MAKING MODULAR STACK UP:
MODERN METHODS OF CONSTRUCTION IN SOCIAL HOUSING

REPORT

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FOREWORD

The shortage of good quality, affordable housing in the UK is well documented. Around 1 in 10 people in England live in a housing association home and those organisations have a vital role in helping to increase the supply of housing.

In February 2017 the UK government highlighted innovative construction techniques as an important step towards building more homes.

Supported by a partnership of housing associations in the East of England, Flagship Group commissioned the University of the West of England to investigate the potential future of modern methods of construction (MMC) in social housing.

The main objectives of the research were:

- To review existing literature on MMC and summarise the wealth of current knowledge.
- To investigate new data on different technologies and construction processes through case studies from the UK.
- To draw conclusions on the potential of MMC in the social housing sector and make recommendations on how to proceed.

This report is the culmination of that research and is the first of its kind in the social housing sector. It demonstrates our desire to innovate, to play our part in building homes that people love and to do so faster and to a higher standard than ever before.

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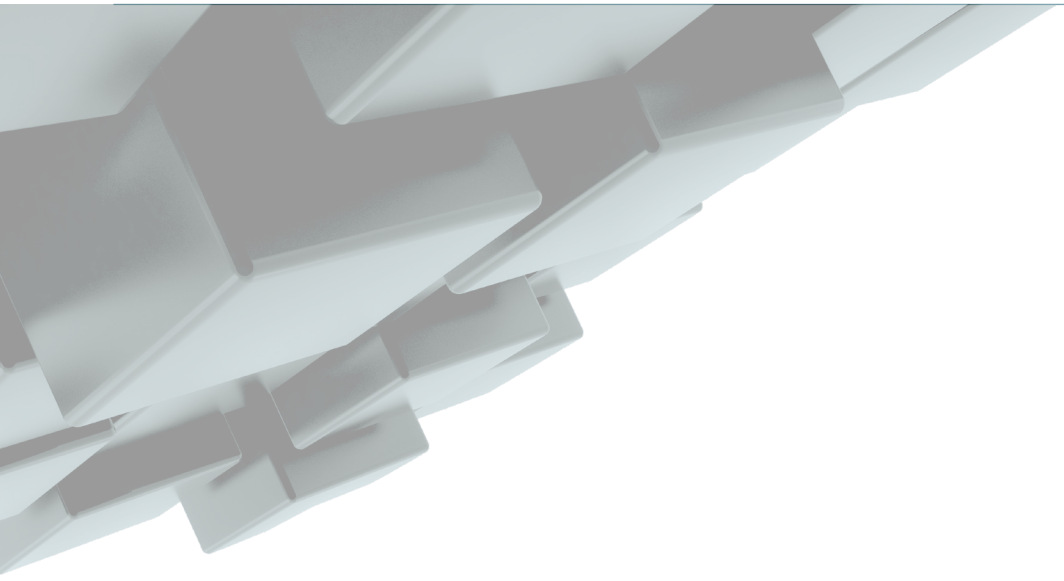
CONTENTS

KEY FINDINGS AND RECOMMENDATIONS

The purpose of this report is to review evidence of MMC application in housing with regards to diverse modes of delivery, lending approaches, customer satisfaction and long-term management/maintenance. Key findings and recommendations are listed over the next few pages, based on areas researched for the report.



Modes of delivery

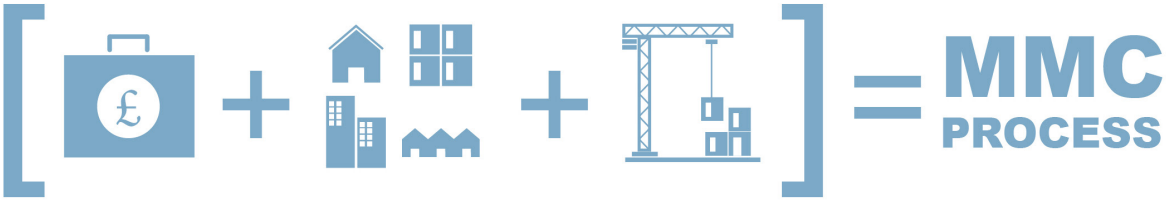
- There are different modes of MMC delivery
- Modes of MMC delivery are dependent on material choices, context, team capabilities and capacity as well as transport
- The role of the client as well as finance routes impact on selection of mode
- Advantages of MMC delivery such as potential cost reduction are mainly reported in international contexts as construction costs rather than contractual – there is also limited discussion on life cycle costs
- Quality, speed of completion and reduced site wastage (though this varied internationally) are quoted as key advantages to MMC; however, there is limited or no empirical evidence to support this

Lending approaches

- Business models for MMC delivery are largely ill considered in the UK. A number of studies of the inter-relationship of business models and offsite manufacture identify the UK housebuilding market's 'current trader' (Calcutt 2007) strategy of accruing benefit from land development as a key inhibitor to the customisation of housebuilding.
- Traditional procurement routes are reported not to be sufficiently well set up to deliver MMC in housing yet
- There is a need for contractual mechanisms better suited to manufacturer/contractor roles

Customer satisfaction and long-term management/maintenance

- Studies suggest there is no difference in MMC housing regarding maintenance
- While build quality is largely seen to be comparable to traditional building, a number of studies suggest dependencies lie in the interfaces between offsite and onsite assembly
- Information management was found as key to successful installation and maintenance of MMC
- MMC needs to be reviewed against sustainable design requirements concerning climate change predictions
- There is a lack of evidence regarding customer satisfaction



Business case

Investment model
Aspirations
Target market
Size of market
Housing typology
Portfolio of housing
Contractual mechanisms
Material/networks
Quality

Evidence

International case studies
Factory need/ processes
Scale of MMC process
Resident feedback
Quality

Pilot project(s)

Test bed for MMC process
Testing parameters
Training
Feedback successes & failures

Factory?
Components?
Modules?
Material?

RECOMMENDATIONS based on the noted findings are outlined below:

- It is recommended that a clear business case is initially developed. The business case would outline the need for investment, likely volume, market as well as housing typology (as illustrated above).
- An evidence base of knowledge gained from built examples is recommended. An evidence base could include visits to international/national leading projects, empirical studies including feedback from residents as well as manufacturers and designers.
- It is recommended that a pilot project is procured in order to test and develop capabilities. This would enable better decision making regarding choice of material, mode of delivery as well as finance and or partnership model.

The report provides a detailed overview of these key areas examined based on evidence sourced. Whilst there are limitations in the evidence reviewed, particularly in relation to empirical work and field studies of built housing, the research discussed provides an account of key issues of relevance to a Housing Association client. Further work is needed to better understand the performance of buildings and resident experiences drawing on Post Occupancy Evaluation methods (POE) specifically related to different modes of delivery in different contexts (urban vs suburban or rural for instance).

SECTION 1
INTRODUCTION

The University of the West of England (UWE) was commissioned by the Flagship Group led partnership to undertake a contained study into effects of different modes of UK MMC housing delivery with a particular focus on modes of delivery, long term management, business models utilised and resident experience.

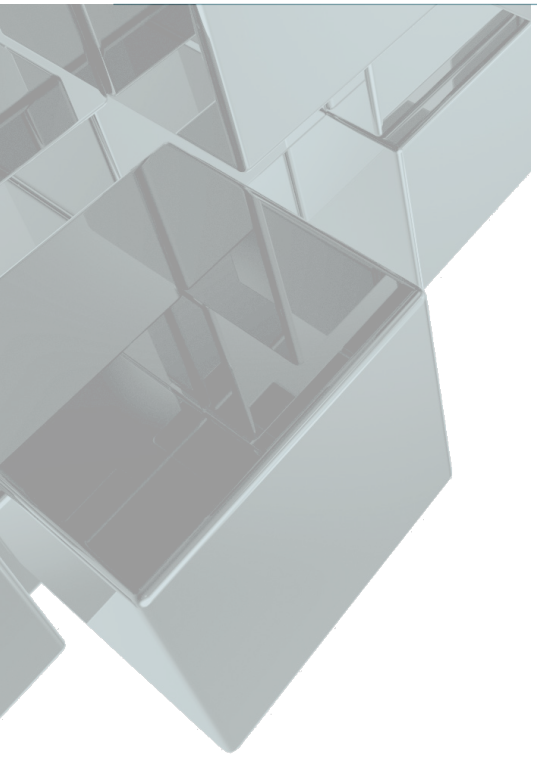
The purpose of the research is threefold. First, the study enables an overview of key UK and international approaches to delivering housing using modern methods of construction (MMC). In addition, the overview discusses and classifies the broad spectrum of terminology currently referred to when describing MMC including offsite, prefabricated, modular to industrialised and manufactured. Second, the study provides new primary data based on four cases including a range of design professionals' views on different modes of delivery regarding both management and designing for and meeting resident needs. Third, the study enables new timely insights on a topic of growing significance to UK housing policy as well as procurement and delivery of housing by non-traditional development clients such as housing associations. Finally, the study offers recommendations for areas that require future work specifically in the context of post occupancy evaluation, largely overlooked in the context of housing delivered via MMC.

1.1 Overall approach and objectives

The overall tasks and milestones for project delivery are set out in Table 1. The overall approach is made up of four key milestones, some of which overlap. The first milestone enables initial agreements and ethics application submission as well as refinement of search strategy for horizon scanning. The ethics application includes the main application form, interview protocol, consent form and participation sheet (can be provided upon request). Milestone 2 involves identifying key case studies, coordination and contacting potential participants for an in-depth investigation. Milestone 3 mainly contains all analysis activities as well as further horizon scanning to enable any updates. Milestone 4 included synthesis of all secondary (Milestone 1) and primary (Milestone 3) data to be analysed, written up and disseminated. Milestone 4 also includes presenting the report at a launch event organised by Flagship Group.

Table 1: Overview of key project milestones and deliverables

Phase of project	Activity (Deliverable)	May 17′	June 17′	Jul 17′	Aug 17′	Sep 17′	Oct 17′
Inception meeting	Agree final scope and protocol with Flagship Group						
Milestone 1 Preparation	Submission of ethics application and literature reviewing						
Milestone 2 Data collection	Coordination and contacting stakeholders for in depth investigation						
Milestone 3 Data analysis	Analysing data and literature reviewing						
Milestone 4 Synthesis	Synthesis and report writing, dissemination and recommendations						



1.2 Structure of report and research design

The report is structured in three sections. 'Horizon scanning' contains evidence gathered and examined for the literature review exercise including a description of the search strategy and databased reviewed. 'Case study comparison' discusses the case studies examined including an overview of the research methods, key participants as well as analysis methodology. The final section synthesizes and concludes the report offering recommendations as well as areas for future research.

1.3 UWE Code of Good Research Conduct

All research projects have a designated Project Manager(s) who has the responsibility for all aspects of the UWE Code of Good Research conduct. This includes ensuring that:

- Research is carried out in accordance with the code and related guidelines, regulations, procedures and Health and Safety standards
- The dignity, rights, welfare and safety of researchers and participants are safeguarded
- The project complies with all legal, contractual and ethical approval processes as required
- The project is carried out as defined in the original proposal and that any proposed changes to the protocol need approval from funder
- Procedures are in place to collect, store and protect project data
- Reports on research progress and outcomes are produced on schedule and to an acceptable standard
- The terms of confidentiality and intellectual property rights are complied with
- Research processes and outcomes undergo internal peer review
- A quality plan is prepared by the PM(s) at the onset of a project.

Full ethical approval was obtained from the UWE Research Ethics Committee prior to conducting case studies research. All details of the application can be forwarded upon request. Every effort is made to protect participants' anonymity and confidentiality, as well as refrain from publishing any information that may that may allow their identification. The following actions are taken to guarantee anonymity of the participants:

- Names and other identifying information are disassociated from data collected by using identifiers and pseudonyms. These are stored on a secure server, where access is restricted to the researchers.
- The research team will particularly guard against data being published or released in a form which would permit the actual or potential identification of participants.
- Identifying information from printed material will be disposed of by recycling as 'confidential waste'.
- Advice will be sought from IT services about destroying the electronic information stored in the server on completion of the project.

The publication of project outputs will be undertaken in an anonymised form to safeguard against privacy issues as a result of inadvertent wider dissemination. UWE embraces and will meet the requirements of the Concordat to Support Research Integrity (Universities UK 2012). To support this policy, the University has set in place a Code of Good Research Conduct. The Concordat to Support Research Integrity sets out a comprehensive national framework for good research conduct and its governance. Good research practice is defined by the Concordat to Support Research Integrity as research which is conducted to the highest standards of rigour and integrity. The UWE Bristol research policy, procedures and guidance can be found at: **http://www1.uwe.ac.uk/research/researchethics**.

SECTION 2
HORIZON SCANNING

The following sections outline the search strategy and databases as well as discuss key findings based on evidence gathered from the horizon scanning exercise.

Section 2.1 describes how the searches were carried out and how academic databases as well as grey literature sources were reviewed. Section 2.2 discusses key approaches to modes of MMC delivery in housing drawing from the UK as well as international contexts. Section 2.3 examines key business models as discussed in the literature that enable particular modes of MMC delivery in the UK context. Section 2.4 discusses how residents' experiences of MMC delivered housing are analysed in the literature, whilst section 2.5 outlines key relevant long-term management issues of particular relevance to housing associations. Section 2.6 concludes and discusses overall findings from the horizon scanning tasks.

2.1 Search strategy and databases

The search was conducted using the following academic databases: Science Direct, Proquest and Google Scholar.

Science Direct: Science Direct is a website which provides subscription-based access to a large database of scientific and medical research. It hosts over 12 million pieces of content from 3,500 academic journals and 34,000 e-books. The journals are grouped into four main sections: Physical Sciences and Engineering, Life Sciences, Health Sciences, and Social Sciences and Humanities. Article abstracts are freely available, but access to their full texts (in PDF and, for newer publications, also HTML) generally require a subscription or pay-per-view purchase.

Proquest: (including Civil Engineering Abstracts, CiS, Avery and Ante) is a content holder of all types, preserving and enabling access to their rich and varied information. Those partnerships have built a growing content collection that now encompasses 90,000 authoritative sources, 6 billion digital pages and spans six centuries. It includes the world's largest collection of dissertations and theses; 20 million pages and three centuries of global, national, regional and specialty newspapers; more than 450,000 ebooks; rich aggregated collections of the world's most important scholarly journals and periodicals; and unique vaults of digitized historical collections from great libraries and museums, as well as organisations as varied as the Royal Archives, the Associated Press and the National Association for the Advancement of Coloured People.

Google Scholar: Google Scholar is an online, freely accessible search engine which searches a variety of sources including academic publishers, professional societies and university repositories. Google Scholar includes journal and conference papers, theses and dissertations, academic books, pre-prints.

In addition to academic databases, grey literature sources were consulted including organisational, institutional and governmental resources such as the National Audit Office (NAO), Building Research Establishment (BRE), Homes and Communities Agency (HCA), Royal Institute of British Architects (RIBA), National Housing Federation (NHF), Royal Institution of Chartered Surveyors (RICS), The Chartered Institute of Building (CIOB), the Timber Research and Development Association (TRADA), Parliamentary Office of Science and Technology (POST), Barker 33 Cross Industry Group, UK Commission for Employment and Skills (UKCES), the Building Services Research and Information Association (BSRIA) and the Steel Construction Institute (SCI). The search criteria were internationally inclusive, however, given the aims and objectives of the study, results were filtered to prioritise evidence that relates to the UK context. After conducting preliminary searches to assess the effectiveness of different search terms, the research team agreed with Flagship Group the strings reported in **Table 2** for each database.

Criteria to select or exclude documents were applied in two screening stages. Stage 1 involved screening based on abstracts, while Stage 2 involved screening full documents. These inclusion and exclusion criteria were developed based on the aim and scope of the project. They are shown in **Tables 3** and **4**.

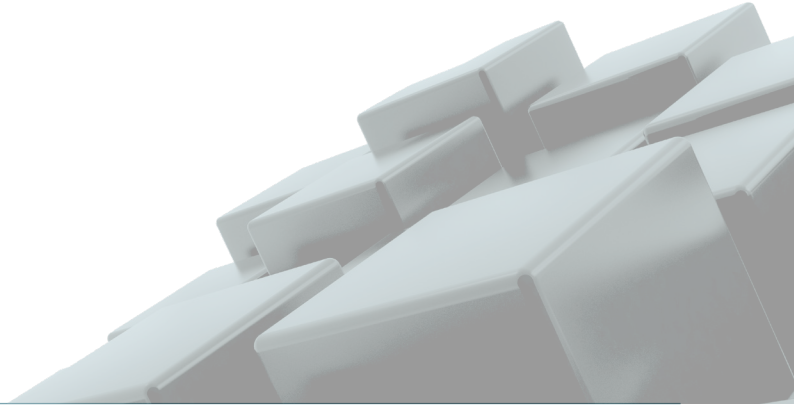


Table 2: List of academic database search strings and terms

Database	Search strings and terms
Proquest	Modular or prefabricated (and construction) or "modern methods of construction" and AB,TI(dwelling* or residential or home* or domestic or apartment) and AB,TI (procurement or cost* or user or occupant*) and not AB,TI ("Non-residential" or "Non-domestic"*) and YR(2000-2017)
Google Scholar	allintitle: modular, prefabricated, modern methods of construction, housing, affordable housing, social landlords, housing associations
Science Direct	Modular or prefabricated (and construction) or "modern methods of construction" and AB, TI (dwelling* or residential or home* or domestic or apartment) and AB,TI(procurement or cost* or user or occupant*) and not AB,TI ("Non-residential" or "Non-domestic"*) and YR(2000-2017)

Table 3: Inclusion criteria used for STAGE 1 Sample

Inclusion Criteria
Screening 1
Documents that are written in English and focus on residential sector
Documents that are written in timeframe 2000-2017
Documents that are available and accessible online within the project's timeframe
Documents that their title or abstract indicate any evidence base for one or more types of modular construction in terms of either (1) methods of construction (2) cost-effectiveness or (3) customer experience.

Table 4: Exclusion criteria used for STAGE 2 Sample

Exclusion Criteria
Screening 1 and 2
Documents that report method(s) of modular construction in housing but do not evaluate their construction methods, cost effectiveness or customer experience
Documents that only study the theoretical approaches to modular construction
Documents that only provide a procurement and cost effectiveness route in terms of off site construction overall
Documents that are a shorter version of another document already included
Documents that fall outside the search timeframe 2000-2017

Figure 1: Key Housing 'problem' components as identified by Parvin and Reeve (2017)

2.2 Modular housing construction modes of delivery – the issue of MMC

Housing shortage in the UK is chronic and acute with 98% of UK local councils increasingly unable to meet demands and describing their housing needs as either 'severe' or 'moderate' (Heath 2017). The Royal Institution of Chartered Surveyors (2017) has estimated that the UK will need 1.8 million new rental homes by 2025 and according to House of Commons (2015), England alone will need additional housing of between 232,000 to 300,000 new units per year, a level not reached since the late 1970s and two to three times current supply. Housing shortage has been described by Parvin and Reeve (2017) as resulting from a 'complex system failure', also referred to as a 'wicked problem' or a 'Gordian knot' as illustrated in Figure 1.

The UK government has identified Modern methods of construction (MMC), as a key vision for meeting the UK housing needs and has promoted its application to encourage the adoption of modularity in the construction sector. For instance, a recent UK government housing report recommended that housing could be delivered through MMC methods as way to boosting productivity and innovation in house building (Department for Communities and Local Government 2017). As such, it has been acknowledged that there are to be limited national regulatory barriers to the increased use of MMC in housing in the UK (Miles and Whitehouse 2013).

2.2.1 UK government approaches to MMC – recent initiatives

Pan et al (2008a) identified the UK government as main advocates of an MMC approach in the UK. Some practical steps have been taken to ensure the effectiveness of this initiative to promoting MMC through increases in government funding (CMP Information Ltd. 2005). Blismas and Wakefield (2009) noted that between 1997 – 2001, the UK government has invested approximately £5 million in research projects that aimed to promote modularity in the construction sector. From 2004 the Housing Corporation, the social housing regulator for England and Wales, started to require at least 25% of new social housing it funds to be built using MMC (Housing Corporation 2003).

In a recently released Housing white paper, the government has set out ways to stimulate the growth of this sector through the Accelerated Construction programme and the Home Builders' Fund (DCLG 2017). There are also increasing calls for use of MMC in the UK housebuilding industry (Barlow et al. 2003, Steinhardt and Manley 2016a), with a general agreement on the need for house builders to include modularity in their house building strategies (Institution of Mechanical Engineers 2015). Boosting productivity, innovation, sustainability, quality and skills have become designated key outcomes of modular housing through MMC use (Department for Communities and Local Government 2017, Gibb and Isack 2003).

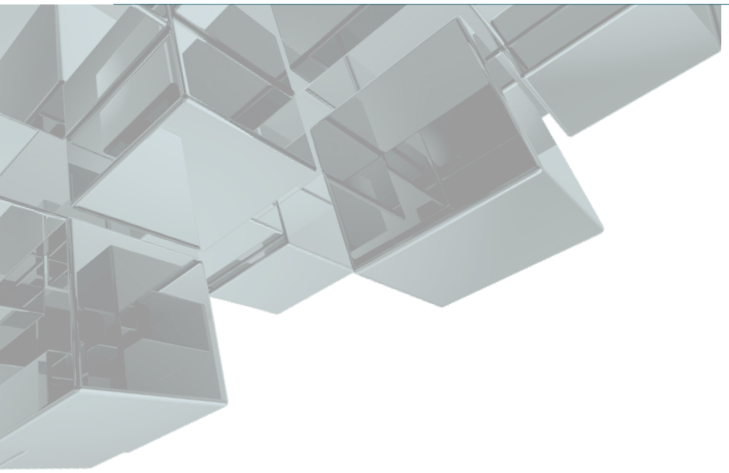
"The housing shortage in the UK is chronic and acute with 98% of UK local councils increasingly unable to meet demands and describing their housing needs as either 'severe' or 'moderate'."

However, despite the wide promotion of MMC use in housing, there are still limited applications in the UK social housing sector compared to some other countries in Europe (Collins 2016).

The review of evidence discussed in this section revealed mostly anecdotal and largely limited findings regarding MMC application in housing and for housing associations specifically. Furthermore, the implementation of effective strategies to achieve MMC in the social housing sector has still not sufficiently been met in UK. Lovell and Smith (2010) identified social, cultural and technical differences of housing construction markets as critical issues underpinning the UK resistance to modular housing. Furthermore, barriers lie in the diversity of meaning, purpose, relevance and approach to modes of delivery of modular housing (Pan and Goodier 2011). For example, the social housing construction sector is seen to advocate and incorporate modularity into their construction process, but others such as lenders, large housing developers and investors less so.

Clarke (2014) pointed out that lenders' decisions on properties built by MMC may be shaped by other professionals such as providers of building warranties, as well as property valuation agents' and insurers' views. Connor (2003) suggested housing associations are concerned that MMC could make some sites economically unavailable. Despite the increased interest around MMC among stakeholders in the UK social housing sector, there is limited practical guidance on how housing associations are to deliver modular building in an efficient manner.

The above discussion suggests that raising social housing numbers needs to be considered in relation to the diversity of relationships and approaches from all stakeholders involved. In addition to diversity of approach, there are also different understandings of MMC as well as varying use of terminology in the UK as well as internationally. Section 2.2.2 reviews international approaches to MMC in housing with a specific focus on definitional approaches.



2.2.2 Overview of terminology and definitions – UK and international approaches

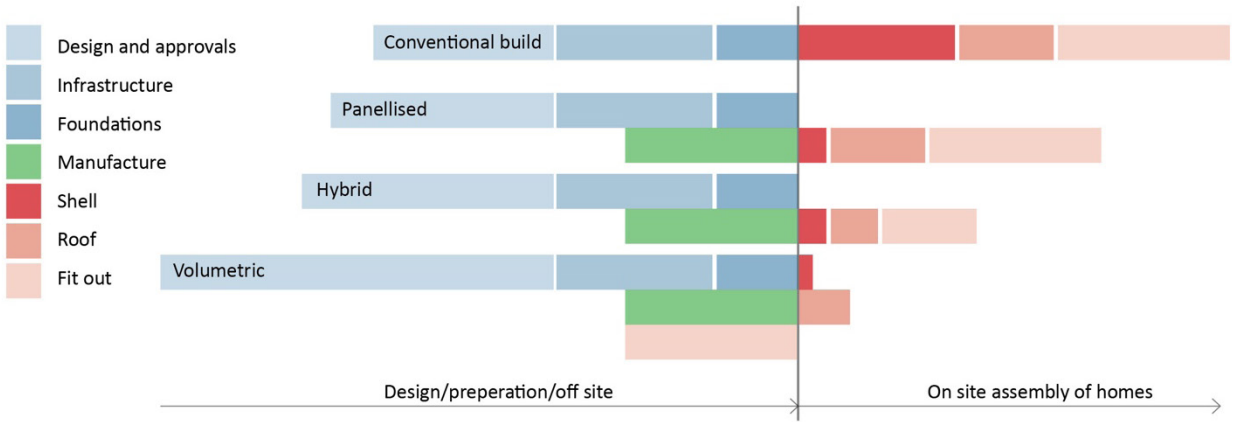
There is increased international awareness of the importance of MMC, also referred to as offsite construction industrialisation in the housing sector (Steinhardt and Manley 2016a). Offsite construction is widely perceived as key to meeting demands to alleviate the growing housing deficit (Egan 1998), and a way to create efficiency in the housing construction sector (Kamali and Hewage 2016, Sousa et al. 2017). However, the terms used to describe MMC and associated off site technologies in house building are largely ill defined. Terms are often used interchangeably and their precise definitions often depend on user's experience and understanding, which vary from country to country (Azman et al. 2010, Kamar et al. 2011). This lack of uniform definition and uncertainty may contribute to the apparent confusion and misunderstanding. As suggested by Martin (2004), the lack of uniformity among stakeholders militates against achieving significant progress in the sector.

The terms used vary between countries as well as across industry, academic and policy domains. Azman et al (2010) identified common terms used in different countries. In the US, the spectrum of applications where buildings, structures or parts are manufactured and assembled remote from the building site prior to installation in their final position is described as Off-site Construction Techniques (OSCT) (Lu 2009).

In the UK, Modern Methods of Construction (MMC) is the term used by the government and policy makers to describe innovations in house building, most of which are off-site technologies (The Parliamentary Office of Science and Technology 2003). The term Offsite Manufacturing or Construction (OSM) is used both in Australia and the UK construction industry to refer to the process of planning, designing, fabricating, transporting and assembling building elements for rapid site assembly to a greater degree of finish than in traditional piecemeal on-site construction (Blismas and Wakefield 2009, Smith 2014).

In Malaysia, the term used is Industrialized Building System (IBS) which is broadly used to refer to all concepts representing the prefabrication and construction industrialization (Kamar et al. 2011). In addition, some authors have suggested sub-categories of some of these concepts. For instance, Nadim and Goulding (2010) suggested that offsite manufacturing is a sub category of MMC. In this report, the term Modern Methods of Construction (MMC) which is widely used and common in the UK policy sector will be referred to. MMC Wales (2008: 3) described MMC as "a wide range of processes that aim to produce more sustainable social housing of better quality, to cost and in less time. This process will involve the use of efficient management processes and may involve elements of off-site manufacture".

Figure 2: Overview of MMC (panelised, hybrid and volumetric (modular) against conventional construction (MMC Wales 2008)



See Figure 2 for an overview of MMC approaches (largely seen as panelised, hybrid and volumetric/ modular) against conventional methods of construction across a design/build timeline.

There are equally diverse terms used interchangeably both internationally and in the UK to refer to the products or buildings constructed through these means. These include, modular building, pre-fabricated building and manufactured building. While in this report we use the term "MMC housing" to refer to all forms of homes built through offsite methods, we do acknowledge that a distinction is made in some instances between these terms. For instance, Jelitzer (2015), categorised modern methods of construction into pre-fabricated (prefab) and manufactured homes.

Prefabricated homes can be largely viewed as two types – modular and panelised. Modular housing has been commercially possible since the industrial revolution and has been used considerably more in Europe, the USA and Japan than in the UK (MMC Wales 2008). In a study by Steinhardt and Manley (2016a) which explored prefabrication usage in the housing market of some selected countries (Australia, Japan, Sweden, Germany, Netherlands, United States and United Kingdom), it was found that the use of modular technology across the entire UK construction sector (residential, non-residential, and civil) ranged from 2% in 2007 to 7% in 2010 while in Germany, 9% of new residential building permits are for modular buildings.

The study went further to categorise countries into three: those that have an acknowledged high application of prefabricated housing such as Japan and Sweden; those that have been identified as having both relatively high levels of prefabrication and highly efficient traditional or 'craft based' house-building industries such as Germany and the Netherlands and major economies that have an infrequent application of prefabricated housing such as the United States, United Kingdom, and Australia. This suggests that the UK is not currently considered a front runner in the use of modular technology in the housing sector.

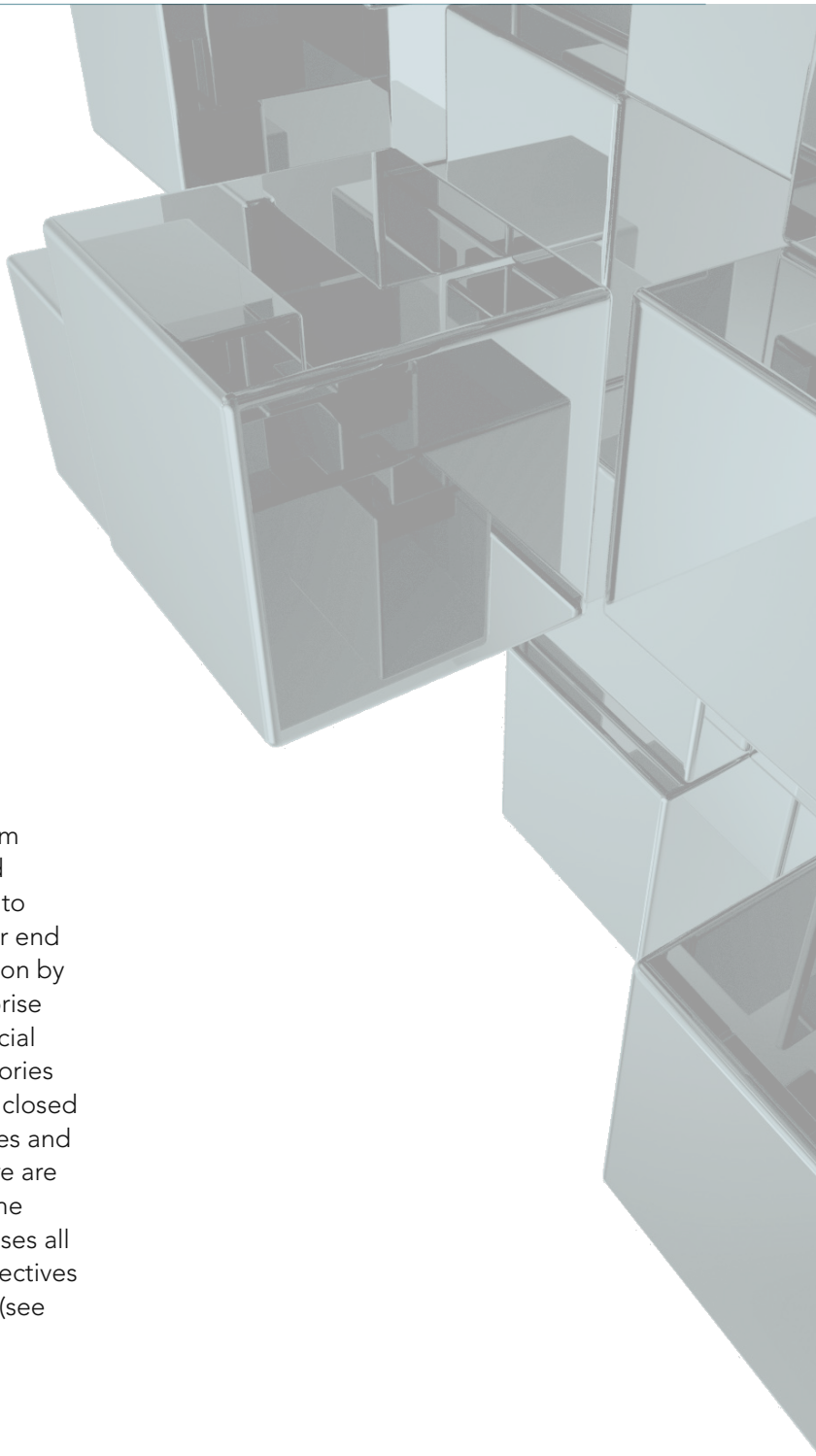
Whether modular or panelised, homes are delivered using different modes of delivery. Section 2.2.3 examines approaches to modes of delivery in the UK as well as advantages and disadvantages of each mode.

2.2.3 Modes of delivery – categories and classifications

Mode of delivery is understood as the process through which housing is procured, assembled and delivered to the client. MMC approaches overlap with onsite work as shown in Figure 2, making it difficult to differentiate what constitute offsite practice (Kamar et al. 2011). The client in this instance is understood to be a housebuilder and/or housing association. There have been many attempts to classify modes of delivery (see Table 5) based on design guidance, surveys with housebuilders as well as scoping or pilot studies. Table 5 provides an overview of various modes of delivery from different international perspectives.

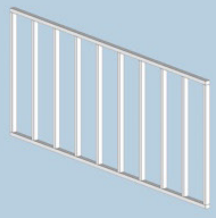
Table 5: Categorization modes of delivery of modular housing – adapted from Azman et al. (2010) and Kamar et al. (2011)

Categories of off-site system	Context/Country	Source
Offsite preassembly Hybrid system Panellised system Modular building	Based on offsite construction techniques in the United States construction industry	Lu 2009
Component manufacture and sub-assembly Non-volumetric preassembly Volumetric preassembly Modular building	Summarised based on the views of the UK construction industry on offsite	Goodier and Gibb 2005
Non-volumetric pre-assembly Volumetric preassembly Modular building	Based on a scoping study undertaken to determine the 'state-of-the-art' of OSM in Australia	Blismas and Wakefield 2009
Component Non-volumetric Volumetric Hybrid Modular building	The evolution pattern of the categorization of off-site system in Malaysia	Azman et al. 2010
Component manufacture and sub-assembly Non-volumetric pre-assembly Volumetric pre-assembly Modular system	Categories based on typical materials and examples (taken from a major building context) in the UK	2003
Volumetric system Panelised system Hybrid system Subassemblies and components system Modular (whole building) system	Based on relationship between other existing categories from various literature	Abosoad et al. 2009



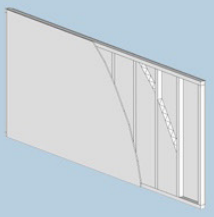
Collectively, these classifications present a wide range of possible modes of delivery from volumetric (modular) systems on the one end of the spectrum through hybrid construction to modular (whole building) system on the other end of the spectrum. In this report, the classification by Venables et al. (2004) which is found to comprise all the categories of modes of delivery for social housing in the UK is referred to. These categories are volumetric systems, open panel systems, closed panel systems, hybrid systems, sub-assemblies and components. Whilst it is recognised that there are complex broad classifications (Taylor 2010), the classification by Venables et al. (2004) comprises all the categories of MMC applicable to the objectives of this report and relevant to the UK context (see also **Figure 3**).

Figure 3 Categories of systems as classified by Venables et al. (2004)



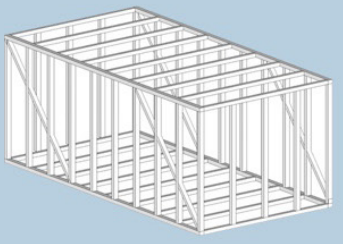
Open panel systems

The construction of the structural frame for the building using panels assembled in the factory. Open panel systems are typically delivered to the site purely as a structural element with services, insulation, cladding and internal finishes installed in situ.



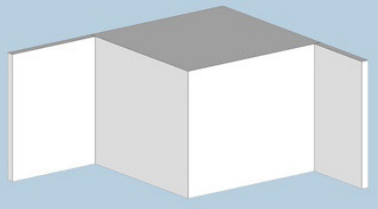
Closed panel systems

These are similar to open panel systems in that the structural elements of the building are delivered to the site in flat panels. However, closed panel systems typically include more factory based fabrication such as lining materials and insulation and may even include cladding, internal finishes, services, doors and windows.



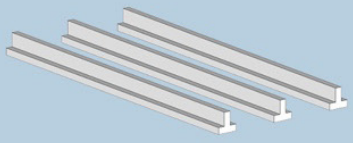
Volumetric systems

The most factory-based form of production, volumetric systems involve three dimensional modules that can be used in isolation or in multiples to form the structure of the building. These modules can be pre-finished in the factory to include all fixtures and fittings, requiring a very limited amount of installation work on site.



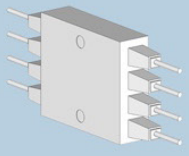
Hybrid systems

A combination of volumetric and panelised systems where the high value areas (kitchen and bathroom) are typically formed from volumetric units (sometimes referred to as pods) and the rest of the structure formed from some form of framing system.



Sub-assemblies

Major building elements that are manufactured off site but do not form the primary structure of the building. Foundation systems and cassette panels are typical examples.



Components

Non-structural elements that are assembled off site. Although currently less common than structural elements, components such as mechanical and electrical services infrastructures are being developed with significant assembly work being carried out off site.

"Volumetric systems are the most factory-based form of production and involve three dimensional modules that can be used in isolation or in multiples to form the structure of the building. These modules can be pre-finished in the factory to include all fixtures and fittings, requiring a very limited amount of installation work on site."

Open panel systems include the construction of a structural frame for the building using panels assembled in the factory. Open panel systems are typically delivered to the site purely as structural elements with services, insulation, cladding and internal finishes installed in situ. Closed panel systems are similar to open panel systems in that the structural elements of the building are delivered to the site in flat panels. However, closed panel systems typically include more factory based fabrication such as lining materials and insulation and may even include cladding, internal finishes, services, doors and windows.

Volumetric systems are the most factory-based form of production and involve three dimensional modules that can be used in isolation or in multiples to form the structure of the building. These modules can be pre-finished in the factory to include all fixtures and fittings, requiring a very limited amount of installation work on site. Hybrid systems are based on a combination of volumetric and panelised systems where the high value areas (kitchen and bathroom) are typically formed from volumetric units (sometimes referred to as pods) and the rest of the structure formed from some form of framing system. Sub-assemblies include major building elements that are manufactured off site but do not form the primary structure of the building. Foundation systems and cassette panels are typical examples. Components include non-structural elements that are assembled off site. Although currently less common than structural elements, components such as mechanical and electrical services infrastructures are being developed with significant assembly work being carried out off site.

There are, however, limited studies that refer to particular systems. Rather most research refers to broad use of MMC or modular without identifying a particular category. It is also unclear what systems are most commonly applied. Blismas and Wakefield (2009) in a study of the construction sector overall (not housing specifically) in Australia suggest that non-volumetric preassembly (76%) is the most commonly used followed by modular building (15%) and volumetric pre-assembly (9%). In the UK, based on study by Goodier and Gibb (2005), most of the categories were used by more than half of those surveyed, with panel and volumetric used by approximately 70% of the respondents. In another study by Ross (2000), involving around 200 social housing organisations and 100 builders/developers in the UK, it was found that majority of firms used panellised construction but less than one fifth utilised volumetric approaches.

In addition to not knowing what systems have been used in particular studies, there is also a lack of evidence as to the advantage or disadvantage of a particular approach. Research has instead focused on the overall advantages and disadvantages of prefabrication. Moreover, most of the existing studies have focused on a range of stakeholders including builders, material suppliers, designers and academics, without consideration of the unique position of housing associations.

2.2.4 Modes of delivery – advantages and disadvantages

This section reviews key advantages and disadvantages of MMC in general as well as particular modes of delivery as discussed in evidence sourced. The articles reviewed showed that overall cost reduction was largely viewed as a key advantage though this was not the case in all studies reviewed.

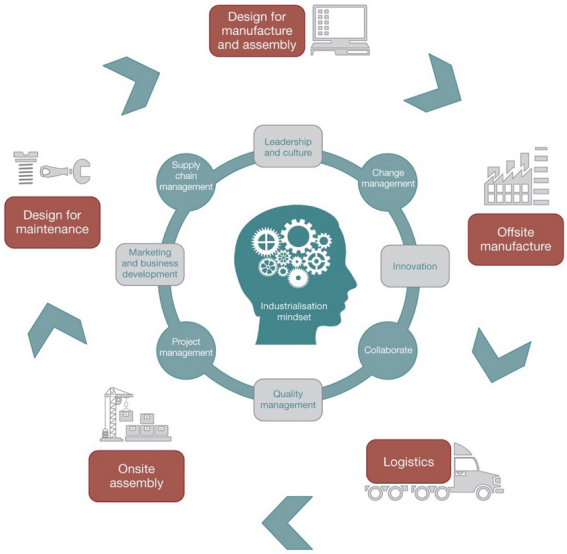
While the study by Edge et al. (2002) based on data from Germany found that cost of construction was reduced using modular construction, Jaillon et al. (2009) in a study of Hong Kong suggested modular housing (especially for high rise social housing) could be more expensive than traditional in-situ construction. Although, they found that it could achieve lower overall cost by incorporating the construction time reduction because of lower material and labour cost in place of production. In addition, at least 35% of the respondents thought that according to their experience, the amount of waste reduction on building sites by using offsite construction when compared with conventional construction was about 10–20% whereas others viewed that the waste reduction level when using modular techniques would be over 30%.

This evidence suggests that broadening use of prefabrication could considerably reduce construction waste and alleviate the burdens associated with its management, suggesting that local factors may play a significant role in the cost of modular housing construction. The studies were unanimous on the fact that MMC could contribute to waste reduction. See also Table 6 overleaf.

Table 6: Generally identified advantages and disadvantages of prefabricated housing

Advantages	Disadvantages	Source/Country
Construction waste reduction (average wastage reduction level was about 52%)	Higher expense (overall cost per unit floor area by using modular method was about 20% greater) Conflicts with traditional design processes Lack of incentives	Jaillon et al. (2009)/Hong Kong The study is based on questionnaires administered to 354 professionals in the building industry and actual field measurement of waste generation in fourteen recent building projects (this study was only focussed on residential buildings) in Hong Kong.
Reduced construction time Simplified construction processes High levels of consistency Improved working conditions Reduced onsite risks Better energy performance	Longer lead-times High set-up costs Negative stigma Difficult to finance Restricted by manufacturers Constrained by site conditions Long-distance transport Interface problems on site due to low tolerances	Blismas and Wakefield (2009)/ Australia The study employed a variety of methods to collect data, which included industry workshops (3 workshops with forty-five participants, ranging from clients, designers, constructors, suppliers and researchers), case studies (seven case examples, spanning four states) and interviews conducted across Australia
Cost of preliminaries reduced (by having a shorter construction time, a saving of £420000) Shop fit-out cost and construction time reduced by 10%. Cost of aircraft pavements reduced by 18% over 2 years Unit cost of hotel bedrooms 20% lower than 10 years ago.	Contractors not experienced enough Late deliveries exacerbated by over ambitious sales team predictions The volatile nature of the supply chain with some suppliers going into receivership, but both are now looking for reduced costs on future projects	Gibb and Isack (2003)/UK This is a UK study based on interviews conducted with 59 senior personnel from 42 of the largest, or most frequent, construction client organisations in the UK. However, this is not specific to housing but broadly the construction sector.
Cost savings from housing prefabrication of around 22%.	Supply base in the UK was poor with limited alternative suppliers.	Edge et al. (2002)/UK The methodology for the 30-month project was based around: literature review and interview survey
N/A	The study found that struggles over the assemblage and agencement of housing construction markets – are the critical issues underpinning UK resistance to prefabrication	Lovell and Smith (2010)/UK The data include 25 intensive interviews conducted in 2003 with UK government, housebuilders and consultants about the introduction of prefabrication as an element of social housing policy.

Figure 4: Interconnectedness of design and build processes in MMC delivery (adapted from RIBA 2015)



In addition to the advantages and disadvantages, studies identified processes that need to be addressed within the industry. First is a recognition that a modular design process is highly interactive and requires early collaboration between designers and builders as well as early decisions in the design (see also **Figure 4**). Therefore, late design modifications which are a major cause of waste during design, are suggested to be avoided.

Many identify constraints within the industry, and the immense difficulty involved in change. While the above is a general overview, **Table 7**overleaf reviews evidence based on distinct modes of delivery and categories of MMC construction based on Build Offsite 2010. Generally, the identified benefits include cost predictability and increased time predictability leading to greater certainty of handovers to residents; faster construction time; high thermal insulation; quality control and low wastage. Although, some studies benefited from no increase in scheme costs compared with traditional approaches, there were two projects that came out more expensive than traditional approaches. This further underscores the fact that achieving cost efficient modular construction may be project specific.

Table 7: Identified benefits/advantages/ disadvantages/challenges of each modes of delivery in the United Kingdom – Evidence from Build offsite 2010.

Mode of delivery	Project details/ Date/Location	Identified benefits	Identified challenges
Hybrid	This modular apartment project was completed in June 2000 for Josephine Rowntree Foundation, The Architect was Levitt Bernstein Associate Ltd.	Cost minimised while high standards was provided at affordable rents. On-site construction time was minimised – design, assembly on site and completed building achieved in 36 weeks from site possession.	Not discussed
Closed panel system	Timber panelised system for 172 social housing project for the Lefevre Housing Scheme in Tower Hamlets.	There was no increase in scheme costs compared with traditional approaches. In addition, the use of modularity ensured cost predictability and increased time predictability leading to greater certainty of handovers to residents. The faster construction meant earlier occupation by tenants and by extension earlier generation of rental income and reduced time for regeneration of existing neighbourhood. The project also achieved high thermal insulation of the building envelop that reduces running costs.	Not discussed
Volumetric	This is a project for the construction of 125 pre-fabricated apartments for students and key workers. The project was carried out by Unite in house Architects for Unite.	The use of modularity ensured that parts were produced in a factory to agreed schedules and guaranteed quality. The use of modular approach also ensured that the project was pre-engineered to reduce life cycle cost.	Not discussed
Closed panel	The project used the External Insulation and Finishing System (EIFS) used in the construction of this commercial property for Bellway Homes North East.	The project achieved high thermal efficiency and cut at least ten weeks off traditional build time. High aesthetic value and reduced site waste was also achieved while allowing for the use of lightweight frame and panel which meant foundations need not be as strong.	Not discussed
Component	Not discussed	Increased predictability in costs and build time, reduction in installation time, excellent thermal values and wall heights of up to 12m.	Not discussed
Closed Panel	This is a fifteen apartment homes built for Sandwell Metropolitan Borough Council by INTEGER	The achieved reduction in cost in use, reduction in construction time and an enhanced standard of living for tenants.	Total cost of project came to around 107% of the build cost comparable to traditional social housing.

Table 7 Identified benefits/advantages/ disadvantages/challenges of each modes of delivery in the United Kingdom -Evidence from Build offsite 2010.

Mode of delivery	Project details/ Date/Location	Identified benefits	Identified challenges
Component	Social housing by Southern Housing Group in New Romney, Kent	The project achieved reduced costs; reduced onsite development process by up to 70% and ensured factory based quality control and achieved good insulation. The project is not dependent on weather or skilled labour availability.	Not discussed
Component	A project by Prime Focus that produced 131 specialist social housing units for frail elderly.	Built to high performance specifications and with the special need of tenants incorporated and achieving easily maintained building.	Not discussed
Closed Panel	A Project for Longhurst Housing Association.	The project achieved fast track low wastage construction and low U- values. In addition, it yielded air leakage rates as low as 0.08 air changes per hour and carbon index of 8.8.	Not discussed
Panel	100 houses constructed at West Malling, Kent	The project completion date was achieved. Also, the problem of labour shortage was resolved while maximising available space and achieving good insulation.	Not discussed
Hybrid	The project consists of 38 flats completed in 2006 for Tower Hamlets Community Housing.	The project is a modular construction of up to 17 storeys – currently Britain's tallest modular construction. The rapid construction system reduced overall development time by 14 months and logistical problems was minimised. Waste generation on-site reduced by over two-thirds and achieved excellent acoustic insulation. The project was also estimated to have a 60-year life, enabling purchaser to obtain mortgage.	Not discussed
Hybrid	The project is made up of 177 houses and 72 apartment modules for South Chase New Hall Ltd.	Rapid construction technology was achieved – construction periods reduced by 50%. The project has an Eco Homes Excellent Rating – Code for Sustainable Homes Level 3*. The buildings were constructed to be extendable and adaptable building forms with high level of quality control.	Not discussed

2.3 Modes of delivery – key business model formats

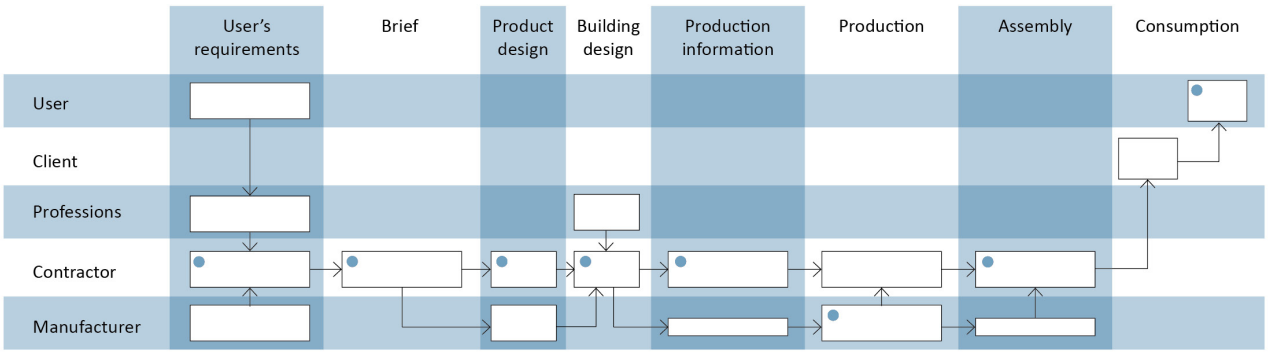
This section reports on literature related to UK lending approaches for MMC/off-site manufacture. There seems to be limited evidence examining lending mechanisms for MMC/off-site housebuilding. Recent initiatives related to the Government White Paper on Housing (DCLG 2017) are discussed in press releases and journalists' commentary (Lloyd 2017). However, there is a lack of research on approaches to investment and lending mechanisms related to MMC housing delivery. Instead a broader literature that examines 'business models' for housebuilding is used.

2.3.1 Models of housebuilding

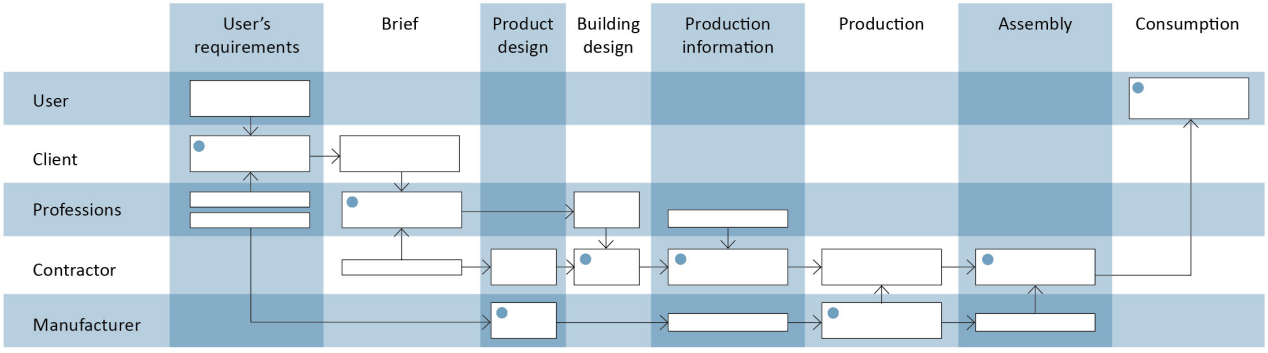
Viewing a 'building as a process' rather than as a product, is considered central to the analysis of off-site manufacture of housing (Turin 2003). Turin's (1967) paper is an important starting point in this discussion - so much so that it was re-published in an academic journal's special issue on 'Re-engineering Construction' (Winch 2003a). Turin classifies patterns of building into four approaches, each of which can be characterised by a different set of relationships between the participants in construction. See edited Comparative Diagrams of Turin's Model 3 and Model 4 in **Figure 5**.

Although these were formulated 50-years ago, the approaches Turin defines remain clearly recognisable as ways of building in terms of modes of delivery. He first identifies the 'One-Off' unique building where information is handed sequentially from User/Client to Professional designer, then to Contractor and Manufacturer. He then continues to characterise three further approaches to prefabricated or industrialised building, as he terms it (Turin 2003, p. 180). The first of these is a 'Component'-driven approach, where the relationship between Professional and Manufacturer dominate the process and the Client's requirements are governed by the dimensional co-ordination of component systems. The completed building Model is only introduced to the individual Client at the point of consumption. Turin identifies this as the "conventional speculative housebuilding" approach (Turin 2003, p. 184).

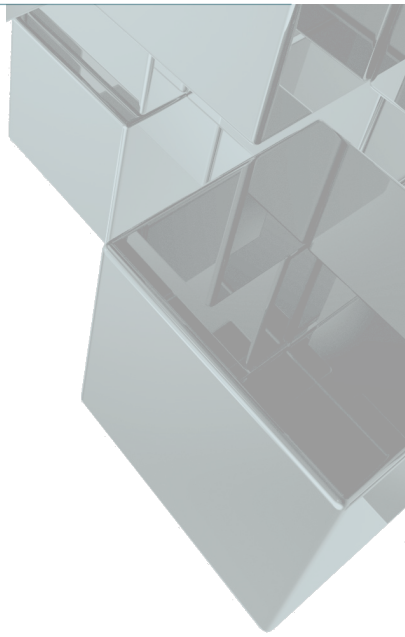
Figure 5: Diagrams of Turin's model



Model - after Turin (2003)



Process - after Turin (2003)



It could be viewed that the 'Model' building approach is the dominant way in which social housing has been procured using a Design & Building contractual route over the last 25-years (Clamp et al 2012); and Turin identifies the single-point of responsibility and better value for money as benefits of this 'Model' approach – where these similarly are the assumed benefits of Design & Build procurement. Turin also notes that the Model approach either limits client choice or in reaction to these limitations leads to a proliferation of special adjustments to the Model until a point is reached where: "nobody really knows what is a 'standard' and what is a 'special' and […] few manufacturers are prepared to state clearly the economic rules of the game by realistically pricing both standards and specials" (Turin 2003, p. 185).

In response to this, Turin concludes with his description of a 'Process' approach to industrialised building where the skills of different participants are combined across the development of the building. He notes here that "the distinguishing feature of this approach is precisely the permanence or stability of the team" (Turin 2003, p. 186), which suggests a range of partnered relationships that were recommended in Latham (1994) and Egan (1998). This paper identifies the characteristics of the speculative housebuilding model and contrasts these with other component-based or process-driven models for off-site manufacture, suggesting that the approach to housebuilding that still predominates may not be conducive to effective off-site manufacture.

2.3.2 Types of business model scales – the role of housing associations

Two key approaches to studying business models and off-site manufacture applicable to the housing sector are discussed. These two approaches can be viewed as either:

- macro-economic - whereby business models for housebuilding relate to procurement routes, some of which involve off-site manufacture (Pan and Goodier 2012; Turin 2003);
- micro-economic - where the business models for off-site manufacture relate (Barlow et al 2003; Brady et al 2005; Hofman et al 2009; Winch 2003a) to housing design and functional requirements including production methodologies for off-site manufacture.

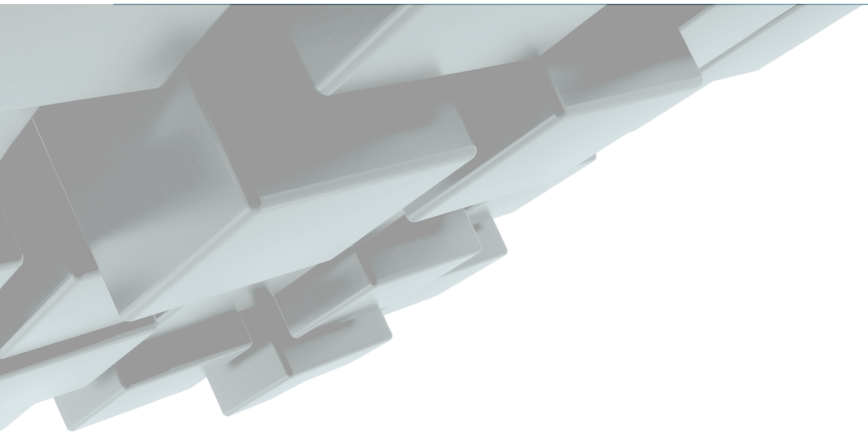
At the macro-economic level, it is suggested that the UK's speculative approach to housing development can inhibit effective development of off-site manufacture (see also Barlow et. al. 2003). At a micro-economic level the inter-relationship between housebuilding business models and production methods for off-site construction are studied, which offers a useful perspective on the nature of supply chains and design strategies for off-site manufacture.

"There has been more academic investigation of the relationship between housebuilding business models and manufacturing processes at a micro-economic level."

There has been more academic investigation of the relationship between housebuilding business models and manufacturing processes at a micro-economic level. That is, the way in which established manufacturing processes might transfer into use in industrialised housebuilding and the nature of appropriate manufacturing strategies for housebuilding business models.

Veenstra et al (2006) have studied a related approach to customisation and the de-coupling points in the process of offsite manufacture. They collaborated with the housing contractor Vos Construction and the architect Jan Wind in the development of a housing system that defined assembly modules from the point of view of spatial use and viability of manufacture by suppliers. Their study used the concept of 'product platform architecture', which is "defined as a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be developed and produced efficiently" (Veenstra et al. 2006, p. 158).

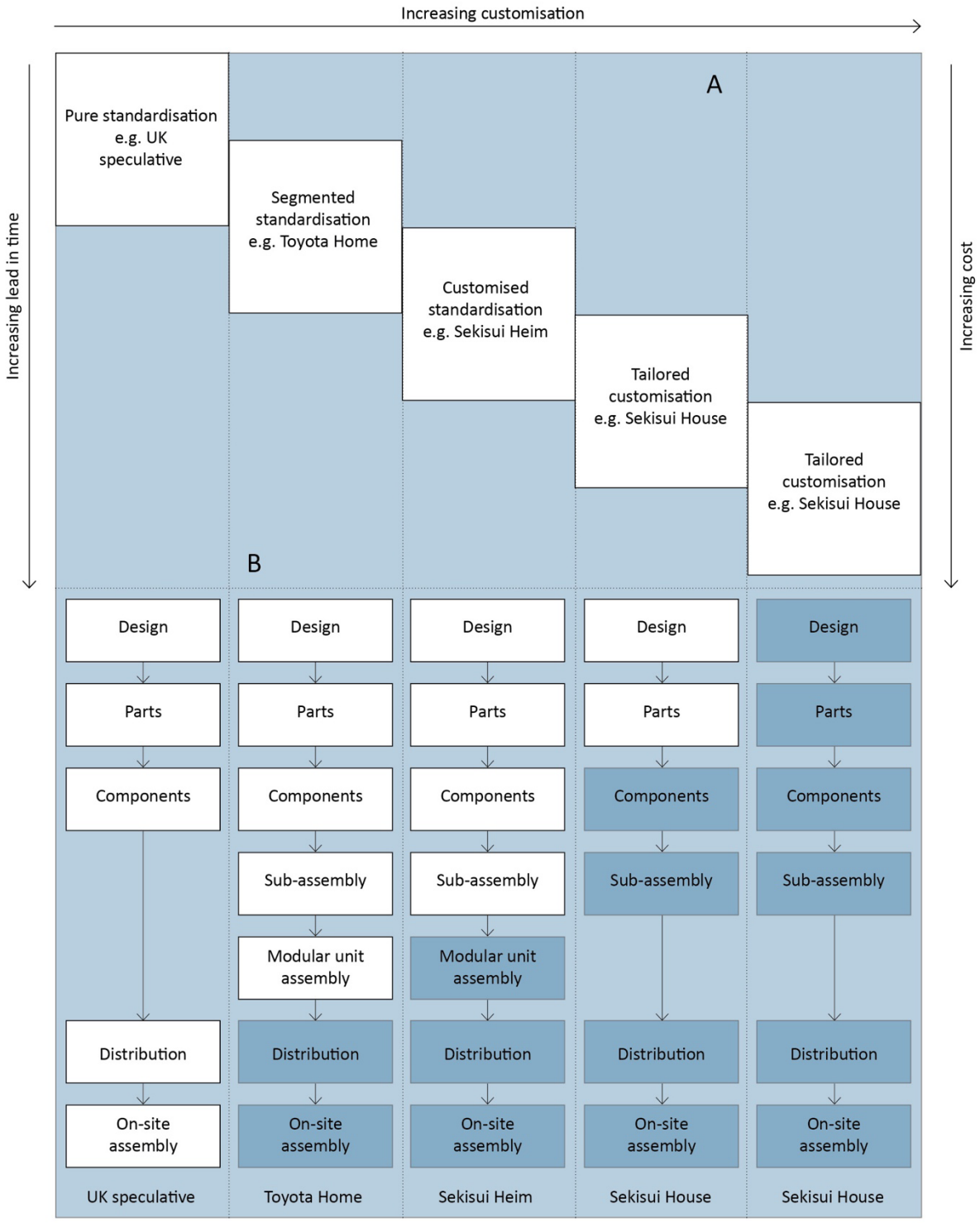
In this approach, commonalities are defined by spatial use rather than construction element. For example, the hallway of the house is defined as the 'traffic module' within which entry and circulation into the house, – both of the occupants and also the servicing systems for the house - can be standardised (Veenstra et al. 2006). Once product platforms such as these are defined, standards for interface design and dimensional control are agreed at which point there is the potential for a range of suppliers to contribute to manufacturing. Hofman et al (2009) later study analyses supplier-contractor networks within this business model and the extent to which suppliers become integrated into off-site manufacturing processes. This study concludes that suppliers contributing to the common product platform may be integrated into the contractor's supply chain and those add product customisation on to that platform will not.



Some of the literature investigates what might be called the rhetoric of offsite manufacture in the UK over the last 25 years – the 'rethinking' of construction (Egan 1998) in terms of 're-engineering' processes and 'lean' methodologies. Winch (2003b) counterpoises this dominant model with a 'complex systems' approach that concentrates on the creation of an infrastructure and its related systems rather than a mass-market product. Complex systems share lower volumes of production using a skilled workforce to create complex products. Winch argues that this complexity cannot be re-engineered out of this production process (2003b: 111). Winch (2003b) suggests manufacturing needs to be considered in terms of 'product information flow' rather than the dominant model of shaping and assembly of materials and, echoing Turin (2003).

Winch (2003b) categorizes housebuilding as a 'Make to Forecast' process because of the emphasis on development gain rather than production efficiency within the UK housebuilding business model. He also notes that where development gain can be separated from housing production, as in Japan, which could be categorised as a 'Make to Order' customised approach (p. 115). Barlow et al (2003) study Japanese offsite manufacture in detail, seeking to understand how supply chains are structured to achieve standardisation-customisation in relation to cost and production lead-time. They argue that mass-customisation can be delivered through several generic supply chain models that are distinguished by the points at which a process of planned standardisation of manufacture is de-coupled to introduce customer choice (p.135). See **Figure 6** for an illustration of supply chain models against forms of standardization.

Figure 6: Supply chain models against forms of standardisation



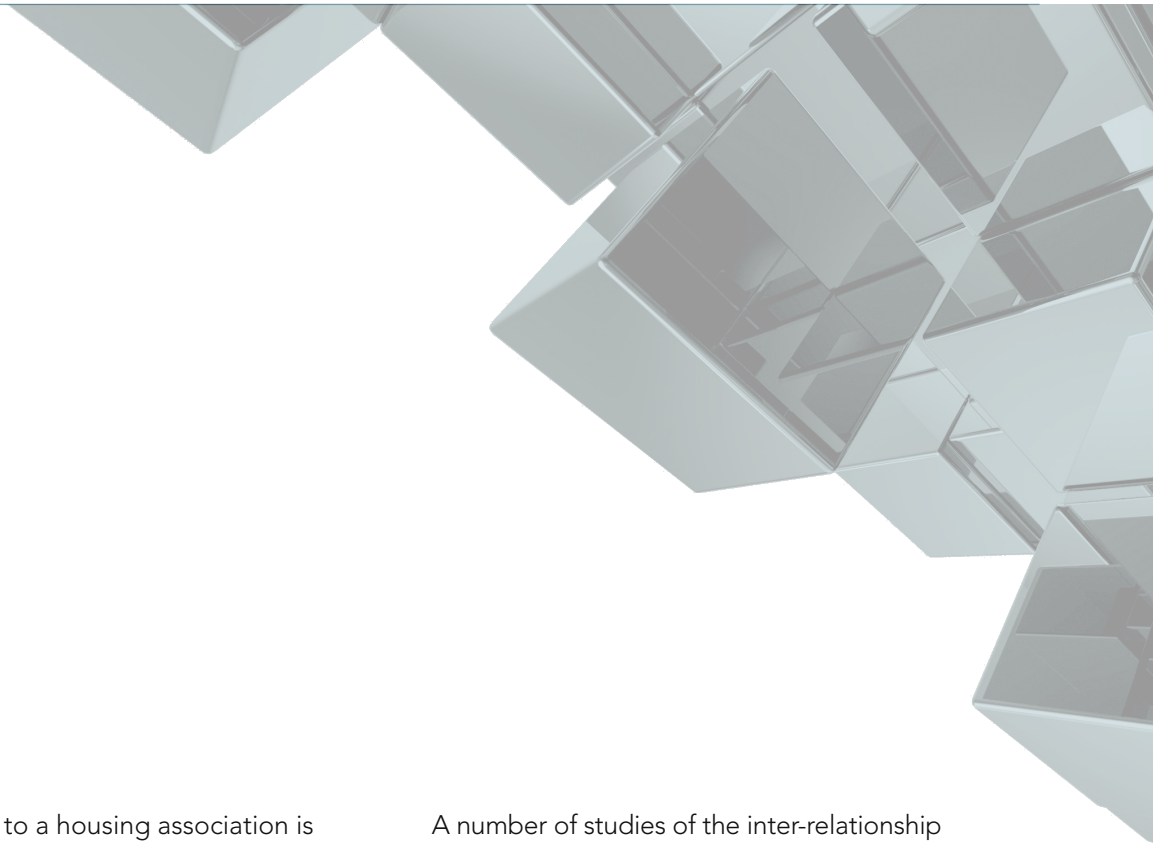
Supply chain strategies uber diagram!

Pan and Goodier (2012) relate housebuilding to off-site manufacture by analysing the business models of house construction and relating these to adoption behaviours for off-site manufacture. This establishes a more direct connection between social housing models and off-site manufacture. The paper includes four case studies in the UK, of two housebuilders and two system-manufacturers, and analyses the relationship between the business models of each company and the off-site production technologies they employed. From this study, they draw a more general conclusion that construction companies adjust business models to benefit from offsite-techniques where these might be seen to support the core business values of the company, which Pan and Goodier (2012:22) take to be "capturing and creating value in the development, rather than manufacture and supply or construction technological innovation per se."

Other than study by Pan and Goodier (2012) there is limited research into this connection between business models and modes of housing delivery within a UK context. A greater number of studies focus on specific relationships within the process of offsite manufacture (Barlow et al 2003; Winch 2003; Brady et al 2005 and Hofman et al 2009) but only two appear to link housebuilding business models to offsite manufacture including: Pan & Goodier (2012) and Pan et al (2007).

Pan & Goodier (2012) suggest, based on review carried out by Calcutt (2007), that there are four business model routes for MMC housing delivery in the UK. The four models are described as:

- The current trader business model, which consists of a cycle of land acquisition, development and outright sale, followed by the vast majority of UK housebuilders, where the housebuilder retains no long-term interest in the property.
- The investor model, which denotes that developers retain a long-term interest in a developed site, which may consist of housing for rent or the retained portion of shared ownership sales. Therefore, the developer trades a proportion of the up-front development profit for the opportunity of long-term revenues and future capital growth. Yields are likely to be relatively smaller than under the current trade model, but more secure.
- The self-build model, which is related to both the individual owner who builds the dwelling or contracts to architects, builders and other suppliers as needed.
- The RSL (Registered Social Landlord) build-for-sale model, which aims to create mixed communities in which the social and market sale homes are indistinguishable.



The most relevant to a housing association is suggested to be the fourth category, however, this does not fully describe what the mode or role of the housing association should be in the entire process. This, the second important dimension of the mode of delivery of prefabricated housing is in the role of the client in the procurement process. In this, there are three main approaches as described in **Table 8**.

Pan and Goodier (2012) note that the predominant 'current trader' model of land acquisition, development and outright sale generates high short-term risk that precludes investment in off-site manufacturing; whereas an 'investor' model, where the developer maintains long term investment in the developed site, encourages longer term investment and a longer return of revenue that may encourage related investment in offsite manufacture. The fourth model – Registered Social Landlord build-for-sale- offers overlapping characteristics of the 'investor' model although within a 'current-trader' market economy. Pan and Goodier (2012) conclude that "within such a context of business models, offsite production has largely been, and is still being, regarded as a technological solution, often associated to images of offsite manufactured components and systems, rather than as an innovative process potentially affecting the businesses strategically" (2012: 17).

A number of studies of the inter-relationship of business models and offsite manufacture identify the UK housebuilding market's 'current trader' (Calcutt 2007) strategy of accruing benefit from land development as a key inhibitor to the customisation of housebuilding. (Barlow et al. 2003; Brady et al 2005; Meikle 2008; Winch 2003a). The 'current trader' strategy also transfers financial risk to the individual homeowner and their mortgage provider. To alleviate this risk, the Building Societies Association has called for greater clarity on offsite manufacture techniques, including a standardisation of systems and descriptive terminology, and the recording and testing of this in property information and warranties (BSA 2016). It is perhaps telling that they recommend an image change and that the term 'prefab' should not be used because of its association with "poor quality emergency housing of the past" (BSA 2016: 27).

As an alternative to this dominant model some financial industries and pressure groups are beginning to argue for development aligned with Calcutt's 'Investor model' (2007). One such example is Legal & General's initiative begun in 2014 to secure a long-term portfolio of housing let to the Bristol-based residential developer Places for People Homes to develop new housing with a mixed tenure.

Table 8: Mode of delivery and possible role of Housing Association

Mode of delivery	Detail/Role of housing association	Example	Source
Developing and building	Larger private house builders invest in MMC factories. The housebuilders normally take the role of developing and building houses.	United Kingdom: The house builder Westbury Homes opened its Space4 housing factory near Birmingham in 2001. The factory can produce up to 6,000 houses per year. House builder own the industry.	The Parliamentary Office of Science and Technology, (2003)
Assemble to order strategy	Some supported by in-house design teams and partnered with their manufacturers and suppliers.	Japan – Toyota Home, Sekisui Heim, Sekisui House. Theoretically, according to Barlow et al 2003, there are five approaches: buy to order, make to order, assemble to order, make to stock and ship to stock. In the Japanese market, the main approach is adopting an assemble-to-order strategy.	Barlow et al.(2003)
Subcontract entire process	Some developers have no construction capability and subcontract the entire construction process.	The housebuilder does not undertake the construction work but rather supervises others.	Hsieh(1997)
Joint venture	Strategic partnering alliances that exist between housebuilding organisations and manufacturers.	Advance Housing was a joint venture established in 2002 between Barrett Developments Plc, one of the largest housebuilders in the UK, and Terrapin International Ltd, a market-leading steel frame and modular manufacturer.	Blackman (2007)

"While the study is mostly about residents' expectations regarding new build 'customised' housing rather than specifically modular, it is useful in terms of understanding the broad expectations residents place on housing in terms of customisation."

2.4 Customer experience of modular housing construction

Research in housing overall and modular housing specifically has largely focused on identifying customer/resident views and attitudes towards MMC. There are very few studies that examine residents' experiences of living in MMC housing whether panelised or volumetric. In addition, there seems to be a dearth of published post occupancy evaluations or field studies that explore residents' experiences longitudinally or comparatively (between different house types or across different UK locations). However, the following evidence gathered in housing and in some instances student residences aims to shed light on some of the key themes and issues that may be relevant in the context of this report. Key themes include: customer/resident views towards modular housing, satisfaction levels amongst residents in student accommodation and designing for residents needs.

2.4.1 Customer/resident expectations and preferences – UK and the EU

Hofman et al (2006) suggest a key approach to successfully designing modular housing when taking residents needs into account lie in identifying residents' preferences and expectations. They conducted a survey with potential house buyers in the Netherlands with the objective of understanding what 'elements' such as bathroom, kitchen and or roof types potential buyers prefer. The survey explored views based on 5 'priority' dimensions. These dimensions are: (1) technical systems; (2) interior finish; (3) floor plan; (4) house volume and exterior; and (5) environment. Sample included 304 potential buyers who were contacted via postal survey; 24 did not participate.

Hofman et al (2006) argue the priority listing is of 'great importance for building developers who offer (or are considering offering) customised housing' (customised housing is often referred to in context of MMC in the Netherlands). Although it was found that potential buyers prefer having a priority list, decisions on particular options were made based on cost implications. While the study is mostly about residents' expectations regarding new build 'customised' housing rather than specifically modular, it is useful in terms of understanding broad expectations residents place on housing in terms of customisation.

Expectations on housing needs are often linked to satisfaction levels. The UK 2016 CSS survey on conventional housing noted only 78% were satisfied with the condition of their property when moving in and 75% were satisfied with the standards of finish when they moved in. These figures as outlined also in section 2.5 are often referred to as a way of promoting offsite methods.

Customer preferences and expectations are often seen as key barriers to wider uptake of MMC housing. NHBC (2016) notes a key issue limiting uptake of volumetric construction is the concern regarding customer expectations regarding 'prefab' construction. Kempton (2010) also highlights that the stigma of non-traditional methods may impact on the way potential purchasers or tenants view MMC. A survey undertaken by the journal Inside Housing (2003) found that 46% of social housing tenants would object to being offered a home built using MMC. NHBC 2016 adds that its industry participants saw the opportunity to offer bespoke options to customers as more limited with volumetric construction in particular since decisions need to be made earlier on in the process– restricting buyer options particularly if, for example, an off-plan buyer withdraws from purchase or the home is sold post construction.

The NHBC (2013) refers to research carried out by Pam Brown Associates (2001) on two volumetric MMC projects that confirmed: the look and feel of the building did matter to people and affect their decision to move in and stay. Residents surveyed were pleased with the design and appearance; the spacious nature of their apartments (space standards were seen to be generous and met Lifetime homes criteria) as well as levels of acoustic separation. This later point is backed up by discussion in design guides noting the principle of separate modules creating robust acoustic details on separating walls to flats. On another MMC case study described by NHBC (2013) resident feedback was noted as 'very positive'.

Clearly house unit size is particular to a project not construction type (unless modules themselves are seen as in some way restricting) however if off-site methods can achieve cost saving then size may be increased. Reports such as RIBA (2011) The Case For Space: The Size of England's New Homes on low space standards in developer housing have led to development of nationally described space standards with new rules introduced giving local authorities the option to set minimum space standards based on these. They are not, however, compulsory and RIBA (2015), Space Standards for Homes: Homewise still drives for an increase in space standards and their inclusion in the building regulations. Social housing standards are generally in advance of developer standards particularly where Lifetime Homes are required.

"The findings report that students main concern was noise (64% had an issue with noise)."

2.4.2 Learning from feedback and designing for residents needs

Although there are no published post occupancy evaluation studies or reports regarding modular housing, McGrath and Horton (2011) conducted a post occupancy evaluation (POE) on a recently built student residency completed using MMC methods. POE was conducted primarily to understand student levels of satisfaction in a MMC student residency. Random sampling was applied based on use of questionnaires. There were 39 respondents out of a potential population of 500. There are a number of key methodological issues regarding the study. For instance, the paper does not discuss how questions were designed making it difficult to interpret findings.

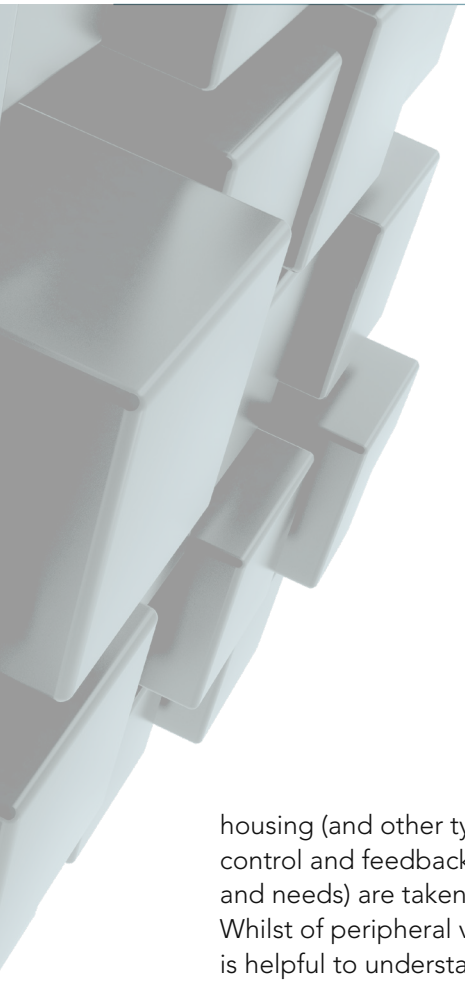
There is also no understanding regarding control samples or how comparisons were made.

The findings report that students main concern was noise (64% had an issue with noise). Reasons for a 'noisy environment' were explained by students as coming from noisy neighbours and the 'construction of the home' as well as other neighbours having similar lifestyle patterns. It is unclear, however, if students generally report on noisy environments in student residencies making it difficult to contextualise findings. Overall 51% of students noted they would select modular build noting high satisfaction levels; though again it is unclear if this may be the case in a large number of student residencies.

Johannes et al (2008) discusses modular approaches to housing in the Netherlands based on companies wanting to compete more effectively therefore needing to meet customer needs. The report concludes that 'platform thinking' (also discussed in 2.3) can offer consumers tailor made housing at affordable prices. The platform approach to housing can be defined as standardisation but with controlled and researched variations and the concept is applicable to offsite construction 'systems' in terms of meeting a variety of possible client requirements or aspirations for their housing units through 'options' available in the system.

Johannes et al (2008) notes that project-based organisations (traditional construction) can provide good customer focus but struggle to accumulate and then disseminate corporate learning among individual customers and projects or capture the potential benefits of standardised work processes and integrated automation. The subject of platform links to recent UK developments in 'Custom Build' as customer focused approach to housing provision with user participation and involvement. In its broadest terms this approach may or may not involve off-site methods.

A working paper by Johnsson and Meiling (2009) raises the issue of quality management in Sweden's industrialised housing - equivalent of prefab/ modular/MMC in the UK. The study interviews contractors involved in delivering industrialised



housing (and other typologies) on how quality control and feedback (including residents' views and needs) are taken into account and managed. Whilst of peripheral value to this report the study is helpful to understanding how other contexts approach feedback including residents' views and needs during design. The study suggests industrial house builders (equivalent to MMC in the UK) benefit more from experience feedback than traditional construction firms, since the repetitiveness is higher. However, despite the recognition that feedback is critical, authors suggest it is rarely used. The manufacturing process of four industrial house builders in Sweden was studied and mapped. The results show that much focus was put on streamlining the production process at the factory, but that experience feedback between departments at the company was small and non-existent from quality audits within the company.

In terms of offsite construction in the UK the inference could be drawn that there are great possibilities in terms of customer feedback integration but it is not guaranteed. The possibilities are related to system development compared to each traditional project that is new excepting that house builder house types can also be informed by feedback while housing associations routinely feedback into their standard project briefs.

2.5 Long term management and maintenance issues

Long term management issues are not explicitly discussed or examined in the literature in relation to housing delivered using MMC methods. However, there are overlapping design and or build issues that could be viewed as directly or indirectly linked to long term management. The three issues are discussed in detail and outlined in this section including: Build Quality; Snagging, Defects and Maintenance and Adaptability, Flexibility and Sustainability. These issues have been identified from the literature reviewed as key features relating to the use of offsite MMC construction that are of particular relevance to any organisation accepting the handover of, and the responsibility for, long term management of housing units.

2.5.1 Build quality

'Quality' is viewed as a key driver for the uptake, and an expected benefit of the delivery of offsite construction when compared to more traditional onsite methods. It is discussed here since 'quality' suggests a durable and robust product with a long-life span and reduced requirements for ongoing maintenance. Quality is defined in the context of this section as 'build quality' rather than 'design quality'. The build quality issues though not exclusive were found to be of greatest relevance to issues of long term management including: increased mechanisation, improved workmanship due to conditions, process improvements and quality checks and increased possibilities of standardisation.

These are set against perceived poor quality of work on site with limited QA checking. Issues of tolerance and links between on and off-site elements (interfaces) or issues of transport and delivery are key aspects of ensuring quality of completed off-site constructions along with design issues of co-ordination on and off-site.

Quality as a driver of offsite construction

Miles and Whitehouse (2013) conclude based on findings from a review panel consisting of leading members of the Construction Industry Council, that 'build quality' is one of the 'potential' advantages of offsite construction (others included are speed of delivery, construction health and safety, energy in use, whole-life carbon footprint and reduced transport pollution). They describe improved build quality as 'widely accepted'. This view is supported by Goulding and Nadim (2009) who report findings from a survey conducted with 36 large construction organisations. They suggest that the majority of respondents (86%) agreed/totally agreed that the reasons for a company to opt for using OSP (offsite production) was to improve the 'quality' of the final product. Lawson et al (2014) suggest superior quality is achieved through a "factory-based construction process and pre delivery checks". Kamali and Hewage (2016) also describe how high quality can be achieved with the use of MMC due to controlled manufacturing facilities with repetitive processes and automated machinery.

CIC (2013) also suggests manufacture in a factory using production engineering techniques ensures accuracy that building on a construction site cannot.

NHBC (2016) explore attitudes to a range of (Modern Methods of Construction) MMC across the industry through initial focus group sessions and then 135 interviews with house builders and housing associations. The report concludes that it was widely perceived that MMC would have a role to play in improving quality of construction and that this improvement was shown in practice. As with much of the research available however the results relate generally to a variety of categories of MMC with limited direct reference to specific modes of delivery that may have differing credentials as for example volumetric steel construction or panelised cross laminated timber. In addition, the term 'quality' is not explicitly defined other than mentioned as 'improved build quality'. NHBC (2016) do highlight some limited specific observations on volumetric construction and the use of 'pods'. In terms of volumetric construction, the report notes both positive and negative feedback from the interviews. The feedback suggests that to achieve the build quality benefits that were reported as a possibility good upfront co-ordination and rigorous inspection is required.

Johnsson and Meiling (2009) use case studies of two Swedish timber module prefabrication firms to study quality control processes related in this instance to defects in timber modular offsite construction. These firms are wholly responsible for large parts of the building process and therefore have greater opportunities to control and improve quality in a more consistent way than ordinary construction companies. As a result of this control they conclude from quality audits of three phases of the building process that the case study companies were better in terms of product quality than conventional housing.

Specification and Consistency of Offsite Construction

NAO (2005) conclude that MMC can provide at least as good quality as more established building techniques provided they are appropriately specified. The report drew on contributions of 50 leading sector practitioners in four workshops, together with further detailed information from over 20 organisations active in the home building industry. The report focussed on durability (long lasting) cost to maintain (whole life costs) and operation (performance). In terms of durability it notes that all structural components of the methods analysed have an expected life in excess of 60 years – this is the typical industry period for assessing expected component service lives. TRADA and SCI design guides while clearly industry promoting back up these anticipated lifespans. NAO (2005) continues that in terms of whole life costs "Materials are of similar or identical specification so will have the same durability and whole life cost. Maintenance regimes for components, such as windows, will be the same regardless of the building technique deployed because the specifications ensure that the components are the same". This implies the same specification should result in the same 'quality' on or off site.

Robert Hairstans (TRADA 2010) suggests similarly that MMC can deliver at least as good a quality as more established building techniques, providing they are adequately specified. Offsite may not guarantee enhanced 'durability' but it should reduce risk of 'non-conformities'. CIC (2013) similarly describes 'predictable quality' and 'predicable performance' as characteristics of offsite product supply. The same specification may be developed for offsite or onsite but the former is more likely to meet that specification.

"This may be seen as a disadvantage over say on site wet trades concrete/brick/block, in terms of 'durability'."

Kamali and Hewage (2016) note, however, that for modules – high quality materials are required that are durable and lightweight due the transport requirements. This suggests in some cases both specification and predictability may be improved over equivalent on site methods. It could be added however that most of the MMC's discussed in the literature are lightweight in nature such as steel or timber frame. This may be seen as a disadvantage over say on site wet trades concrete/brick/block, in terms of 'durability'. Gaze et al (2007) similarly suggest specific design requirements in MMC that must be appreciated to maintain quality.

Nadim and Goulding (2010) analyse transcripts from 54 questionnaires carried out under the ManuBuild EU Research Project 'Open Building Manufacturing'. Interviews were of construction industry stakeholders from 4 European countries – Germany, The Netherlands, Sweden, and the UK. The report records a negative image of prefabricated/modular homes including poor quality. It notes the need to provide assurance that the prefabricated approach is of similar quality and longevity to traditional construction.

In fact MMC products will need to demonstrate better quality than their traditionally built products, thus avoiding structural damage, and defects. In order to ensure this a better management of tolerances and inaccuracy was needed. That said all respondents seemed to agree that the production approach had the added benefit of: improved safety; climate independence; improved quality.

2.5.2 Snagging, defects and maintenance

Whilst linked to issues of quality and durability some studies have examined in more detail related 'quality' issues including: 'snagging' 'defects' and 'maintenance'. Though not specifically linked to long term management, snagging is discussed here in terms of its importance to timely and successful handover to the management team and as a potential cause of defects if not corrected. Defects are referred to as those elements subsequent to a building contract that require resolution by the original contractor or the management team usually later.

As with discussion on quality a reduction in snagging, defects and maintenance requirements is a 'perceived' benefit in most, if not all, the literature regarding off-site construction with similar reasons given for the likely improvements. There is little empirical evidence available and even less discussion that relates particularly to differences between MMC's with different levels of off-site construction. There is no discussion on the benefits of offsite assembly set against possible issues of delivery and tolerance. Some concerns are raised regarding supplier related maintenance/service issues that while they apply to both offsite and onsite construction have potentially increased implications with the supply of more comprehensive off-site elements by single suppliers. Some key factors for improvement are discussed in the literature reviewed and these are summarised on the right. A primary consideration is possible benefits in terms of process leading to successful uptake of digital handover manuals started in the offsite environment.

The Offsite Industry View: skills and experience, management of interfaces and QA management

Build Offsite (2013: 16) suggests that snagging and fixing defects following tenant occupation are by-products of an imperfect production process and that "the defect norms for buildings are far worse than they are for manufactured products." The report suggests that defect rates may be significantly lower in buildings consisting of pre-assembled and commissioned offsite elements or pods such as HVAC units, bathrooms/toilets and or kitchens. The report estimates up to an 80% improvement over 'conventional construction' in terms of 'reduced snagging and defects' and describes this as being of significant financial benefit to builders/developers.

Gibb and Pan (2008:7) specifically examined maintenance performance evaluation of offsite and insitu bathrooms (located in University Hall of Residence) and suggested off-site bathroom modules outperform in situ bathrooms in terms of maintenance. "The maintenance of in-situ bathrooms was more complex than offsite modules, and involved more diverse problematic areas. The main causes of the problems included inappropriate design; poor build workmanship, lack of quality of component materials and improper usage by occupants.

They note that this supports their parallel study Pan et al (2008) that found that the costs associated with maintenance were significantly higher for in-situ bathrooms than for the equivalent offsite solutions. Most of the offsite modules that were studied were however precast concrete modules and therefore care must be taken in generalising these findings. McCarney and Gibb (2012) conclude specifically relating to bathroom pods that by the very nature of the construction methods offsite forms of construction should have fewer interfaces to manage but that the management of interfaces is more important when introducing offsite forms of construction. This suggests benefits of fewer onsite interfaces need to be set against the more critical need to manage these interfaces.

In the NHBC (2016) analysis of interviews with house builders and housing associations high build quality and reduced levels of snagging of bathroom pods with greater overall construction efficiency are the main reasons cited for using them. Kempton (2010) however surveyed 130 RSL asset managers to determine their views on incorporation of MMC into RSL housing portfolios and its implication for long term maintenance (asset management) and notes contrary to Gibb and Pan that 'pods' seemed a particular cause of concern. He notes that the Gibb and Pan research discussed above was based on 3 years feedback and therefore full lifecycle costs remain un-defined. The research indicated a generally negative view of its maintenance liability and suggests the MMC supply chain should focus on developing and promoting the maintenance aspect of their products to ensure that an "un-maintainable legacy, such as that left by some types of past non-traditional housing formats, is not repeated" (Kempton 2010: 130).

The specific concerns raised in Kempton's (2010) study were clearly depended on the questions asked – the questionnaire was developed from both previous literature and a previous qualitatively based study by the same author and are therefore relevant in their own right. The question subjects included: the availability of MMC components for reactive and planned maintenance and how this may be a problem in the future, the long term integrity of structure and how this may be suspect and cause future problems, whether whole pod kitchens and/or bathrooms may become difficult in terms of reactive and planned maintenance, how the quality of finishes, e.g. external wall panels, internal finishes such as door sets etc. may be a problem in the future, and how the commercial integrity of suppliers/manufacturers of MMC may be a cause of future problems. Some of the questions seem not necessarily related only to issues of MMC while respondents were working on a mixture of MMC and traditional projects.

On the question regarding the commercial integrity of suppliers being an issue for future maintenance Kempton (2010) notes that the economic climate at the time of the survey was a factor in the responses received while such issues also apply to traditional construction. He does note however that the "brand nature" of MMC may leave them more susceptible to this risk of suppliers going out of business. This issue was also noted in the previous qualitative study Kempton and Syms (2009) and the Barker Report (2004) called for increased standardisation to address this issue.

Vernikos et al (2013) report extends to where defects materialise in offsite construction in noting particularly that defects did not occur during the manufacturing phase but predominately during the delivery and installation phases and that this could be attributed to lack of experience of site staff in offsite methods. One respondent in Vernikos et al (2013) noted that offsite usage provided 'a different set of challenges', supporting Nadim and Goudling's (2010) findings on the difficulties in utilising offsite solutions. In Vernikos et al (2013) sizing issues with offsite deliveries from the manufacturing facility are mentioned along with the difficulty of adjusting to incorrectly provided or late changes in dimensions. These could be managed more easily with in-situ techniques.

A need for process improvements: Importance of continual development and QA HCA (2010) reviews the output of the Design for Manufacture Competition 2005 and the 10 winning schemes on site and up to completion. The schemes are not volumetric and the review focusses more on design than construction outputs, however of relevance to information management issues. It notes that the adoption of MMC can provide significant benefits but that ensuring that it corresponds and connects with in-situ work is essential. "Factory produced components manufactured to finer tolerances need a more accurate base for the assembly process. The foundations also need to be better programmed than conventional construction. Thus, the timeliness and accuracy of foundations are a very important factor in achieving a speedy assembly and management of the system" (HCA 2010: 59). The HCA (2010) report also notes the benefits of continual improvement in MMC "Continual learning and product/process adaptation will ensure mistakes are learnt from and efficiencies maximised."

James Pichard co-founder of Cartwright Pickard notes in Green and Forster (2017) modules can be fully inspected in advance and tested in the factory enabling them to be handed over with zero defects. This particularly relates to mechanical and electrical services and their commissioning. There is a logical extension here to the testing required in low energy buildings both in terms of review of thermal insulation incorporation and air-tightness and even 'passivhaus'. Factory testing offsite should be able to offer significant benefits in these areas - reducing the risk of testing at building completion with its programme and contractual implications.

"While factory testing should reduce defects, it should therefore be noted that any issues may be replicated as has sometimes occurred with large scale car return calls."

Vernikos et al (2013) reports however that by using only one source of manufacture for offsite elements, there may be a risk that problems at the source would affect all of the supplied projects and that strong management of information and quality within the manufacturing facility is needed to ensure this does not occur. While factory testing should reduce defects, it should therefore be noted that any issues may be replicated as has sometimes occurred with large scale car return calls. At Explore Offsite 2017 SouthWest event, Roly Ward of Offsite Solutions described their 'full' tests of every 5th bathroom pod to ensure if they did arise issues would be limited to any 5 units.

In Homes at Speed, NHBC (2013) reporting on the Stadhaus Project it was noted that because of the high degree of pre-fabrication and quick construction, the programme was less susceptible to inclement weather. The report did note however that panels must be stored raised off the ground and carefully wrapped in polythene and that maximum onsite storage is usually two to three days (generally over a weekend). On another project (Boubon Lane) the main contractor, was inexperienced in the form of construction used and lessons about when and how to provide protection to avoid damage to panels were learned on the job rather than in advance. Issues with the sequencing of construction and achieving water tightness slowed progress.

In terms of commentary on workmanship Homes at Speed, NHBC (2013) in discussing a particular MMC construction (The Castelfields Estate Regeneration Project) discusses how the contractor perceived the form of construction to offer a truer structure than traditional masonry with the result that trades found it easier and quicker to work with kitchen fitters for example. They also drew a comparison with wet-plastered traditional masonry where the interior can be very damp when joinery commences which can lead to warping of architraves and skirtings. On another case study at Park Central feedback from the registered provider, on the five blocks constructed appeared to be positive. The provider specifically highlighted that unlike other buildings, their project did not suffer from shrinkage or cracking.

2.5.3 Adaptability, extendibility, flexibility and sustainability

Some literature related to offsite construction does discuss adaptability and flexibility with a focus on either:

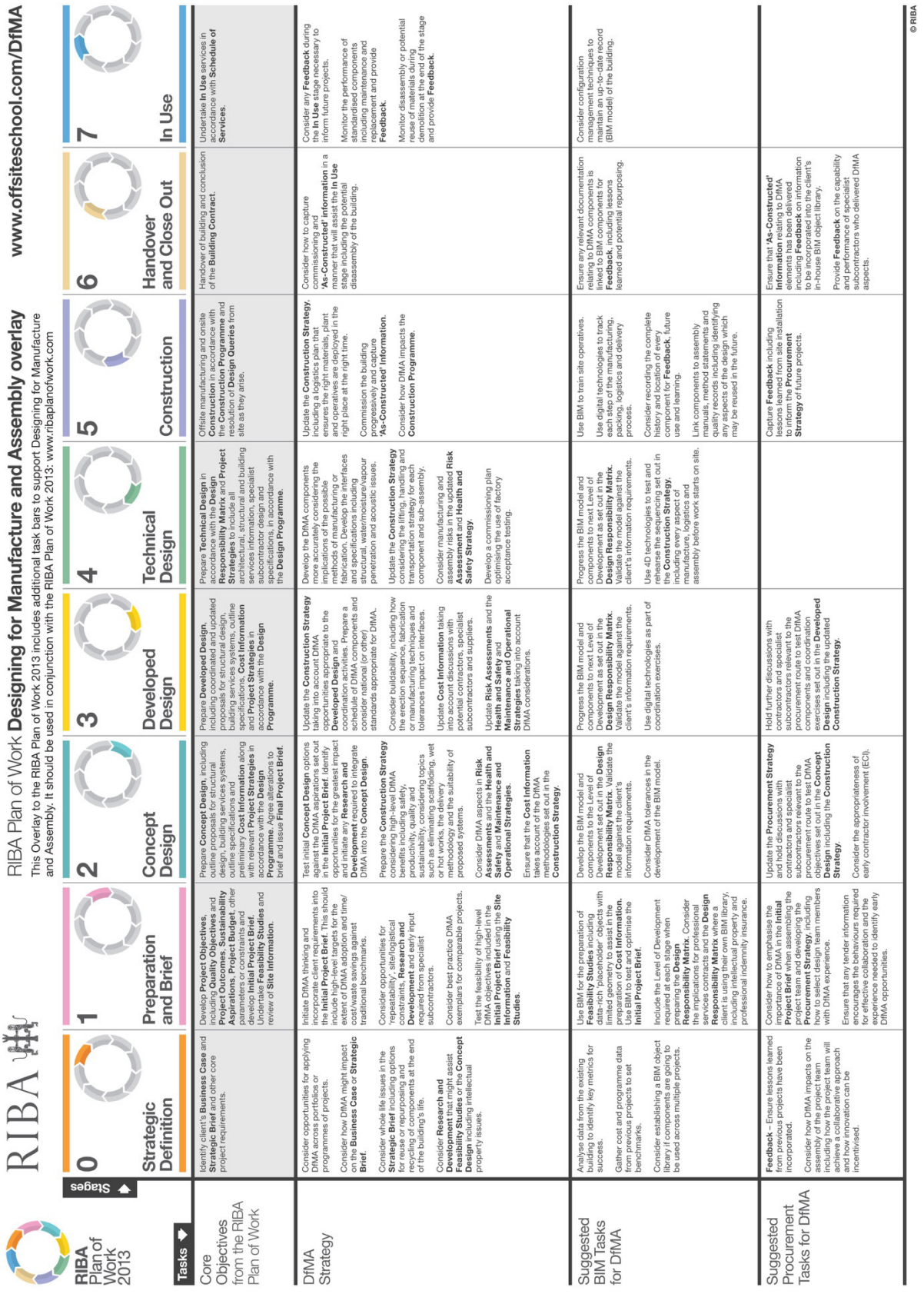
- design flexibility and issues concerned with last minute design changes conflicting with the off-site process or;
- the ability to adapt the interior or extend houses following construction.

The latter is clearly relevant here in terms of long term management and the former in terms of quality of delivered product. Design for adaptability, extendibility and flexibility can be accommodated (or not) in both on-site and off-site scenarios. In developing an offsite manufacturing system or approach to such considerations can potentially be 'designed in' to a greater extent than in either partnering approaches to off-site delivery (using established suppliers) or specific project approaches with on-site methods.

Design flexibility and changes

Participants in the focus group discussions covering the industry and academia reported in Goulding et al (2015) noted that off-site construction was different from building cars and that the manufacturing processes needed to be flexible in order to accommodate its bespoke nature and design changes. In manufacturing buildings or houses a high level of automation was altruistically unfeasible for manufactured construction; but, a 'justifiable' level of automation or mechanisation could be implemented. Goulding et al (2015) also notes the findings of Shi et al (2008), who investigated problems with standard models that had limited flexibility to assemble different requirements of various customers, particularly within the construction industry (with disparate stakeholders).

Figure 7: DfMA Overlay to the RIBA Plan of work (adapted from RIBA 2016)



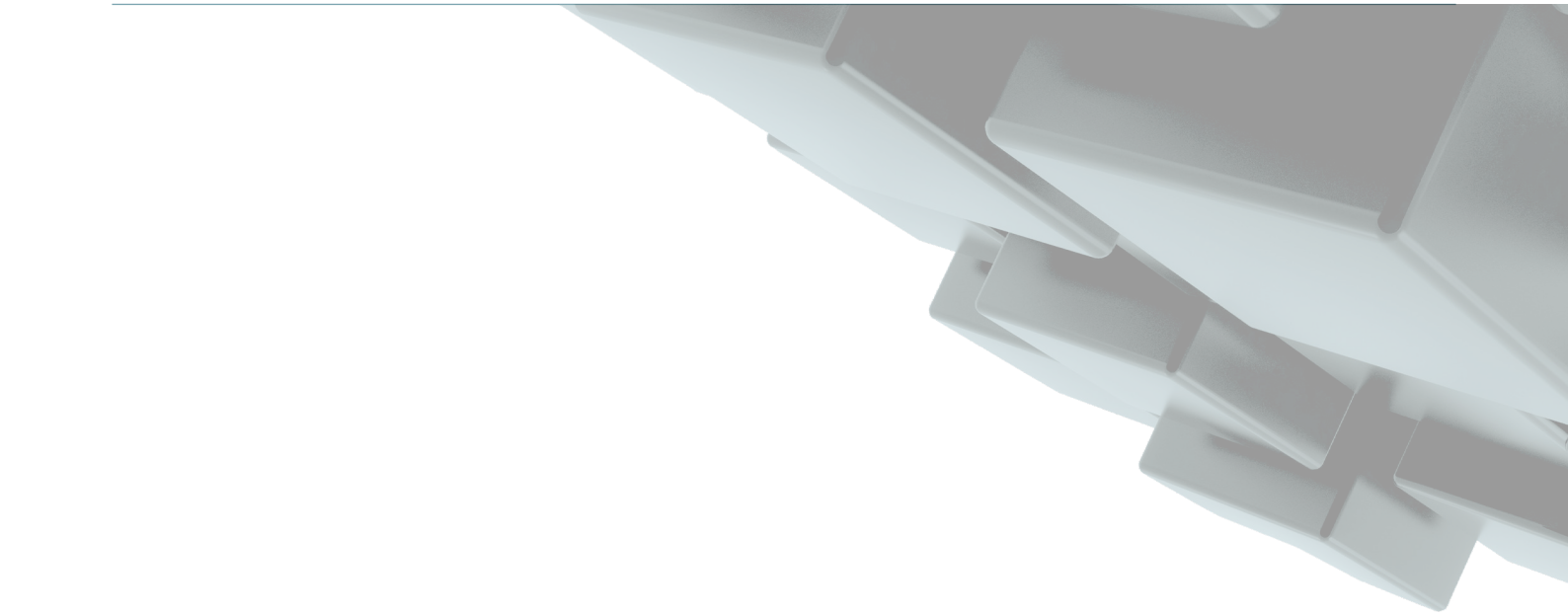
Vernikos et al (2013) report that in some projects drawing changes were being made after offsite components had been manufactured and dispatched to site, causing fabrication problems. Designed for Manufacture –Lessons Learnt, HCA (2010) notes limited ability to make site changes (if required) because of the offsite methods. Offsite and modern methods of timber construction, TRADA (2010) also notes risks associated with late design changes.The lack of flexibility in offsite designs is seen by some as a barrier to greater uptake (Nadim and Goulding, 2010; Goodier and Gibb 2005).

These observations are related to design stages and the link between the project designers and manufacturing process (see Figure 7). Such points are only relevant here where for example: the inability to accommodate last minute design changes results in a project not meetings its requirements; the lack of resolution leads to delays; and the lack of flexibility in this system will also impact on ability to adapt long term. Some should be resolved through rigorous design and review programmes.

Adaptability and sustainability

Nadim and Goulding (2010) notes that negative past experiences included "softer" issues/concerns of the flexibility of the OSP approach…and the ability to adapt OSP buildings to older generations' needs. "From a design perspective, respondents seemed to be concerned with the adaptability, customizability, flexibility, quality of interfaces for buildings". Communities and Local Government (2008) raises some structural robustness concerns relating to ICPT (Innovative construction products and techniques) and particularly with residents changes or other alterations subsequent to construction completion. This seems however less of an issue with offsite per-se but more the technologies that may be associated with it – steel frame, timber frame.

CABE (2004) notes despite the small sample in the study it seems reasonable to conclude that with more specialised forms of construction where alteration work is required consultants with prior experience might be necessary to advise. The implication here is difficulty and expense in extending or adapting. By contract Marl Lawson note the ability to dismantle the building and maintain the asset value by re-using modules elsewhere. It should be noted however that, for example, bathroom pod may actually be more difficult to adapt over time given their constructional form e.g. moulded finished GRP.



Offsite construction and sustainability

Goulding et al (2015: 181) notes "The growing emphasis on sustainability is an opportunity for offsite construction to present itself in a very positive new light. Offsite has the ability to deliver a tighter building envelope, using materials such as structurally insulated panels, along with smart materials and components. It can also openly demonstrate reductions in waste, and also the use of embodied energy in the construction process." CITB (2017) refers to the Gold Standard for Sustainability in Scotland that required statements on disassembly and recyclability of housing as an example of a sustainable driver for offsite.

CIC (2013) notes possible benefits relating to, energy-in-use, whole-life carbon footprint, and reduced transport pollution (congestion and emissions). In TRADA, (2010) Dr Robert Hairstans notes in summary that the off-site controlled environment allows lean production theories not as applicable on site that can improve sustainability. 'Lean' is a term used to describe an approach to construction which targets improved efficiency and reduced waste while preserving quality. Lean methods often involve challenging traditional ways of doing things. Lehmann (2012) discusses sustainability related to the specific use of the offsite technology of cross laminated timber panels (CLT). Monahan and Powell (2011) discuss embodied carbon comparisons between an offsite panelised modular timber frame house and two traditional alternatives. John Quale et al (2012) compares environmental impacts of building modular and conventional homes in the United States. Lawson et al (2014) note the lightweight nature of the technologies often implied as an advantage in terms of material use. This lightweight nature however may be seen as a disadvantage in terms of design for climate change and requirements for a level of 'mass' in housing construction.

Relevance to long term management

According to NHBC (2016) meeting sustainability targets or reducing site waste are not major drivers for the use of MMC for house builders or housing associations. Indeed, many of the potential sustainable benefits generally reported are not strictly relevant to the long-term management and maintenance of offsite constructed housing e.g. reduction of waste, increased efficiency, transport impacts or the reduced embodied energy/carbon of some of the MMC's. Those involving a possible reduction in long term energy use, lifecycle costing, building element re-use and improved user satisfaction are however potentially important considerations.

The main potential benefits of MMC/off-site construction in respect of energy use and thermal comfort would seem to be possible approaches to 'airtightness' of the building envelope. NHBC (2013) in discussing a particular case study (The Stadhaus constructed from CLT panels) notes that construction tolerances are smaller than that achievable with concrete. Typical concrete tolerances of 10 mm compare with +/-5 mm achieved with the Stadthaus. They argue that good tolerances simplify construction and help reduce air leakage (provided joints are properly taped).

Goulding (2015) notes benefit of the controlled factory application of an air barrier. This benefit could extend to improvements in sealing of penetrations and element links where they were part of the offsite process. In addition, improvements in the consistency of the application of thermal insulation (rather than increases in insulation values per-se) maybe possible. Such issues would address a reduction in the 'performance gap' discussed widely in the industry as, for example, Carbon Trust (2011) 'Closing the Gap' between actual and predicted energy performance. As noted elsewhere in this section the link between the offsite and on-site elements are then critical.

2.6 Discussion and conclusion

Based on the evidence reviewed, it can be concluded that, whilst there have been a growing number of initiatives to promote wider adoption of MMC in housing delivery, there are limited studies that review completed housing projects with respect to mode of delivery, customer satisfaction or long-term management. Most of the evidence is based on surveys conducted with mainly housebuilders or practitioners involved in the design or manufacture of MMC housing. Surveys, however, largely focus on broad conceptions of MMC with little or no discussion of particular modes of delivery whether panelised, hybrid or volumetric.

Amongst the offsite industry and within best practice literature it is widely reported that quality is improved and therefore defects and maintenance requirements reduced through the use of MMC instead of what are seen as out dated onsite practices. The proponents suggest that defects are an accepted part of the construction industry compared to manufacturing industries and that there is an on-going need to evolve the construction industry to deal with on-site skill shortages. The recent CITB (2017) report, however, does not mention quality in its executive summary

as a driver for offsite construction (it does discuss increased productivity, reduced timescales, lower build costs, reduced waste and improved health and safety). The report highlights that there has been resistance to offsite in the construction industry as it can be perceived as 'risky' partly due to long-held perceptions of poor quality of pre-fabricated construction compared to traditional construction. In this respect insurance requirements and development of product standards are key hurdles in setting up offsite systems or manufacturing facilities if also a key potential benefit in terms of predictability of systems and continual improvement (accepting discussion on interfaces noted above).

Housing associations have a long-term interest in management of homes and therefore quality of asset, cost of ownership over time and achieving performance standards can benefit from the theoretical improvements in quality and reduction in defects in the use of off-site construction. Based on a summary of literature discussed in sections 2.2-2.5 the following aspects (related to both finance, design and delivery) are largely suggested to be of significance in order to realise the full potential of MMC in housing delivery:

1) Business model innovation and development of clear procurement strategies and relationships:

- Enhancing or innovating procurement methods including partnerships to limit issues with the supply chain of what become major subcontract packages with major implications for delay and payments etc.
- Thorough QA systems in the manufacturing facility with developments in lean processes both of which are generally assumed by advocates.

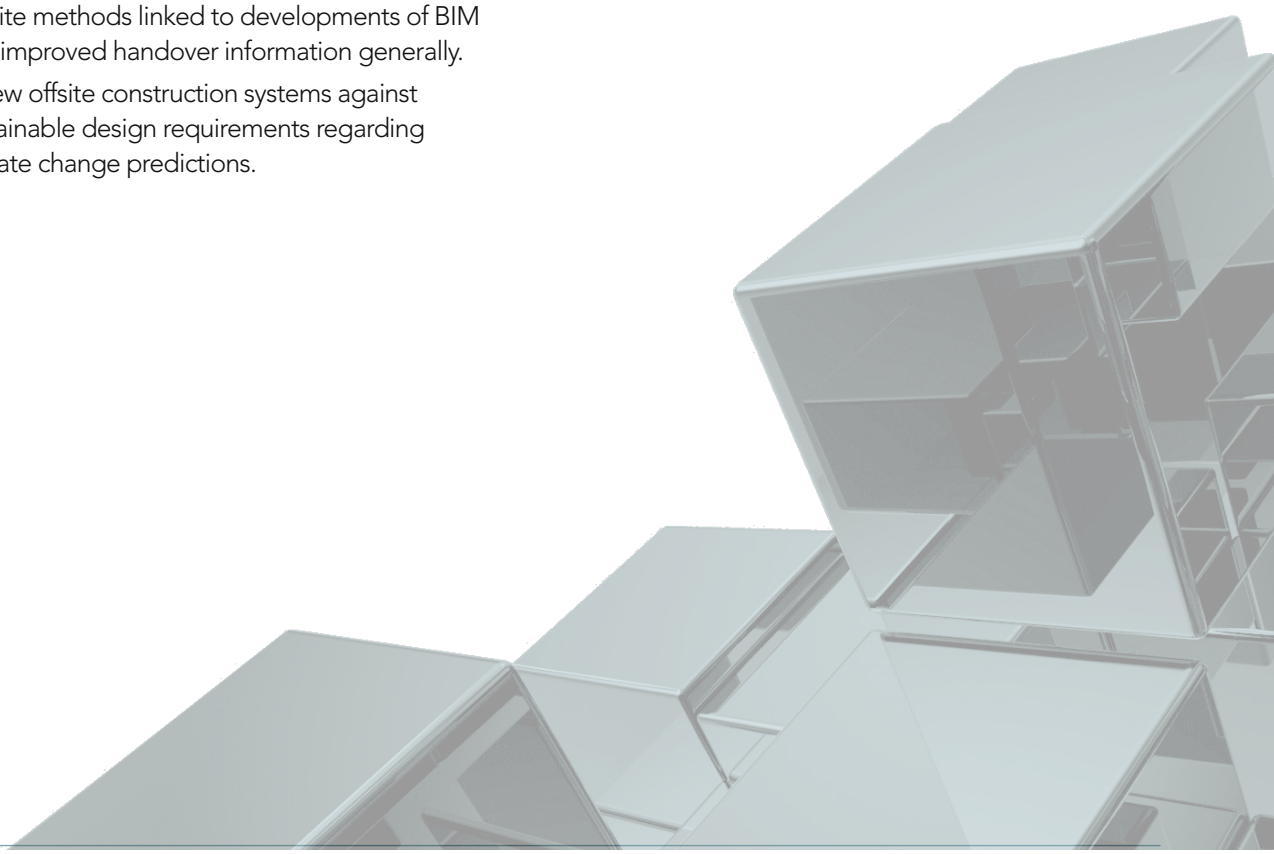
2) Design strategy and QA systems throughout the design/build process

- A focus on the implications on the initial design stages and 'fixing' a design that is well co-ordinated with the major offsite package(s). Particularly, for example, ensuring the system is known pre-planning and that construction drawings are co-ordinated well in advance of manufacture and construction starting.
- Flexible systems that can accommodate site design changes and promote adaptability to future needs.
- Design and construction tolerance and communication between the manufacturing facility and site.

3) Aftercare and follow-up

- Continuous product and process improvement systems linked to feedback. This is particularly discussed in Industrialised house-building – development and conceptual orientation of the field by Lessing et al (2015).
- Coherent and manageable handover information for managers and links through BIM/Digital Design development. Information management is key to successful installation and maintenance of off-site methods linked to developments of BIM and improved handover information generally.
- Review offsite construction systems against sustainable design requirements regarding climate change predictions.

The literature covered is largely based on views as to the possibilities. There is limited direct primary research evidence in the UK context presumably because the industry remains limited in scope. There is some primary research evidence regarding the maintenance requirement due to the use of pre-finished bathroom pods. Most research and detailed responses are dependent on housing associations or contractor views of how the industry might be.



SECTION 3
CASE STUDY COMPARISON

The study is a research consultancy project being undertaken for a consortium of housing associations led by the Flagship Group to examine industry professionals' (in this instance primarily architects) views on effects of different modes of UK MMC housing delivery.
The research provides an initial overview of effects of different modes of MMC housing delivery in terms of resident experience and maintenance as perceived by architects.
Architects were chosen as key participants in this research as their role is not only central to design development but to every stage of the construction process from the initial concept to completion and beyond completion in some projects. Architects also play a leading role in the documentation and coordination across other practitioners and stakeholders including clients and regulatory bodies.

3.1 Research methods and empirical setting

The research method is rooted in comparative case study research principles as advocated by Simmons (2009). Simmons (2009) defines case study research as an in-depth exploration from multiple perspectives of the complexity of a particular context or project. The case study approach is an established research strategy which is usually based on mixed data collection methods, including the use of archives, interviews, questionnaires and observations (Eisenhardt 1989). Case study approaches involve single or multiple cases (Yin, 1984) however multiple cases provide a richer understanding of the research problem being investigated (Miles and Huberman, 1994). The cases in this study are four architecture firms seen as leading in MMC housing in the UK.

There has been a noticeable change to housing delivery in the UK recently. More houses are urgently needed to meet the increasing demand. The move is to deliver houses quickly and efficiently hence the need to investigate MMC housing delivery in further detail. Architects play a vital role in this context and therefore were selected as key participants to talk to in this study.

3.2 Data collection and sampling

The research methodology is reliant on a combination of data collection techniques including documentary analysis of the housing design projects designers in the firms worked on. These documents were collected to establish leading firms and relevant case studies. In addition, at least 3 semi structured interviews involving associate architects, project architects and architect assistants were conducted in each firm in July 2017. Telephone interviews lasted from 30-45 minutes and were based on the questions outlined in an interview protocol (which can be supplied upon request). The interview protocol had 3 main sections focusing on modes of delivery – drivers and outcomes on resident and client; key post-delivery actions; and key process delivery ideas. Phone interviews were digitally recorded and then transcribed.

In addition, 14 case studies that successfully completed at least 1 MMC housing project were initially identified. 3 cases were discarded as the projects were completed between 1999 and 2004. 11 firms were contacted via phone calls, emails and various contacts. 5 firms responded and interviews were arranged with 4 firms due to availability issues. Background information regarding cases studies in which interviews were conducted is summarized in Table 9.

Table 9: Overview of participant firms

Firm	Services	Staff
Studio A	Specialises in housing design and regeneration and won an impressive number of awards. Projects include architecture, landscape design, planning, urban design, and graphic design and communications.	A multi-disciplinary practice that employs 160 staff.
Studio B	Projects include commercial, retail, residential, and educational elements. Won recent outstanding housing design awards.	Established since late 1980s and grew to over 300 people.
Studio C	World leaders in engineered timber and environmentally sustainable architecture. Experience in delivering a range of building types, including residential, commercial, mixed-use, cultural, and leisure.	Established in 1997 and employs over 30 people.
Studio D	Won or were shortlisted for prominent industry awards. Offer a range of services including residential, commercial, and master planning.	Employs over 19 people and designers of more than 25 years of experience.

3.2.1 Selection of participants

Firms were contacted in June 2017 through phone calls and emails with some contacts helping to broker access and arrange interviews. Key participants in research are those who have the expertise required for the research (Andrade 2009); in this case architects who have worked on MMC housing projects. See Table 10 for a description of key participants' roles in each firm.

In all instances participants had over 5 years' experience working on housing using MMC methods of delivery. In some instances, participants included partners and directors with over 20 years' experience working in the housing sector using MMC modes of delivery.

A strategic type of sampling was therefore applied where the size of the sample in terms of how representative is less of a consideration (Buchanan and Bryman 2009). Rather the key question for this research was whether the sample could provide accurate enough data, with the right focus to enable the research to address the research question (Silverman 1997). The questions in all the sessions focused on three key aspects: modes of delivery that were mainly applied, how resident needs were approached during design and how long-term management issues were addressed. All discussions started with overall views on a participants' background, role in the firm and experience in delivering MMC housing.

3.3 Data analysis

The data was collated into a data bank and analysed in NVivo initially using descriptive themes (Buchanan and Bryman 2009) grouped under the topics discussed: modes of delivery, accounting for resident needs, assessment of long term management. This descriptive coding resulted in an initial understanding of how MMC housing was described and promoted in the specification and delivery of particular projects across diverse contexts and for different clients. The second stage of analysis focused on exploring themes in relation to literature on effects of MMC delivery in housing. See Table 11.

Table 10: Overview of key participant roles within each firm

Firm	Participants	Background	Role in modular housing projects
Studio A	1	Senior Director	Led and delivered large modular housing projects in England since 2000
Studio B	1	Senior Associate	Led and delivered large modular housing projects in England since 2006
Studio C	2	Partner	Led and delivered large modular housing projects in England since 1998
Studio D	1	Senior Associate	Led and delivered large modular housing projects in England since 2007
	1	Associate	Delivered large modular housing projects in England since 2010
	1	Architect	Delivered large modular housing projects in England since 2012
	1	Director	Delivered large modular housing projects in England since 2010
	1	Associate	Delivered large modular housing projects in England since 2010

Table 11: Overview of key themes

Categories	Themes		
Modes of delivery	Building an MMC portfolio	Influencing client 'material' choices	Obtaining support
Accounting for resident needs	Needs as obstacles	Predefined needs	Housing association/vs developer clients
Assessment of long term management/maintenance	Maintenance as implicit	Maintenance as client dependant	Maintenance dependant on material choices

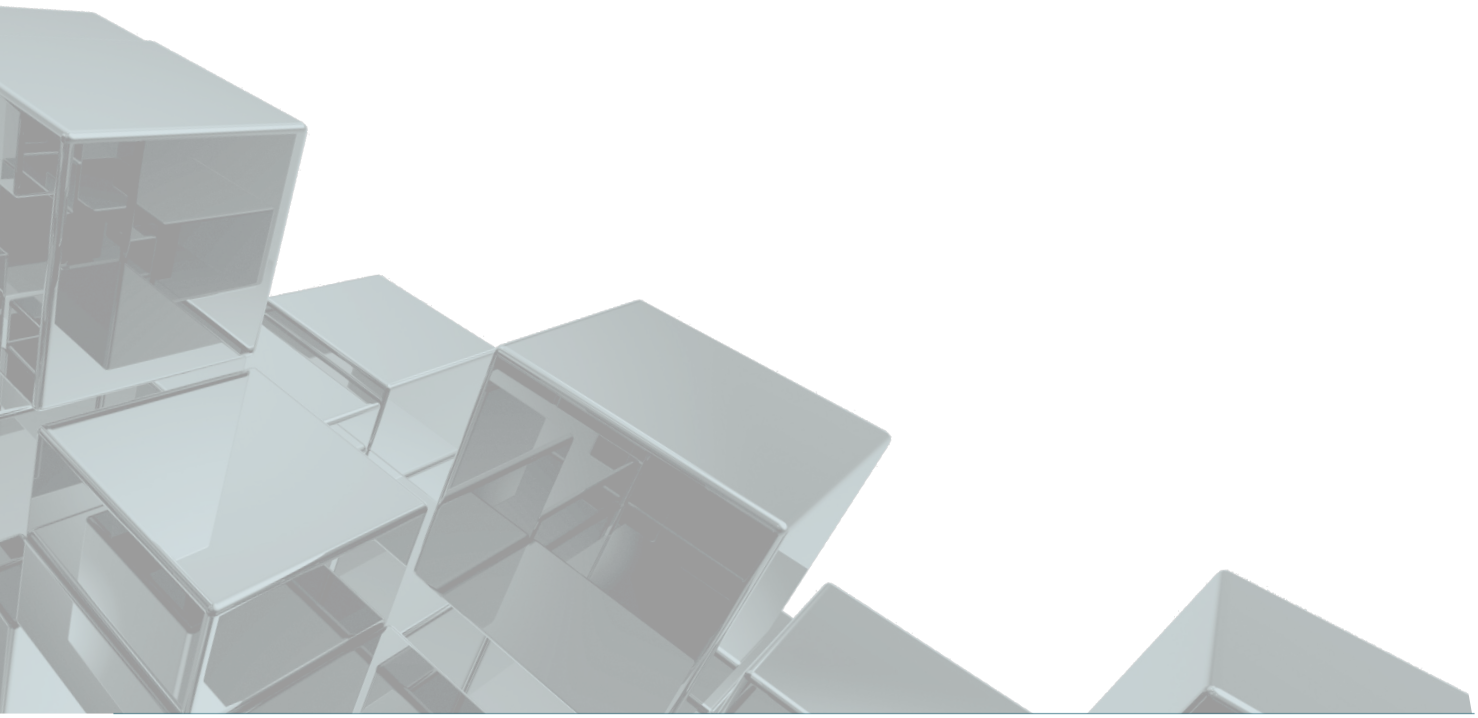
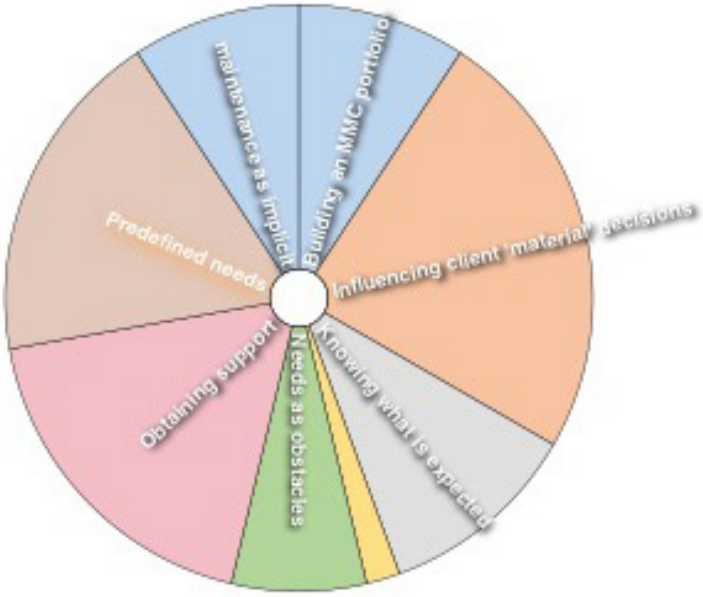


Figure 8: Frequency of themes



3.4 Key findings

Findings are discussed under the key themes that emerged from the analysis: Modes of delivery, Accounting for resident needs and Assessment of long term management. The data suggests participants share common views on what requirements an MMC delivered housing project needs to meet in order to be successful. However, regarding ways MMC housing is delivered, different expectations and perceptions of delivery emerge. Variations in delivery mode related mostly to the networks and relationships a firm had developed with a particular manufacturer and or client (whether developer, housing association and or local authority). For instance, in the case of studio C, long standing working relationships had been developed with CLT manufacturers leading to mostly MMC housing delivered using CLT. In the case of studio A, however, there was a preference for steel based primarily on relationships developed with contractors as well as internal resourcing and knowledge harnessed within the firm. See Figure 8 for illustration of frequency of themes across discussions. Each of the themes are discussed in detail as follows.

3.4.1 Modes of delivery – importance on networks, expertise, gaining support and influencing material choices

Most participants discussed the evolution of MMC housing capability in their firm as led by building a large MMC profile. For example, one of the participants discussed the importance of building a profile linked to a reputation in a particular mode of delivery and material capability. Reputation was also noted to be developed through establishing networks and relationships with particular manufacturers and or contractors; often linked with expertise developed in a particular building material. One of the participants described how his firm developed expertise in MMC by speaking to a lot of different manufacturers thereby 'developing a reputation for being interested'. This then led to one of the manufacturers (turned developers) approaching them to design MMC system housing.

For many practices, choice of material and developing an established portfolio in that material establishes particular modes of delivery. One of the participants, when asked to describe their background and role (not material choice in projects) describes expertise in terms of materials choice:

"Our practice specialises in CLT construction. We have been pioneers for the technology over the last 10 to 15 years, culminating in the 'X' Development in 2009/2010, which went on to win the 'Y' Award for Research…"

"…So the challenge we have is it's not that things change, it's that design is not completed early enough because our clients are not used to procuring that design early in the process…"

In addition to describing choice of material as key to expertise regarding MMC housing, often the choice was justified in environmental terms and overall sustainability aspirations of the practice. One of the participants describes choice of CLT in this instance as superior to concrete or steel based primarily on environmental terms as well as on ease of construction. CLT in this instance is described as the choice for MMC housing for all:

"…I suppose what we want to achieve, as a practice, would probably be to get people to build houses out of CLT because we think that's really important from the most sustainable perspective and also it gives a really robust house, that's quite structurally sound, but I think the developer we're working with, what they want to achieve is just build as quickly as they possibly can and reduce their overheads and reduce their site time…"

Whereas one firm specialised in delivery of CLT housing, others discussed the benefits of steel. One of the participants discusses his firm's preference for steel, outlining the potential benefits compared with other materials.

"We are working primarily with steel, so hot load steel and light gauge steel, so it lends itself to manufacturing very well, it's got very small tolerances, even on tall buildings. So, the taller buildings that we're building couldn't be made with another material - they could be maybe concrete - but they couldn't be made with CLT, since we've had the height restrictions…"

Gaining wider support for a particular mode of delivery in addition to choice of material was also seen as critical. Support was viewed as needed from a client, manufacturer but also local authority, planners and associated stakeholders to ensure a particular mode of delivery (whether specific material choice or mode (volumetric, hybrid or panelised). One of the participants describes projects whereby support and encouragement from the local authority ensured the project success:

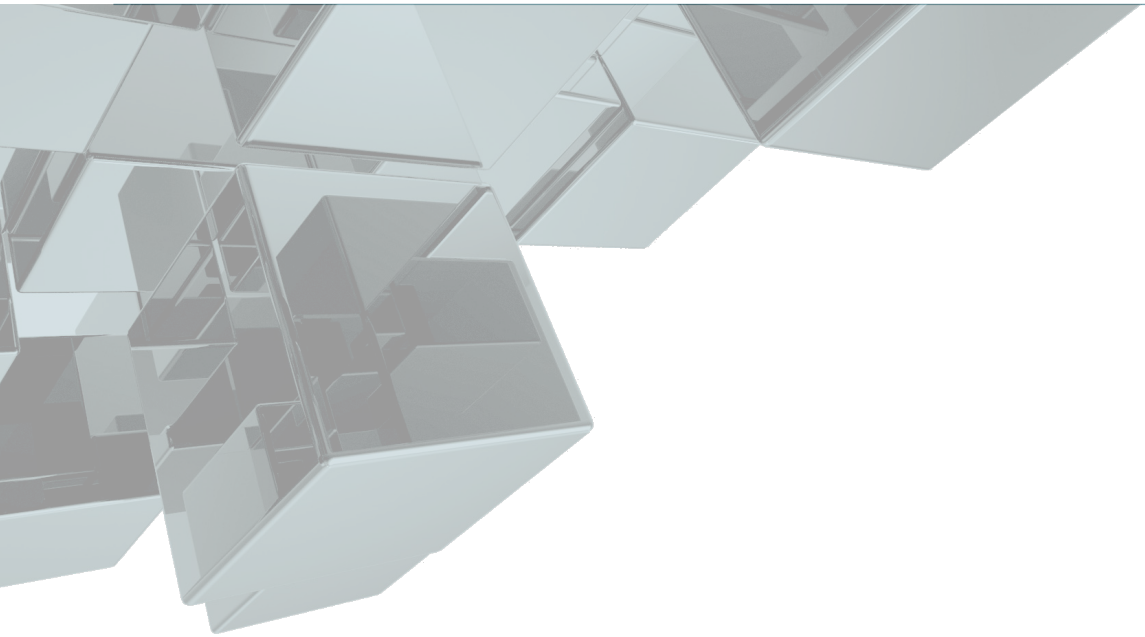
"The support for that came significantly from the local authority, so 'HB' Council were very supportive and that was then enshrined in the planning consent documents…"

The need for wider support is discussed as a key requirement to enable investment, delivery and positive experience of MMC projects. Challenges are described by most participants as constituted in unchanged procurement routes. A participant describes how contractors and mostly private house builders work on business models based on making large investments that mean fast delivery on site. In MMC projects, investment is needed upfront as well, however work on site does not start as early as in traditional projects meaning design needs to be procured a lot earlier.

"…So the challenge we have is it's not that things change, it's that design is not completed early enough because our clients are not used to procuring that design early in the process…"

Most participants described the need to gain support and obtain influence throughout the supply chain. Participants discuss 'hands on involvement' from helping 'set up the factory' so that better windows, better standard of fittings and fixtures are used to getting contractors involved early. One of the participants suggests those making components also need to be involved in their design. Without wide influence and support there are risks to 'being pushed by the developer (to) use cheaper windows and cheaper materials'. In addition to investing time and resource early in the process, participants discuss offering more during tender in order to enable accurate pricing. A participant discusses the tendering process as a critical aspect of a multi-stage process of greatest risk to the client. He describes how going out to tender with 'half of the design information' may not give them best value or an accurate enough price. The participant then goes on to describe how his firm works with tenderers to give them 'enough information to give an accurate pricing'.

"That puts an awful lot of risk on the client's part, who's spending the money, to therefore not so much break it down into a multi-stage process of tendering and procuring. So they go out for an initial tender with half of the design information, shall we say, or early design information not fully finalised, but enough to get a more accurate cost and to get a flavour for the market and who's going to be able to give them best value and be able to forward the design on with those specialists and especially when you're working with a timber framed contractor, for example, or somebody who's going to make prefabricated elements."



3.4.2 Accounting for resident needs – obstacles and predefined factors

When asked to discuss how resident needs are approached during design, most participants did not identify specific issues. Instead, needs were seen as implicit within the design process and constraints. For some participants, particularly those working with private developers, resident needs were often overlooked.

"It is sadly lacking from quite a lot of the processes that we do and we're almost discouraged from going and finding that information by the private developers because of course, in a lot of cases, they see this as attacks on their developments, so they don't really want to go above and beyond either in time, or cost…"

For other participants, specifically in the case of projects involving housing associations, resident needs were described to be pre-defined and often constraining. One of the participants noted that at times housing association client briefs can be extremely detailed involving "management, access, metering and all those kinds of things (related to diverse resident needs)", thereby involving greater resource and upfront management of the project. One of the participants described a project involving a housing association, whereby resident needs were discussed largely in terms of obstacles and issues to avoid. Needs were often associated with 'avoiding problems' rather than 'creating benefit'.

…"We often get a long list of the problems caused by residents and that is often a tack that we get a little bit from RSLs. A lot of the nuanced information that we get from them will tend to be 'oh, the residents are always leaving mattresses in the bottom of the lobby and setting fire to them,' it's more like 'these are the problems that my tenants cause,' rather than 'these are the aspirations and desires that I would like to share with you from our client'…"

Sharing past client experiences was described as potentially helpful in terms of planning ahead despite the fact that the statutory requirements may not demand it, for example (in this instance providing additional storage needs):

"(we needed) to provide storage for bulky items for refuse, but a particular bit of feedback was to say 'we always have this problem, people leaving old bookcases, or whatever, sat outside the thing; we need some storage for that' and that is this kind of long term thinking."

In many cases participants describe that it is quite hard to take residents' needs into consideration during early design stages when future residents are not known:

"Obviously, you can't talk about individual users because there are no individual users at that stage in the project."

"Obviously, you can't talk about individual users because there are no individual users at that stage in the project."

One of the participants noted discussing recent experiences with a new resident who recently moved into an MMC delivered flat and was disappointed with the quality of the fit out. A certain degree of flexibility and choice of material finishes in the internal fit out could improve the experience and perceptions of new residents according to one of the participants:

"… actually, what people want these days is the ability to customise and select and see things before they buy it - particularly where you're buying off plan..."

In some situations, residents are described to potentially have some flexibility regarding layouts to choose from while in other projects the standard house type is only available due to particular material and or module or component constraint particularity relating to potential future structural modifications:

"…I think because of using CLT, it actually might be problematic in the future if residents do want to change their house as it's not a very flexible building system."

In most instances, resident needs were viewed as part of a particular system, dependant on a client brief and or preference as well as type of tenure designed for. In some instances, needs were seen to be shaped by particular material choices and modes of delivery. Where a client is a private housing developer needs are described as driven by a client's preference for a particular system/ mode of delivery:

"Yeah, it's very much they're driving this because they want to use this project as a way of setting up routines and principles, to then carry out to their multiple, other projects."

On the other hand, when discussing work with housing associations, participants describe a connectedness with residents' needs as a housing association 'needs to look after these properties for a very long time and look after the residents'. A participant describes working with housing associations as being in tune with the process and:

"Hav(ing) their own sensible, very high, employer's requirements, which say about the standards, but then also, hav(ing) to ensure that they meet all of the required standards such as life time homes…"

In addition to private house developers and housing associations, some participants discuss the importance estate agents have on ways resident needs are articulated.

"No, absolutely and as an industry, I would say the needs of the whole are mostly driven by the estate agent market for private homes …"

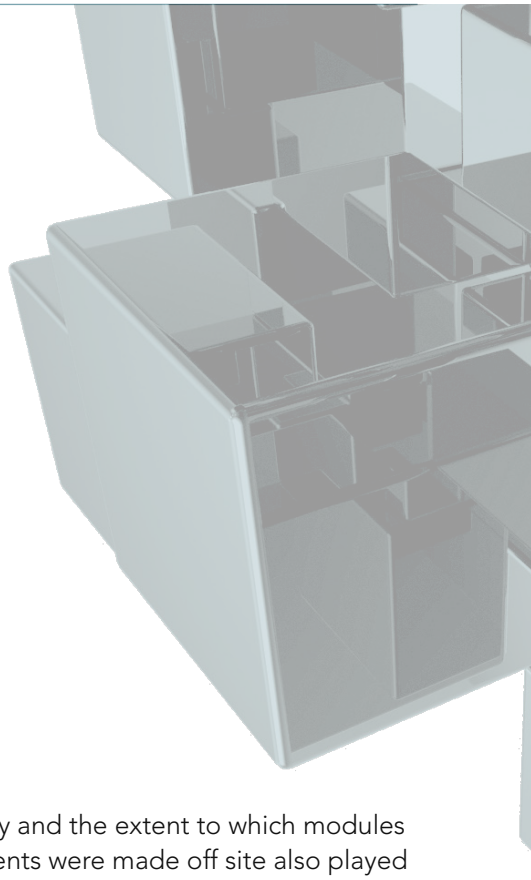
In addition to being client dependant, many participants discuss needs as being intertwined with material selection and factory testing. A participant discusses post-occupancy requirements and understanding resident experiences as being part of how a material or product is tested in the factory; giving the example of plasterboard dependant on manufacturer warranties and fixing mechanisms related to onsite installation rather than factory production.

"…Systems which they have had complaints about and whilst some of those systems are very easy to be installed on site, they might not be as easy to be installed in a factory, or they may not be as efficient to install in a factory because if a fabrication has 30 parts…"

3.4.3 Assessment of long term management – implicit dependencies

Issues related to long term management and overall maintenance of housing built and delivered using MMC modes of delivery were largely viewed as implicit and part of any inherent design process. In many instances participants were found to often question what was being asked regarding maintenance:

…"It's difficult because the whole system lends itself to just being built once and then being left as is, really. Do you mean maintenance by the people living in it, or maintenance by like a housing association?"



In some instances, maintenance was viewed to relate to particular client approaches to costing. Particularly, housing associations were seen to 'take costing of repairs very seriously' whereas private housing developers often 'did not appreciate future users'. One of the participants suggests that insisting on high quality products is "always better for maintenance." In all instances maintenance was viewed as directly related to the choice of material. One participant whose firm specialises in delivering MMC housing using mainly timber discusses the importance of considering implications of that materials with respect to fire and water. Access to modules in order to manage repairs was also discussed as a key component of long term management in order not to end up removing large areas of the building fabric to repair small problems:

"…So from the outset, we were concerned about how the modules would be maintained because doing it in a factory, it means that you can install stuff that's then completely covered up and it becomes inaccessible once it's installed on site, so you really have to … "

Mode of delivery and the extent to which modules and or components were made off site also played a big part. Some of the participants describe the difference between building components that can withstand journeys to those that are self-supporting. Moving components to site was seen as a key aspect of future maintenance needs.

"…I suppose if you're designing something to be erected into a room, a space, half a flat and it has to be strong enough to withstand a journey down from, say, York, that's quite an onerous performance requirement on a bit of building; whereas if you carry component to a site, they don't have to be self-supporting in the same way…"

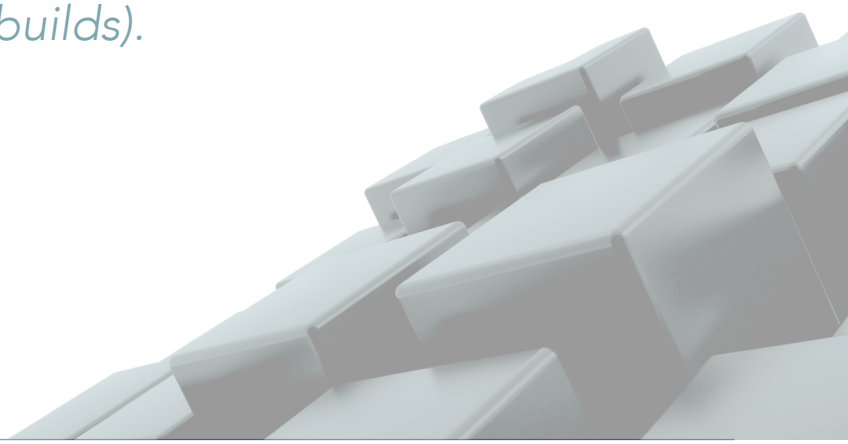
Overall participants consider overall regular after care of the building would inherently address any maintenance issues:

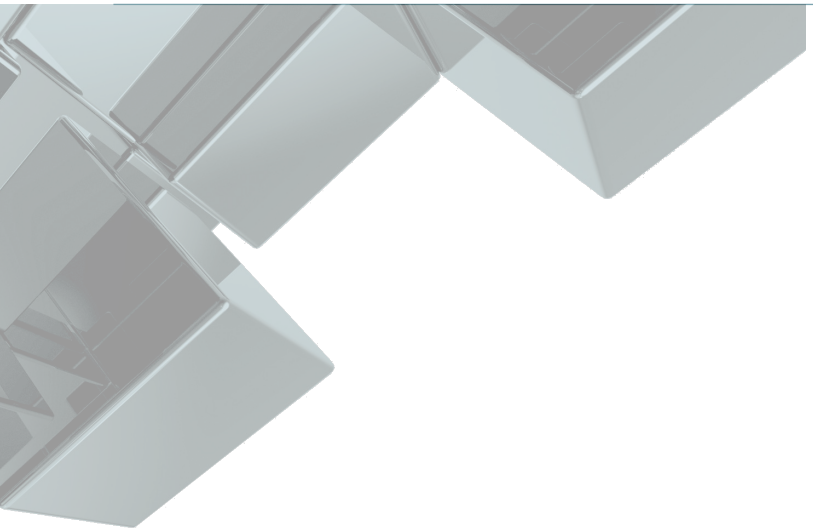
"…Well, you know the fact that the Chinese say 'a building is never finished' and I think you have to look after what you have…"

SECTION 4
RECOMMENDATIONS AND AREAS FOR FUTURE WORK

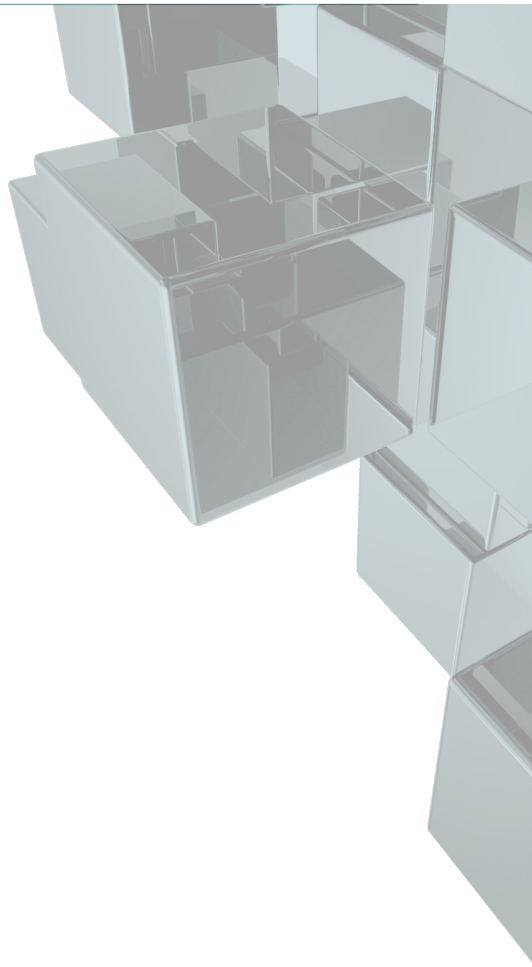
Based on data collected from both secondary and primary sources, it is clear that decisions and choices on particular modes of delivery are driven in the most part by established relationships with particular manufacturers, clients, as well as approaches to resource and time management within an organisation. Initial links made with particular manufacturers in either timber or steel meant building a portfolio of work in that particular material often linked with a certain mode of delivery.

The primary data collected echoes some of the observations made in the literature related to difficulties in procuring MMC due to established ways of working amongst mainly private housebuilders. In most instances participants in the case study research (discussed in section 3) observed the need for new procurement routes and an acknowledgement of the important place a manufacturer has in the process (in comparison to a contractor in traditional builds).

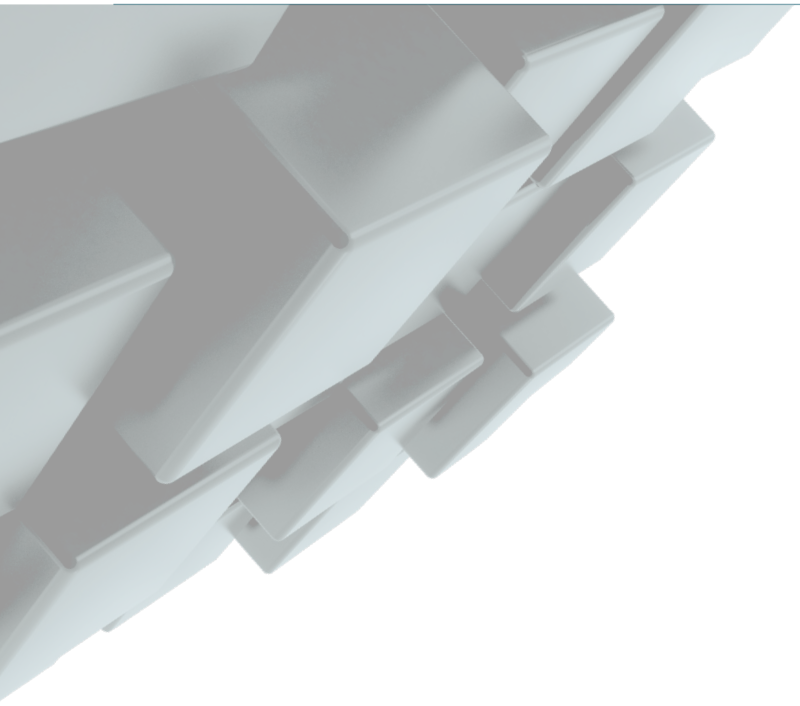




Resident needs were largely viewed as implicit and part of an inherent design process. In most instances, needs were viewed as dependant on the client and/or brief set. Private housing developers were seen not to participate in most cases in discussions on resident needs; whereas housing associations were viewed as active contributors often with predefined criteria. In some cases, criteria were described as problems to avoid rather than ambitions to aim for.



Long term management was similarly viewed as either dependant on client preference of mode of delivery and or choice of material. Obstacles were seen in how products were warranties; with many manufacturers providing warranties based on assembly on site – not in a factory. A warranty for a particular product was seen to relate to how a property may be maintained over the longer term.



Overall a number of areas are identified as needing further research:

1) post occupancy evaluations of completed housing focusing in particular on resident experiences and performance of systems

2) understanding of the differences in design and build processes mapped against different modes of delivery.

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