



Review

# Offsite Construction Methods—What We Learned from the UK Housing Sector

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**Abstract:** Offsite construction has become popular in recent times due to the numerous benefits it offers compared to traditional construction methods. This paper explores the different offsite construction methods, the motivations for adopting these approaches, and the cost-effectiveness of these methods in the UK housing sector using multiple case studies. Firstly, the literature and data were obtained from various sources including professional body reports, industry reports, government websites, and journal articles. Following the review, twelve completed housing projects from the UK which used offsite construction approaches were analyzed. The review of these projects showed that different offsite methods were used in these projects. These include Structural Insulated Panels (SIPs), Timber Frames, Precast Concrete, Steel Frames, Volumetric Construction, Gyproc Habito Plasterboards, and Light Gauge Steel (LGS) technology. The key motivations for adopting offsite construction in these projects include the speed of construction, durability of the products, aesthetic considerations, thermal quality, low air leakage requirements, and quality of construction. Of the 12 cases, only two recorded a higher cost for the offsite construction method compared with the alternative using traditional approaches. The outputs of this paper provide evidence-based strategies which would inform practitioners on the best practices for adopting offsite construction methods and what to expect.

**Keywords:** offsite construction; housing; method of construction; United Kingdom



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## 1. Introduction

The term “Modern Methods of Construction” (MMC) is accepted as a collective term that is used to describe several different construction methods with no universally agreed definition. It is commonly used to represent construction processes that may be significantly different from the perceived popular traditional methods, such as brick-and-mortar-based construction [1]. It is widely acknowledged that the use of MMC involves the use of superior processes leading to better products. Some additional benefits offered by the use of MMC in construction include improving the outcomes for businesses and their projects. Improvements for businesses may be in terms of the quality of products, efficiency, product sustainability, environmental performance, customer satisfaction, and the predictability of project timescales [1]. Terms used to describe this include modular construction, prefabrication, and modern methods of construction [2].

MMC represents the range of new and innovative approaches to construction, in particular those approaches that take much of the traditional building processes offsite. The term offsite construction (OSC) has been used in general terms to represent this approach that involves the manufacture of elements, components, or modules in a factory before pre-assembly, and installation on a construction site. OSC is thus acknowledged as one of the recognisable approaches within the array of Modern Methods of Construction (MMC) according to [3], which leads to mechanisation and automation [4].

The modularisation, prefabrication, and standardisation of construction processes and assets within a factory and under controlled settings is the description of offsite construction provided by [5]. This represents all aspects of the construction process that occur away from the location of construction. Such activities may take place in a designated factory but sometimes can also take place in an ad-hoc facility within the proximity of a construction site [6]. The literature reviewed uses the terms “offsite manufacture” (OSM) and “offsite construction” (OSC) generally to describe this construction approach. Offsite construction has been described in some of the literature as a panacea to the many problems associated with cost, time, and quality associated with traditional construction processes [7]. Five main levels of offsite construction described by [8] are as follows: Component manufacture, Sub-assembly, Non-volumetric preassembly, Volumetric preassembly, and Modular buildings. The RIBA [8] levels of offsite construction describe modular buildings as distinct from volumetric preassembly, whilst some of the literature such as the Institute of [9] suggests they are similar. The various levels are all used to different extents in housing provision in the UK. In the past, prefabrication was used for simple structures [10]. In contemporary times, prefabrication is now more adaptable to diverse types of structures [11] and has the potential to help achieve high levels of standardisation in the industry. This will lead to manufacturing-style productivity levels [12] where buildings could be manufactured in low-cost manufacturing centres and shipped to destinations anywhere in the world for final assembly. Such a development could significantly improve the competitiveness of the global construction industry [13].

Offsite construction usually involves significant levels of manufacturing in a factory environment as a means of adding to the overall value of a project. This approach incorporates different elements such as prefabrication, manufacture, modularisation, standardisation, pre-assembly of components, and modules [14,15]. Offsite construction is seen as receiving additional impetus from the general advances in manufacturing. It has been identified as an effective solution to address speed expectations and quality issues facing the construction industry globally. The adoption of such methods improves overall contractor competitiveness [16]. OSC has the potential to become the mainstream approach to construction in the immediate future [17]. This construction approach could rise from 34% of construction activity to 55% of overall output, with the offsite construction sector projected to grow by up to 4.5 times within the next decade [18].

Some of the benefits associated with the use of offsite construction in housing provision include the production of higher quality housing, faster production at a reduced cost as well as opportunities to better manage costs. Efficiency is also improved, waste is reduced, the effect of inclement weather is reduced, labour and material requirements and the overall environmental impacts are reduced with less disruption to residents [1]. Whilst a lot has been written about the potential benefits that offsite construction and the related processes offer, the focus on the specific offsite construction methods is not always pronounced. Some methods used in offsite construction are outlined in the existing literature such as [19,20]. These, however, do not cover the reasons provided for choosing these approaches and likely outcomes. There is a lack of agreement on how the different OSM methods can be appraised and compared against traditional construction methods. This situation is worsened by a lack of documented sources of information on the use of modular techniques in construction [21]. Following a systematic review of 309 relevant studies, [22] concluded that the existing literature on OSC focused on a few specific OSC types such as Precast Concrete components, without considering other available types. This paper seeks to address this gap in the literature by exploring other lesser-known OSC methods. Cases of completed projects using offsite construction approaches are explored to identify the specific methods used in pre-manufacture in the UK housing sector. The reasons for choosing these methods and an appraisal of the methods against traditional methods are also explored. The review of projects undertaken by some of the leaders of OSC in housing in this paper helps to identify the trends and developments in the methods used, the reasons for using these, and the outcomes.

### *Offsite Construction Methods*

Many different approaches can be adopted for pre-manufacture and offsite construction. The most popular offsite construction methods used by the top 20 housebuilders were explored by [20]. The study identified at least 30 different ways that premanufacturing and offsite practices were integrated into construction processes. The techniques identified in this study included complete modular buildings (volumetric), the use of pre-manufactured lifts and stairs, flat-pack kitchens, kitchen pods, flat-pack bathrooms and toilets, bathroom/toilet pods, offsite constructed plant rooms, pre-assembled roofs, and pre-manufactured upper floors. Other approaches involve the use of upper-floor timber cassettes, pre-manufactured concrete beams, and blocks used in upper floors, pre-manufactured upper-floor concrete holocore, offsite manufactured internal wall panels, pre-manufactured dry lining in internal walls, pre-manufactured blockwork internal walls, pre-assembled balconies, and parapets, offsite constructed complete walls with both skins and pre-manufactured internal skin panels in external walls. The rest include pre-manufactured Timber Frames, pre-assembled formwork for use on-site, Precast Concrete frames, preassembled structural Steel Frames, pre-assembled drainage, and underground services, offsite constructed basement M&E plant, basement precast floors, basement precast walls, precast foundation slabs, precast foundation pads, and precast piles [20]. These represent the main ways that pre-manufacture and offsite construction practices are integrated into construction processes. Clients, designers, and contractors may choose different combinations of these techniques as required in their schemes.

The different typologies of OSC, which reflected the advances in construction technology were explored by [19]. The study identified six typologies commonly used in OSC as follows: components, panels, pods, modules, complete building, and flat pack construction. It is argued that there will be a significant boost in productivity if construction departs from entirely project-based approaches and employs a manufacturing-like system of mass production more consistently with increased use of standardisation and modules and parts manufactured in factories offsite [23]. Under the construction production system, standardised designs can be customized and built in factories, and assembled on-site in less than a week for single-family homes [24].

Offsite techniques have been successfully used in the construction of homes in Sweden where offsite manufacturing is used to build at least 45% of its new homes. About eight out of 10 detached houses in Sweden are built using modern methods, according to a study by the University of California. The study also shows at least 30% of new-build multi-residence buildings in the country use a significant degree of prefabrication, and at least 45% of overall housing is produced using some form of offsite manufacture.

Two of the common approaches involve the use of Structural Insulation Panels (SIPs) and Volumetric Construction. Some of the features associated with the use of SIPs include the use of excavation and foundation work as with traditional methods of construction. The prefabricated SIPs once delivered to the site and installed form a continuous interlocking layer that forms the insulating inner skin of the building. SIPs are structural load-bearing elements of buildings and thus provide support to the floors, roof, and other internal loads on the structure. In this case, the roof can be constructed using traditional roof trusses or from additional SIPs which incorporate open, usable, and insulated spaces [25].

There are positive benefits to the overall time taken for the process, the quality of products, efficiency, health and safety, and adherence to building standards. These were some of the key drivers of the process [26]. The most critical technical development which could promote the increased use of offsite solutions in housing will be the UK Government's proposals to increase the thermal performance requirements of new homes through a revision of Part L of the Building Regulations. As long as improving the thermal performance of new homes continues to be a core component of the Government's sustainability strategy, the performance requirements of homes will continue to increase. It will become increasingly more expensive for housebuilders to achieve the build quality required to achieve prescribed performance standards using traditional construction methods. This

could be the significant change that tips the scales in favour of increased use of offsite approaches in housebuilding. The current overall industry housing output needs to increase from the current levels of around 100,000 to 140,000 to meet government targets [13,27]. According to the Offsite Housing Review, the industry reports a capacity to increase the overall industry output from the current levels of 100,000 to between 130,000 and 150,000 using traditional construction approaches if given the time and support to improve their capacity [13]. However, the industry needs to resort to offsite construction solutions to meet the levels of demand of around 230,000 [27]. It is predicted that modular will develop most where there is cheap land and where there is a desire for quick delivery. This will thrive where local authorities are pragmatic and open to innovation [28].

If used appropriately, manufacturing building components offsite provides for more controlled conditions, improved quality, and precision in the fabrication of components, lower project costs, shorter schedules, improved quality, and more efficient use of labour and materials [29]. The degree of prefabrication ranges from simple two-dimensional building components, like walls, truss elements, or ceilings, through modular structures which comprise larger volumetric elements like entire rooms or storeys; to entirely prefabricated assets [30]. This shows that there is a potential to apply prefabrication in a wide variety of project types, ranging from residential housing to large-scale industrial plants. Offsite construction offers opportunities for smart construction which can be achieved by equipping everyday construction products with the capacity to process and exchange information without any impacts on their original form, structure, and functions [31].

Design for Manufacture and Assembly (DfMA) has been said to be the critical first step to factory-based production systems. Significant reductions in construction programmes using DfMA are the first major benefit of this approach [32]. It promotes a collaborative approach to work throughout the value chain taking on board the respective inputs of all stakeholder teams such as clients, design teams, contractors, offsite manufacturers, and suppliers [33]. It encompasses many techniques such as volumetric approaches, “flat-pack” solutions, and prefabricated components. Using DfMA, construction processes can be integrated into industrial processes to ensure more efficient, cleaner, sustainable, cheaper, and safer projects, and increased programme certainty [34]. DfMA can be applied to one-off small-scale projects as well as to large-scale projects and frameworks, it has been argued that there will be a significant boost in productivity if construction were to depart from entirely project-based approaches and employ a manufacturing-like system of mass production more consistently [23].

The development of modular solutions in urban settings can be challenging due to the practical constraints imposed by urban environments. Logistical issues involving the transporting of modules, and storage space availability are some of the key issues that constrain modular developments in urban settings [35]. Knowledge and awareness of the different offsite methods are required to enhance outcomes in urban settings. There is a need to systematically synthesise the mechanisms that shape the desirability of offsite construction methods for industry practitioners. This will enhance the desirability and the uptake of offsite construction solutions [36]. The supply chain model commonly used in the construction industry impedes the growth of offsite construction is argued by [37]. It is therefore essential that a more integrated system of the supply chain is facilitated through enhanced collaboration and vertical integration. This is more relevant in emergency and disaster situations where [38] argued that OS approaches provide opportunities for the rapid mobilisation of construction material for projects.

The review in this paper concurs with the conclusions of [22], based on a systematic review of 309 relevant studies that the existing literature on OSC focuses on a limited range of approaches without considering other available types. Therefore, this paper contributes by the review of projects undertaken by some of the leaders of OSC in housing to identify the trends and developments in the methods used, reasons for using these, and the outcomes.

## 2. Materials and Methods

Strategies for integrating the use of offsite production technologies in house building were explored by [39]. Using an action-research approach, a case study review of a leading U.K. housebuilder was used to explore the processes used to adapt and utilise offsite technologies. The study identified strategies employed which were used for promoting offsite approaches to key stakeholders and improving overall business efficiency [39]. Despite the acknowledged and wide-ranging benefits associated with the use of offsite construction as an effective alternative to conventional construction, the wider take-up has been inhibited by factors such as the perceived costs of offsite construction.

The cost barriers that inhibit the uptake of offsite construction were explored by [40]. The study examined the cost performance of four types of construction methods: steel frame, timber frame, insitu reinforced concrete (RC) frame, and Precast Concrete cross-wall panel. The study used data from a leading UK housebuilder over five years (2004–2008) for 20 medium to high-rise residential buildings relating to eight projects. Detailed cost comparisons for the respective build methods were undertaken by [40].

It was demonstrated through case study reviews and a survey of professionals in Hong Kong by [41], that prefabrication, employed in conjunction with modular design and the use of standard components saved time and construction/design costs, arising from the use of buildings systems across projects. The findings from these studies confirm the worth and the benefits that can accrue from reviewing and learning from completed projects and a justification for the approach used in this paper. The research methodologies employed in the OSM literature are explored in [42]. Despite resorting to mixed methods increasingly, case study approaches were the most popular methods used in studies relating to offsite construction. Whilst by far the most common approach used was solitary case studies, multiple case studies were also popular in the literature sample. Relying primarily on the literature review as a methodology in addition to one case study which was used to demonstrate how a similar problem is being tackled in the UK was used by [43]. In line with these findings from the literature review, this paper is based on a desk-based multiple case study of completed projects which used offsite construction approaches.

Following a review of relevant literature on the subject, 12 cases of completed housing developments that used offsite construction methods were reviewed. The case study was based on a desk review of official reports on the completed housing projects. The reports on the completed projects were contributed by professionals who worked on these projects to the More Homes Through Manufacture Report produced in 2015 by The Housing Forum. The paper also considered cases from the Housing Forum's "Building Homes Better: The Quality Challenge" report produced in 2017. In contributing to the reports, professionals who had worked on the projects featured in the case studies provided information on key areas of the projects, including a brief description of the project, the offsite method of construction used, the reason for choosing that method, any lessons or observations from the contractor's experience as well as answering two questions: whether the contractor would use the method again and another on the cost comparisons between the approach used and the alternative costs had traditional methods been used instead. General lessons arising from these projects were also provided. For each case study, the details provided included a brief description of the project, the main offsite construction method used, why this method was chosen, and whether there were additional/unusual approvals needed. Other details presented included how costs compared with traditional methods, whether the contractor would consider using this method again and the reasons for their response, and any lessons and observations provided by the contractors. Table 1 presents details of the case-study projects, a brief description, and the contributors.

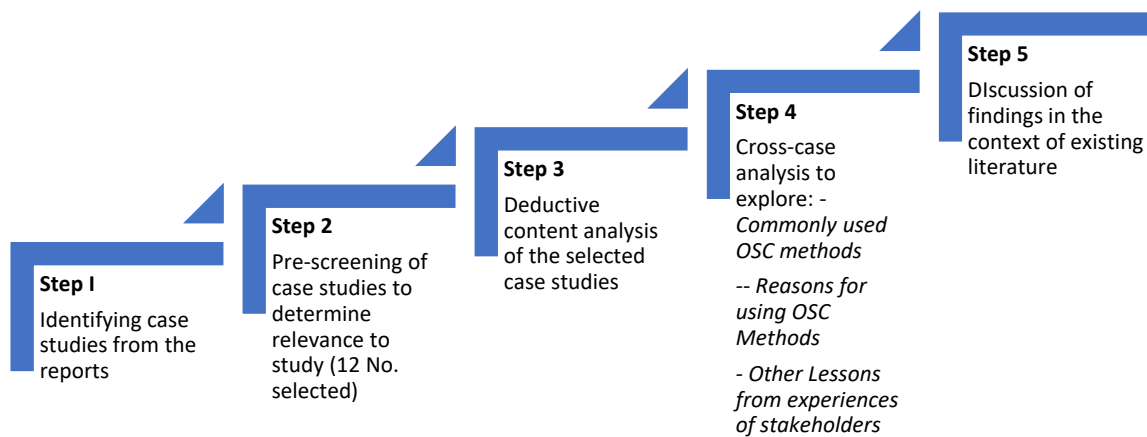
**Table 1.** Details of the case studies Source: [27,44,45].

	Project Details	Description
1	Showell Court, London (reported by Paul O’Driscoll, Wates Living Space, Main contractor)	A 64-apartment extra care home development with communal facilities including a sensory garden located in Wolverhampton. The £7.2 m development was constructed at an average cost of £114,286 per unit over 60 weeks achieving a 10-week saving on time compared to traditional methods.
2	Kirklees PFI/Huddersfield and Dewsbury (reported by Rick Burgess PRP Architects)	This project involved the construction of three extra-care older people’s housing schemes comprising 140 new units. There were a further 291 single- and two-bedroom homes developed over 27 separate sites. The project cost £69 m in total with a £100,000 average unit cost and was completed in 33 months, saving 6 months compared to traditional methods
3	School Mews, Hastings (reported by Bev Grey Wates Living Space, Main contractor)	The School Mews project comprised fifteen new homes at a total cost of around £1.5 m and an average cost per unit of approximately £100 k. The project took 40 weeks to complete as against the 50 weeks projected to be needed if traditional methods had been used. The project earned many awards for including the Building for Life, Code for Sustainable Homes, Secured by Design, and Housing Quality Indicators.
4	Sampson Close, Coventry (By Richard Barwick Southern Housing Group, the client for the project)	5 two-bedroom and three-bedroom terraced houses in addition to 18 two-bedroom apartments which were developed using the Passivhaus approach. Built at an average cost per unit of £152,000, the project cost £3.5 m overall and took 12 months to build as against 14 months if traditional methods had been used.
4	Sampson Close, Coventry (By Richard Barwick Southern Housing Group, the client for the project)	5 two-bedroom and three-bedroom terraced houses in addition to 18 two-bedroom apartments re-developed using the Passivhaus approach. Built at an average cost per unit of £152,000, the project cost £3.5 m overall and took 12 months to build as against 14 months if traditional construction methods had been used.
5	Park Heights, Stockwell, South London (reported by Paul O’Driscoll Wates Living Space, the main contractor for the project)	Park Heights is a 20-storey residential block made up of 159 apartments and including a café facility. The external works for the project incorporated car parking and soft landscaped areas. The project was designed to Code Level 4 and Lifetime Homes standards and cost £27.4 m in total with an average unit cost of £172,000. The project which took one hundred weeks to complete would have taken 106 weeks if traditional construction methods had been used instead.
6	Kidwells Estate, Maidenhead (reported by Kingspan Insulation the offsite manufacturer)	Kidwell’s estate is a mixed tenure 204-unit scheme consisting of seven apartment blocks ranging from 3 to 5 storeys in height, which offer one-, two-, three-, and four-bedroom accommodation in addition to the provision of new communal space. The development which cost £26 million in total took 57 months to construct—a 6-month saving on the 63 months that would have been required had traditional methods been used.

**Table 1.** *Cont.*

	<b>Project Details</b>	<b>Description</b>
7	Oval Quarter, Lambeth (formerly Myatts Field Estate), London (reported by Stephen Busbey Wates Living Space, main contractor)	The Oval Quarter is a 982 new-home development comprising 134 houses, 160 maisonettes, and 688 apartments. The £110 million development also included the provision of infrastructure for the community, external works, a community centre, a new public park, and a new district combined heat and power system) and features.
8	Riverlight, Nine Elms, Vauxhall, London (reported by Leona Eze, Martin Arnold, Employer agent)	Riverlight is a 116-unit development on a five-acre industrial estate surrounded by private gardens and a new piazza developed for £17.5 Million over a two-year duration.
9	Olympic Way, London (reported by Paul Inch Innovaré Systems, the manufacturers)	Olympic Way comprises a 158-home development and a 237-room hotel with associated parking, landscaping, and play areas. It is a high-quality mixed-use scheme that provides private affordable housing and social amenities. This project cost £44 million overall to construct. Despite an external delay during construction of six months, this project took 1.5 years to complete, leading to a 12-month programme savings compared to if traditional methods had been used.
10	Enfield Small Sites, Enfield, London (reported by Rory Bergin HTA Design LLP)	The project comprised seven schemes with a collective total of 94 dwellings. This project included apartments and houses developed for rent on the open market, social housing, and others for sale through shared-ownership schemes. The project cost approximately £15 m with an average cost per unit of £160 k. The project took 18 months to complete in December 2015.
11	London Borough of Newham, Newham, London. (reported by Iain Stevens Airey Miller Partnership LLP, the employer’s agent)	This development was London Borough of Newham’s first own offsite timber development. It comprised six affordable housing units each made up of three bedrooms in the first phase. Before the initiation of this development, a test house was constructed
12	Carleton Manor Park Development, Penrith, Cumbria (reported by Rory Bergin, HTA Design LLP)	This development is made up of 44 new luxury home units which consist of six bespoke designs. The scheme comprises three-bedroom bungalows, four-bedroom houses, and single, double, and triple-bedroom apartments situated within the ‘manor’ and commenced in February 2016.

In this paper, secondary data has been analysed and discussed with cross-case analysis to investigate if there are dominant types of pre-manufacture methods and the rationale for using pre-manufacture typologies within the UK housing sector. Figure 1 illustrates the data gathering and analysis steps.



**Figure 1.** Research flow diagram.

### 3. Results

The review for this paper found that offsite construction is accepted as a broad term incorporating different typologies, techniques, and variations that involve the premanufacture of construction components in a factory setting away from the site, and later transferred to the site for assembly. The approach not only offers competent options to traditional construction approaches but also holds the promise of providing accelerated transformation and improvements in construction performance in terms of project costs, quality, time, predictability, and safety. It can be deduced that offsite construction thus essentially typifies the same concepts identified with the five stages of construction industrialisation. Offsite construction presents many acknowledged benefits including faster construction, higher tolerances, enhanced quality, lower costs, and reduced labour re-works on-site.

Whilst there are several different terminologies used to describe offsite and prefabricated construction in the literature reviewed, the key commonality is that all of them involve moving some construction-related activities from the site into a factory setting. Under the construction production system which is the basis of offsite construction methods, standardised designs can be customised, built in factories, and assembled on-site in some cases in less than a week for single-family homes.

Five main levels of offsite construction are identified in this paper as follows: Component manufacture, Sub-assembly, Non-volumetric preassembly, Volumetric preassembly, and Modular buildings. All offsite prefabricated developments will fall under one of these five categories. Good consideration of these levels is required in choosing which offsite method of construction to use. The review in this paper shows the successful use of offsite approaches in a range of developments from small residential developments to multistorey developments. The case study of 12 UK residential developments highlights the offsite construction methods used, the reasons for choosing these approaches, and the outcomes. The results and findings from the review of cases are summarised in the next section.

#### 3.1. Findings from Case-Studies

##### 3.1.1. Case Study 1 Offsite Method Used and Reasons for the Choice of Method

The offsite method used for this project involved the use of structurally insulated panels (SIPs) and Precast Concrete floor planks and stairs. Traditional brickwork with look-alike copper cladding was used externally over the SIPs, with additional structural steel transfer slabs for communal facilities. Due to the limited designs available at the tender stage of the project and a need to delay the start of the project on-site, the choice of SIPs with Precast Concrete (PCC) planks instead of traditional construction was projected to yield more time at the front end of the process to deliver a design that met the client's brief.



### 3.1.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

Due to the unusual nature of the SIPs and Precast Concrete floor, an engineer was required to ensure that the SIP–Precast Concrete composite system was structurally sound. The engineer working for the contractor collaborated closely with the manufacturer of the SIPs and the company responsible for the Precast Concrete planks to ensure that the innovative structural solution developed met stringent building regulations. Again, as this was the first time the system had been used in residential developments, there was a need for specially agreed Robust Details with Building Control and NHBC.

### 3.1.3. How Did Costs Compare with Traditional Methods?

The costs of construction materials for this project were slightly more expensive than for traditional methods. However, the preliminary savings made as a result of using offsite processes offset the additional costs arising from material costs.

### 3.1.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

The contractors allude to speed and ease of build and the high thermal mass, which helps reduce overheating. They are thus happy to use this approach in future projects.

### 3.1.5. Lessons and Observations from the Contractor

The offsite components used for this project were considered to be “good quality products” manufactured in “a quality environment” by the contractor. However, the contractor comments on the design issues encountered and suggest that the use of BIM may have prevented the design and sizing issues.

## 3.2. Case Study 2

### 3.2.1. Offsite Method Used and Reasons for the Choice of Method

The offsite method used in this project was the pre-insulated open-panel timber frame method. The pre-insulated open panel timber frame method was used because of the greater predictability of programme delivery offered by this approach as a result of the reduction in labour resources and the exclusion of brickwork from the critical path.

### 3.2.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

No, there were no additional/unusual approvals needed.

### 3.2.3. How Did Costs Compare with Traditional Methods?

A distinct cost benefit has not been established for this project. Rather the contractor considers that the main benefit accruing from the use of offsite methods was time-saving.

### 3.2.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

Early completion enabled the client to maximize early rental income from the completed scheme. For this reason, the contractor would consider using this approach in future schemes. Additional reasons for this conclusion are the increased time predictability and significant reductions in critical labour resources.

### 3.2.5. Lessons and Observations from the Contractor

The use of Timber Frames enabled a more predictable delivery programme and contributed to a simplification and standardisation of details which led to a high standard of construction resulting in a greater degree of confidence for both client and contractor from the outset. A major difficulty encountered during the process was the effect of inclement weather and control of moisture content owing to which there was a need to allow for a drying-out period within the construction programme.

### 3.3. Case Study 3

#### 3.3.1. Offsite Method Used and Reasons for the Choice of Method

The School Mews project involved the use of a mix of timber and steel frame, volumetric, and timber-finished insulated panels with triple-glazed windows and pre-installed plumbing. This was a one-off design that won the Design for Manufacture competition and was then adapted for the project.

#### 3.3.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

No, there were no additional approvals required.

#### 3.3.3. How Did Costs Compare with Traditional Methods?

The overall costs in comparison with traditional methods were 10% higher.

Would the contractor consider using this method again and what are the reasons?

The Clients would use this method again due to the opportunity to collaborate with a proven German company with a high-quality system and a good track record.

#### 3.3.4. Lessons and Observations from the Contractor

The contractor's view at the end of the project was that whilst there can be challenges with OSM, however, success can be achieved if an enlightened client is working with a recognised manufacturer and an experienced design team.

### 3.4. Case Study 4

#### 3.4.1. Offsite Method Used and Reasons for the Choice of Method

The OSM used was a German panel that involved the use of composite panel superstructure which included windows and installed services incorporating 250 mm of cellulose insulation, rendered external brickwork, and thermowood. This approach, tried and tested on the continent, was used to ensure that the thermal quality and low air leakage requirements were met. This method enabled high precision levels and the panel system used in this scheme was installed and made watertight and weather-tight within two weeks after it was delivered to the site. The reasons for choosing the German panel in this project were not provided.

#### 3.4.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

No, there were no additional approvals required for using OSM.

#### 3.4.3. How Did Costs Compare with Traditional Methods?

This approach costs more in comparison with traditional methods for two reasons: firstly, owing to the scheme being an R&D type project. The other reason was the fact that there were few manufacturers of specialist heat and ventilation products in the UK, if any, at the time the frame and mechanical/ventilation were required.

#### 3.4.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

The contractors would not use this method again because it is expensive and had significant associated risks. Again, in Germany, apartments tend to be larger than in the UK. Thus, it is easier to achieve air leakage requirements in Germany than in the UK. Another point on the air leakage is that the standard is higher in the UK at 7 (was 10 at the time of the project) than the Passivhaus standard which is 0.6.

#### 3.4.5. Lessons and Observations from the Contractor

Another difficulty encountered with the use of the OSM method in this project was a lack of sufficient understanding of the design which strongly impacted the cost to build and efforts to achieve Passivhaus certification. Again, the need for larger property designs and the non-availability in the UK of products to help cope with air movement as well

as a lack of robust mechanisms for achieving air leakage requirements need to be readily available in the UK.

### 3.5. Case Study 5

#### 3.5.1. Offsite Method Used and Reasons for the Choice of Method

For this project, offsite manufactured Precast Concrete frame elements were used. These were made from Precast reinforced Concrete structural columns together with twin-wall core walls. Lift shafts were built into post-tensioned flat-slab reinforced concrete frames to speed up the rate of construction of the superstructure. Two 65 mm thick concrete leaves were joined together by steel lattice reinforcement to form a structural panel that made up a twin-wall system. Once installed on site, concrete was poured into the panels to fill them. The main reason for choosing this approach was to speed up the rate of construction of the reinforced concrete frames by reducing the total man-hour requirements. Another reason was the need to enable effective quality control and to ensure a high-quality finish.

#### 3.5.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

No, there were no additional/unusual approvals needed.

#### 3.5.3. How Did Costs Compare with Traditional Methods?

A value has not been put on the overall costs achieved through the use of offsite methods in this project. However, the considered view is that considering the reduced labour requirements, the time savings, and savings on preliminaries, assessed holistically, this method was considered more cost-effective than a traditional approach.

#### 3.5.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

Yes, owing to the reduced labour requirements and savings on preliminaries, the contractor would consider using this approach again in the future.

#### 3.5.5. Lessons and Observations from Contractor/Additional Comments

For this approach to construction to be successful and to deliver the anticipated benefits, it is recommended that there should be specialist design input through the reinforced concrete frame contractor. There is therefore a need for effective design management and coordination during the design phase of the project. For this project also, the contractor's structural engineer reviewed the manufacturer's design and calculations whilst the architect undertook a coordination review exercise. It is recommended that this should be standard practice with any contractor design package for offsite construction.

### 3.6. Case Study 6

#### 3.6.1. Offsite Method Used and Reasons for the Choice of Method

This project required the use of structurally insulated panel (SIP) infill to the concrete frame. The 162 mm i-SIP panels used helped to attain a reduced u-values of  $0.19/W/m^2K$ . The sub-structure was made of a mass-fill foundation. i-SIP infill consists of Structural Insulated Panels manufactured offsite and transported to the building site. The project site had constrained access and noise restrictions due to the closeness in proximity of several low-rise buildings in the estate. Residents on the estate remained in their properties as work began.

#### 3.6.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

No, there were no additional or unusual approvals required for this project.

#### 3.6.3. How Did Costs Compare with Traditional Methods?

Using i-SIP OSM techniques on this project led to a 25% cost savings in the costs of electrical and mechanical installations in comparison to if traditional methods were used in addition to 10% savings to the programme. There were also significant savings arising from

the fact that no scaffolding was required by the manufacturers when they installed their products on-site. Additional cost savings accrued from the inclusion of a timber barrier to all apertures which replaced the edge protection as each floor was completed.

#### 3.6.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

Both the contractor and the SIP manufacturer expressed their readiness to use this approach again in the future mainly because of the reduced scaffolding costs associated with the method. Where scaffolding is used, the periods are reduced through the use of SIPs. Another benefit that encourages its use is the fact that the infill is fast to install and has a high thermal performance.

#### 3.6.5. Lessons and Observations from Contractor/Additional Comments

Some site-related construction-related risks are avoided as the SIPs integrate well with pre-trades and follow-on trades on site.

### 3.7. Case Study 7

#### 3.7.1. Offsite Method Used and Reasons for the Choice of Method

The project uses Light Gauge Steel (LGS) superstructure frame integrating prefabricated wall panels and floor and balcony cassettes as the main OSM. This approach involved the use of a Light Gauge Steel (LGS) framing system for the superstructure and prefabricated wall panels on load-bearing walls. Like some floors, balconies were prefabricated and delivered as “cassettes” for installation on site.

The decision to use OSM was motivated by the many efficiencies which derive from this rigorous approach and the many acknowledged benefits associated with this approach such as reduced onsite construction time, improved overall health and safety, increased quality, reduced waste, reduced requirement for skilled labour on site and fewer defects. Other reasons for using OSM were the projected reduction in foundation loads as a result of the accuracy offered by this system in terms of anticipated loads which minimized the likelihood of overdesign. This reduced foundation loads leading to lower groundwork costs. Another benefit of choosing this approach was the absence of issues of differential movement which is usually associated with timber frame construction. Finally, the integrated design concept offered by OSM provided early technical input on design requirements for the OSM system. This enabled both deliverability and accuracy to be embedded in the construction process at the planning design.

#### 3.7.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

No, there were no additional approvals required.

#### 3.7.3. How Did Costs Compare with Traditional Methods?

The project cost £110 million (includes infrastructure, external works, and community centre). Cost comparisons with traditional methods were not available at the time of compiling the report.

#### 3.7.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

Yes, the contractor expressed a willingness to use this OSM again in the future.

#### 3.7.5. Lessons and Observations from Contractor/Additional Comments

A major success factor for this project was the early decision made at the design stage to use the OSM system and excellent collaborative working between the Design Team, Steel Manufacturers, and contractors.

### 3.8. Case Study 8

#### 3.8.1. Offsite Method Used and Reasons for the Choice of Method

The project employed the use of bathroom pods manufactured offsite including all fixtures, fittings, and services ready for connection on-site. The use of ready-to-install pods helped to significantly reduce the construction time on site. This led to a more efficient construction programme and reduced the project's overall carbon footprint. The factory manufacturing of these pods ensured high-quality finished pods arising from the stringent quality control systems in place.

#### 3.8.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

No, there were no additional or unusual approvals needed.

#### 3.8.3. How Did Costs Compare with Traditional Methods?

At the time of compiling the report, the construction for this development was still ongoing. As a result, the cost saving, as compared to the costs for traditional options were difficult to measure.

#### 3.8.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

Yes. This is because risks, and health and safety issues were reduced through the use of offsite construction methods which included the production of the pods abroad. The method was also credited with a high-quality finish.

#### 3.8.5. Lessons and Observations from Contractor/Additional Comments

The contractor developed bathroom pods in Europe and had these shipped ahead of time to the UK. These were transported to the site and craned into position. In addition to the opportunities offered by the overseas manufacturing of the pods, this MMC approach enabled the client's specification requirements to be addressed before construction. The contractor was optimistic that the use of the bathroom pods will add immense value to this project.

### 3.9. Case Study 9

#### 3.9.1. Offsite Method Used and Reasons for the Choice of Method

This project was developed based on the volumetric solution called Vision Modular System which was designed for offsite manufacture delivery. The project used steel frame modules with slip-form concrete used for cores and rain-screen cladding as part of a volumetric system of construction. A concrete podium was erected over the parking spaces. The approach to design incorporated the envisaged construction of the entire system from steel volumetric pods. The use of Volumetric Construction resulted in the minimisation of waste from construction, faster construction, and improved overall build quality. The construction of the modules integrated the tower balconies which provided support for the façade works. This precluded the need to scaffold the building during construction. Several benefits include the enhanced speed of construction, reduced number of defects, and increased flexibility in the delivery of the tower and other parts inherent in the design.

The system was reported to be the contractor's preferred construction method. However, no official reason(s) were provided for the contractor's choice of this method.

#### 3.9.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

No, there were no unusual approvals required for this project.

#### 3.9.3. How Did Costs Compare with Traditional Methods?

The overall costs of choosing this approach to offsite construction were similar compared to the alternative costs had traditional methods of construction been employed. However, this approach led to a shorter construction period.

#### 3.9.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

Yes. The satisfied client requested three additional projects to be developed by the contractor. The client's reasons for requesting the approach be used in future schemes were the quality of the build and the speed of construction. For the contractor, it was the opportunity for repeat business from the client.

#### 3.9.5. Lessons and Observations from Contractor/Additional Comments

It was learned from this project that design decisions must be made on time projects which involve pre-manufacture and offsite construction to enable the factory to start production of the modules.

### 3.10. Case Study 10

#### 3.10.1. Offsite Construction Method Used and Reasons for the Choice of Method

This project used the EcoTech Timber Frame system as the offsite construction method. These were supplied by Climate Energy Homes and provided sustainable housing at an affordable price and on time. All the units in this development met the standards for the Sustainable Homes Level 4 Code, as well as the achieving zero carbon, and passive house standards. Elevated levels of quality, a fast delivery programme, and sustainability were the main reasons for using the EcoTech system.

#### 3.10.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

No, there were no additional/unusual approvals needed.

#### 3.10.3. How Did Costs Compare with Traditional Methods?

The costs of the development using the EcoTech System were comparable to the costs had traditional construction methods been used. However, the EcoTech System provided additional long-term benefits such as lower whole-life and in-use energy costs.

#### 3.10.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

Yes, and according to the contractor, this was because using this construction approach resulted in faster project delivery and improved quality. The early completion enabled the client to accrue income from the private rental which generated funding for future development in the borough.

#### 3.10.5. Lessons and Observations from Contractor/Additional Comments

Integrating the Ecotech System into the scheme originally approved during the planning application, which was based on traditional methods of construction, presented some design challenges. However, these were successfully overcome.

### 3.11. Case Study 11

#### 3.11.1. Offsite Method Used and Reasons for the Choice of Method

The development was based on British Gypsum-manufactured Gyproc Habito plasterboard constructed using Timber Frames before they were assembled on site. This approach led to reduced construction and maintenance costs. The reinforced core made the plasterboard up to five times stronger as compared to standard products. The enhanced durability resulted in improved resistance to wear and tear which reduced the frequency of maintenance callouts and in overall maintenance costs over the lifetime of the units.

#### 3.11.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

Aligning designs with efficient manufacturing processes and sequences during the testing phase ensured that the final product met high-performance expectations. The novelty of the Gyproc Habito product meant British Gypsum needed to oversee the installation process at the start.

### 3.11.3. How Did Costs Compare with Traditional Methods?

Using Gyproc Habito board added about £1000 to individual unit costs. Countered against the potential costs arising from ongoing call-out charges, repairs, and void periods, the expectation was that the additional expenditure incurred in the form of upfront costs would be recouped within 12 to 24 months. Overall customer satisfaction levels, a factor that is difficult to quantify in financial terms, were improved by the flexibility and ease of fixing the boards.

### 3.11.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

Yes. The client decided to specify Gyproc Habito for their future developments. This was a result of the experience and the improvements made to the overall timber frame construction designs in the development's first phase. Another reason was that it provided a long-lasting and robust product. The products were easy to install and replace which helped lower maintenance costs. The opportunities offered to personalise rooms provided additional benefits.

### 3.11.5. Lessons and Observations from Contractor/Additional Comments

The successful trials provided a firm indication of the evaluation of initial CAPEX costs against recurring RMI and operational costs, using better quality products even if more expensive, during construction could yield commercial benefits. Again, maintaining a more holistic view of the design process, construction phase, and maintenance-related activities, as well as the overall satisfaction amongst residents, were likely to result in the creation of an optimum environment which allowed for better project decisions and led to the delivery of better homes.

## 3.12. Case Study 12

### 3.12.1. Offsite Method Used and Reasons for the Choice of Method

The properties featured acoustically insulated floors (Silent Floor), future-proof walls built from Gyproc Habito boards, and magnetic plaster using Thistle Magnetic Plaster. This construction approach was adopted because the client wanted to create a distinct product whilst improving value for their customers. Whilst the company had an already established reputation in the region as a quality builder, it wanted to explore innovative technology as well as enhancements to the building envelope. These measures were to be used to demonstrate that significant improvements to the quality of completed homes were attainable.

### 3.12.2. Were There Any Additional/Unusual Approvals Needed and What Were They?

Not directly, however, initial concerns about subcontractor reluctance to use the new products were resolved through the provision of on-site guidance and support. The developer's pessimism about homeowner perceptions and appreciation of the value of proposed fabric enhancements were addressed through the generation of market feedback. To achieve this, three homes were selected to receive all three fabric enhancements.

### 3.12.3. How Did Costs Compare with Traditional Methods?

The enhancements to the fabric resulted in an additional £3000 to the total budget for the construction of a 2000 sq. ft house. This applied to all three different options—magnetic plaster on walls, silent floor system, and Habito board option throughout.

### 3.12.4. Would the Contractor Consider Using This Method Again and What Are the Reasons?

As a result of the incredibly positive feedback provided on the fabric enhancements by the prospective homebuyers, the developer decided to provide the three fabric propositions as the standard specification for the entire development and future developments. The developer is also aware that the experience of the homeowners has provided differentiation from competitor products and enhanced their brand, increasing sales.

### 3.12.5. Lessons and Observations from Contractor/Additional Comments

The overwhelming success of the trial has demonstrated to the developer that key performance indicators such as increased profitability, increased customer satisfaction, enhanced brand image, etc., are not mutually exclusive. These can all be achieved through the offering of a better product. It was learned that whilst benefits may not be immediate, customers appreciate quality, and eventually, this translates into increased sales for housebuilders.

## 4. Discussion

Historical developments in the construction industry show periods where demand for prefabrication justifies the need for efficient offsite manufacturing and on-site automation in construction. Mechanisation and automation not only offer a fast means of providing accommodation but also have financial benefits. It has been argued that increased demand for automation solutions will enhance offsite construction outcomes.

Offsite manufacturing, offsite construction, manufactured construction, industrialized building systems, and modern methods of construction have been used in general terms, sometimes interchangeably in much of the existing literature to describe construction that involves prefabrication. Whilst the methods used in the respective examples may differ, the basic premise in all these cases is to shift as much of the related construction activities into manufacturing establishments under factory conditions. Among the common types, there are several different variations and combinations with more possibilities added to the list as this sector continues to evolve. Five main levels of offsite construction are identified in this paper as follows: Component manufacture, Sub-assembly, Non-volumetric preassembly, Volumetric preassembly, and Modular buildings. All offsite prefabricated developments will fall under one of these five categories. Good consideration of these levels is required in choosing which offsite method of construction to use.

The knowledge, awareness, and practice of modern methods of construction mainly characterised as offsite construction could be further expedited through improved standardisation of building components and elements to facilitate easy specification, reproduction, and market structure for the elements. This can be achieved through the Design for Manufacture and Assembly (DfMA) approach. DfMA is an approach to designing projects that enables small or large parts of a project to be manufactured offsite for later installation on-site. This implies that critical decisions regarding the deployment of OSC and OSM should be made at the design stage at the latest. Described as the major prerequisite for the adoption of factory-based production systems in construction, DfMA offers significant benefits by enabling all the associated benefits of OSC. Adopting DfMA involves adopting the most efficient approaches to project delivery minimising the use of resources such as carbon, cost, and time, and enhancing benefits such as health and safety, quality, and project certainty. DfMA is applicable to both small and large project contexts as well as in frameworks. This approach to design ensures that following the manufacture of elements in a factory, they can be assembled either remotely, or sometimes in a specially designated facility close to the construction site.

A range of offsite solutions is already being used extensively in the UK house-building sector as evidenced in multiple sources [14,16,18]. A prominent example is the wide use of factory-manufactured truss rafters for constructing pitched roofs in nearly all new low-rise homes built and the wide use in the UK industry of factory-finished windows and doors. In addition, different varieties of factory-manufactured timber-frame walling systems are in extensive use in the UK housebuilding industry. A uniqueness associated with modular construction is the ability to simultaneously construct a building's floors, walls, ceilings, rafters, and roofs. During traditional site-based construction, walls cannot be set until floors are in position, and ceilings and rafters cannot be added until walls are erected. Modern modular methods of construction avoid these limitations by enabling walls, floors, ceilings, and rafters to be built at the same time, and then brought together in the same factory to



form a building away from the site. This process allows modular construction times of half that of conventional, site-based construction.

Modular construction is sometimes referred to as Volumetric Construction. This involves the production of three-dimensional units offsite under controlled factory conditions before they are delivered to the site to be installed. Volumetric (modular) modules come in different forms ranging from basic empty shells which require finishing on site to completely fitted-out units which have all internal and external finishes as well as service installations completely fitted. In the UK, Volumetric Construction has been used in student accommodation, hotel construction, hospitals, and office construction as well as in family accommodation spaces and probably has the greatest potential for application in housing. There is evidence that making use of modern techniques will lead to homes being built faster and with fewer skilled workers [14,26]. The successful deployment of OSC in housing depends on an appreciation of the broad scope of methods, and the reasons for using these.

#### *4.1. OSC Methods and Reasons for Choosing Specific Methods*

The main OSC methods identified from the reviewed cases are Structural Insulated Panels (SIPs), Timber Frames, Precast Concrete, Steel Frames, Volumetric Construction, Gyproc Habito Plasterboards, and Light Gauge Steel (LGS) technology. This addresses the gap in the literature by identifying additional methods to the more popular Precast Concrete options. There is no single offsite method that appears to be the dominant method used in the cases reviewed. SIPs, Timber Frames, Pre-cast Concrete, Steel Frames, Volumetric Construction, and Gyproc Habito Plasterboards were used at least twice. Light Gauge Steel (LGS) technology was used in one project as well as a Composite panel superstructure incorporating windows, cellulose insulation, external brickwork, render, and thermowood. Different methods were selected based on client needs and the benefits associated with them. This is evidenced by the varied reasons provided by consultants for choosing these methods. The commonest reasons provided for choosing a particular offsite construction method were speed of construction and quality of construction considerations. So particular methods were selected to speed up construction, reduce programme time, improve the quality of the completed scheme, or increase the control over quality. Other methods were selected to provide increased predictability, to enhance sustainability, or because of limited designs available at the tender stage of the project. Other reasons included the durability of the products, aesthetic considerations, thermal quality, low air leakage requirements, and reduced load on foundation requirements. A study of the reasons provided by consultants who worked on these case studies does not provide any pattern relating to the available offsite construction method used. It would appear that potential methods should be explored against client priorities and the confirmed benefits associated with the respective methods.

Structurally insulated panel (SIP) infill in conjunction with concrete frames was used because of constrained site access as well as noise restrictions on the site. Another reason was the limited designs available at the tender stage of the project. The use of a high-performance infill solution as part of the SIP helped to reduce energy costs for the development. The reason for using a pre-insulated open panel timber frame was because of the greater predictability it offered. The predictability was achieved as a result of the reduction in labour resources and the exclusion of brickwork—which is a time-consuming activity—from the critical path. In the case of the iComposite panel superstructure incorporating windows and services with 250 mm cellulose insulation, external brickwork, render, and thermowood, their use ensured increased thermal quality in the developed schemes as well as helped to meet low air leakage requirements. Using these offsite construction methods also enabled high precision levels to be achieved in the developments.

Where Precast Concrete elements were used, these comprised Precast reinforced Concrete structural columns together with twin-wall core walls. These were used to speed up the rate of construction of reinforced concrete frames and provided a high-quality finish. In the development which used Light Gauge Steel (LGS) superstructure frame integrated

prefabricated wall panels and floor and balcony Cassettes, these were used because of the accuracy offered by this system in terms of anticipated loads. As a result of the accuracy in predicting the loads, the tendency to overdesign was lower leading to a reduction in foundation loads and lower overall groundwork costs.

For the project which used bathroom pods, these were manufactured offsite including all fixtures, fittings, and services ready for connection on-site. This construction approach reduced the construction time on-site yielding an efficient construction programme as well as a reduced overall carbon footprint. The project used Volumetric Construction with steel frame modules integrated slip-form concrete for cores with rain-screen cladding, and a concrete podium over the parking lot. Tower balconies were constructed as part of modules and used as supports for façade works. This OSC approach improved build quality, reduced construction waste, and increased the speed of the construction process.

In the project which used the EcoTech System, the reason provided by the project team for this choice was to achieve high sustainability credentials for the project as well as quality levels. The EcoTech System also helped to achieve a fast delivery programme. Using Gyproc Habito on the other hand provided a robust, long-lasting product, which was also easy and cheap to install, replace and maintain. The Gyproc Habito boards, used in conjunction with magnetic plaster, provided acoustically insulated floors (Silent Floor) and future-proof walls. The use of Thistle Magnetic Plaster improved aesthetics and the fabric of the building and technology to adapt to the changing needs of homeowners.

#### *4.2. Cost Comparisons between Offsite and Traditional Methods*

It is important to note that despite the lower costs of some of the schemes as a result of using offsite construction methods, cost was not cited as a reason for choosing any of the methods. Cost savings, where available, provided an additional benefit. One project which used SIPs had a clear 25% cost saving in the costs of electrical and mechanical installations in addition to 10% savings to the programme. In the other project using SIPs, despite materials costing more, there was an overall cost saving due to savings in the costs of preliminaries. In one project based on ECOTECH Timber, whilst the initial costs of construction were higher, whole-life costs were lower with additional benefits arising from lower running energy costs. In another case based on Precast Concrete elements, whilst there was no confirmed financial saving at the time of the report, however, the reduced labour requirements, time savings, and savings on preliminaries make this method more cost-effective than a traditional approach. In two other cases with no direct cost benefit, savings in construction times provided a distinct advantage. Whilst it appears to be against the popular perception in the literature that OSC is cheaper, the fact that there was a willingness amongst stakeholders in the majority of the projects underscores the long-term cost-effectiveness of this approach.

Of the cases reviewed in this study, there were four cases in which the costs of using offsite construction exceeded the comparative costs of traditional approaches. Two of these projects used Gyproc Habito board as the offsite construction method. Despite the higher costs, these two projects provided distinct benefits such as durability of the elements, improved aesthetics due to fabric enhancements, lower construction, and lower maintenance costs. In one case, the contractor commented about the excessive costs and also the fact that the German technology employed was not cost-effective in the UK context. In the other case involving German technology, however, the contractor was happy to use it again in the future despite the higher costs as a result of the opportunity to work with a reputed German manufacturer.

#### *4.3. Lessons from the Experiences of Stakeholders*

In response to the question asking contractors involved in the case study projects about their willingness to use the offsite construction methods in future projects, all but one of the contractors involved in the case studies were happy to use the offsite construction approaches in future projects. The only exception was in a project involving German

technology which did not appear to thrive in the UK context. Some of the reasons cited for their readiness to use the offsite construction again in the future included the speed of construction, improved quality, increased predictability, enhanced aesthetics, and overall lower costs of schemes.

Among the lessons shared by stakeholders of the reviewed cases, it was learned that design and sizing issues encountered in one of the projects could have been addressed through the use of BIM. It was also recommended that for projects involving recent technology, there was a need to agree on a new suite of robust details with Building Control and NHBC the first time using the system. Again, in schemes employing Timber Frames and high timber content, there was a need to allow for drying-out periods within the programme to cater to the effect of inclement weather and control moisture content.

Among other lessons emerging from the review, it was established that a lack of sufficient understanding of the design strongly impacted the cost to build and efforts to achieve Passivhaus certification where such certification was desirable. The lessons from the review show that for the offsite construction approach to be successful and to deliver the anticipated benefits, there is a need for effective design management and coordination during the design phase of the project. Significant savings arose from the fact that no scaffolding was required when installing products on-site. A major success factor for some of the reviewed projects was excellent collaborative working between the Design Team, Steel Manufacturers, and contractors following the early decision to use offsite construction. The success of the trial in some of the cases reviewed proved that by considering upfront CAPEX costs versus ongoing repair, maintenance, and improvement (RMI)/operation costs, investing in better, more expensive products in the construction phase can be commercially viable and beneficial. Having a holistic view of design, construction, maintenance, and resident satisfaction levels create the right environment for better decisions and for building better homes. A key lesson was that a developer can improve brand, profitability, and customer satisfaction levels by providing 'better' products.

The findings from the literature and the case-study review reported in this paper attest to the strong potential for the deployment of OSC in housing. It is associated with benefits in quality, and schedule. Its potential application in the provision of shelter in disaster situations has been pointed out. This paper provides useful insights for developers, policy-makers, and industry professionals when making choices about methods of construction for housing schemes.

## 5. Conclusions and Recommendations

### 5.1. Conclusions

In this paper, it has been demonstrated that in the context of the UK Housing sector, no single offsite method of construction appears to be the dominant method used in the case studies reviewed. SIPs, Timber Frames, Precast Concrete, Steel Frames, Volumetric Construction, and Gyproc Habito Plasterboards were some of the offsite construction methods used with the same frequency in the projects reviewed. Others, less so, included Light Gauge Steel (LGS) technology as well as a Composite panel superstructure incorporating windows and services with cellulose insulation, external brickwork, render, and thermowood. It is thus concluded that methods were selected based on specific client needs and the relative benefits associated with each of the methods. This shows in the varied reasons contractors gave for choosing these methods.

The commonest reasons provided for choosing a particular offsite construction in housing developments in the UK were speed of construction and quality of construction considerations. Methods were selected to speed up construction, reduce programme time, improve the quality of the completed scheme, or increase control over quality. Other reasons included the durability of the products, aesthetic considerations, thermal quality, low air leakage requirements, and reduced load on foundation requirements. Additional reasons provided for choosing methods included increased predictability, enhanced sustainability,

or because of limited designs available at the tender stage of the project. Potential methods are explored against client priorities and benefits associated with each method.

It is important to note that despite the lower costs of some of the schemes as a result of using offsite construction, the cost was not cited as a reason for choosing any of the methods. Cost savings, where available, provided an additional benefit. The paper also found that despite higher initial costs when using offsite construction methods, cost savings arise from other areas such as preliminaries, and lower running and maintenance costs. This meant that the offsite construction methods resulted in overall lower life cycle costs. In a few cases, there was a clear cost advantage for using offsite construction methods in addition to other benefits. Whilst some of the projects did not have a confirmed cost advantage at the time the reports were prepared, there were other benefits. Some of these included reduced time and opportunities for rental income. Only two out of the projects reviewed recorded a higher cost for the offsite construction method compared with the alternative using traditional approaches.

All but one of the contractors involved in the case studies were happy to use the offsite construction approaches in future projects. Some of the reasons cited for their readiness to use the offsite construction method again in the future included the speed of construction, improved quality, increased predictability, enhanced aesthetics, and overall lower costs of schemes. It was also learned that developers can improve brand, profitability, and customer satisfaction levels by including 'better' products within their homes.

### 5.2. Recommendations

The observations and the experiences of the contractors involved in the cases reviewed provide useful lessons for the industry. Amongst them is the need for effective design management and coordination during the design phase with opportunities for the contractor's structural engineer to review manufacturer design and calculations for example.

Again, whilst the use of timber has been seen to enable a more predictable delivery programme, this can be affected by inclement weather and the need to control the moisture content. Some allowance should therefore be made in such circumstances for drying-out time. It has also been suggested in one of the cases where design and sizing issues were encountered that the use of BIM may help avoid any such issues in the future.

It is recommended that the supply chains for components be explored to establish the cost-effectiveness of importing elements where technologies are not available locally.

### 5.3. Further Research

Further investigation may be required to explore the probable causes of the higher costs in the instances where the offsite methods of construction yielded higher costs compared to the alternative of using traditional construction approaches.

Again, whilst all the cases studied demonstrated savings in time with reductions in the programme ranging from six weeks to 24 weeks. A larger study will be required to demonstrate if specific methods provide bigger time savings than others.

A quantitative evaluation of the impacts of using OSC methods on cost, schedule, quality, and safety outcomes can be explored.

Again, it is suggested that further investigation be undertaken into the potential contributions of BIM to addressing design and sizing issues in projects using offsite construction approaches.

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