

Cambridge Centre
for Housing &
Planning Research

BIM in the UK house building industry: opportunities and barriers to adoption

Dr Gemma Burgess, Michael Jones and
Kathryn Muir

March 2018

Contents

1. Abstract.....	1
2. Introduction.....	2
3. Research questions.....	3
4. Methodology.....	3
5. Discussion.....	4
7. Conclusions and further research.....	31
8. Acknowledgements.....	33
9. Appendices.....	34
10. References.....	38

1. Abstract

The Centre for Digital Built Britain commissioned this study to explore the use of Building Information Modelling (BIM) in the UK house building industry, and to consider the opportunities and barriers to its wider uptake. The study included a review of existing evidence and literature. Telephone interviews were conducted with practitioners from the industry about the use of BIM. A round-table discussion was held with key stakeholders in the house building industry.

What the study has shown is that the potential benefits from the adoption of BIM have been recognised within the industry. Potential benefits include reduced construction costs and time efficiencies, fewer design clashes and costly reworking on site, greater accuracy in design and build, and fewer defects in new homes.

However, the take up of BIM has been slow and has been prohibited by several factors. Adoption of BIM within house building companies requires a considerable investment of time and resources, and there are skills shortages across the industry. Progress has been made in encouraging suppliers to make greater use of BIM, but the nature of the house building industry, with many small sub-contractors over multiple sites, has meant that downstream adoption by such sub-contractors has been more difficult. There needs to be an increased awareness of what BIM actually is, how it can be used and what benefits it can offer in order to make its adoption more widespread throughout the house building industry. This may need to come from various sources, and will need to be both top down and bottom up. Further research and discussion with the industry about what could be done to facilitate change and the wider use of digital technologies would be useful.

For more information about this study please contact Dr Gemma Burgess on glb36@cam.ac.uk.

2. Introduction

The Centre for Digital Built Britain was announced by HM Government on 29 November 2017. The University received funding of £5.4 million from BEIS via Innovate UK to support the creation of a Centre for Digital Built Britain (CDBB) at the University of Cambridge, focusing on the ongoing transformation of the built environment through the digital tools, standards and processes that are collectively known as Building Information Modelling (BIM).

The Cambridge Centre for Digital Built Britain will support the digitally enabled transformation of the full lifecycle of the built environment to increase productivity and to improve economic and social outcomes in the UK and, where appropriate, internationally. The Centre will achieve this by developing and demonstrating policy and practical insights, leading to new standards and guidance that will enable the exploitation of new and emerging technologies, data and analytics to enhance the natural and built environment. In turn, this will increase productivity, help to create 'high performing assets' in terms of construction and operational efficiency, leading to an improvement in the services they were created to deliver, creating commercial opportunities and enhancing citizen quality of life and well-being. The Centre, with its government, industry and academic partnership approach is conceived as a national focal point for this work and the custodians of the integrity of the UK BIM and Digital Built Britain Programme.

The Centre for Digital Built Britain commissioned this study as part of a series of projects across the University of Cambridge, looking at how digital technologies impact the built environment and how society might be affected by the changes which may follow from the employment of these technologies.

The aim of the study was to explore the use of BIM in the UK house building industry, and to consider the opportunities and barriers to its wider uptake.

The UK has a chronic under-supply of housing, with numerous negative social impacts, and there is cross-party governmental support for the need to increase house building rates. Current home-building rates are just half of the 300,000 required to replace the housing which falls below Government standards and to provide for the backlog of unmet need. The housing crisis in the UK demands innovative and affordable models of housing production and design. Although innovation has been claimed as the key to meeting the challenge, many researchers into construction comment on the inherent conservatism and lack of innovation in the house building industry.

In relation to the UK house building industry, the report covers:

- a definition of BIM
- how it can be used in house building
- current uptake of BIM
- innovation in the industry
- BIM and off-site housing manufacture
- barriers to the adoption of BIM

3. Research questions

The research set out to answer the following questions:

1. What benefits could BIM offer to the house building industry?
2. How is BIM currently used in the house building industry?
3. What are the barriers to the adoption of BIM in the house building industry?

4. Methodology

The study included a review of existing evidence and literature. Telephone interviews were conducted with practitioners from the industry about the use of BIM. A round-table discussion was held with key stakeholders in the house building industry.

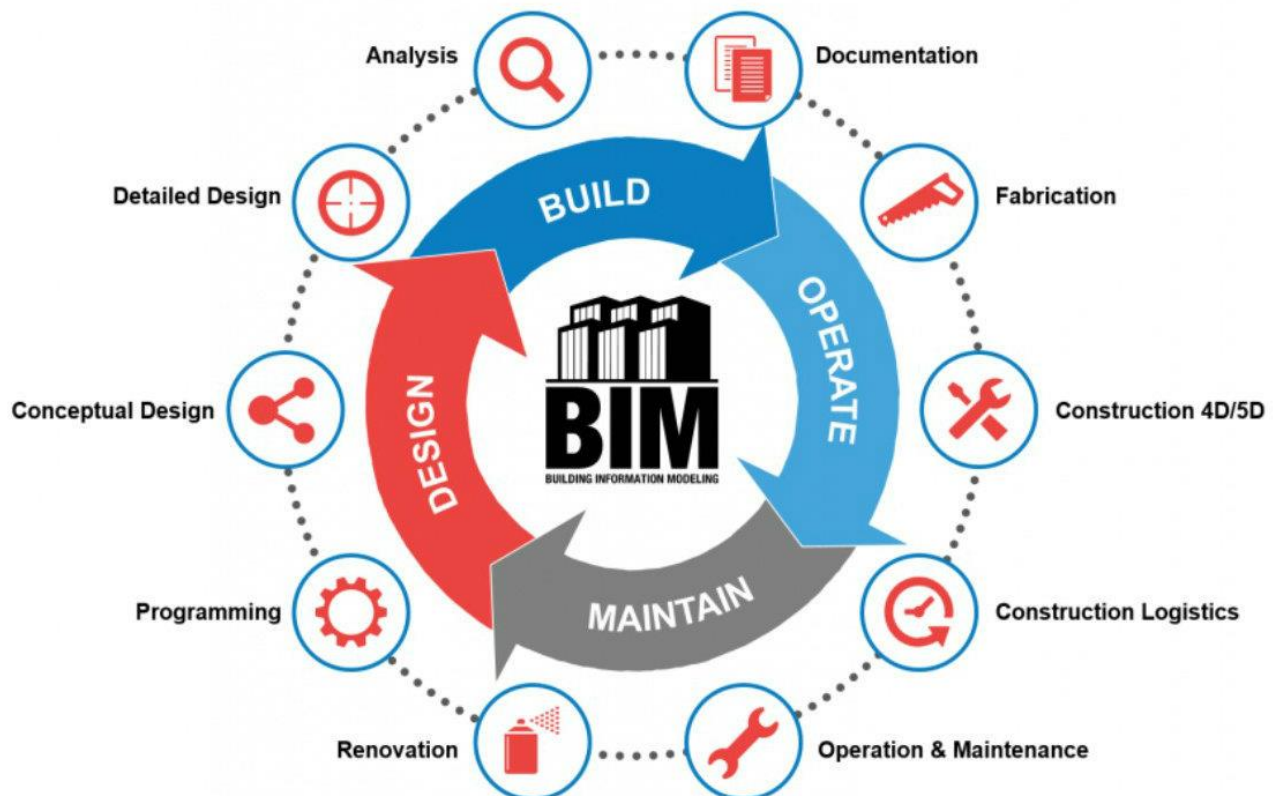
5. Discussion

5.1. What is BIM?

Autodesk (2018) define Building Information Modelling, or BIM, as:

“An intelligent 3D model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure.”

As part of the construction process, a wide range of documents need to be shared between clients, designers and developers, including drawings and schedules. Traditionally, this information has been exchanged using paper (or electronic paper). BIM provides a shared data environment which allows all the stakeholders in a project to collaborate and share information. BIM allows key product data to be embedded within 3D images that can be used for project management, with potential gains in efficiency. Figure 1 summarises how BIM can be used through the construction cycle.



(c) Dortek.com

Figure 1 The top 10 benefits of using BIM (Dortek, 2017)

5.2. The house building industry: an overview

The structure of the UK house building industry is an important consideration in developing and embedding the use of digital tools and technologies. This section provides some contextual information about the size and nature of the house building industry.

The existing housing stock represents 80% of the total built floor space in England, as shown in Figure 2. By value, housing represents 35% of all new construction work, and 53% of all repair and maintenance work.

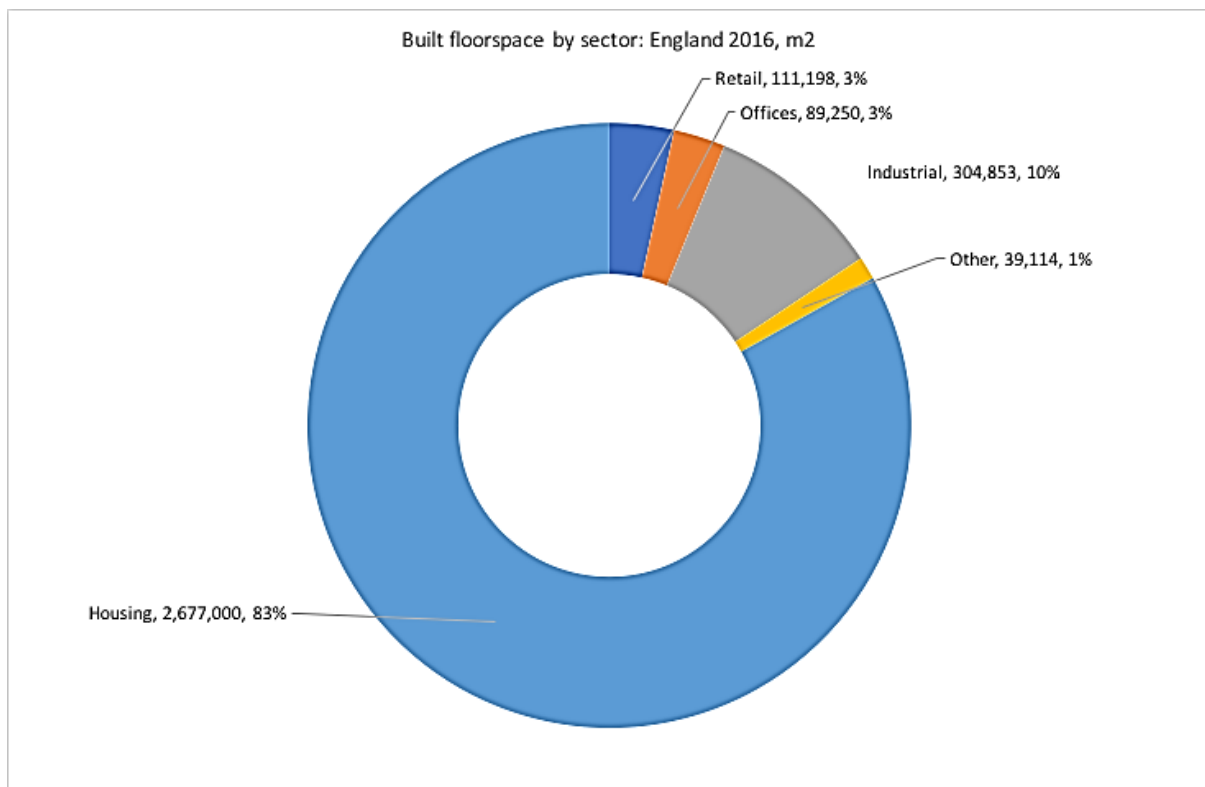


Figure 2 Built floor space by sector – England 2016 (Valuation Office Agency, 2012; DCLG, 2016; ONS, 2017)¹

¹ Non-residential floorspace from Valuation Office Agency (2012), residential floorspace from DCLG (2016) and ONS (2017)¹

House building firms and housing production

Over the seventy years from 1946 to 2016, house building contractors provided three out of every five (62%) homes built, as shown in Figure 3. Nearly 40% of output was built by general contractors employed by local authorities and housing associations.

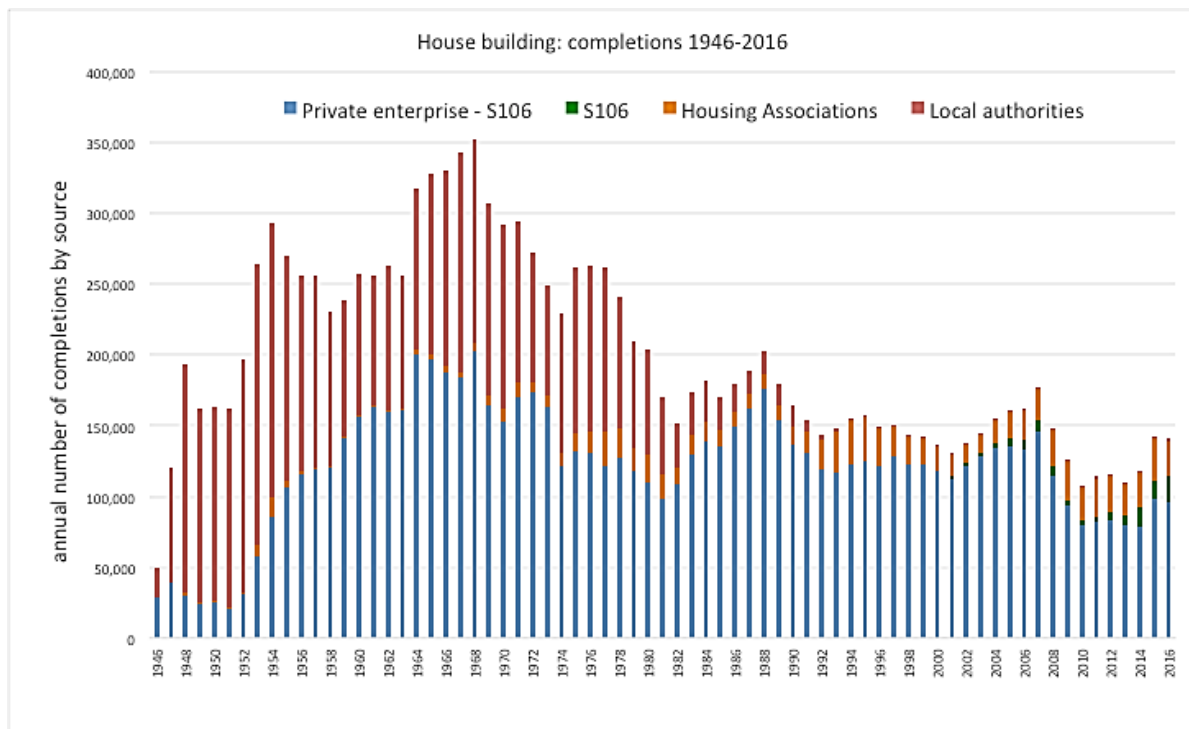


Figure 3 House building completions 1946-2016 (Source: MHCLG Live Table 244)

Although the output of the house building industry is markedly cyclical, the longer term average annual output of the industry has been relatively stable. Output at the peaks of the cycle has fallen from just over 200,000 homes in 1968 to around 175,000 in 1988 and to around 155,000 in 2007. The long term average annual output of the house building industry, from the relaxation of post-war controls around 1953 until 2016, was 132,600 homes.

The house builder business model

The business model of the house building industry is very simple: land is purchased, planning permission is obtained and houses are built and then sold.

The selling prices of houses are primarily determined by location: more floor area, higher quality specification, lower running costs or superior environmental performance have only a marginal effect on selling prices. The price that house builders are willing to pay for land in a competitive market is determined by the selling price of the house minus its total cost of

construction: given (relatively) fixed selling prices, house builders maximise the price that they can afford to pay for land by minimising construction costs at every level. Improvements in efficiency in construction therefore mean that house builders can afford to pay more for land. House builders aim to retain no asset or interest in the product following its sale, aiming to move on from one site to another with no ongoing commitments. Apartment blocks require a different financing model, since the individual flats cannot be sold and occupied until the building is complete overall, requiring the developer to carry the cost of finance until completion.

Minimising the cost of finance during construction is a key element in cost reduction. Houses take roughly a year to build, and the costs are only recouped (other than the small element of reservation deposits) when the completed house is sold to a purchaser. House builders therefore attempt to match the rate of house building to the likely rate of sales on any individual site. The industry believes that it is difficult for a house builder to sell more than one house per week on any individual site. A site for 100 homes will therefore take at least two years to 'build out'. Large sites are often split between several firms, each offering a slightly different product or price point in order to attract more purchasers. In some cases, the different firms operating on a particular site may be subsidiaries of the same group.

Although there are a large number (10,500) of house building firms registered with the NHBC (who supply 80% of the new build warranty market), the industry is highly concentrated, with 50% of output provided by the top 10 house building firms, and 80% provided by the top 100.

The UK house building market is more concentrated than that of the USA: the top 20 house building firms in the USA built 153,000 homes (12% of the total market) in 2015, while the top 20 firms in the UK built an average of 75,000 homes, or 69%, of a market less than one tenth the size.

The larger house builders have each developed their own range of standard house types, which might be used for up to 80% of output, with elevations and external materials varied to suit local planning constraints. Sites with specific constraints, such as Conservation Areas, might have bespoke designs prepared by architects. London is generally treated as an entirely separate market, with one off designs commissioned from architectural firms, partly reflecting the complexity of sites and planning constraints, but also reflecting the much higher proportion of flats and apartment blocks in the housing mix.

The impact of the financial crisis on house building

In the ten years leading up to the financial crisis in 2008/09, the proportion of smaller (mainly two bedroom) flats in house building output almost quadrupled, from 12% in 1997/98 to 46% in 2008/09. The financial crisis resulted in a sharp downturn in sales, and an even sharper downturn in bank lending to the industry, leaving house builders exposed to the costs of financing bank lending for land purchase and for working capital. The response of the industry was to revert to constructing larger 'family' houses rather than flats (and, in some cases, a reversion to explicitly 'traditional' architectural styles) in order to reduce working capital requirements, and a shift from bank finance for land purchase to the use of 'land creditors', where the price of land is paid for following the sale of completed units rather than upfront.

The proportion of flats in the housing mix had more than halved by 2016/17 to 21% of output, while the proportion of one and two bedroom homes fell from 53% of output to only 29% by 2016/17. The overall result was that the industry effectively turned from building homes for first time buyers to building homes for second or third time purchasers.

A consequence of the effect of the financial crisis in forcing a change in the output mix of house builders has been the loss of skills and expertise in apartment block construction, and a parallel reduction both in repetition and in the need for more complex documentation of the project. The construction of two or three storey houses on a building site, at a rate of one completion per week, using traditional materials and methods, allows the industry to operate with minimal documentation and to employ very small subcontractors for the actual construction work.

Quality control in house building

As a consequence of the construction process adopted by the industry, quality control across multiple sites and multiple small subcontractors presents major problems. The claims experience of the NHBC, which offers a ten-year warranty against construction defects for 80% of new homes in the UK, illustrates the problem. The NHBC produces a comprehensive standards manual covering virtually every aspect of housing construction, runs an extensive programme of technical training for the industry, employs 375 inspectors who carry out 914,000 site inspections per annum, and still pays out £85m per annum to rectify defects experienced by house purchasers. The most common reason for claims (40% of total claims), are for repairs to the external structure and rendering of properties. The most common defects in this area result from incorrectly installed damp proof courses, a standard, common element in house building, and a source of entirely preventable defects.

Summary

This overview of the house building industry highlights a number of issues confronting the industry which include:

- The structure of the industry appears to inhibit its ability to expand output to meet demand;
- The cyclical nature of the industry results in the loss of skills in recession and labour and materials shortages in growth periods;
- Reliance on using sub-contractors, combined with low levels of training, create problems of quality control on site;
- Although experiments with innovative methods of construction exist, these have not gained widespread acceptance;
- Limited uptake of BIM and digital technology affects quality control on site which contribute to building defects, warranty claims and customer dissatisfaction.

The next sections of the report address the opportunities for the application of BIM across the house building industry.

5.3. What are the opportunities for house building?

The NHBC Report *'Building Information Modelling: An introduction for house builders'* (NHBC, 2013) details the potential of BIM to assist in the house building and construction industries. It describes how BIM software tools can be used (in place of Computer Aided Design products) to generate drawings and schedules which can then be accessed by all stakeholders.

BIM software can be used to virtually 'trial' potentially difficult construction projects, meaning that any problems can be resolved in the virtual environment, preventing costly re-workings on site. The models can also be used to generate schedules of items required, such as doors, windows and radiators, whereas traditionally these items would need to be manually counted from drawings.

Quite complex information can be embedded in the models, as described by Patrick King, Head of BIM technologies at ECD Architects:

"When you click on a window in the 3D model, it gives you loads of parameters – height, width, fire ratings, warranties...same with a wall: the paint finish, how many coats, its acoustic rating, whether it's timber framed – any information you want." (King cited in Brandon, 2017)

BIM offers an efficient method of designing and creating buildings through the entire life-cycle of a project:

"It allows greater transparency and collaboration between all stakeholders and thereby reduces waste (procurement, process and material) through all levels of the supply chain." (Homes and Communities Agency, 2015)

Hyde (2016) suggests that using BIM can reduce costs, save time and energy, and summarises the main benefits of BIM as:

- Reduction of design errors, by making it easier to identify errors before a site commences; this may save on cost and time by eliminating rework.
- Reducing conflicts and design clashes, which would otherwise result in construction changes; saves on construction costs and time.
- Construction of sustainable buildings, using materials that could decrease environmental impacts; this reduces energy use.
- Efficiency improvements for maintenance and operation companies. By having historical design data instantly available, up to 15% can be saved on maintenance time and sometimes may remove the need for costly site visits.

In 2011, the government mandated the use of BIM on all their construction projects by 2016 (Cabinet Office, 2011) and is now aiming to enable BIM Level 3 adoption, in conjunction with industry, under the remit of the Digital Built Britain Strategy (Infrastructure and Projects Authority, 2016). In its Industrial Strategy "Construction 2025" (HM Government, 2013), the government commits to:

- Build the UK's competitive advantage in smart construction and digital design through the Digital Built Britain agenda.
- Work with academic and research communities to bring forward more research, development and demonstration to the wider industry and work to remove barriers to innovation.
- [Support] a UK industry that leads the world in research and innovation, transformed by digital design, advanced materials and new technologies, fully embracing the transition to a digital economy and the rise of smart construction. (HM Government, 2013)

The government recognises that the process of moving the construction industry to 'full' collaborative working will be challenging, and have defined distinct milestones in this process. Richard McPartland of NBS provides the following definitions of these milestones (NBS, 2014):

Level 0 BIM

In its simplest form, Level 0 effectively means no collaboration. Only 2D CAD drafting is utilised, mainly for Production Information. Output and distribution is via paper or electronic prints, or a mixture of both. The majority of the industry is already well ahead of this.

Level 1 BIM

This is the level at which many organisations are currently operating. This typically comprises a mixture of 3D CAD for concept work and 2D for drafting of statutory approval documentation and Production Information. CAD standards are managed to BS 1192:2007, and electronic sharing of data is carried out from a common data environment (CDE), often managed by the contractor. Models are not shared between project team members.

Level 2 BIM

This is distinguished by collaborative working. All parties use their own 3D CAD models, but are not necessarily working on a single, shared model. The collaboration comes in the form of how the information is exchanged between different parties and is the crucial aspect of this level. Design information is shared through a common file format, which enables any organisation to be able to combine that data with their own in order to make a federated BIM model, and to carry out interrogative checks on it. Hence any CAD software that each party used must be capable of exporting to one of the common file formats such as IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange). This is the method of working that has been set as a minimum target by the UK government for all construction work on public sector projects, by 2016.

Level 3 BIM

Level 3 represents full collaboration between all disciplines by means of using a single, shared project model which is held in a centralised repository. All parties can access and modify that same model, and the benefit is that it removes the final layer of risk for conflicting information. This is known as 'Open BIM'. Current nervousness in the industry around issues such as copyright and liability are intended to be resolved, the former by means of robust appointment documents and software

originator/read/write permissions, and the latter by shared-risk procurement routes such as partnering. The Construction Industry Council (CIC) BIM Protocol makes provision for these.

5.4. How is BIM currently used in the house building industry?

Awareness of BIM is starting to spread through the construction industry, driven by the UK Government mandating its use on their construction projects. NBS carry out an annual 'National BIM Survey' of those working in the construction industry. The 2012 survey found that 31% of respondents were using BIM (NBS, 2012). By 2017, NBS reported that 62% of respondents were using BIM (NBS, 2017). In the 2017 survey, participants were asked how they thought their organisation would use BIM in the future. Ninety percent think they will be using BIM in the next year, and 95% think they will be using BIM in the next three years.

How would you describe your organisation's future use of BIM?

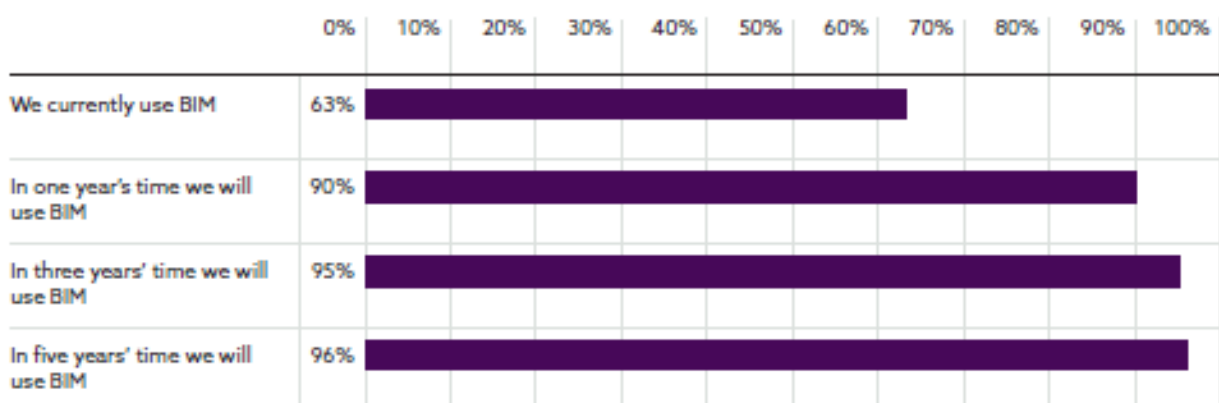


Figure 4 NBS (2017) *NBS National BIM Report 2017*. [Online]

Uptake by the housebuilding sector has, however, been slower. In February 2017, Nigel Walley from Chimni described house building as:

"The BIM industry's most notable failure to date, with only those parts exposed to public sector procurement having made significant progress." (Walley, 2017)

In 2013, the NHBC surveyed eighteen major house builders in the UK to assess their levels of awareness and understanding of BIM (NHBC, 2013). They found that only 11% of the major house builders were currently engaged in BIM. Twenty-five percent had not heard of BIM, and the majority (64%) had looked into it but could see no obvious application or benefit to their business in using it. Those house builders that did use BIM used it in only limited ways:

“Generally, the practitioners did not require their supply chains to engage with BIM, but issued information, generated from the model, via electronic files or hard copy.” (NHBC, 2013, p. 7)

In contrast, almost all of the architects, electrical engineers and mechanical engineers surveyed by the NHBC were aware of BIM, and more than half were already using it. House builders appear to be lagging behind other players in the construction industry.

There have been some shifts towards using BIM within the house building industry. In 2017, Nottingham City Homes became the first developer to use BIM technology to build social housing, when it built The Meadows, a £5.5m, 54-home regeneration scheme in Nottingham. The former head of development at Nottingham City Homes stated that on a per-unit basis, the development cost five percent less than a development it built at the same time using traditional methods (Brandon, 2017).

Wienerberger (a leading provider of wall, roof and landscaping innovations), together with ARUP (a global engineering and design consultancy), have designed and built a ‘e4 brick house’ that they state “has been designed to exemplify best practice BIM, to push boundaries and to showcase the full extent of what can be achieved through digital construction in the UK housing sector.” (Wienerberger, 2018a).

Wienerberger describe how using BIM enabled them to structure the build process to encourage collaboration and optimise time and material efficiency. At the planning stage, they were able to provide bills of quantities generated by BIM. They were also able to offer planning support, including live clash detection, once multiple parties had access to the model. This meant they could detect and resolve any issues that arose during construction. They explain the benefits of using BIM:

“Essentially BIM enables an e4 project to be built “twice” - once digitally modelled and then physically constructed on site. This process allows greater control over the project and uses the Information Management to provide efficiencies and savings by removing duplication and errors” (Wienerberger, 2018b).

Richard Whittaker, former head of development at Nottingham City Homes, reiterates its advantages in improving accuracy in design, meaning fewer expensive corrections have to be made on site once construction has begun. He also states its advantages in increasing accuracy in materials schedules, as the system automatically updates the quantities of materials required as changes are made to the design (Brandon, 2017).

However, despite these individual examples of the uptake of BIM, there is a long way to go. In a 2016 review of the construction industry, Farmer suggested that there is:

“A large scale reality gap related to the industry’s BIM adoption strategy. The government’s own measures to lead this agenda as a client of the industry have not reached significant parts of the design and construction world, which unfortunately includes the majority of house builders and private developers.”
(Farmer, 2016, p.36).

5.5. Innovation in the UK house building industry

This section gives some wider context about innovation more generally in the UK house building industry. Farmer’s 2016 review of the UK construction labour model was dramatically titled ‘*Modernise or Die: Time to decide the industry’s future*’. The report was damning of the current situation, suggesting that if fundamental changes are not made, the construction industry will become “seriously debilitated” (Farmer, 2016, p.8).

The perceived problems in the industry identified in the report included:

- low productivity, due to not embracing the role of technology;
- problems of future workforce capacity, due to an ageing workforce, a low level of new entrants, and deep and recurring recessions;
- a lack of collaboration and improvement culture, which prevents organisations from scaling up, sharing risks and creating more business plan certainty;
- lack of R&D and investment in innovation.

The report strongly advocates the uptake of off-site manufacturing and BIM to address the issues above. Farmer states that “now is the time to allow the opportunities from digitisation to offset the risks of continued reliance on labour intensive techniques” (ibid, p.5).

However, Farmer reports that the construction industry is widely rejecting innovation:

“Negative perceptions have... led to many innovative approaches to construction design and construction processes immediately being considered as high risk... terminology such as ‘modern methods of construction or ‘prefabrication’ are often viewed with suspicion” (ibid, p.35)

Lloyds Bank’s ‘*Housebuilding Report 2018*’ gives a more positive picture of the uptake of innovation among house builders, suggesting that the housebuilding sector is “proving eager to adopt innovative new building techniques, which hold the potential to address

challenges around the supply, quality and affordability of new homes, as well as boosting productivity and profitability” (Lloyds Bank, 2018, p.10).

Lloyds Bank highlight modern techniques centred on building housing components off-site for delivery and assembly, and also cite futuristic techniques including robot bricklayers and 3D printed homes. Through their research, they found that the majority of building firms are investing in new building techniques, led by modular housing (68%).

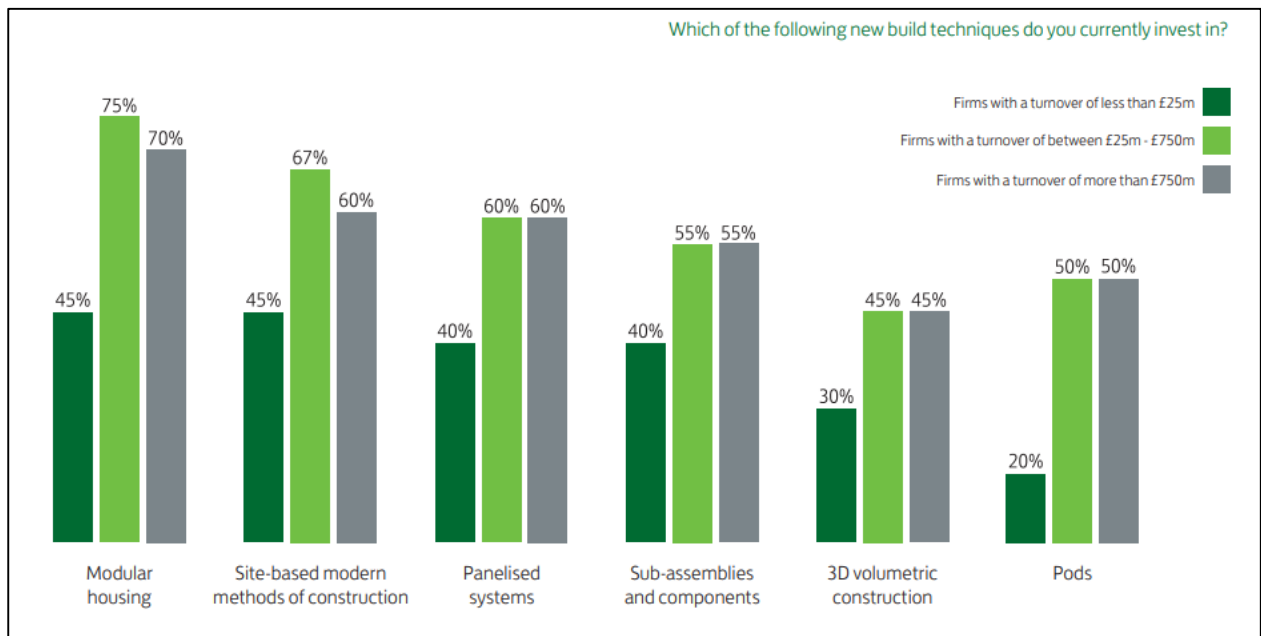


Figure 5 Building firms’ investment in new build techniques (Lloyds Bank, 2018, p.10)

They cite a broad range of motivations behind firms’ adoption of various new techniques, including:

“Efficiency, growing margins, ease of build, better construction standards, better energy performance, elimination of waste and customer affordability” (ibid, p.10)

Many new building techniques are available. The NHBC Foundation split these “Modern Methods of Construction” (MMC) into five main categories (NHBC Foundation, 2006), as shown in Figure 6.

Types of Modern Methods of Construction (MMC):

1. Off-site manufactured – volumetric (three-dimensional units produced in a factory, fully fitted out before being transported to site and stacked onto prepared foundations to form dwellings).
2. Off-site manufactured – panellised (flat panel units built in a factory and transported to site for assembly into a three-dimensional structure or to fit within an existing structure).
3. Off-site manufactured – hybrid (volumetric units integrated with panellised systems).
4. Off-site manufactured - sub-assemblies and components (larger components that can be incorporated into either conventionally built or MMC dwellings).
5. Non-off-site manufactured MMC (innovative methods of construction used on-site and the use of conventional components in an innovative way).

NHBC Foundation (2006) *A guide to modern methods of construction*.

Figure 6 Types of Modern Methods of Construction (NHBC, 2006)

The NHBC Foundation (2016) carried out telephone interviews with 135 house builders and housing associations around modern methods of construction. Those who reported using MMC in the past three years were asked about the benefits they experienced from doing so. Responses are presented in Figure 7 below:

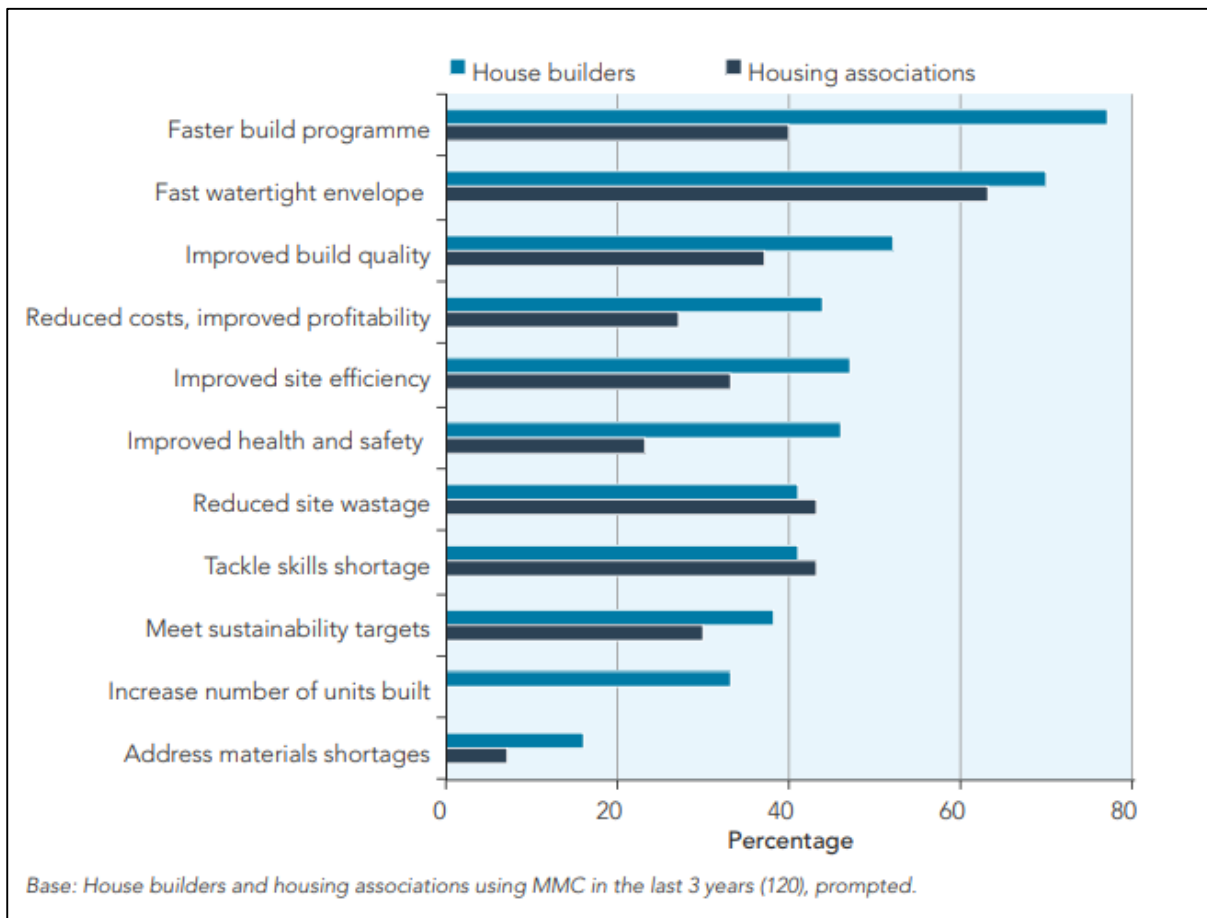


Figure 7 Main benefits of MMC experienced in practice (NHBC Foundation, 2016, p.19)

In recent years there has been support from the government for a larger contribution from “offsite” manufactured homes using MMC. The government promoted innovation in the 2017 Housing White Paper ‘Fixing our broken housing market’ (DCLG, 2017).

“The housebuilding industry is less productive than the wider economy, partly because it has been slow to modernise and make use of more efficient and faster ways of building. By increasing innovation and making greater use of modern methods of construction we can change this.” (ibid, p.54)

In the 2017 White Paper, the government outlines the ‘Home Builders Fund’, an existing source of support for innovators, which was launched in 2016 and provides short-term loan finance targeted at SMEs, custom-builders and innovators to deliver homes. It also announced the ‘Accelerated Construction programme’ which will involve the government partnering with small and medium-sized builders, contractors and others to build out surplus public-sector land. They specifically link these to modern methods of construction.

“Accelerated construction will... catalyse changes in the wider housing market, through supporting offsite manufacturing techniques and increasing the number of participants in house-building” (DCLG, 2017, p.48).

The NHBC Foundation (2016) explored potential barriers to using full volumetric or modular construction. They asked respondents to name two main barriers to using these modes of construction. The reasons most frequently given were capital costs and the lack of suppliers (NHBC Foundation, 2016, p.24).

Construction 2025, the government’s 2025 industrial strategy, identified five main barriers that prevent innovation in the construction sector:

1. The nature of construction procurement frequently restricts collaboration between client and supply chain, particularly at an early enough stage to fully explore options for innovation;
2. Companies are not confident that innovation will be commercially rewarding, with particular concerns about levels of demand for innovative products and services;
3. Companies that do want to innovate find that the necessary finance is too expensive and/or difficult to access, that the approach to risk and insurance of works deters innovation and that some of the Government support available to the industry is not sufficiently visible;
4. There is a failure to capture learning from successful innovations and take this forward to future projects; and
5. Collaboration between industry, academia and research organisations is patchy, which limits effective knowledge transfer. (HM Government, 2013)

Modern Methods of Construction: Case studies

The review identified some recent examples of the adoption of MMC on a relatively large scale.

Berkeley Homes

Berkeley Homes, London's biggest house builder, has committed 20 per cent of their output to factory-built homes. Their housing scheme in Kidbrooke, south-east London, includes twenty-two "Urban Houses" produced on a Midlands production line. The structural frame, walls and parts of these houses were assembled in the factory and then transported as "pods" or modular units (Spittles, 2016). Berkeley Homes has now been given planning permission to build a modular homes factory in Ebbsfleet, which will produce up to 1,000 properties a year.

Prior, G. (2018) *Berkeley gets green light for modular homes factory* [Online].

Legal and General

Legal and General invested £55m in a 580,000 sq. ft. offsite factory in Leeds in 2016, the largest offsite housebuilding factory in Europe. They anticipate that they will install their first factory-built modular homes in mid-2018. They are taking end-to-end control of development, design, delivery and operation, in a way that has been compared to the car industry. In June 2017, L&G appointed a senior Rolls Royce executive, Rosie Toogood, as chief executive of L&G Modular Homes.

Barratt (2018) *L&G expecting first factory homes by June* [Online].

Persimmon

Persimmon's 'Space4' business operates an off-site manufacturing plant producing timber frames, highly insulated wall panels and roof cassettes, but they have stopped short of producing entire homes off-site. Over 30% of the homes they build use Space4 products.

Persimmon (2014) *Space 4* [Online].

5.6. BIM and off-site housing manufacture

Farmer (2016) links BIM with the move towards MMC. He describes BIM as “a critical change agent for the industry, completely intertwined with the move to manufacturing led approaches” (p.36).

The government also makes explicit links between BIM and off-site housing manufacture:

“Industry and Government must commit to the Level 3 agenda in order to fully realise BIM’s potential. Availability of digital information will also enable more effective design for manufacture and assembly. This will make offsite construction solutions, which are often precluded by current procurement practices, more readily applicable in the future.” (HM Government, 2013)

Ezcan et al. (2013) reviewed BIM research to analyse the potential impact of BIM on off-site manufacture (OSM). They summarise criticisms of OSM in the literature and discuss how OSM can benefit from BIM to overcome these perceived weaknesses.

They suggest that BIM can:

- help contribute to high level IT integration;
- combat the poor reputation of OSM gained during earlier “prefab” systems by redefining OSM as a modern method of construction, which makes the process controllable before production and component assembly;
- help designers and contractors who have limited experience of OSM by using BIM based simulations for training, which improve interaction in a more visual way;
- reduce concerns about off-site manufactured modules being difficult to modify, because the buildings can be tested and adapted virtually before reaching the site;
- reduce concerns about transportation, because the use of BIM based simulations and 4D schedules will provide advancements in construction logistics planning, which will enable the production and transportation of smaller components;
- enable faster production processes, better logistics, and better collaboration in OSM;
- lead to cost reduction through budgeting and cost estimating capabilities;
- improve aesthetics through its ability to derive different model views with respect to the aesthetic and performance needs of users.

Ezcan et. al. (2013) visualise these benefits in the table below:

Table 3: Barriers/Benefits Matrix

BIM Benefits \ OSM Barriers	Optimized Schedules	Reduced Costs	Improved Design	Better Training	Better Collaboration	Better Logistics	Reduced Design Errors	Accurate & Extensive Amount of Information	Reduced Modification
Need for high level of IT integration					●			●	
Bad reputation	●	●	●						
Limited experience				●	●				●
Modification Difficulties			●				●	●	●
Transportation problems	●		●			●			
Longer lead-in times	●		●		●	●	●	●	
Higher costs		●	●		●	●	●		●
Poor aesthetics			●					●	

Figure 8 How BIM can address barriers to off-site manufacture. (Ezcan et. al. 2013, p.6)

Abanda et al. (2017) highlight the scarcity of literature reporting the benefits of BIM in off-site manufacturing, and also urge caution when reading some of the existing literature because “most of the benefits are not measured and thus, arguably are assertions” (p.94).

They carried out research into the use of BIM in leveraging the benefits of off-site manufacturing, and found both qualitative and quantitative benefits of BIM when used on off-site manufacture. Their research concludes that:

“BIM adoption on off-site manufacturing projects is rapid, efficient and one of the best ways to improve on the long standing challenges that have plagued the construction industry for generations” (p.89).

However, they highlight the challenges they faced in quantifying the benefits from the small number of reported studies, and strongly recommend that future studies make serious attempts to report the benefits in quantitative terms.

5.7. Barriers to the adoption of BIM

Park and Kim (2017) suggest that current efforts to adopt BIM in the housing sector have to tackle three main barriers: 'business barriers', 'technical barriers' and 'human or organisational barriers'.

Business and legal barriers include a lack of standards; a lack of clarity on roles and responsibilities; a lack of clients/market demands; ambiguity in data ownership and legal risks; and high investment cost and low incentives. Technical barriers include interoperability and lack of a BIM library/dataset. Human or organisational barriers include a resistance to changing current practices; a lack of knowledge and skills; and a lack of initiative and training.

Nigel Walley from Chimni set up the 'BIM 4 Housing' working group in 2014. The founding group held seminars and workshops with house builders and contractors looking at the issues of adopting BIM. Walley describes the participants as keen to evolve, but facing commercial and operational barriers that currently seem too high:

"What became clear from these sessions was that developers and contractors felt that home building was different to many other construction sectors in its exposure to BIM, and there were hurdles to adoption that would need a unique approach." (Walley, 2017)

He summarises the main perceived hurdles to adoption in house building as:

- **Lack of scale**
BIM was perceived as beneficial for large scale projects, but not smaller-scale projects. Outside the top 10 housing companies, housing is in large part an SME industry, and participants from smaller organisations felt that BIM was not relevant to them.
- **Standardisation**
Participants felt that a key advantage of BIM was allowing for broader standardisation. While the larger house builders would be able to achieve this, small

and medium-sized home builders are more likely to be dealing with fragmented and irregular areas with a need for greater variations in design.

- **Difficulty in ensuring that the final built home conformed exactly to the CAD or BIM models**

House builders spoke about the leeway they have to give to their onsite teams in procurement and final build decisions, allowing them to source materials locally if necessary, or respond to site conditions dynamically. This means that the CAD model is treated as a statement of intent, not a rigid construction guide.

- **Lack of a fourth stage for BIM**

Participants would want the ability to hand BIM data and models over to owners at the end of the construction stage.

- **Slow progress in creating BIM objects for domestic building materials and products**

It was felt that the manufacturers aiming their products at the residential market had done the least to create new information models and BIM data for their products.

Andrew Carpenter, chair of 'BIM 4 Housing', identifies the main barrier to adoption of BIM as the culture change that is required:

"The biggest challenge when it comes to BIM is people – essentially, BIM will only work well if everyone is on board." (Carpenter, 2015)

In addition to a willingness to engage with BIM, staff will need the necessary digital competencies to work with this software. Steve Cooper, general manager at Aconex, suggests that this is challenging, but not impossible:

"Re-orienting an organisation to become digitally savvy is no small feat, but it can be accomplished by developing individuals with relevant digital skills and building upon an organisation's technological capabilities." (UK Construction Online, 2017).

Menary (2017) outlines more potential reasons why the take up of BIM has been slow among house builders. One reason is that the software originally on offer was sometimes unwieldy, due to the large amounts of information that some manufacturers provided in their BIM files. This meant that files took a long time to upload and manoeuvre. Work has been done to prevent this problem, by minimising the amount of detail at early stages of projects, when this information is not required.

A second reason given for the slow uptake of BIM was that it was not mandated until recently. The mandate of BIM for centrally procured government projects in April 2016 is realising big benefits, including:

“Standardised data sets, steadily retrievable information on asset maintenance, object libraries and a clearer ability to assess design and immediate ability to cost from models.” (Menary, 2017)

However, there is still doubt over whether this will be enough to encourage house builders to make the required changes, and uptake still remains patchy. A final reason for slow uptake is that, since 2011, the industry has come out of recession and looked to dramatically increase output, which is very difficult to do whilst importing a whole new set of software.

Menary (2017) suggests that the continued shift to modern methods of construction will improve understanding of digital construction, and also open the way for even more innovative methods of construction, such as 3D printing of homes.

The evidence review suggested that the adoption of BIM has been slow amongst house builders, but is more prevalent in other parts of the industry such as amongst architects. This was reflected in the interviews, as demonstrated in the following case studies.

Case study: the architect

The clearest difference between the architect and the house builder is that the architect uses BIM on all their projects, whatever their size. They identified a number of benefits from using BIM, including improving the speed of production, the accuracy and quantity of information produced and, as a result, the productivity as a practice is much greater.

“We fundamentally use it as our primary tool for all modes of work...The reason that we switched to it is because I like the fact that we can use it for all stages of the workflow. It can be adapted to suit whatever stage of the project you’re in. So we gain benefits from that.”

They can use BIM most successfully where they are involved in a project from start to finish. However, it has been difficult for them to deliver projects with that continuity because of the way procurement processes work in the public sector housing industry. There tends to be a clear split between pre contract and post contract, so they may only be involved up to the planning approval phase, and not in the construction phase. This means that they can’t pass on the benefits of BIM:

"One of the frustrations for us as architects in the public housing sector is that we aren't always able to offer that continuity and make the most of that BIM information that we invest time in at the front end of the project."

They have found this split in procurement to be a consistent problem and they wouldn't put the same amount of information into the model if they knew that they were only doing the initial design stage.

In their experience, there was little impetus in the house building industry to adopt BIM, reflected in the quote below:

"There's little appetite from the volume house building sector for BIM information. Because their supply chain, and procurement decisions beyond them, subcontracting out packages of work, isn't geared up to accept that information anyway."

The architect felt that the use of BIM could improve house builders' construction processes and also their 'as built' information and handover pack information. However, the interviewee's experience with volume house building was not very positive:

"It's not unusual for a plumber or electrician to just make it up as they go along".

The interviewee was pessimistic about change:

"I've certainly not seen evidence of change in last five years."

Case study: the volume house builder

This volume house builder first started developing the use of BIM in 2012. In describing their experience, they said:

"It has been a long, hard slog".

They found it to be a very time consuming process. Working towards the adoption of BIM took a whole team out of the design office to work on developing the first models. A lack of staff skills and shortages of staff have been a problem. They estimate that it takes at least three months for a new recruit with some BIM software skills to become productive in the office. Information sharing via BIM with outside companies poses major problems of cyber security for the company.

Upstream, it took a long time and effort to get suppliers to put products into BIM. For example, it requires suppliers to conform to using only one or two specific file types that the BIM software can handle.

Their view is that “house building is fundamentally still a cottage industry” with large numbers of small scale suppliers, each using their own working methods. Examples included:

- Window manufacturing: the house builder specifies the U values required, the timber sections that they want using, and the external appearance: the actual ‘design’ and manufacture of the window is then up to the supplier;
- Roof trusses: the house builder supplies calculations for roof trusses to manufacturers, who then redesign the truss to fit their standard method of assembly;
- Staircases: the tolerances (or error margin) in constructing a house are such that the storey heights can vary by 10mm: as a result, each staircase is effectively bespoke, manufactured to the actual storey height of each individual property.

The house builder uses at least four or five suppliers to spread the risk of financial failure or failure to deliver e.g. for kitchen cabinets, or windows, or doors. They have group deals for most building materials, but there is a good deal of latitude for regional offices in terms of which supplier to use. Regional offices and sites also buy materials directly from suppliers and builders’ merchants for less standard items such as foundation blockwork.

Downstream, there is little, if any, sharing of information using BIM, and few, if any subcontractors have BIM, or any interest in acquiring it.

Asked whether plumbing and electrical layouts would be a suitable application of BIM, their view was that while plumbing might be possible, electricians were ‘hopeless’ and that it could be difficult enough to get them to position sockets in the specified place, let alone to adhere to a wiring layout.

Internally, only a few of their own regional offices have BIM software and most use engineering CAD software. The BIM software models are shared with sales and marketing who produce ‘augmented reality’ presentation material. This house builder sees themselves as leaders in using digital material in sales and marketing. It is possible to visit a site, select a house type, pick a plot, specify a wide range of ‘extras’, and purchase online, without having to visit the actual site: “you can buy a house from abroad, if you want”. They are interested in experimenting with digital technology, but the problem lies in identifying which innovations

are likely to be successfully adopted. They are currently installing heating controls operated via a mobile phone in show homes in order to test buyer interest.

Their view is that the next steps in BIM will be to realise cost savings “in the ground” in excavation, foundations, drainage etc. They do not do any work for government and see little point in progressing to BIM Level 2.

Case study: the cross-industry trade body

The fundamental issue that the trade body raised with introducing BIM was the difficulty of getting the supply chain to produce documentation that is not only BIM compliant but also contains the data needed by house builders. They hope that they will be able to create a ‘BIM bible’, working with NHBC to link BIM data to the NHBC Manual.

The BIM group in the trade body has tried to get suppliers to produce details for BIM drawings, but with limited success so far. Initial contact was made with 230 suppliers, but initial responses were received from only 12 suppliers. A further round of contact increased the number of respondents to 82 respondents, and a further round of contact is being planned. They felt that they have made even less progress downstream with subcontractors.

The early adopters of BIM in the house building industry had to work with individual suppliers to have BIM documentation produced. Early examples tended to be over specified, resulting in enormous and unwieldy file sizes. While architects and designers would typically use Revit for BIM drawings, there was little supplier knowledge of Revit, or of the file protocols for information transfer, and so it was necessary to create content from scratch.

Introducing BIM requires a significant investment by house building firms:

“The technology is there, but it is the investment of time that is the problem.”

As a result, the trade body’s view is that the introduction of BIM needs to be supported or driven by the CEO. They noted that the early adopters probably had the advantage of introducing BIM in the period following the recession, when workloads were lighter, but with the industry now working at full capacity, it may be more difficult to allocate the staffing resources necessary to introduce BIM. There are also problems of staff skills. The trade body noted that staff in house building companies tend to be either competent in BIM or technically competent in construction, but not both.

The trade body felt that the introduction of BIM presents particular problems for SME house builders who source materials and individual components for constructing a house locally from various other small suppliers who may not have the skills or resources to invest in BIM.

Up to now, the trade body's view was that the advantages of using BIM have been seen above ground. There has been little application of BIM below ground, but they felt that there are potentially large gains to be made below ground by using BIM, for example, for foundations and landscaping works.

The trade body had found that the introduction of BIM can have unexpected benefits in other areas, such as in visualisation. The creation of images for brochures previously involved numerous revisions because the illustrators did not have accurate data and so simply made up the appearance of the finished house. The ability to supply 3D information to the illustrators meant that the cost of production of an illustration for a brochure fell by up to 90%.

6. Round table discussion

To discuss these issues further, a round table event was held at the University of Cambridge with key stakeholders and experts. It was attended by seven representatives from the house building industry – including house builders, developers, architects and representatives from organisations that provide software or support around BIM. It was also attended by four academics from the University of Cambridge, in addition to the research team.

A presentation of the findings from the research was followed by discussion around the following key questions:

- Is the use of BIM growing in the industry?
- Who uses it and who does not?
- What are the benefits of using BIM?
- How does it support off-site manufacture/MMC?
- What are the challenges and barriers in adopting BIM?
- Who struggles the most to adopt and use it?
- What can be done to support more widespread use of BIM?
- Is it important?

This section summarises the key points and views raised in the discussion.

6.1. What is BIM?

There is still a lack of understanding about what BIM is: many people think it is just about working in 3D but they do not understand the information exchange part of BIM. They also do not understand the potential advantages of it for their organisation. There is a need for greater communication and awareness raising.

6.2. What are the opportunities for house building?

There was a strong view that having accurate, precise information at every stage of the process would make house building more efficient, which could help to reduce costs and produce higher quality, more energy efficient homes. Engaging with BIM has clear benefits for main contractors and sub-contractors, such as more efficiency, fewer design clashes and fewer visits to site, but these potential benefits have not yet been sufficient to drive a wider uptake of BIM.

6.3. How is BIM currently used in the house building industry?

Some builders and SMEs have adopted BIM. However, rather than sharing information in digital form through cloud-sharing technology, many builders, suppliers and contractors are still sharing information in PDF or paper form.

6.4. Innovation in the UK house building industry

Off-site, modular construction offers potential in terms of increasing productivity, increasing standardisation and avoiding inefficiencies and mistakes in on-site construction. But these methods of construction still have a long way to go in terms of utilising robotics and of moving beyond simply being indoor building sites. More standardisation of housing is needed for the benefits of modular construction to be realised.

6.5. BIM and off-site housing manufacture

Off-site housing manufacture has the potential to overcome the labour shortages that are experienced in traditional house construction, although the use of robotics and BIM will require new and different skills.

6.6. Barriers to the adoption of BIM

The experts at the round table were also of the view that the housebuilding industry is stretched to its limits, meaning that traditional builders do not have time to adapt to different processes. The volume house builders have a business model for house building that is profitable so there is an attitude of "why change?".

There was a view that government did not sell the benefits to the house building industry when it brought out the mandate for BIM Level 2. It could have used the mandate as an opportunity to inspire the industry. However, the common experience is that the mandate is not currently effective because it is not being policed.

The overall conclusion was that technology is already available, house builders just need to utilise it but the take up of BIM is inhibited by issues around skills, awareness, resources and willingness to change.

7. Conclusions and further research

7.1. Conclusions

What the study shows is that the potential benefits from the adoption of BIM have been recognised within the industry, but that take up has been slow and prohibited by several factors. Potential benefits include reduced construction costs and time efficiencies, fewer design clashes and costly reworking on site, greater accuracy in design and build, and fewer defects in new homes.

However, adoption of BIM within the main house building companies takes a considerable investment of time and resources, at a time when the industry is at the upward part of a building cycle and working at capacity. There are issues of skills shortages, both for house builders and their numerous suppliers. Progress has been made in encouraging suppliers to make greater use of BIM, but the nature of the house building industry, with many small sub-contractors over multiple sites, has meant that downstream adoption by such sub-contractors has been more problematic.

7.2. Recommendations

Reflecting on the research, we propose some recommendations that might be explored to increase the use of BIM by UK house builders.

The overall recommendation is that there needs to be a general raising of awareness of what BIM is, how it can be used and the benefits it can offer within the house building sector. This may need to come from various sources and will need to be both top down and bottom up. There is already quite a lot of guidance about BIM (see Appendix) available, but it is not targeted specifically at the house building industry. Specific guidance tailored to the industry may be more successful in increasing awareness, as should BIM-specific training, and, in particular, the inclusion of BIM on training and education in college courses to embed BIM in the learning of the next generation in the industry. Awareness would be raised by the sharing of experience and good practice. Useful communication could include stories from successful case studies and real life examples.

7.3. Related and further work

This project on the uptake on BIM in the UK house building industry suggests that further research would be beneficial in several different areas. These might include:

- the role of public policy in supporting and promoting BIM, and in particular the potential role of Homes England in mandating the use of BIM;

- the use of BIM in housebuilding in other countries, and how this was facilitated and supported;
- the relationship between other areas of regulation, such as planning and house building;
- the quantification of evidence on the potential benefits of BIM in improving quality (including environmental issues) and in reducing defects;
- the role of BIM in supporting and developing improvements in the energy efficiency of the housing stock;
- the advantages of BIM for portfolio landlords (such as housing associations or Build to Rent investors) in improving quality control and long term facilities management;
- the role of BIM in modernising construction methods, both in current practice (such as the widespread manufacture of bathroom pods) and in emerging factory production of panellised or modular/volumetric solutions;
- the wider utilisation of BIM by subcontractors, and how this might be facilitated and encouraged;
- the wider use of digital technologies, particularly in communicating building design issues to investors and customers;
- the potential benefits of BIM to wider audiences, such as home owners, the real estate sector and investors.

8. Acknowledgements

This project was supported by a mini-projects award from the Centre for Digital Built Britain, under InnovateUK grant number 90066.

9. Appendices

9.1. Existing guidance on BIM

The review identified several sources of existing guidance about the use of BIM, although they are not specifically targeted at the house building industry.

UK Government guidance

In the Government Construction Strategy 2016-20 (Infrastructure and Projects Authority, 2016), the government commits to: “develop the skills, experience and capability around BIM”. Guidance for construction professionals on implementing BIM is available from several online government sources:

- The Department of Business, Energy and Industrial Strategy and BSI have collaborated on a reference website which provides guidance on the adoption of BIM Level 2 (and provides standards and specifications which can be downloaded):
<http://bim-level2.org/en/>
- The Centre for Digital Built Britain is now building on the work of the BIM Task Group to consolidate and build on BIM Level 2 processes, and ensure widespread adoption across the industry. The objectives of the Centre include: developing and inspiring an industrial community who will provide leadership on adopting and implementing new digital approaches, and delivering a range of events and activities designed to engage industry in defining and adopting BIM Levels 3 and 4.
<https://www.cdbb.cam.ac.uk/>

EU guidance

The EU BIM Task Group, a pan-European collaboration of public sector organisations across 21 countries, has released a handbook for the introduction of BIM by the European Public Sector (EUBIM Taskgroup, 2017). It presents a strategic framework to deliver robust and effective BIM programmes, identifying the following strategic areas:

- establishing public leadership;
- communicating vision and fostering communities;
- developing a collaborative framework;
- growing client and industry capability and capacity.

Figure 9 sets out recommended actions in each of these strategic areas:

Public leadership	<ul style="list-style-type: none"> ■ Define compelling drivers, a clear vision and goals ■ Describe the value of BIM to the public and private sector ■ Document the general approach for moving the industry towards the defined vision and goals ■ Identify a public sector champion to sponsor the initiative ■ Establish an implementation team to drive the programme. The value proposition and sponsor can unlock the required funding and resources
Communication and communities	<ul style="list-style-type: none"> ■ Early and frequent engagement with industry stakeholders is essential to support the industry change process ■ Participate in and provide encouragement for regional and special interest networks to disseminate best practice ■ Use mass communication tools, such as online media, events, web and social media to reach audiences
Collaborative framework	<ul style="list-style-type: none"> ■ Assess and address legal, regulatory, procurement and policy barriers in order to facilitate collaborative working and sharing of data. ■ Develop or use international standards for data requirements ■ Reference international standards for encouraging collaborative processes and sharing of data ■ Produce guidance and tools to support the upskilling of industry and development of academic curricula
Capability and capacity development	<ul style="list-style-type: none"> ■ Run pilot projects and promote training to encourage early successes. ■ Increase the use of public procurement as a driver for industry capacity development ■ Measure progress, produce case studies to increase industry awareness and support

Figure 9 Strategic framework for public sector BIM programmes (EUBIM Taskgroup, 2017, p. 25)

Other guidance

Other guidance is available online:

- BIMTalk collates information about BIM: <http://bimtalk.co.uk/>. It also provides an extensive list of other websites with information about BIM: http://bimtalk.co.uk/other_sites_for_bim
- Designing Buildings Wiki provide a step-by-step guide to using BIM on projects, which breaks down the process into 7 stages: https://www.designingbuildings.co.uk/wiki/Step-by-step_guide_to_using_BIM_on_projects
- The BRE (Building Research Establishment) Group website provides a clear guide to BIM, including an extensive guide to terminology: <https://www.bre.co.uk/bim-terminology.jsp>

- NBS provide a 'periodic table of BIM', showing the key terms and concepts in a visual way: <https://www.thenbs.com/knowledge/periodic-table-of-bim>
- On Twitter, the hashtag #ukbimcrew offers peer advice from those who have experience implementing BIM

9.2. BIM Training

In its Industrial Strategy "Construction 2025" (HM Government, 2013), the government suggests that capability in the workforce needs to be improved in order for the construction industry to meet the demands of the digital economy:

"If the construction industry is to fully embrace the digital economy, it will need to mobilise the country's brightest talent in order to effectively apply technology in our built environment. Digital design techniques are already creating an imperative for this, but the next decade will demand multi-disciplinary skills that enable integration right through the supply chain." (HM Government, 2013)

The Construction Industry Training Board (CITB, 2017) conducted evidence on the likely skills, training and qualifications that will be needed to meet the industry demand for offsite construction and onsite assembly over the next five years. As part of this, they mapped out the skills required in 'digital design', including technical skills (e.g. BIM enabled design, creating 3D models, producing product/service specifications), knowledge (e.g. appreciation of how buildings are constructed, understanding of full range of materials and products used, waste management). They highlight the training available in these areas, and highlight the gaps in training on design for off-site production, as shown in Figure 10.

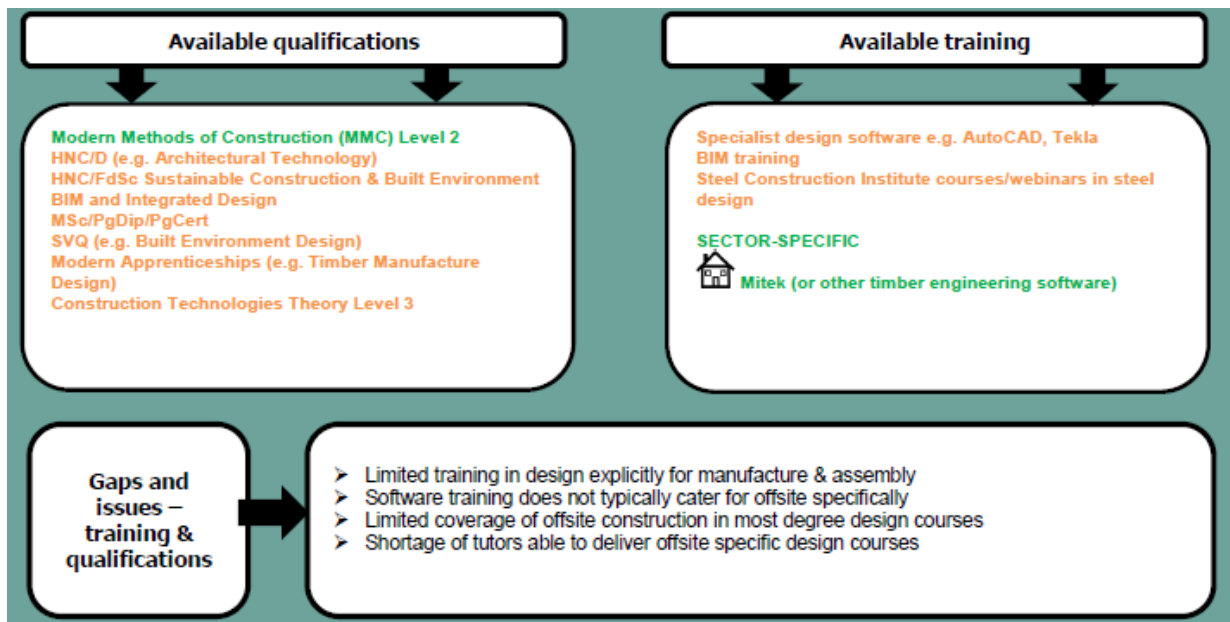


Figure 10 Gaps and issues (Construction Industry Training Board (2017) *Faster, Smarter, More Efficient: Building Skills for Offsite Construction*)

They highlight the key issues for consideration in preparing for the digital design required by offsite construction and onsite assembly as the following:

- There is insufficient coverage of design, specifically for offsite manufacture and assembly within existing training and qualifications. Where this does exist, it is typically integrated training in design and BIM rather than for offsite manufacture per se;
- There is more relevant coverage within Scottish degree courses compared with the rest of the UK, but this can focus strongly on timber frame rather than other materials, given the dominance of timber frame in Scotland;
- Software training typically focuses on how to use the software, not on how to use it specifically for offsite construction; and
- It is difficult to find tutors or trainers with the relevant knowledge of design for offsite manufacture and assembly, to deliver training and qualifications.

BIMTalk provides a list of training courses covering BIM: <http://bimtalk.co.uk/events:list>

10. References

Abanda, F.H., Tah, J.H.M and Cheung, F.K.T. (2017) *BIM in off-site manufacturing for buildings*, Journal of Building Engineering 14, pp. 89-102,

Autodesk (2018) *What is BIM?* [Online]. Available at:
<https://www.autodesk.com/solutions/bim> [Last accessed 19 March 2018]

Barratt, L. (2018) L&G expecting first factory homes by June. *Inside Housing* [Online] Available at: <https://www.insidehousing.co.uk/news/news/lg-expecting-first-factory-homes-by-june-53749> [Last accessed 21 March 2018]

Brandon, S. (2017) How the first BIM project in social housing could provide a model for the future. *Inside Housing* [Online]. Available at:
<https://www.insidehousing.co.uk/insight/insight/how-the-first-bim-project-in-social-housing-could-provide-a-model-for-the-future-52464> [Last accessed 21 March 2018]

Cabinet Office (2011) *Government Construction Strategy*. [Online]. Available at:
<https://www.gov.uk/government/publications/government-construction-strategy> [Last accessed 19 March 2018]

Carpenter, A. (2015) BIM for housebuilding the right way. *PBC Today* [Online] Available at:
<https://www.pbctoday.co.uk/news/bim-today-articles/bim-housebuilding-right-way-3/19761/> [Last accessed 19 March 2018]

Walley, N. (2017) Is BIM failing the house building sector? *Chartered Institute of Building* [Online]. Available at: <http://www.bimplus.co.uk/people/bim-failing-house-building-sector/#comments> [Last accessed 19 March 2018]

Construction Industry Training Board (2017) *Faster, Smarter, More Efficient: Building Skills for Offsite Construction*. [Online] Available at: <https://www.citb.co.uk/research-and-insight/innovation-technology/faster-smarter-building-skills-for-offsite-construction1/> [Last accessed 19 March 2018]

DCLG (2016) *Dwelling Stock Estimates*. [Online] Available at:
<https://www.gov.uk/government/statistics/dwelling-stock-estimates-in-england-2016> [Last accessed 21 March 2018]

DCLG (2017) *Fixing our broken housing market*. [Online]. Available at: <https://www.gov.uk/government/publications/fixing-our-broken-housing-market> [Last accessed 19 March 2018]

Dortek (2017) *The top 10 benefits of using BIM* [Online]. Available at: <http://www.dortek.com/news/the-top-10-benefits-of-using-bim/> [Last accessed 19 March 2018]

Ezcan, V., Isikdag, U., Goulding, J.S. (2013) *BIM and Off-Site Manufacturing: Recent Research and Opportunities* in CIB World Building Congress, Construction and Society, 5-9 May 2013, Brisbane, Australia.

Farmer, M. (2016). *Modernise or die: The Farmer Review of the UK construction labour market*. [Online]. Available at: <http://www.cast-consultancy.com/wp-content/uploads/2016/10/Farmer-Review-1.pdf> [Last accessed 19 March 2018]

Homes and Communities Agency (2015) *Building Information Modelling, changing the process of construction*. [Online]. Available at: <https://www.gov.uk/government/case-studies/building-information-modelling-changing-the-process-of-construction> [Last accessed 19 March 2018]

HM Government (2013) *Industrial strategy: government and industry in partnership Construction 2025*. [Online]. Available at: <https://www.gov.uk/government/publications/construction-2025-strategy> [Last accessed 19 March 2018]

Hyde (2016) *How Building Information Modeling (BIM) Can Improve Future Energy Consumption*. ENER-G Combined Power [Online]. Available at: <http://chpblog.energ-group.com/how-building-information-modeling-bim-can-improve-future-energy-consumption> [Last accessed 19 March 2018]

Infrastructure and Projects Authority (2016) *Government Construction Strategy 2016-20*. [Online] Available at: <https://www.gov.uk/government/publications/government-construction-strategy-2016-2020> [Last accessed 19 March 2018]

Lloyds Bank (2018) *Housebuilding Report 2018*. [Online] Available at: <http://www.lloydsbankinggroup.com/Media/Press-Releases/2018-press-releases/lloyds-bank/housebuilders-innovating-and-investing-to-plug-the-housing-gap/> [Last accessed 19 March 2018]

Menary, S (2017) *BIM and Beyond*. Housebuilder [Online] Available at: <https://www.house-builder.co.uk/news/bim-and-beyond/> [Last accessed 19 March 2018]

NBS (2012) *National BIM Report 2012*. [Online] Available at: <https://www.thenbs.com/knowledge/nbs-national-bim-report-2012> [Last accessed 19 March 2018]

NBS (2014) *BIM Levels explained*. [Online] Available at: <https://www.thenbs.com/knowledge/bim-levels-explained> [Last accessed 19 March 2018]

NBS (2017) *NBS National BIM Report 2017*. [Online] Available at: <https://www.thenbs.com/knowledge/nbs-national-bim-report-2017> [Last accessed 19 March 2018]

NHBC (2013) *Building Information Modelling: An introduction for house builders*. Milton Keynes: NHBC.

NHBC Foundation (2006) *A guide to modern methods of construction*. Berkshire: ISH BRE Press.

NHBC Foundation (2016) *Modern methods of construction: views from the industry*. Berkshire: ISH BRE Press.

ONS (2017) *House price per square metre and house price per room, England and Wales: 2004 to 2016* [Online]. Available at: <https://www.ons.gov.uk/releases/housepricepersquaremeterandhousepriceperroomenglandandwales2004to2016> [Last accessed 21 March 2018]

Park, K.S. and Kim, K.P. (2017) 'BIM Application and Adoption in the UK Housing Sector' in Wu, P., Li, H and Wang, X. (Eds). *Integrated Building Information Modelling*. UAE: Bentham Science Publishers.

Persimmon (2014) *Space 4* [Online] Available at: <https://www.persimmonhomes.com/corporate/about-us/our-brands/space4> [Last accessed 19 March 2018]

Prior, G. (2018) *Berkeley gets green light for modular homes factory*. Construction Enquirer [Online]. Available at: <http://www.constructionenquirer.com/2018/01/25/berkeley-gets-green-light-for-modular-homes-factory/> [Last accessed 19 March 2018]

Spittles, D. (2016) Modular goes mainstream. *Homes & Property*, 5 October, p.6 [Online]. Available at: <https://static.homesandproperty.co.uk/s3fs-public/files/file/2016/10/06/17/binder1.pdf> [Last accessed 19 March 2018]

UK Construction Online (2017) *Productivity houses the answer to the government's new targets*. [Online]. Available at: <https://www.ukconstructionmedia.co.uk/features/productivity-houses-answer-governments-new-targets/> [Last accessed 19 March 2018]

Valuation Office Agency (2012) *Business Floorspace*. [Online]. Available at: <https://www.gov.uk/government/statistics/business-floorspace-experimental-statistics> [Last accessed 21 March 2018].

Wienerberger (2018a) *e4 leading the way in BIM for housing*. [Online] Available at: <https://wienerberger.co.uk/about-us/e4-leading-the-way-in-bim-for-housing> [Last accessed 19 March 2018]

Wienerberger (2018b) *e4: Using BIM*. [Online]. Available at: <https://wienerberger.co.uk/about-us/using-bim-in-the-construction-stage-of-e4-brick-houses> [Last accessed 19 March 2018]