steel-framed housing systems; temporary 'portable' buildings constructed from galvanised corrugated iron; reinforced concrete; mass concrete used to create the solid external walls of a home; precast concrete panels; no-fines concrete; insulating concrete formwork; modular timber frames; and structural insulated panel systems. In the decade following the end of World War II, around 450,000 'permanent' non-traditional homes were delivered (ibid). As such, even though prefabricated housing has generated a range of negative perceptions around modular building, the history of experimentation with this approach to construction has undeniably laid the foundations for modern approaches to construction. Currently, around 75% of homes being built use cavity masonry construction and 16% are timber framed, according to NHBC statistics (NHBC 2019).

Current delivery and policy

The statistics about current levels of construction of modular housing in the UK vary and currently there is no comprehensive database. Multiple data sources may detail the use of modular construction or wider MMC in housebuilding, but without distinction between them, which makes it difficult to evaluate the actual numbers. For example, Pinsent and Mason (2017) identified that 15,000 modular homes are constructed each year by the housebuilding industry, whereas Hollander (2018, 2019) identified that the Top 50 Biggest Builders built 4,667 homes in 2017/18 and 5,389 homes in 2018/19 using MMC.

2.2. What environmental and aesthetic issues are associated with modular housing?

Environmental considerations are a fundamental issue for the deployment of modular housing. The use of new construction technologies and delivery mechanisms could contribute to meeting net zero carbon targets, as MMC have the potential to allow more energy efficient designs. For example, sustainably managed forests produce timber, recognised as 'a unique material that has the ability to lock up or 'sequester' carbon dioxide absorbed while the tree was growing' (NHBC 2020: 42). De'Ath and Farmer (2020: 16) state that higher productivity and efficiency of modular-developed housing means its construction produces 'up to 80% less waste than with traditional construction and as much as 97% of any

waste [from modular-built homes can be] recycled'. However, given the legacy of the post-war mass production of housing and the use of modular techniques for temporary housing solutions, there are longevity concerns surrounding the use of MMC and the broader environmental consequences.

In addition to environmental challenges, aesthetic issues associated with new build modular homes also need to be addressed. Post-war prefabricated housing had an austere look due to the speed of construction and lack of resources (NHBC 2020), and this history still deters customers from purchasing non-traditionally constructed homes. Given this, an increasing emphasis should be placed on the need for modular homes to be well-designed, beautiful, and reflective of local character (see, for example, National Design Guide; MHCLG 2019b).

3. Why is deploying modular homes important for the housebuilding industry?

In recent years, a wide range of advantages of deploying modular homes have been put forward. The most crucial of these relate to tackling housing shortages and to addressing problems of housing affordability, low housing quality and maintenance issues. Deploying homes delivered with the use of modern methods of construction (MMC) is on the list of key priorities set out by the government for the industry to tackle the housing shortage (Homes England & MHCLG 2020). Modular housing may also prove to be instrumental in addressing the environmental challenges faced by the housing sector.

3.1. The housing crisis in the UK and affordability of homes

The current housing crisis in the UK, associated with insufficient numbers of new homes being built and the failure to meet the demands for new and affordable housing, has been widely acknowledged (DCLG 2017; Burgess et al. 2020).

The supply of new build housing is low and does not address the needs of the UK population. There is therefore a need to increase housebuilding rates (Burgess et al. 2018), and the government has set out its aspiration to deliver 1.5 million new homes by 2022 (HM Government 2018a). However, current home-building rates are just half of the 300,000 required annually and as such are insufficient to meet the accumulated need (ibid). The failure to meet these recommended supply levels is partly explained by the challenges that the industry is facing, such as low productivity, labour shortages, lack of collaboration and a failure to embrace new technologies (Burgess et al. 2018). This has serious consequences: the under-supply of new housing has contributed to escalating problems of housing affordability, which in turn has resulted in a decline in home ownership, the growth of the private rented sector, long waiting lists for social housing, and increased homelessness (Burgess et al. 2020).

One crucial aspect of the UK's current housing crisis relates to the quality of housing, in particular how homes are designed and built (Burgess et al. 2020). The conventional design process involves fragmented input by different professionals at different stages. This fragmentation can be problematic and commonly results in quality issues remaining undetected until construction begins. Furthermore, traditional construction techniques involve the assembly of several components by different subcontractors, which often leads to a need to deal with design problems onsite, poor coordination and, consequently, poorer final build quality. This can lead to housing quality problems developing over time.

The ongoing maintenance of traditionally built housing is another crucial element of the housing crisis, given that the UK's housing stock is one of the oldest in Europe (Burgess et al. 2020). One of the consequences of poor maintenance of housing in the UK is that around 15 million people are living in poor housing, which converts into about 70% of health service costs (DCLG 2017). Data from 2015 indicated that a £10 billion investment in improving the 3.5 million worst homes in the UK would save the NHS £1.4 billion in first-year treatment costs alone - broadly speaking, poor housing costs the economy £18.6 billion a year (BRE 2016). The Grenfell fire tragedy highlighted poor maintenance practices and the urgent need to review building regulations and fire safety.

3.2. Government backing for offsite manufacturing

In light of the housing shortage and the failure of traditional housebuilding approaches to deliver new homes at the required rate, the UK government has identified a need for innovation in the construction industry. Innovations in construction aim to enhance productivity, speed up delivery and overcome delays, reduce the cost and use of onsite labour, reduce the environmental impacts of construction, and improve the overall quality of the end product (HM Government 2018a; House of Lords 2018). As part of this, MMC, manufacturing methods that harness digital techniques, Building Information Modelling (BIM) and offsite manufacture (House of Lords 2018), have been widely promoted as a solution to industry challenges, with a particular emphasis on the potential of offsite manufacturing for residential housing. As stated in the Industrial Strategy, the goal is to 'build new homes in weeks – and even days – rather than months; that can deliver new buildings at a third of the cost; that can provide affordable, energy efficient homes' (HM Government 2018a: 3). The use of BIM, for example, can ensure quality design, eliminate defects through object modelling and analysis, and will provide the data and information needed to enable better maintenance and management (Burgess et al. 2020). As a result, offsite manufacturing and BIM have the potential to produce better quality housing at faster rates, increasing supply and potentially making new homes cheaper to produce. Therefore, the potential of offsite construction and MMC to tackle the housing crisis in the UK is substantial.

Following this move towards the use of innovative methods in housebuilding, the government's Affordable Homes Programme places significant focus on and investment in MMC, promotes their use alongside high-quality sustainable design, and outlines their delivery as a strategic objective (Homes England & MHCLG 2020). The updated MMC section of the Capital Funding Guide lists seven categories of MMC that are eligible for investment (Homes England 2016). As a result of the central role of MMC in the Affordable Homes

Programme, many housing associations intend to sign 'strategic partnership' deals with Homes England to build large numbers of affordable homes. By participating in this programme, they will have to commit to using MMC to build at least 25% of their pipeline of new homes (Housing Today 2020). More broadly, the government's intention to 'support innovative developers and housebuilders […], those looking to build a diverse range of types and tenure of housing, and those using innovative modern methods of construction (MMC)' has been highlighted among the priorities in Planning for the Future (MHCLG 2020: 18). Altogether, this means that we should expect further expansion of MMC, offsite and modular construction in the housebuilding industry in the near future.

3.3. Environmental and aesthetic challenges

The need to address sustainability challenges has been brought to the fore on the agenda of the construction sector. In particular, the 2019 Consultation of the Future Homes Standard includes a commitment to introduce, by 2025, a standard for new build homes that are future-proofed with low carbon heating and world-leading levels of energy efficiency (MHCLG 2019c). Emphasis on energy efficiency standards, and commitments to reducing carbon emissions across the construction industry, also derive from the UK's commitment to achieve carbon net-zero by 2050. The use of MMC and offsite construction rather than traditional construction methods is expected to contribute to this goal.

The aesthetic attributes of new build homes are also a priority for the construction sector. The independent report Living with Beauty (Building Better, Building Beautiful Commission 2020: 10) recommends prioritising an increase in the use of high-quality designs for new build homes and neighbourhoods in the UK, and suggests that developers should aim to produce 'beautiful buildings'. Reflecting these recommendations, Planning for the Future (MHCLG 2020) puts forward 'planning for beautiful and sustainable places' as one of the priority pillars for the industry to focus on. The use of innovative MMC has been proposed as a means of addressing these goals. Steps have been taken to encourage this, including a design competition, Home of 2030, initiated and funded by the government (HM Government 2020), and created to attract talent in the housing industry, including small businesses, designers and manufacturers, 'to drive innovation in the provision of affordable, efficient and healthy green homes for all'.

4. Opportunities

There are numerous benefits of non-traditional and offsite construction, including the speed of onsite operations; fabrication quality; safer working conditions; material efficiency and reduced waste; and less noise and disruption for residents and neighbours.

Faster, cheaper build

Modern methods of construction are expected to improve industry productivity, although many developers experimenting with modular home building have yet to find the process either quicker or cheaper than traditional build. It is expected that, if such methods could be deployed at a greater scale, they may provide an opportunity to deliver new homes more quickly, with higher quality and at a potentially cheaper cost than traditional methods. Such advantages are based on high-precision, factory-based approaches to construction. Increased speed of construction means that offsite manufacture for housing construction could be a useful tool in attempts to increase numbers of new-build housing units at a rate fast enough to meet government housing supply targets (Burgess et al. 2020). However, more evidence is still needed about the impact of modular development on both the speed and cost of delivering new homes.

Tackle labour shortages

The automated processes, offsite factory production of components, digital systems and other innovative elements that are a part of the use of offsite manufacturing and MMC require less time and input from construction workers onsite, and could help address the labour shortages that the construction industry is currently facing.

Minimise onsite reworking

The traditional approach to housebuilding involves the assembly of multiple components (e.g., bricks, windows and door sets, etc.) in an open-air, site-based environment by workers from multiple trades and subtrades. When multiple subcontractors are involved in the construction process, onsite rectification of design problems and poor inter-trade coordination often results in increased reworking, and contributes to poor overall quality (Burgess et al. 2020). Prefabrication of components or structures can reduce the need for onsite design alterations and reworking late in the construction process, both of which are time-consuming and costly.

Higher quality

Offsite manufacture of housing and modern methods of construction can create opportunities for better build quality. Detailed, well-thought through design is essential for this, especially at the early stages of a project, as it can mitigate the risks of offsite

construction. Early design freeze is required. Digital technologies and solutions such as BIM can provide detailed layouts as well as specifications of all components required for construction. This helps to ensure that all defects and inconsistencies are detected and removed before manufacture begins, resulting in a higher quality end-product.

Health and safety benefits both in production and asset management

The poor management and maintenance of housing, which have been linked to tragedies and loss of life (e.g., the Grenfell fire tragedy), have highlighted a clear need for a 'golden thread' of detailed data and information for built assets (Hackitt 2018). From the perspective of building regulations and fire safety, BIM offers 'an opportunity to create, store and share data and information to ensure their effective management and maintenance in the future' (Burgess et al. 2020: 3). The opportunities to monitor health and safety protocols in the production process, as well as in subsequent asset management, makes offsite housing construction an important element of a safer regulatory system for the future.

Reduced local disruption

The current model of construction is highly localised, whereas modular construction involves the outsourcing of many stages of the construction process to specialised facilities or factories, thereby reducing the time taken for installation on site. Modular construction creates less disruption for the local area and residents, including reductions in noise, dust, and road blockages. As De'Ath and Farmer's (2020) report indicates, modular deployment of homes requires up to 60% fewer operatives on site, increasing site safety and causing less disruption for surrounding residents, with fewer materials and less construction traffic.

New skills

The CITB (2017) notes that there are several skillsets specific to offsite construction which need to be developed in order to improve performance throughout the building process. These include, among others, digital design skills tailored to offsite construction, collaborative working, and precision in onsite assembly. Compared to traditional construction, the different knowledge and skills needed for modular construction provides an opportunity to improve diversity in the construction workforce and to attract more young people (HM Government 2018). The collaborative working environment associated with modular building and the range of professional roles required, as well as the possibility that factory production may lead to more regular working hours than those on typical building sites, may appeal to a wider base of potential employees (LABC Warranty 2019). It is hoped that the shift to modern methods of construction and the specialised roles involved in such a shift will attract more women to the industry (HM Government 2018).

New geographies of production

The shift to offsite construction provides an opportunity to rebalance the spatial distribution of economic benefits associated with construction in the UK. Currently, 15% of construction employment is based in the South East, with a further 14% based in London, while the North East of England hosts only 3% of the UK's construction jobs (ONS 2018). In theory, offsite construction could change this geography: given the nature of offsite construction, there is no need for the factories producing buildings to be located in the same region as the end site. For example, construction projects located in the South East could use offsite construction firms based in the North East, diverting the economic benefits of construction from already affluent areas to other regions of the UK. This has the potential to be an important step towards reducing regional inequalities in line with the government's 'levelling up' agenda, and could enhance the employment opportunities associated with offsite factories in the areas which would benefit most from these advantages (House of Commons 2019a).

Collaborative business models

The use of offsite construction will require a significant paradigm shift towards more collaborative procurement routes, highly coordinated design processes and early-stage design finalisation (Burgess et al. 2020). The rate of delivery is intended to match the sales rates and maintain price levels that keep housing units profitable for the developer. Furthermore, multiple actors (developers, contractors, lenders, etc.) are bound by contracts that tend to promote adversarial relationships, a lack of trust and an aversion to risk (cf. Farmer 2016). This supply chain model does not support the collective risk-taking and collaborative working needed to embrace innovation. Thus, there is an opportunity within the shift towards offsite construction and MMC to embrace a more collaborative approach to working, perhaps using outcome-based contracts, which could bring benefits to quality and attract a more diverse workforce.

New aesthetics and greater diversity

The government-funded competition, Home of 2030 (HM Government 2020), sought to bring innovation to housing design and provision, and particularly encouraged designs that show how housing in the UK could be reimagined. Many modular manufactured houses highlight possibilities for delivering such innovations, as the new technologies allow for the adaptation and customisation of designs. This has the potential to change the aesthetics of the built environment, making it more diverse and attractive, delivering homes with unique character. This aligns with the proposed directive of the Living with Beauty report (Building Better Building Beautiful Commission 2020: 10) that 'new development should be designed to fit into the life and texture of the place where it occurs; […] an illustration of the way in which a new street may be more beautiful than the buildings or fields that preceded it'.

Reduced carbon emissions

Modular housing offers improvements in embodied CO^2 compared with traditional construction. Research demonstrates that offsite technology can generate nearly 40% lower emissions than traditional construction. Recent research from Herriot Watt University indicated that just one modular-manufactured building at Greenford Green saved the equivalent CO^2 to planting 160,000 trees (De'Ath and Farmer 2020). Modular housing can contribute to meeting the current ambitions for zero carbon in housing development and achieve the proposed Future Homes Standard (MHCLG 2019c), which is crucial for the UK's committed target of net zero carbon by 2050.

Housing as a service, enabling customisation and user feedback

Offsite construction and MMC open up opportunities for developing the housing industry into a broader service provider that is not only restricted to the production and sale of a unified housing unit, but rather one that offers a life-cycle service. In such a service, changes could be programmed by designers and a customer from the initial design layouts, which could be identified and modified with the use of BIM. This would enable the production of tailored housing solutions based on customer preferences and feedback to original designs. There is customer demand in the housing industry for variety (Hofman et al. 2006) and offsite construction could help deliver this.

There are already examples of customisation in modular housing. For instance, Inholm, the second phase of development at Northstowe in Cambridgeshire, will see the construction of 406 modular homes of a range of housing types, including later living homes and mixed-use buildings (Construction Enquirer 2020). Designs will allow buyers to configure their homes before being built in a factory and delivered to site. Similarly, the Beechwood West regeneration project in Essex will use modular factory construction to deliver 251 new homes that can be customised using innovative digital software (De'Ath and Farmer 2020). Incorporating customer experience into the production of housing can bring a number of benefits: when customers participate in the design process, their needs are better met, and designers are supported to develop more efficient, tailored housing solutions (Parn at el. 2015). As highlighted by De'Ath and Farmer (2020: 2), provision of 'mass customisable pattern books aligned to local design codes could accelerate delivery, restore competition, and increase certainty for neighbours and builders'. Such a service-based approach would also enable the integration of opportunities created by the Internet of Things, smart home technologies, and digital twins for the post-deployment and maintenance stages. This has potential for creating a new construction economy around the custom-built market.

The UK's current model of housebuilding is largely driven by speculative development (Burgess et al. 2020), and the shift to a new economy of housing as a service would create more consumer choice in design optionality and connect that with manufacturing and delivery (De'Ath and Farmer 2020). Further value could be added through intelligent planning reform incorporating the digitisation, pattern book and design code agendas that were presented in Planning for the Future (MHCLG 2020).

5. Risks and challenges

The potential for offsite and modular technologies to help tackle the problems related to the housing crisis and open up opportunities for advances in the construction sector is widely recognised. These innovations could deliver faster construction speed, better quality of housing and could provide a 'golden thread' of information needed for effective management and maintenance of housing (Burgess et al. 2020). Yet there are also a number of risks and challenges associated with their deployment which have led to a low uptake of these innovations in the housing sector.

Housing delivery models and maintaining viability

The current model of housebuilding in the UK operates within the context of a housing shortage, and the relatively slow delivery of homes to the market regulates house prices at a level which keeps production financially viable for developers (Burgess et al. 2020). Scaling up delivery through modular manufacturing and creating a stable and growing pipeline of new build homes could significantly change the structural base of the housing market and would require different yield-based income models. Faster, factory-based production of homes can take only take place with guaranteed access to sites, ensuring homes are absorbed by the market as they are completed. This could pose a challenge for deploying more modular homes within existing land and planning regulations. As De'Ath and Farmer report (2020: 27), modular homebuilding at scale will only be viable if it is also fundamentally aligned to market absorption. There needs to be a large and consistent pipeline of demand to make factory-built homes viable.

Higher costs of investment

The cost of investment required to adopt modular housing models is high, and this represents a major barrier to the uptake of new technologies in the housing sector (Burgess at al. 2020). In particular, modular housing requires large up-front investment in housing production facilities, and this often deters housing developers who are primarily interested in reducing costs and increasing profit. It is currently a fragmented market, and modular construction has higher costs than traditional building in terms of initial capital investments: developers using traditional construction methods do not bear the costs related to investment in factories and training their workforce in the skills specific to offsite construction (De'Ath and Farmer 2020).

UK skills gap

As previously noted, the skills required for offsite construction are not the same as those used in traditional construction, and this acts as a barrier to uptake in the UK (Burgess et al. 2020). Investment in training to address this gap is required. Those companies which cannot

adapt will likely lose work to those that can, and small companies which lack the resources to upskill their workforces are most at risk of losing out (Milbank 2019). Should demand for offsite construction increase, it is probable that, if these skills gaps are not sufficiently filled in-country, an increased proportion of contracts for projects in the UK will be awarded to large global firms. As such, the economic benefits of modular construction may not be effectively harnessed by the UK. Indeed, countries such as Sweden and Japan already have a strong offsite offering, with highly competitive firms able to operate internationally (ilke Homes 2020). A step towards closing the skills gap in the UK has recently been made by the CITB via the investment of £1.2 million in materials for both classroom-based and practical training to upskill the workforce and enhance the UK's capacity for offsite construction (CITB 2019).

Embracing new business models

One of the most pressing structural challenges for the industry is that deployment of modular housing requires a structural shift from current supply and delivery chains to new and different business models. Possibly the key challenge inhibiting this shift is the lack of a pipeline of demand that is large enough and stable enough to ensure the market absorption of new homes and to maintain the financial viability of offsite factories.

These structural constraints relate to how the housebuilding industry traditionally functions, the nature of business and supply chain models used in the sector, as well as the lack of regulation to govern the use of these innovations (Burgess et al. 2020). The traditional housebuilding industry operates on a location-based model with a fragmented, flexible supply chain that is able to accommodate late, onsite design alterations. The low level of coordination and complex, highly localised supply chains pose a barrier to the implementation of BIM and offsite construction, and greater use will require a paradigm shift towards more collaborative procurement routes, highly coordinated design processes and early-stage design finalisation (Burgess et al. 2020).

Reduction in local economic benefits

Moving a major part of the construction process offsite inevitably poses the risk that local economic benefits of construction will be reduced. Unlike traditional construction, the labour force for offsite construction does not need to spend lengthy periods onsite. As noted by the House of Commons (2019a), such construction methods can lead to a 70% reduction in the labour needed onsite. It follows that local economic contributions associated with the onsite element of construction are therefore likely to be much smaller, which may have negative implications for local employment. One suggestion as a possible feature of delivery in the future, and which could potentially mitigate against these risks, is the notion of the 'flying factory'. Flying factories would be temporary manufacturing facilities which would enable

production to occur near to the location of the site, and which, in theory, could use local labour (House of Commons 2019b). Developing a standardised 'kit of parts' of housing components may allow a variety of construction businesses, including local SMEs, to supply components for modular homes.

Lack of evidence of benefits

One of the key constraints for the uptake of new technologies in construction is the lack of evidence to confirm the benefits of the use of offsite and modular techniques. Some large developers and housing associations have made investments in the use of these innovations, but there is still a lack of sufficient comprehensive evidence to demonstrate clear commercial gains from offsite construction and modular approaches over traditional methods. Also, there is insufficient evidence in relation to the short and long-term financial benefits, which prevents wide uptake by developers. Low interest in the additional value of lifetime operating cost savings (e.g. energy efficiency savings) to be gained from using innovative construction technologies means that developers frequently lack the motivation to invest in the use of offsite construction and MMC (Burgess et al. 2020). Developing a strong evidence base has the potential to boost confidence among lenders, encouraging them to finance housing projects that employ innovative approaches.

Consumer perceptions

As has already been mentioned, housing consumers in the UK are known to have a historically negative view of housing built with the use of offsite and modular technologies. Indeed, systematic failures in mass construction during the twentieth century substantially undermined public and professional opinions of this type of housing production (De'Ath and Farmer 2020). As a result of lingering negative perceptions of post-war prefabricated buildings, housing customers in the UK still have a cultural preference for traditionally built 'bricks and mortar' homes, and overcoming the belief that modular houses are inferior to traditional houses is one a major challenge facing the construction sector today. Tackling this challenge will require the sector to increase quality standards and ensure that modular buildings are aesthetically pleasing. Furthermore, a lack of public trust means that, in the short term, modular homes are likely to face greater scrutiny than homes produced via traditional methods.

Issues of customisation

There are certain concerns and risks associated with deploying modular housing that relate to the issue of customisation. In particular, developers might not be able to work with individualised customer feedback on a large scale, and standard house types are likely to be created to meet the most common needs among customers. To ensure possibilities for customisation and variability of housing solutions, standardisation of components to be used

by different manufacturers across the industry would be required in order to avoid issues of interoperability that might emerge, as non-standard components could generate onsite fit issues and subsequent additional work. Furthermore, in order to proceed with customised modular housing, the industry will need improved understanding of customer experiences and feedback. A recent review of offsite construction literature (Oti-Sarpong et al. Forthcoming) has shown that post-occupancy evaluation of end users of offsite-constructed properties is clearly missing, and very little work has so far been done to explore the experiences of modular homeowners and tenants.

Risk-averse insurers and lenders

Organisations in the housing sector wanting to shift to a modular housing model often encounter substantial financial expenses, and necessary funds can be difficult to access. The cost of borrowing to fund investment in innovations can be high (Burgess et al. 2020). Lenders and insurers are risk averse to financing developers and contractors applying innovative approaches as they are seen as high risk compared to conventional housing approaches. Warranty provision for modular built homes is important, although De'Ath and Farmer believe that progress is being made in this area:

> *'Recently, a major step forward was achieved in terms of building confidence in the financing and insurance of MMC. A collaborative Memorandum of Understanding has been agreed amongst the leading new build warranty providers to work towards aligning technical assessment methods used for MMC. Greater uniformity is vital if we are going to avoid confusion over required minimum standards. In addition, the MMC assurance market has been expanded with the recent introduction of the NHBC Accepts standard that manufacturers can now secure. This builds on the pioneering development of the Buildoffsite Property Assurance Scheme (BOPAS). Both of these standards provide a scalable basis for the mainstreaming of modular and MMC delivery with the finance and insurance communities'. (De'Ath and Farmer 2020: 21)*

Resistance to change

Resistance to change among individuals and management at the organisational level in the housebuilding sector can present another constraint for the use of modular and offsite construction techniques. This is valid across many innovations in the economy but is particularly true in traditional industries, like construction, which can still find a market for their traditional products. The shift to innovations is associated with risks which are perceived as unnecessary, and would require organisations to make not only substantial investments, but also major organisational changes, including the development of relevant new capabilities for deployment. Resistance at the employee level is linked to fears of job or

status loss, and insufficient awareness or understanding about the new technologies (Burgess et al. 2020). For example, employees may not have the required level of digital literacy to implement and use BIM systems, requiring time-consuming and expensive training.

Lack of regulation, insurance and standards

As previously mentioned, the lack of regulation governing the use of innovative technologies in construction presents another challenge. In particular, the construction sector's current operational environment has been designed for traditional housing, with regulations and standards across the planning system, government grants, and insurers and funders' policies all being based on onsite building rather than factory production (De'Ath and Farmer 2020). In order to roll out modular housing on a larger scale, adaptation of regulations and standards to construction processes, business models, standards, operational structures, procurement, planning and building regulations, warranties, and funding of the modular approach will be needed, and agreed standards should be implemented across the industry.

Lack of incentives

The current housebuilding industry model is largely profit-driven and has low incentives to build faster or at scale given that this would potentially lower prices and consequently reduce profits for developers (Burgess et al. 2020). To support the programme of large-scale modular housing production, it will be necessary to facilitate a positive policy environment (De'Ath and Farmer 2020) for those developers who adopt it, including mechanisms such as public funding incentivisation, discounting and planning breaks. There is also a need for mitigation strategies to attempt to balance developers' risks. As posited by De'Ath and Farmer (2020: 27), 'developers will not build out projects unless there is an end client, whether it be a domestic purchaser, a housing association, a local authority, an institutional investor or fund, or indeed the Government'. Given this, a diversification of tenures and adjustment of financial solutions will be needed to produce a larger number of homes and to deliver infrastructure using a modular approach.

Storage, transport to site and onsite fit issues

Finally, several issues arise in relation to the logistical side of modular manufacture of housing. In particular, if the industry reaches the target production rates, this will create further infrastructure demands in addition to factories, such as a need for additional facilities to store the produced units or modular components prior to onsite installation. Furthermore, given that production sites are to be located in certain areas while housing delivery is needed across the whole country, there could be issues with transporting elements produced offsite to the construction site. Not only would this create additional pressure on major transport routes, but the movement of large modules will require suitable safety protocols,

including escort vehicles, and weather considerations will need to be taken into account. Additional risks and compatibility issues derive from the onsite fitting of prefabricated elements.

6. Recommendations

- The greater deployment of modular housing could be facilitated through further financial commitments (e.g., government grants, tax breaks and subsidies aligned with modular approaches) and planning policy incentives from the government (such as 'fast-tracking' of planning permission for modular housing development).

- Given the anticipated greater scale and increased speed of production of modular-manufactured homes compared with homes built using traditional approaches, a stable pipeline of demand is needed to ensure the market absorption of new homes and to maintain the financial viability of offsite factories. This could be achieved through the promotion of investment in the private rented sector (e.g., Build to Rent), or through utilising public land supply to help ensure access to sufficient suitable sites for modular housing development. It could also be achieved through greater housing provider collaboration in modular procurement.

- A clear and coherent set of standards and regulations (including technical issues, quality, and health and safety) for the industry is needed to mitigate risks and provide certainty and confidence for clients and contractors who decide to use modular approaches, offsite manufacturing and MMC, as well as for consumers. Modular homes need the same warranty provisions as traditionally constructed homes in order to create confidence amongst consumers, lenders and insurers.

- The deployment of modular housing requires different skills compared to those needed for traditional building methods. To ensure the industry's labour force is equipped with the necessary skills (such as digital literacy, use of new software and knowledge in offsite manufacture), retraining schemes and education programmes need to be delivered in collaboration with national and local government, education providers, industry bodies (e.g., the Construction Leadership Council) and the housebuilding industry.

- Local authorities should ensure that the recommendations of central government are supported at the local level. This could be achieved by incentivising modular manufacture methods in local planning policy or by promoting local education and skills training to develop a suitably skilled workforce.

- In addition to upskilling schemes and training at the organisational level in the industry, it is recommended that housebuilders and developers identify and support individuals or teams to lead and champion their innovation journey through

incremental adoption and use of modular methods, offsite manufacturing and MMC, and to combine this with their digital innovation strategy. Such leaders should boost employee confidence in the vision, the implementation strategy, and the expected outcomes from the transition to greater use of digital innovation and modular housebuilding.

- The industry needs to provide strong backing to innovation champions among housebuilders and developers who actively use modular and offsite approaches and MMC, in order to boost their efforts and promote the benefits of innovation.

- Systematic data capture and evidence collection by housebuilders and developers around the use of modular and offsite methods are needed to create a strong evidence base of the benefits of offsite housing construction and MMC. This would help to combat customers' mistrust, overcome risk aversion, and boost confidence among lenders, and provide benchmarking for new housebuilders entering the modular housing production sector.

- Construction in general, and housebuilding in particular, will play a vital role in the UK's post-COVID recovery. More can be done within the construction and housebuilding sector to develop a vision of how the uptake of modular methods, offsite manufacturing and MMC will be part of this recovery, and could also help to tackle regional inequalities and address the 'levelling-up agenda'. This will require collection of data on where components are both manufactured and used, in order that the geographies of production can be understood and used to inform decision-making about sustainable and responsible procurement.

- Housebuilders and developers could do more to engage with customers in the design process, and with end users, to gather post-occupancy data. Feeding this data back into house design will bolster the aim of increasing resident satisfaction and improving building performance.

- To overcome the problem of interoperability between different components manufactured offsite, which can create onsite fit issues and other additional work, standardisation of the components, e.g., having a 'kit of parts' to be used across the industry by different manufacturers, is recommended. Suitable collaboration platforms in the construction sector (such as through the Construction Innovation Hub) could play a role in the development of standards, tools, designs, and regulation methods and support a sustainable marketplace for modular and offsite manufacturing.

- To share learning about deploying modular housing, initiatives to promote collaboration need to be pursued both within the housebuilding industry (e.g., the Building Better group, NHF 2020) and the wider construction sector. This would provide structures for effective communication and exchange of experience, synthesise learning, and help to build networks and collaboration opportunities.

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