Modular Construction Innovation in the UK: The Case of Residential Buildings

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Abstract

The construction industry in the UK within the last decade has seen an increasing demand for housing and wider concerns over the need to improve performance. Comparatively, other UK industry such as car manufacturing has rapidly developed and modernised itself. Offsite technologies seem reluctant to be adopted by the construction industry. Several surveys have been carried out to examine the limitations and explore remedial actions however, house builders are uncertain in their views, hence are reluctant to embrace this innovation in helping to meet the current demand for new homes. This study has been carried out to understand the benefits and barriers of modular construction and the level of satisfaction with the modular construction over the traditional construction. The investigation was carried out through using 3 case studies, within which a combination interviews, questionnaires, site observation and document review were used for data collection. The results suggested that in comparison with traditional construction, modular construction will offer a better quality finished product, significant savings in construction programme, improved health and safety and increased end-user satisfaction. The projects reviewed have shown excellent market achievement. The authors have hence concluded that given changing client perception, improved design and procurement, and increased awareness, modular techniques will be the future home construction trend. To achieve this, increased awareness and training opportunities in modular techniques are necessary to enlighten traditional builders about the potential benefits of modular techniques.

Keywords
Modular building, Innovation, Offsite construction, Prefabrication, UK

1. Introduction

The construction industry in the UK, as of 2018, contributed £117 billion to the UK economy, 6% of the total economic output, where the growth was bolstered by demand for housing, commercial, infrastructure, other public and industrial sectors (Rhodes, 2019). Despite such huge growth, the industry in the UK continues to underperform in some critical areas of the industry such as productivity, the certainty of delivery on time, skilled labour and data transparency. Housing accounted for highest value of new orders in 2018: £21.6 billion, 35% of all new orders. The government has an ambition to deliver 1 million homes by the end of 2020 and to deliver half a million more by the end of 2022 (Rhodes, 2019).

The industry is dominated by conventional construction methods especially in the area of residential accommodation. Contractors in the industry are used to "onsite labour and resources to build raw aggregate materials and some prefabricated components" (KPMG, 2016). The adoption of prefabrication into their works enables them to adapt quickly and effectively to changing demands and design. In 2009 it was estimated that modular construction total value share of the construction industry was £6 billion representing just 7 per cent. A drop in the ocean considering the fact that of this fraction almost a negligible percentage can be ascribed to residential sub-sector. Since the Barker review of 2003, designers and developers have been working on different types of home construction from different perspectives. Nevertheless, there has been rapid development of prefabricated home design from different aspects such as sustainability and cost-effectiveness as well as energy and time saving (Meen, 2005). Particularly in the housing sector, the report recommended aspects of the industry where improvements can be made to follow the steps of manufacturing companies as a step towards effectiveness and efficiency. This drive is aimed at the Government agenda producing the quantity of quality housing needed in the UK.

Conversely, some house buyers are so strongly influenced by negative perceptions of the post-war 'prefab' that they will withstand any innovative improvements in house construction that impact on what a 'traditional' house looks like (Pan et al., 2007). Likewise, there also exists among architects and other designers the grounded human perception of the historical challenges of offsite fabrication (Mao et al., 2013). Added to this, technical challenges such as interfacing issues, site specifics, high cost and other fragmented frameworks hinders designer's acceptance of modular construction. Lusby-Taylor et al, (2004) suggest that much research has not been carried out to ascertain clear evidence about the relationship between design quality and modular construction. Speed of construction appears to be the main reason for off-site prefabrication as opposed to cost savings which are expected when compared with traditional construction. Modular construction is considered to have the capacity to construct affordable housing adding to the national stock. However, traditional house builders are considered slow to act in embracing technological advancement (O'Neil and Organ, 2016). Countries such as Japan, Germany and Scandinavia are heavily reliant on modular construction in comparison to a conservative UK building industry.

2. Theoretical Review

2.1 History of modular construction in the UK

The aftermath of the Second World War recorded enormous destruction of UK infrastructure particularly homes due to bombs; creating a housing crisis, which required being quickly and effectively resolved. Significant push for homes aided by innovation was encouraged. The Industrial Revolution and the war meant more homes needed to be built across Britain to serve a temporary solution lasting ten years (O'Neill and Organ, 2016). However, there were concerns with delivering large-scale building programmes to deal with this crisis.

The demand for mass social housing became crucial for a systematic approach to home construction. Bungalows became the ideal form of housing surviving long beyond their design life of 10-15 years even though the survival occurred in the wake of adverse criticism from the industry when the provision of temporary accommodation after the war was first suggested (Russell, 1996). A little public consultation was carried out about the type of temporary housing required because the bungalows represented considerable innovation, which was prefabricated, and factory produced. Non-traditional gradually gathered momentum, delivering about 450000 homes a decade after the war (Turner and Partington,2015). Prefabrication then became a household name due to its off-site production and mass production rapidly.

Prefabrication of these homes consisted of a range of materials of various degree from steel frame, precast concrete, in-situ concrete and timber-frame. Prefabrication of homes from steel and timber soon became the new scheme due to its off-site manufacturing and assembled in a few days. Government intervention in that regard witnessed a significant increase in either temporary housing, which was manufactured, or imported (Hayles, 2010). It was envisaged, that these 'portal houses' as it was called could be removed as soon as the ordinary building programme catches up (Vale, 2003). O'Neill and Organ, 2016 suggest that the housing drive was an unstructured approach without recognition for the building industry to provide housing by skilled labour. However, this move could not match up with the numbers required which generated the widening perception of poor performance. In that same period, building techniques had not developed steadily and consistently instead; it was evolving in a sporadic fashion where it was totally disregarded

at times. To some degree, prefabrication gained a stigma due to problems in delivering this intervention on a large-scale building programme (O'Neill and Organ 2016).

The collapse of Ronan Point, Newham, East London in 1968 and other associated problems led to the increased public perception of prefabricated buildings as low quality and insecure. However, governments assessment of these problems did not conclude flaws with design and construction but rather, poor workmanship. Evidence suggests that although there is an improvement in building techniques and systems, there continues to be a prevailing stigma attached to offsite building manufacturing. For off-site manufacturing to be thriving there must be collaboration and unity between designer, manufacturer and contractor to recognise and overcome the problems and perceptions facing off-site manufacturing. Considering the gloomy days of off-site manufacturing, general improvements and innovation in home construction have enabled the benefits of off-site manufacturing to be recognised (Goodier and Pan, 2010).

Sir Michael Latham review into roles, responsibilities and performance of the participants, including the 'client' (Latham, 1994) was set up to offer solutions to issues that were affecting the industry from procuring high-quality projects. The report concluded that the industry's performance could be enhanced with collaboration between all stakeholders (Jackson, 2002), reduction in construction cost using innovative construction building materials in the form of offsite manufacturing. The ideas coincided with the debate on lean construction and prefabrication aimed to minimise waste, speed of construction and maximise performance for the customer at the project level (Williams and Dair, 2007), it became necessary to broaden the traditional concentration on construction methods. Similar review was carried out by Egan (1998) to provide a radical framework for improvement through modernisation and be responsive to its end users. It aimed at placing the client's objective at the center of construction projects encouraging partnering in the development and implementation of projects. Egan and his team acknowledged that the industry requires some mechanisms to deliver the change (Murray, 2003).

Off-site manufacture, prefabrication and pre-assembly and modularisation constitute a wide range of modern innovative techniques available to developers pursuing cost-effectiveness in construction (Gibb, 1999). Industry players in some instances have defined these terms interchangeably to refer to any form of construction process taking place outside the construction site. Mawdesley and Long (2002) define prefabrication as any segment of a construction process where elements are manufactured off-site in factory-controlled conditions. Defining prefabrication is not pedantry; however, contractors, designers and manufacturers do so in their quest for a competitive advantage in cost, speed and quality. Prefabrication describes the off-site manufacturing of component aspects of a structure and transported to assembly on-site (Davey-Wilson, 2001). Pre-assembly was defined as the manufacturing and assembly of structure sub-component, non-volumetric and volumetric components on-site (Tatum et al., 1987). Pre-assembly involves the process of merging diverse materials and prefabricated components of a structure for subsequent installation as a unit (Gibb, 2001).

2.2 Modular construction

Modular construction comes in several forms such as volumetric modular systems, panel systems and pod systems. In volumetric module system, prefabrication is relied on producing a 3-dimensional (3-D) structural unit typically cut out of steel, concrete, or timber or in combination with one another. This constitutes units, which are created for useable space, fully factory finished and installed within or as part of an independent structure such as toilet pods, shower rooms and plant rooms (Gibb, 2003). Prior to site delivery, the modules are joined together in the factory. When brought to the site, the modules are secured in place by methods such as bolts and dowelled connections. The panel system, 2-dimensional (2-D) panels are prefabricated into required wall panels and joints, assembled on site to form a complete structure (Gibb, 1999). It has been integrated successfully into conventional construction to allow versatility. The panel system controls about 7 per cent share of the construction market value in UK (KPMG, 2016).
A modular building is one, which entails a number of volumetric units such as external wall systems, manufactured in a factory depending on project requirement and transported to its final destination. Currently, modular construction can be constructed from steel frames, plywood and precast concrete. Babcock et al. (2007) suggest that modular buildings have previously been low-rise. However, advancement in construction has enabled high-rise housing construction, which is either constructed as a self-supporting structure or designed to rest on separate structural supports.

Modular construction generally describes the aspect of building construction that is carried out in a factory and delivered to site for assembly for the end-user. This process involves planning, designing, fabricating, transporting

and assembling building elements for rapid site assembly to a greater degree of finish than it is in traditional piecemeal on-site construction (Davies et al., 2018; KPMG, 2016; Rogan, Lawson et al., 2000). It is for this reason that modular construction is also sometimes referred to as offsite or volumetric construction. In this kind of construction, modules are pre-engineered in a factory according to customer specification as would any manufacturing process in a factory. This mode of construction is deemed to be cost-effective while it is also to accelerate the delivery time of construction. It is therefore recommended as the best alternative to a conventional constructional method and has the potential to provide a solution to many of the shortfall in conventional construction (Lusby-Taylor et al, 2004).

Modular construction is not so much a new concept in the industry; it has been in use for at least since the Second World War. This was so much convenient at the time because of the high demand for new houses following the Second World War (Musa et al., 2016). In the early ages of modular, according to Musa et al. (2016), the houses produced were seemingly huts for temporary accommodation but modular construction was truly born when a housing manufacturer first produced a two-section house that conformed to applicable building code of 1958. In the early years of modular construction, technology was not so much advanced, only a few sections of buildings were produced in the factories and those that were produced were deemed less durable compared to conventional buildings. But with recent advances in technology, especially Computer Assisted Design (CAD) and Building Information Modelling (BIM), modular buildings have improved greatly and can rival conventional buildings both in design and function. Available evidence further suggests that modular construction so far has remained successful in its application in the building of facilities for schools, prisons, hospitals, and retail supermarkets (Goodier & Gibb, 2005; Musa, Yusof, Mohammad, & Samsudin, 2016).

2.3 Challenges and Prospects of Modular Construction

Modular construction is being promoted widely as the future of the building industry because it promises to offer a better advantage over conventional construction in terms of speed, quality and cost. Available literature (Davies et al., 2018; KPMG, 2016; Rogan et al., 2000) suggest that in modular construction, buildings are constructed with a considerable speed of 50 per cent reduction time compared with its conventional counterpart. Modular construction is associated with such speedy delivery because in some circumstances processing plants can work continuously for 24/7 rolling off finished products. This is also made all possible because the factory production process is not controlled or affected by the same external factors such as adverse weather, logistical challenges, shortage of skilled labour, among others that are present in conventional construction. For example, according to KPMG (2016) in 2015 almost 50 per cent of all onsite construction projects failed to predict reliably programme completion dates. In a factory setting, modular construction processes are closely monitored and tested by specialised workers who work at every stage of the process to ensure that the highest standard is met. This factory thus has an impact on the completion time of projects. In a survey carried out by Goodier and Gibb (2005), 90 per cent of their respondents noted that time-saving on-site was a good advantage for modular techniques. Of this same group 69 per cent listed time-saving as their number one advantage and preference for modular construction.

Pre-project planning is key to the option of modular construction. Modular design is significantly different from conventional design. Undoubtedly, the complexity of the various models and incorporating different aspects of the module, transported and placed in its final location is made possible by adequate targeted project planning (Choi et al., 2016). Scope of the project is required at this stage to enable connection of the various interphases thereby limiting changes during the construction stage. Restraints on transportation is a major challenge during modular construction. During the planning stage, it is vital that the project team assess any potential transportation challenge likely to impede on the delivery of the project to its destination. Issues such as traffic regulations on the proposed route must be assessed. Transportation of completed houses to another destination is costly and requires complex arrangements (Boyd et al., 2013). Dimensional sizes of the modules will be dictated by the traffic regulations of the intended destination. These challenges could cause delays to the project. Modular home construction is regarded as pricey due to the high initial cost required to set up and operate it (Rahman, 2014). Availability of a good functioning local economy is to the success of modular construction (Kamali and Hewage, 2017). A well functioning local construction industry makes it feasible for the sourcing of experienced experts such as engineers and designers for modular construction.

Despite the tremendous acclamation of modular construction, its use and adoption have been relatively slow due to poor public perception of prefabrication buildings and lack of confidence in non-conventional methods of building. Currently, almost 15,000 modular homes are built annually (Davies et al., 2018), meanwhile in order to meet the house

demand shortfall the industry must be producing nearly 300,000 homes annually (Goodier and Gibb, 2005). These among other factors such as the initial commitment of investment, lack of competition and lack of accreditation that guarantees its durability, have in part been a barrier to adoption of this construction technique. Evidence suggests that there are some efforts being made to embrace the use of this approach in the industry if not entirely replace conventional methods.

Mitigating the uncertainty and risk, the Build Offsite Property Assurance Scheme (BOPAS) was jointly developed by various interest groups, to provide assurance to the lending community that innovatively constructed properties will be sufficiently durable as to be readily saleable for a minimum of 60 years (KPMG , 2016; Davies et al., 2018; and Krug, 2013). The UK housing minister Gavin Barwell in 2016 noted that the government sees a huge opportunity in manufacturing houses offsite and is looking to increase access to finance for modular housing providers to help secure the delivery of more than 100,000 ready-made homes by 2020 (Davies et al., 2018). Arguably, with the growing concerns of climate change, it is imperative that the construction industry reduces its carbon emissions.

3. Methodology

The research adopted a mixed method approach which is predominantly qualitative. Qualitative method seeks to understand a phenomenon by focusing on the total rather than breaking it down into variables with the intent to gain a holistic and in-depth understanding rather than numeric analysis of data (Jacob et al., 2017). Qualitative research method enables an in-depth understanding of human behaviour and the rationale for such behaviour. Fellows and Liu (2015) suggest that during qualitative research, the subject is explored without formulations to gain understanding, collect information and data to enable theories to emerge. Hence a case study approach was used in order to understand the factors influencing modular construction, the satisfaction level of clients, the benefits and challenges associated with the construction. 3 case studies have been selected where the data was collected using a mixed method. 6 semi-structured interviews targeting the contractor and client involved with each of the 3 case study, a questionnaire survey from the end-users to get the satisfaction level, site-visits to the case study projects to make observation and documentary reviews related to the case studies were used as the methods to collect data. 50 questionnaires were distributed, of which 32 were received contributing to a response rate of 64%.

4. Introduction to the Case Studies

Case study A: The project was a 30 unit one-bedroom apartment with an internal area of 2,150m^2 and a net area of 1894 m^2. This was the first of its kind project situated at this location. The project used an innovative steel frame modular construction technique to improve construction quality. The development was aimed at key workers such as intended to rent it for an average of £270 weekly. The client chooses the design and construct procurement route with client standard amendments negotiated and agreed with the contractor. This was accomplished by a partnership with the architects and the contractor on the efficient use of off-site manufacturing. Client choice of volumetric manufacture was influenced by its confidence that if "volumetric" techniques are widely used to build hotels and fast-food outlets then it could be adapted to provide high-quality homes (Goodier and Gibb, 2005; Musa et al., 2016). Figure 1 shows the erection process and the finished product.

Figure 1: Site erection process and finished product (Case Study A)

There were growing concerns over built quality, time and confidence in traditional construction building (Williams and Dair, 2007). The fragmentation with traditional construction influenced the idea of modular construction (Jackson,

2002). The client felt compressive correlation and collaboration will mitigate any potential risk (KPMG, 2016; Davies et al., 2018 and Krug, 2013). Since the project was a test case of modular construction in the UK, the client is confident and optimistic that increased investment into modular construction could be the answer to the key-worker housing crisis by penetrating into the private market to bring prices below conventional building costs.

Case study B: It is an eight-unit development of one and two-bed flats of 50.7 m^2 and 65.4 m^2 respectively and spread over four floors. The project is the first modular construction in this location. The target market for this development is key workers who desperately need housing but find it difficult to rent or buy in the current market. Since modular construction is a new concept, the client chooses a traditional procurement method to offer much control to the architect about the design before providing enough details to the manufactures and installers. In selecting modular design, the client highlighted three factors as "highly important": a revolutionary development, cost and building time. The project was described as a ground-breaking innovation as the technique was still comparatively unproven and it was their first modular manufacturing project. Figure 2 shows the exterior of the finished product.

Figure 2: Exterior of the finished product (Case Study B)

Case Study C: 220-bedroom modern hotel project is situated on a 1.75 acre site. The development used a modular construction technique to see the fully furnished shipping containers connected to build the 220 bedrooms. Working in collaboration with other professionals, it created a coordinated BIM model making it possible to off-site production works. The construction of this project have involved steel, concrete, and bricks to form the various units. However, with modular construction, all the steel containers are fitted out with all interior fixtures and fitting before being delivered to site. The contractor was therefore able to start construction of the ground floor and podium slab. The modules are then stacked singularly on top of the podium. This allows speedy construction and greater collaboration (Mawdesley and Long, 2002). Each module consists of fully equipped en-suite rooms, separated by a circulation corridor segment, and all construction facilities. For a building of this housing scheme, space is key to the amount of income generated, hence, this could be realised quickly due to the use of off-site methods in relation to speedy construction, lower labour cost and reduced overhead (Mawdesley and Long, 2002). Figure 3 shows the erection of the shipping containers and the finished product.

Figure 3. Erection of containers and finished product (Case Study C)

The client opted to a traditional method to volumetric modular approach based on the concept of offering a modern, clean and simple scheme for today's smart traveler (Gibb, 2003). The design team was tasked to study the implications of using a volumetric modular approach using a purpose-built container system, with a new BIM model to incorporate the various container elements to allow the manufacturing factory to procure materials and deliver a prototype in three weeks. The benefits for adopting modular construction such as quality and construction speed (O'Neill and Organ 2016) was evident in the case study. However, it acknowledges that this may not be appropriate in all situations but

given the site logistics and project brief, it was a significant choice. The project took nine months to complete from start on site to completion, saving six months of construction compared to the traditional method had that been adopted. The project team believed that the various components and contractors could run concurrently with each other to reduce time and cost. It has been noted that the project progressed into a pace in a smooth and controlled manner. Nonetheless, the client occasionally felt that this method of construction would turn out to be excellent quality. Significantly, the overall cost of the project was key. Hence the adoption of modular construction.

5. Findings and Discussions

The key findings of the case study analysis are associated with factors influencing the choice of modular construction, benefits, challenges and the level of client satisfaction with the modular construction. The client envisages that modular construction is shaking up the market as a revolutionary concept in the UK construction industry and will offer a speedy solution to the UK housing crisis at an affordable cost with better quality and modern appearance. It also recognised that the modular concept allows complex structures to be manageable, allows parallel working with other contractors and can accommodate future uncertainty. The concept allows each module to be developed as a self-sustaining block. Compared to traditional construction, where construction activities are performed in sequential order, modularisation requires greater interaction among construction activities requiring planning of these activities to take place early in the project. The main influencing factors that are also considered as benefits for choosing modular construction are the time, cost and quality of construction, which are discussed in detail within each case below.

5.1 Time, cost and quality benefits as the main factors for the choice for modular construction

In Case A, the project is located in a brownfield site, therefore it needed construction processes which offer less destruction to the neighbouring development and constructed with speed. Modular construction became the obvious choice that 'ticked' the boxes. Construction time was budgeted as 27 weeks, excluding manufacture period for modules. Total completion time taken was 44 weeks from the possession of the site to handover with a construction time difference of 17 weeks. They attributed this to delays with the traditionally constructed external steel and cladding works which originated from problems with the steelworks. Budgeted construction cost was £1.99m compared with actual spending of £2.34m resulting in over budget of £350 thousand. The extra cost to the project was reportedly due to the prefabricated scheme, which was a pioneering project, and the client sought to demonstrate good design through innovation. However, it hoped to recoup these costs through savings from future off-site manufactured development. The client produces a high-quality development that will last longer, perform better and cheaper to run than conventional developments. This translated into a well-insulated building economical to heat with residents reporting a cost of £250 on fuel. It anticipated that for modular construction to achieve its successes would require a discipline between the design and construction team to amplify the competitive use of manufacturing modules. The manufacturing of the modules in a factory ensured adherence to strict quality control to ensure that once the modules arrive on site, defects will not occur or listed as minor if they occur.

In Case B, the construction of the four-storey blocks took approximately four days to complete with cladding and roofs, fully fitted kitchens and bathrooms. The system is unique, the modules were recyclable, erected quickly and repeatedly unbolted and transferred to a new site. The site is quite limited, so it was believed that modular building was a better proposition to provide the number of units needed. Fast-changing urban life requires the flexibility of buildings and sites. Compared to Case Study A, this project was less costly due to the location of its manufacturing plant where technical competence and labour cost were one-sixth of UK rates. The overall cost amounted to at least 12% lower than traditional new build. The client recognised prior to design that adopting a volumetric system of prefabrication was invariably going to cost less compared to a similar project if constructed traditionally. The construction cost was £125,000 over the expected cost which was attributed to changes from the initial design plan and designs for more service core. Nevertheless, by a 12% lower cost, the client envisages that modular construction provided a cheaper alternative to the traditional construction method. Similarly, the type of quality control that it desires can only be achieved in a factory where the modules are not only clad and roofed in the factory but fully fitted with bathrooms, kitchen, paint and flooring.

In Case C, the construction time took only nine months from the start of the construction process to finish compared to the projected time of one and half year if it had opted for the traditional approach. The budgeted construction cost was £17.2 million compared to actual overall costs of £16.2 million resulting in a £1 million saving. The saving of six

months was because of modular construction technique. As a result, the client avoided interest payments on loans worth six months and only paid the contractors on-site for a comparatively brief period. It also meant that, with all the related income generation that brought about, they were able to begin trading six months' sooner. They shared that the vision was to reduce cost of construction on the project with modularisation and BIM at its heart. They informed that the technique consisted of prefabricated multiple sections that were built off-site and assembled on site. Once on-site, the components were installed together to complete the building. It highlighted that the design process took two months to complete reasons being that the designers need to be upfront with their decisions as well as to align with the manufacturing process. This resulted in a 30% reduction in construction time compared to traditional onsite builds. The time it took to build the substructure was unaffected by the transition to modular. Instead, since the modules are usually designed to be weightless, the reduced complexity of the foundation construction yielded some time savings. All these attributes point out to the evidence that modular methods of construction produce shorter build time which in turn results in significant cost savings.

Evidently, Figure 4 shows that the construction time is comparatively less than the time taken for traditional construction.

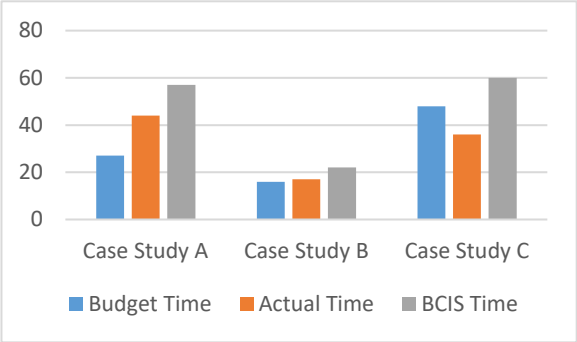

Figure 4. Comparison of construction time in weeks for Case Studies A, B and C

Figure 4 represents a comparison of construction time for all 3 cases against estimated construction period derived from BCIS data. The estimated construction period derived from BCIS has been calculated based on the traditional constructional method. It is clear from the above data that construction time for the modular projects is less than that is expected using the traditional method. It is therefore fair to conclude that modular construction offers speed and significant benefits that can be considered for future project. In addition, massive improvements to construction times can be achieved if much diligence is committed to the planning phase of projects. The reasons for the difference between budgeted and actual time in Case A and Case B, as discussed above, were due to problems with the construction of steel and cladding works and due to unforeseen issues during groundworks and external works, respectively. On the other hand, Case C finished the project earlier than the expected time which is remarkable. Notably, all these projects showed a reduced construction time compared to the BCIS estimated traditional method

5.2 Barriers associated with the modular construction

Despite the benefits discussed above, there have been challenges identified with these modular constructions.

In Case A, since it was a new concept to the UK construction industry, the team was challenged to produce a development which will appeal to the end-user while overcoming some of the stereotypes of timber prefabrication. Overcoming this, the designers disguised the timber cladding to appear as a normal high-quality development than social housing. Post-occupancy assessment of Case A concluded that tenants were still pleased due to its high-quality finishing, excellent layout, great location and light. Furthermore, some of the tenants expressed their positive views about prefabrication as building fast and cheap, changing negative perceptions such as low-quality sixties tower block not meant to last. Poor ventilation and noise from the surrounding building were the negative comments from the assessment.

In Case B, the site limitations, which is usually considered as a barrier for the transportation of modular system, has positively played a significant part. The site is quite limited; therefore, it was believed that modular building was a

better proposition to provide the number of units needed. Hence the client felt modular construction as a better model to adopt over traditional methods. Comparatively, this project had not done too bad with only one week over the budgeted programme considering this was their first modular construction. However, some of the issues that arose could have been prevented through improved cooperation and coordination between all parties involved.

In Case C, modularisation pride itself with distributed collaboration and problem solving between contractors. The contractors noted that due to the disaggregated nature of modularisation every component had to go through some network of interactions before taking place. It hinted that some of the modules required some changes due to the product variant they are used in. These were a result of inappropriate design decisions which were in some way unrelated to modularisation. Transportation of some of the modules to the site was also an issue due to transport route and bulk nature of the modules. The contractors noted that although the size of the containers fitted on the loading-trucks, the uncertain traffic condition in the locality meant some of the deliveries were done on nights.

5.3 Satisfaction level in comparison with traditional construction

The next analysis was on the level of satisfaction with the finished products, where the data was collected from contractors, clients and end users. A 6- point scale was used where 6 denotes extremely satisfied and 1 denotes extremely dissatisfied. Figure 5 shows the analysis.

Figure 5. Level of satisfaction towards the projects

The respondents were asked to compare the respective case study projects with that of traditional construction. As per Figure 5, it can clearly be seen that the modular form of construction gives better satisfaction level in comparison with that of traditional construction. However, this results are based on opinion survey. It would have been a better comparison if the satisfaction was analysis in terms of any performance measurements of the end product which is considered as a limitation to this research.

5.4 Summary

The controlled factory setting of modular construction allows for increased quality control procedures and robust craftsmanship to be implemented. It presents with a much more detailed design with detailed elaborations than in traditional houses. This will enable the buildlings to be delivered with far fewer difficulties and faster commissioning on site. More importantly, it will eradicate the risks of defects not being identified during construction which would otherwise be expensive to rectify after completion. Offsite manufacturing offers a reduced time on site exposing the project to unfavourable weather conditions. Modularisation offers automation of building components and great collaboration among different trades. Subsequently, time assembling on site is reduced significantly. Clients and end-users of modular construction were very satisfied with the end product. Feedback analysis from residents and clients showed that the benefits of modular construction are well above that of traditional building. Modular construction offers an excellent collaborative working relationship between designers, consultants and contractors to ensure that the project programme of events is achieved efficiently. Modular construction will produce whole life cost saving through enhanced specification and build quality by a reduction in energy use, defects and repairs. Modular construction may be an effective cost alternative to home construction compared to traditional construction methods. However, due to its limited use in the industry, these savings are achieved on a project-by-project basis dependent on the modular scheme adopted.

6. Conclusions

The modular construction method is a significant innovation that aims to offer the construction industry modern methods of building residential homes efficiently and speedily to meet current demand. Traditional contractors are reluctant to adopt off-site modular construction techniques mainly due to its poor previous perceptions. Cost was often seen as an obstacle to off-site activities due to increased initial cost required during the planning and design phases inaccessible by traditional builders. However, the primary data conducted using 3 case studies show that there are considerable benefits in terms of time, cost and quality aspects, if adopting modular construction over traditional construction. Barriers were identified too as poor perception, transport difficulties, lack of coordination and collaboration. In addition, other barriers such as lack of knowledge and regulatory guidance, lack of industry and product awareness, shortage of skilled workers have hindered on traditional builders' unwillingness to embrace this innovation. These can be overcome by increased industry knowledge and awareness of the successes of modular techniques

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