Investigating the Cost of Offsite Construction Housing in Western Australia

Abstract:

Purpose: Offsite construction approaches and methodologies have been proffered a potential solution for controlling 'traditional' projects, especially where high levels of complexity and uncertainty exist. Given this, locations such as Western Australia (WA) where there are unique housing provision challenges, offsite construction method was considered a potential solution for not only addressing the complexity/uncertainty challenges, but also alleviating the housing shortage. However, whilst acknowledging the benefits of offsite construction, recognition was also noted on perceived barriers to its implementation, primarily relating to cost uncertainty. This recognition is exacerbated by very limited offsite construction cost data and information available in the public domain. In response to this, this research provides detailed cost analysis of three offsite construction projects in WA.

Design/methodology: In order to hold parameters constant and facilitate cross-case comparative analysis, data was collected from three embedded case studies from three residential housing projects in WA. These projects represent the most contemporary implementation of offsite in WA; where two were completed in 2016/2017, and the third project was still on going during the data collection of this research. The research methodological approach and accompanying data analysis component engaged a variety of techniques, which was supported by archival study of project data and evidence gathered from the offsite construction provider.

Findings: Core findings revealed three emerging themes from residential offsite construction projects pertinent to cost. Specifically, i) the overall cost of delivering residential housing project with offsite construction techniques, ii) the cost variability of offsite construction residential housing projects as impacted by uncertainties, and iii) the cash flow of residential offsite construction projects based on the payment term. These three major cost drivers are elucidated in this paper.

Originality/values: This research presents new cost insights to complement the wider adoption of offsite construction techniques. It presents additional information to address the limited cost data and information of offsite construction projects available in the public domain particularly for residential housing projects (within the bounded context of WA). It also highlights the further stages needed to enhance data validity, cognisant of universal generalisability and repeatability, market maturity and stakeholder supply chains.

Keywords: cost, housing, offsite construction, Western Australia.

Introduction

Complexity and uncertainty are 'typically' intrinsic to construction projects. This also applies to house designing and building, as house building has been considered consisting a complex set of activities, involving many specialised actors and their on-site activities are typically dependent on weather conditions (Lessing 2006). Contemporary house building typically involves complexity and hence uncertainty for builders; in some cases, the requirements for greater speed of construction has also increased as a direct result from the continuous under-supply of housing. These are major challenges facing the builder onsite. Given this, several advocates have proposed solutions which transfer as many of the actual site-based construction activities as possible to a more controlled environment (offsite); where these are later transported back to the construction site for final assembly and installation (Smith 2010; Gibb 1999). This is typically known as the offsite construction method. Whilst there are several hybrid variants of this approach, this philosophy has been successfully implemented in various projects, including the housing sector. In the UK housing sector for instance, offsite construction has been proffered as a viable way forward, so much so that the UK Government termed it as the modern method of construction (Egan, 1998; Latham, 1994), and similarly in Australia (Hampson and Brandon 2004; DISR 1999), where offsite construction was considered the way forward for the entire construction industry. Thus, it is generally perceived that offsite construction can produce superior housing products through the implementation of improved processes in the controlled environment (Steinhardt and Manley 2016). In addition to the expectation of superior quality, off-site construction can (if appropriately managed) also increase the speed of construction by shortening quote-to-delivery cycles, removing non-value adding processes (Nawari 2012). In essence, a controlled environment (typically a manufacturing or factory facility) offers several benefits, particularly: a higher speed of construction, improved quality of the finished product, lower costs and lower labour requirements on-site (Goulding and Arif, 2013; Mullens and Arif, 2006; Gibb and Isack, 2003;).

Given the wide discussion on the potential benefit of offsite construction, there was a general expectation that offsite would be widely adopted. However, whilst pockets of growth and new businesses have emerged, on the whole, adoption and uptake has been disappointing over the years (Khalfan and Maqsood 2014; Rahman 2013). Scholars and researchers have identified various potential barriers, particularly in process, supply chain/procurement and knowledge (Blismas *et al.* 2006). One of the most significant barriers to implementing offsite construction was cost uncertainty - as actors in the industry tend to hold on to well-proven methods and materials rather than developing new ones (Pan and Sidwell 2011; Nam and Tatum 1988). On this theme, a series of workshops in Australia revealed cost as the major constraint to the implementation of offsite construction outweighing any related drivers with offsite construction. Offsite was generally perceived to be a more expensive option due to higher initial capital outlay, design, cranage and transportation costs (Blismas and Wakefield 2009). Informed by an earlier phase of this research that revealed the potential of offsite construction to bring solutions to the housing shortage problems in the Western Australia (Sutrisna *et al.* 2017), this paper presents findings from a case study analysis of three housing case study projects in Western Australia to provide additional insight into this matter. The findings presented here contribute to the currently limited availability of cost information regarding offsite construction projects - particularly residential projects.

Literature Review

Typically contributing about 3–4 per cent to the Gross National Product (GDP), the construction of new houses has been considered a significant contributor to the overall developments in the Australian economy (Hsieh 2012). In the state of Western Australia (WA) for instance, the Australian Bureau of statistics (ABS 2014) has regarded the WA's capital city, Perth, as currently growing faster than any other capital city in Australia. The resources sector boom has been considered the major driver behind the strong population growth that consequently put pressure on housing availability (McKenzie and Rowley 2013). The rapid growth in population has put more pressure on the need for housing that currently outstripped supply (Sutrisna *et al.* 2017). Thus, an effective solution is needed to alleviate this situation.

The housing sector is typically dominated by traditional builders who can only provide a limited range of products mainly to cater for the single-family, owner-occupation market. In Australia for example, traditional masonry construction accounts for about 70% of houses constructed (ABS 2012). Thus, traditional 'brick and mortar home' has been and still is the most popular choice in Australia (Sutrisna *et al.* 2017). Unfortunately, traditional brick-and-block masonry construction is characterised by a relatively long building process and potential quality issues due to its dependency to specialised trades (such as wet trades) that often ended up with delays due to needed remedial works post completion (Roy *et al.* 2003; Bramley *et al.* 1995). This dependency towards specialised trades also brought its own problems when such specialised skills are in shortage. In WA for example, the availability of skilled trades still forms a significant factor to the housing provision in WA and even more so for more remote areas in the state (Sutrisna *et al.* 2017). The traditional house-building process itself often focuses more on the uniqueness and the individuality of each project which are characterised by "unique choices of technical solutions, a limited use of platforms, uniquely combined teams and scarcely developed logistics and procurement strategies" (Lessing 2006, p. 90). These bespoke characteristics of house building has exacerbated the high dependency towards the skilled trades (AHURI 2015) and has limited the ability of the supply-side to provide housing and therefore further contribute to the gap between the supply and demand of housing in Australia in general and WA in particular. Thus, supply-side factors in Australia have been regarded as the main reasons for the delayed availability of new residential developments as well as raising the cost of their delivery (Hsien *et al.* 2012; NHSC 2010).

The traditional approaches to house building have not been capable of delivering the needed level, particularly with the skills shortages discussed above. Increasing the supply of housing but keeping or even reducing construction cost will likely require substantial changes in the delivery technic and organisation of the house building process. However, innovating the methodology to address this will likely require more than simply tweaking the current process such as redesigning the house types. It has been argued that house-building sector can learn lessons from manufacturing industry to meet those challenges (Barlow *et al.* 2003). Such an innovation would require a radical re-organisation of the house-building process including its supply system, viewing the end products as a composition of its component and with more roles to play by its end-users in the design process and reorganised supply chains (Barlow 1999). One of the main alternatives considered suitable addressing the issues on supply-side of housing provision is by shifting the conventional house building method to offsite construction. In the UK housing sector for instance, the UK Government has regarded offsite construction as the modern method of construction carrying the potential to address the housing shortage in the UK (Pan *et al*. 2008; Gibb 1999). The term off-site construction itself typically refers to a spectrum of construction methods that involves preconstruction of certain components outside the building site followed by the assembly of these components to their final position in the construction site (Smith 2010; Goodier and Gibb, 2007). The preconstruction of the components is typically known as pre-fabrication and usually done in a specialised facility, i.e. a factory where materials are brought together to construct the building components. The degree of the prefabrication components used generally determines whether the offsite construction technique is applied as non-volumetric offsite construction or volumetric offsite construction (Schoenborn 2012; Smith 2011; Bell 2009; Gibb 1999). The non-volumetric offsite construction typically includes the use of individual or combined prefabricated building components such as columns, beams, slabs or wall panels. The volumetric offsite construction typically involves the offsite construction and site installation of standing alone building or parts of the building in the form of pods and modules. When combined, the use of both non-volumetric and volumetric offsite construction components in the same project is typically referred to as hybrid. In some cases the term 'hybrid' has also been used to describe the use of offsite construction components and in-situ construction in the same project. In this paper from this point forward, the term 'hybrid' is used to describe a combination of volumetric and non-volumetric offsite construction in the same project.

The benefits of implementing offsite construction techniques are mainly originated from the philosophy to migrate the execution of onsite construction activities into a controlled environment. This enables a better planning of these activities to achieve the required specification and quality through manufacturing processes. By migrating the delivery of these onsite construction activities into a controllable factory environment, it is expected that a high degree of efficiency/productivity, safety and quality could be achieved whilst at the same time reducing waste and impact of the construction towards the environment (Khalfan and Maqsood 2014; Smith 2010). Conducting the construction activities in the controlled environment is also expected to reduce the effect from the weather conditions (Schoenborn 2012; Lu 2007). As in typical manufacturing processes, the activities in the factory can be highly standardised and broken down into simpler tasks and hence can be done by workers with lower skills as long as supervised by other skilled or qualified workers. Therefore, the offsite activities are no longer relying so much towards skilled trades due to the possibility of using semi-skilled or lower-skilled operatives (Nadim and Goulding 2009). All of these potential benefits should, in theory, resulted in a high uptake of offsite construction including in the housing sector. However, it has not been the case. It has been estimated, for example, that only 3% of the new houses built in Australia used significant prefabrication (Steinhardt and Manley 2016). Many researchers and scholars have strived to understand the reasons behind the relatively low uptake of offsite construction in many construction industries (e.g. Arif and Egbu 2010; CRC Construction Innovation 2007; Kelly 2009; Pan *et al.* 2008; Nadim and Goulding 2010, 2011; Rahman 2013) and most of their findings revealed cost of implementing offsite techniques as one of the most prevalent factors.

There are considerable numbers of research and publications about construction cost studies (Warsame 2006) but not many shed lights on the offsite construction cost. Among the rather limited publications, it was reported in these studies that the main cost related issues/perceived issues revolve around the potentially higher initial investment/cost particularly in the earlier part of the offsite project (Pan and Sidwell

2011; Nadim and Goulding 2010; Goodier and Gibb 2007). Thus despite the promotion of the longer term view of the whole life cycle costing for offsite construction projects (e.g. Blismas *et al.* 2006), there appears to be a reluctance, particularly from the builder side, to be exposed to an unfamiliar flow of activities and hence its cost stream. Whilst the offsite construction has been proposed as the most suitable solution to the challenges facing the housing sector to lower its lifecycle cost in a holistic manner, the supply side actors, i.e. the house builders, are typically worried about the unfamiliar cost and cash-flow streams in delivering offsite construction projects. After all, cost have been regarded the major characteristics of constructed products and significantly contributed to the inertia in construction, i.e. a general tendency to use well-proven methods and materials (Pan and Sidwell 2011; Nam and Tatum 1988). The argument made by these scholars is that the lack of publicly available cost data and information has contributed to the reluctance of the house builders to adopt offsite construction techniques. Therefore, there is a need to research and disseminate the cost involved in delivering offsite construction projects particularly in house building projects.

Regarding the total development cost of housing, a study in Australia revealed the construction cost as typically the most significant cost, between 42.8-65.8%, compared to other cost including land, service and finance, government charges and margins (Hsieh *et al.* 2012; Urbis 2011). When zooming into construction cost, it is generally accepted that construction cost is typically determined by numerous factors that could influence its magnitude. The main reason for so many factors affecting construction cost is the fact that construction is a multidisciplinary industry and hence involving many stakeholders (Chan and Park 2005). Because of this, construction cost is not only depending on a single factor but a group of variables that are interconnected with the characteristics of the project and to the construction team as well as the external forces such as the macroeconomics and market conditions (Warsame 2006). These relationship and interconnectivity of factors relevant to the cost of offsite construction projects are generally captured in figure 1.

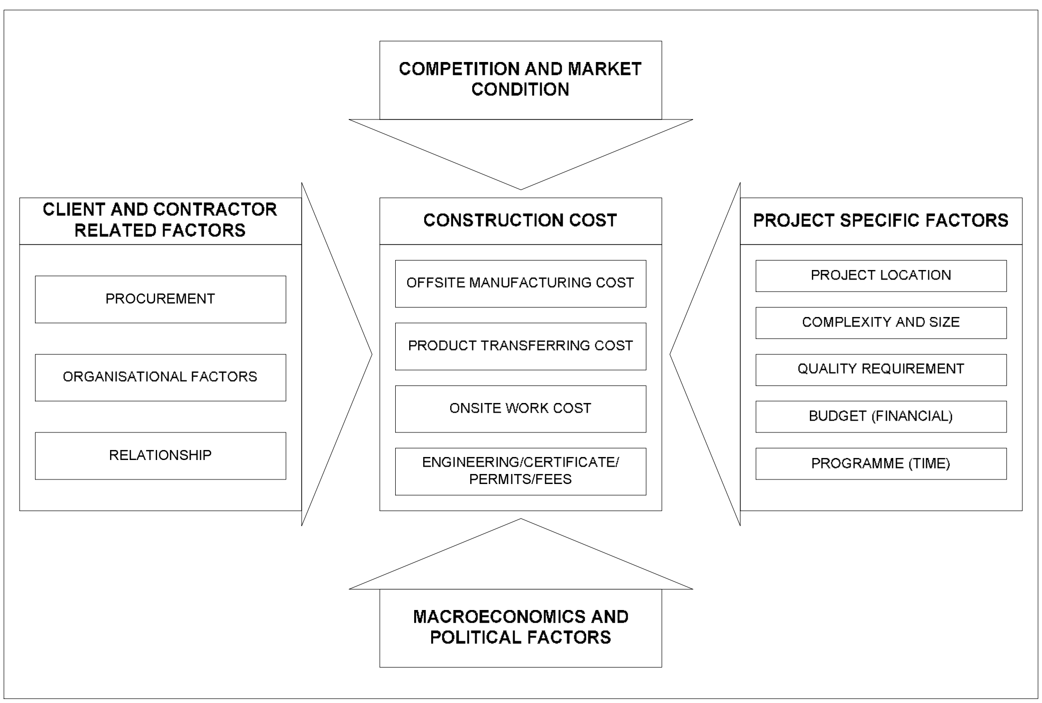

Figure 1. Construction cost components in offsite construction projects and factors influencing the construction cost (adapted from Warsame 2006)

Figure 1 depicted and grouped together influencing factors that have been previously identified and reported by various researchers and scholars. Some of the significant factors affecting construction include: required construction time, contractor's planning capability, procurement methods, market conditions, technological and project design, contractor's expertise and management ability and the required level of construction sophistication (Elhag *et al.* 2005). In addition to those, other factors are also regarded influential including project complexity, technological requirements, project information, project team requirement, contract requirement, project duration and market requirement (Akintoye 2000). Furthermore, the quality and the constructability of the design, management techniques employed by the contractor, location of the project and the macroeconomic conditions have also been considered influencing construction cost (Williams 2003). More specific to housing projects, further factors influencing construction cost include the extent of unionisation within the construction sector, local wages, topography of the area and local regulatory environment (Gyourko and Saiz 2005).

Reflecting the main distinguishing characteristics in the offsite construction techniques compared to conventional onsite construction methods, the main differences in the cost generally lies in the shift of "onsite work cost" into "offsite manufacturing cost" and "product transferring cost". The offsite manufacturing cost has been anecdotally regarded by industry practitioners as a way of fixing the cost in the same manner as purchasing a product from the shop as opposed to subcontracting the work to a construction subcontractor. This is possibly the result of the more regimented approach in manufacturing process that involves the input from a customer order, followed by the establishment of functional components to determine the overall production schedule in which each of these functional components will be mapped to its design engineering, production engineering, purchasing of materials and the actual manufacturing works (Griess and Restrepo 2011). Another component of construction cost in offsite construction projects is incurred due to the necessity to transfer the manufactured building components (non-volumetric or volumetric units) from the offsite facilities to the project site. This necessary transfer typically involves transportation and site handling (usually by crane) of the units to their final position in the project site (Schoenborn 2012; Gibb 1999). The other cost component in offsite construction projects relates to the residual construction activities still to be conducted on site involving site preparation works (such as constructing foundations) and finishing works following the installation of the volumetric units to finalise the project (Schoenborn 2012; Smith 2010). The last cost component in offsite construction projects involves engineering, certification, permit and fees that maybe different to that of conventional projects due to the unique characteristics of offsite construction projects (Sutrisna *et al.* 2017). Based on the on-going discussion, these main components of offsite construction projects are considered the appropriate unit of analysis in this research.

Research Methodology

In conducting an academic research, the research methodology has to be carefully designed to ensure the robustness of the entire research. Research methodology can be seen as the overarching strategy that is systematically designed and applied in order to deal with specific research questions. Typically, research methodology should include the explanation of the philosophical stance taken in conducting the research followed by the details of the research design that includes the sampling matters, data collection procedure, data analysis method and demonstration of the research finding's validity and reliability (Ménacère 2016; Sutrisna and Setiawan 2016; Sutrisna 2009). In discussing the philosophical stance, the researchers typically declare their underlying meta-theoretical assumption in approaching the research, usually represented by their chosen ontology and epistemology paradigms. Ontology is a branch of philosophy that concerns about the nature of reality and epistemology is another branch of philosophy that focuses on how human can gain access to reality. This research is influenced by the critical realist paradigm, recognising that human beings can have access to reality although limited whilst at the same time recognising the co-existence of objective and socially-constructed reality (Sutrisna 2009; Lomborg and Kirkevold 2003). The ontological and epistemological stance of this research accepts the construction cost as both an objective economic entity incurred during the delivery of offsite construction projects as well as an abstract concept of how the project stakeholders ascribe values to the project and its components in defining their working together and interaction with one another to complete the project.

In order to contextualise the construction cost in offsite construction projects, case study has been considered a suitable research approach in this research to fully understand construction cost involved in building residential houses with offsite construction techniques. Both physical and social dimensions of a phenomenon have been known occurring in specific contexts (Robson 2011; Sutrisna and Barrett 2007) and embedded case study approach was considered a suitable approach to capture them within their natural context and setting (Yin 2014). The research approach to be implemented in a research is typically underpinned by the researcher's philosophical stance as well as the nature of the research being investigated (Robson 2011; Sutrisna, 2009; Gill and Johnson, 1997). In order to understand construction cost involved in building residential houses with offsite construction techniques, it was considered necessary to conduct the study using embedded case study approach, i.e. within the real world context of such projects within a single organisation.

The offsite provider selected in this study is a national modular provider with its own manufacturing facilities including in WA. For residential housing provision, there are currently 11 different standardised designs offered to their customers ranging from 147-257 m^2 and between 3-4 bedrooms whilst also catering for bespoke designs as required by customers. The archive shows that in between 2015 and 2017 for example, the offsite provider has completed 38 projects (between 9 to 17 projects/year) ranging from permanent cabins to residential houses. Majority of the residential homes were bespoke designs although resembling similarities to the offered standardised designs. This higher level of customisation represents the typical preference of the residential housing demand side in the WA. Whilst in theory the offsite construction techniques should benefit fully from the higher degree of standardisation in its manufacturing process, the reality faced by offsite providers can be quite different in such a customer driven market. There is, therefore, a need to compare the total cost of these offsite projects to the cost of conventional method of house building. In order to do so, a comparative analysis was performed between the actual cost incurred in these cases against the cost of the same projects using conventional onsite construction techniques. However, the uniqueness of construction outputs and its context-specific nature of location have made it close to impossible to replicate the exact project in the exact location (Emuze 2016; Bryne and Ragin 2013) but using a different method of construction for comparative purposes. As these 2 different methods of building in the same plot of land is a mutually exclusive situation, in this research, the actual cost data from the cases were compared against the theoretical cost of the same projects calculated using the methods set in Rawlinsons (2017) based on the same the design/drawings and specifications. This use of theoretical cost (based on the real cases) was considered necessary to generate an alternative scenario that otherwise will not be possible for a comparative purpose and can be considered acceptable as a means of implementing a case study (Robson 2011).

The selection of the three cases from the same offsite provider was intended to hold the offsite manufacturing, transfer and onsite parameters constant for analysis purposes. Three residential cases in the Western Australia (WA) built by the same offsite house provider have been selected for this purpose. These three cases were selected due to their recent construction and completion, i.e. representing the most contemporary construction cost in offsite construction housing projects. The first two of the selected cases represent such projects in Perth metro areas in WA whilst the third case represents such projects in regional WA for comparison purposes. The profiles of the cases are provided in table 1.

Table 1. The case study profiles

Profile	**Case 1**	**Case 2**	**Case 3**
Project type/scope	New build 2 storey residential	New build 2 storey residential	New build 3 storey residential
Floor area	143.76 m^2	121.20 m^2	181.45 m^2
Offsite elements	4 volumetric units	4 volumetric units	6 volumetric units
Project location	Perth metro, WA	Perth metro, WA	Regional WA
Project duration	107 days	114 days	160 days*
Project value	AU$ 249,607	AU$ 259,889	AU$ 453,316*

Suggested exchange rate £1 = AU$ 1.613

* Estimated, the project was still on-going during data collection

As the main focus was on the construction cost of these three projects, the data collection in this research was facilitated by archival study and when necessary also supplemented by clarification discussions with the offsite construction providers. This is mainly due to the fact that the offsite construction providers in the three cases performed the role of the offsite manufacturers as well as the head contractor offering a complete package solution for the projects. Archival study is therefore considered appropriate to investigate the most contemporary construction cost in offsite construction residential projects in WA. The importance of the project archives encompassing project cost, specifications, drawings and programme to this research has justified its implementation as a standalone data collection method in this research [for further discussion on archival study as a standalone data collection in research, please refer to Bowen (2009)]. Informed by the literature review, analysis in this research was based on the main cost components of offsite construction projects, namely the (volumetric) manufacturing cost, transferring cost, onsite (residual) construction cost and engineering/certification/permits/fees as the unit of analysis, mainly to analyse the cost certainty as well as cash flow profile of offsite projects from the provider's perspective.

The archival study is considered inline with the critical realist stance of this research that accepts both objective values of cost information as well as perspectives in interpreting the archives. It is the role of the researcher to interpret meanings emerging from the findings (Sutrisna 2009). In interpreting meanings, it was considered necessary to seek clarification of certain points with the offsite construction providers but only when needed to develop of a holistic understanding of the three projects. Due to the aim of this research to fully understand construction cost in offsite construction residential projects in WA, findings were allowed to emerge naturally from the archival study of real-life projects rather than from its stakeholder's opinions. It is, however, anticipated that the further development of this research formal interviews with the stakeholders maybe necessary to expand understanding, but this will be beyond the scope of this article. In order to ensure validity and reliability, the results of the analysis were communicated back to the offsite provider for further comments and feedbacks.

Findings and Discussion

This section provides a general description of each case study as well as the key findings of this research explicably emerging into three central themes, namely construction cost, cost certainty and cash flow in residential offsite projects.

General case study description

Case study 1 is a new build 2-storey residential project located within the Perth metropolitan areas in the Western Australia with floor area of 143.76 m^2. Case study 2 is also a new build 2 storey residential project located within the Perth metropolitan areas and represents the smallest floor area (121.20 m^2) among the 3 cases. In general, the design of the two houses can be considered functional but still with a certain degree of aesthetics maintained. Figure 2 presents an isometric view of case study 1 and 2 respectively.

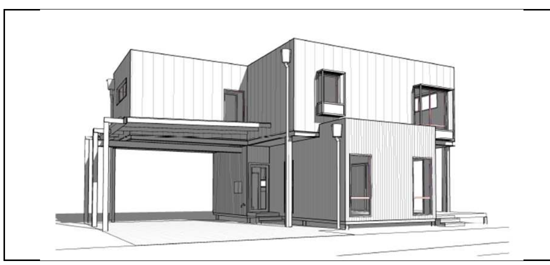

Figure 2. The isometric view of case study 1 and 2.

Case study 3 is the most complex out of 3 cases, it is a new build 3-storey residential project located outside the Perth metropolitan areas, i.e. regional areas in the Western Australia. Case study 3 represents the largest floor area among the three cases at 181.45 m^2 and intended to provide comparative figures for residential projects outside the Perth metropolitan areas (which are also typically larger than that within the Perth metropolitan area). Whilst this particular case is not directly comparable to the other 2 cases due to its size and locations, comparisons can still be drawn to inform the findings. Unlike the other 2 projects that were constructed with flat roof, this project was designed with a pitched roof for a more traditional appearance also reflecting the norms outside the metropolitan areas. This project is also the only one that was still on going when the data collection was conducted for all 3 cases. Figure 3 presents the illustration of building front elevation.

Figure 3. The illustrated building front elevation of case study 3

Construction cost in residential house offsite projects

The first point of investigation naturally emerging from this research was the construction cost in these 3 projects. Table 2 below presents the comparison of the construction cost from the three cases.

Table 2. Construction cost in the studied cases

Cost components	Case 1	Case 2	Case 3*
Volumetric units manufacturing cost	AU$ 178,560 (71.1%)	AU$ 185,190 (71.2%)	AU$ 330,877 (73%)
Volumetric units transferring cost	AU$ 18,625 (7.4%)	AU$ 8,204 (3.2%)	AU$ 16,445 (3.6%)
Onsite construction cost	AU$ 49,104 (19.6%)	AU$ 61,284 (23.6%)	AU$ 85,946 (19%)
Engineering/certification/permits/fees	AU$ 4,734 (1.9%)	AU$ 5,211 (2%)	AU$ 20,048 (4.4%)
Total cost	AU$ 251,023 (actual)	AU$ 259,889 (actual)	AU$ 453,316 (estimated)
Theoretical cost	AU$ 225,421	AU$ 194,013	AU$ 440,924

*Note: Case 3 is an on going case when data was collected

As previously mentioned, case 3 project was still on going when the data collection was conducted. Therefore the cost figures provided here for case 3 is a combination between the actual cost incurred so far and the originally estimated cost. The theoretical cost was calculated to provide a comparison to the conventional method of construction based the adjusted rates from Rawlinsons (2017). From the studied cases, it appears that overall cost of implementing offsite construction are generally higher than the baseline cost. It has to be taken into account that the baseline cost here is theoretical. Thus in practice, it is not uncommon for builders to add contingency on top of their cost estimate to reflect the expected uncertainties (Sutrisna 2004). One possible explanation for the higher cost was the inability to significantly reduce manufacturing cost due to the higher degree of customisation required. From the research's visits and confirmed in discussions with the offsite provider, it has been observed that there is a degree of standardisation in the manufacturing process but limited to the elemental level of the volumetric units and constrained in a particular project. Thus, the lack of continuous demands (volume) as well as the need to allow higher degree of customisation, has constrained the offsite provider to work more efficiently as typically expected from a manufacturing operation. When looking for further explanation at a more macro level, a survey conducted in the US construction industry provided insights that in offsite construction projects, the general cost savings in implementing offsite construction stems from secondary/indirect cost factors such as reduced reliance on skilled trades, the ability to reduce and even avoid unexpected labour cost and onsite resources that maybe required in the project (McGraw-Hill Construction 2011). The results suggested that it is unlikely a single project will directly benefit from implementing the offsite technique alone. An offsite construction project follows a particular supply chain model as described by Vrijhoeff and Koskella (2000) with the focus on transferring activities from site to earlier stages but as a collective effort within an integrated supply chain. The supply chain model connects the entire supply chain and demonstrated the fact that it is unlikely a single project will directly benefit from implementing the technique in isolation. This suggests the actual cost benefit involves the wider supply chain and because of that, it will require the stakeholders to take a proactive role and hence will take longer to realise the benefits at the project level.

There is a worry that offsite construction can be the more expensive option due to perceived higher design, cranage and transport cost (Blismas and Wakefield 2009). From the studied cases it was evident that the engineering, certification, permits and fees are relatively low and comparable to that of conventionally built residential projects (cases 1, 2, 3). The cranage and transportation cost in more straightforward site access (cases 2, 3) range around 3-4% of the project total cost but can be significantly higher when facing a more 'difficult site' (case 1). This highlights the importance of more comprehensive preliminary site survey in reducing uncertainties (Sutrisna 2004; Alhalaby and Whyte 1994), which is unfortunately not yet a common practice in residential building sector. The proportion of offsite manufactured elements in the studied cases are between 71-73% with onsite residual activities between 19-23.6% from the total cost and it is unclear whether this proportion is optimum. A study in New Zealand involving commercial buildings reported a strong positive correlation between the proportion of the prefabricated building elements and the cost performance of the project (Shahzad *et al.* 2014). As the outcome of this research does not indicate any impact from the lower/higher proportion of manufactured building elements towards cost, to draw any meaningful conclusion, a dedicated study on the proportion of offsite residential projects involving volumetric units will need to be conducted.

Cost variability in residential offsite construction projects

In conducting the comparative analysis, another emerging theme was on the cost certainty in implementing offsite construction techniques to build residential projects. In a previous research project, Short *et al.* (2007) was tracking the budget history of construction case study and found that cost certainty in projects constructed with conventional model can bear significant variations from the idealised cost models. Cost variations in the three cases were identified and are presented in table 3.

Table 3. Cost variance in the studied cases

		Case 1	Case 2	Case 3
Volumetric units manufacturing cost	Budget	AU$ 168,768	AU$ 155,097	AU$ 315,581
	Actual	AU$ 178,560	AU$ 185,190	AU$ 330,877
	Variance (%)	- 5.8%	- 19.4%	- 4.58%*
Volumetric units transferring cost	Budget	AU$ 13,216	AU$ 8,685	n/a
	Actual	AU$ 18,625	AU$ 8,204	n/a
	Variance (%)	- 40.93%	+ 5.54%	n/a
Onsite construction cost	Budget	AU$ 30,744	AU$ 22,765	AU$ 84,205
	Actual	AU$ 47,360	AU$ 46,055	AU$ 85,946
	Variance (%)	- 54.05%	- 102.31%	- 2.07%*
Engineering/certification/ permits/fees	Budget	n/a	AU$ 4,701	AU$ 11,794
	Actual	n/a	AU$ 5,053	AU$ 12,714
	Variance (%)	n/a	- 7.28%	- 7.8%*

* only from the cost incurred so far

Whilst in general the studied cases re-affirmed the limited ability of the current cost modelling practices to provide cost certainty, more specifically this study provided an insight into the myth that the manufactured portion of the offsite construction projects will be less affected by cost variance. Even in case 3 where the actual manufacturing process has not started at the data collection time, the purchase of materials had already experienced 4.58% increase form the overall budgeted manufacturing cost. These cost variances were mainly resulted from the inaccuracy in estimating the quantity of materials needed during the earlier stages (cases 1, 2, 3) and/or unforeseen cost increase during the manufacturing processes (cases 1, 2). From observation, it can be concluded that the higher degree of customisation has also made it more difficult for the offside providers to reliably estimate their production cost. It has been generally acknowledged that an offsite construction process must be managed in a particular way to gain the intended benefits. The failure to do so will increase the risk for waste and non-value-adding activities to occur due to poorly managed design, fabrication and site processes (Lessing 2006). From the studied cases, it was observed that even though the offsite components were conducted in a manufacturing environment, the processes can be considered very much manual and do not involve a high degree of industrialisation. It has been accepted that the building industry need to adopt higher degree of industrialisation to its process in order to reduce cost with prefabrication represents the first step of development towards a full industrialisation (Richard 2005). From the discussion with the volumetric unit manufacturer, however, the relatively low volume of production (particularly in house building) has typically made it very difficult to justify the investment for upgrading the level of industrialisation, hence the more manual approach. This lack of volume that can be linked to the higher degree of customisation as discussed in the previous section has reduced the ability of the offsite provider to achieve "economies of scale" and can be considered one of the main barriers in implementing higher level of automation in the manufacturing process to fully benefit from offsite construction techniques.

The cost of transferring the manufactured volumetric units can also vary. Whilst less significant variances can occur simply due to further negotiation with the hire companies (case 2), more significant variances can occur from the underestimated necessity to clear access to deliver the volumetric units in their final positions on site (case 1). One of the basic considerations in transporting the volumetric unit dimension was the capacity of the delivery vehicle that will impose physical limitations of the delivery vehicle on the dimension (i.e. width, length, height) and weight of the volumetric units (Schoenborn 2012). The choice of transportation can impact the cost. Another significant impact to transporting the volumetric unit is the highway agency regulations. In Western Australia for example, the maximum dimension specified by the Mainroads Western Australia is 5.5 m x 5.5 m x 30 m before the load is regarded as an oversize load that requires a special permit whilst a traffic escort will be required where the width of the indivisible load exceeds 5.5 m and the length exceeds 40 m (Mainroads WA 2017). Following transportation, the volumetric units will be installed onsite. Therefore, the existing site condition such as the site logistics, access to site or manoeuvring space and/or any potential obstructions (such as the main power cables in case 1) also need to be considered in transferring the volumetric units (Sutrisna *et al.* 2017).

The engineering, certification, permits and fees aspects of offsite construction in the studied cases are comparable to that of conventional onsite residential projects despite the typical belief (Sutrisna *et al.* 2017). On contrary, the onsite construction cost showed the most cost variances, mainly due to unforeseen site conditions that necessitated additional works to be conducted. The site activities that incurred the most cost variances in the studied cases are carpentry (cases 1, 2), electrical, plumbing and footing (case 2) as well as masonry works for retaining wall (case 3). These are not unique to offsite construction projects and minimising these potential site issues can be considered the main driver to shift the onsite activities into offsite controlled environment in the first place (Barlow *et al.* 2003). It is, however, observed that many of these onsite cost variances (cases 1, 2) occurred after the volumetric units have been installed onsite. This indicated the potential underestimation of these onsite works, particularly after the installation of the prefabricated volumetric units. This ranges from unforeseen rectification tasks to the planned finishing works but with unforeseen complications. Given its low uptake so far, offsite construction methods can be considered an unconventional way of working for many house builders and, therefore, it was considered important to continuously learn and capture the experience to improve practices in offsite construction projects (Meiling *et al.* 2012; Pan *et al.* 2008). These captured and shared experiences will be invaluable to mitigate potential onsite issues in offsite projects to improve cost certainty of offsite projects.

Cash flow in offsite construction residential projects

One of the main concerns for any contractors in undertaking a project is the cash flow. There is a universal view over the significance of cash flow's impacts on the success/failure of a construction project as a lack of robust construction finance planning can be the main source of significant increases in cost and time that in many cases can lead to the financial collapse of a construction project (Al-Joburi *et al.* 2012; Singh and Lakanathan 1992). Due to its importance to house builders, cash flow of the studied cases were analysed and presented in the figures 4 and 5 as well as table 4.

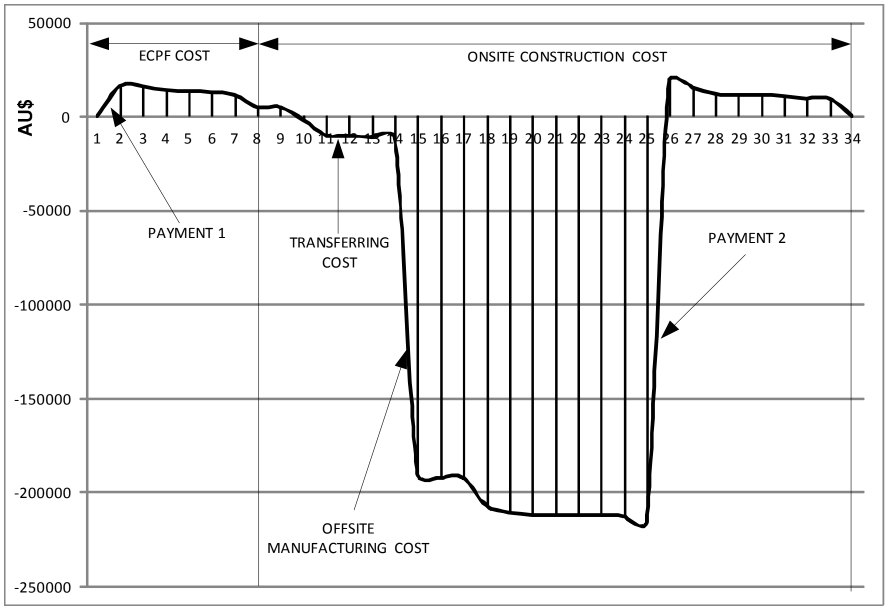

Figure 4. The net cash flow of case 1

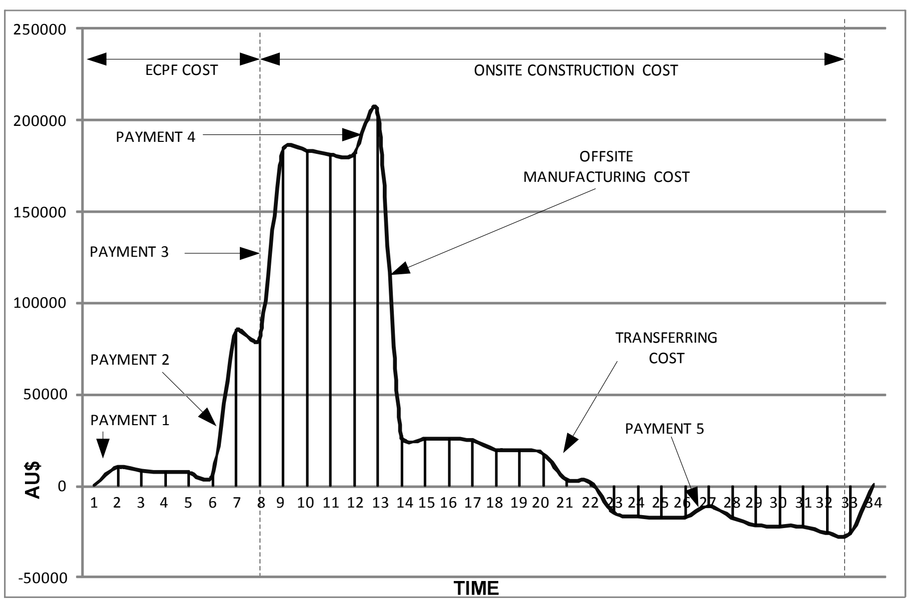

Figure 5. The net cash flow of case 2

Table 4. Cash flow of case 3

Dates	Offsite	Transfer	Onsite	Eng/cert/permit/fees	Payment	Cummulative
16/11/2016					30,554.54	30,554.54
17/11/2016				-1,900		28,654.54
30/11/2016				-2,018.50		26,636.04
16/01/2017				-375		26,261.04
23/01/2017	-33.84					26,227.20
25/01/2017					159,823.74	186,050.90
02/01/2017	-50					186,000.90
02/02/2017	-30					185,970.90
02/06/2017	-312					185,658.90
13/02/2017	-378.4					185,280.50
14/02/2017	-30					185,250.50
15/02/2017				-1,000		184,250.50
17/02/2017				-2,737.70		181,512.80
21/02/2017	-99					181,413.80
03/07/2017	-110					181,303.80
15/03/2017	-30					181,273.80
21/03/2017	-96.12					181,177.68
23/03/2017			-3,560	-540		177,477.68
27/03/2017	-195					177,282.68
29/03/2017			-5,779.10			171,503.58
04/12/2017	-50					171,453.58
18/04/2017	-29.36					171,424.22
24/04/2017			-1,929			169,495.22
27/04/2017				-3,295.89	72,860.83	239,060.16

Due to its level of complexity, the cash flow in case 3 is slightly more scattered than the other 2 case and have several elements of the construction cost overlapped. Also, case 3 project was still on going during the data collection time (have not incurred the main cost of manufacturing activities yet for example). Therefore, unlike the other two cases presented here in the net cash flow diagrams, the cash flow in case 3 is presented in a tabular format. The data used to develop the cash flow diagrams and table was not based on the time when these activities occurred in the project (based on programme/schedule) but was based on the actual payment/invoice due dates to represent the real movement of the cash in and out the project from the manufacturer/contractor's point of view.

Consistent with the literature regarding the higher initial investment/cost particularly in the earlier part of an offsite project (Pan and Sidwell 2011; Nadim and Goulding 2010; Blismas and Wakefield 2009; Goodier and Gibb 2007), the net cash flow in case 1 shows a relatively long period for the offsite construction provider of being exposed to a negative cash flow situation. Whilst the impact of negative cash flow exposure towards success of the project delivery and the survival of construction companies have been covered rather extensively in the literature, the advance payment and payment cycle on project cash flow as well as the trends and patterns of negative cash flow have rarely been addressed in the literature (Al-Joburi *et al.* 2012). The term of payment in case 1 was 6.5% deposit to get the project started followed by 93.5% payment upon the handover of the project. This "turnkey" style of payment term captured in figure 4 has exposed the offsite construction provider to a negative cash situation for most of the project period. Whilst the project duration can be considered typically shorter than conventional onsite residential construction, it was evident that this payment term is not financially sustainable for the company and hence the change of payment term in subsequent projects (cases 2, 3). This new payment term requires:

- 6.5% deposit,
- 34% at the purchase of materials stage (2 weeks prior to build start date),
- 29% at the lock up stage (water tight structure completed),
- 15.5% at the internal fix stage (internal work including walls, cabinetry, painting, tiling, and so on),
- 10% at the transport stage (volumetric units ready to be transported),
- 5% at handover stage

As identified in cases 2 and 3, the final agreement for payment were not rigidly applied as the six payments above, but can be negotiated with individual client. The new payment term, however, has helped the offsite construction provider to stay comfortably in the positive cash flow situation. Even in case 2 where the onsite construction turned out to be significantly more than the originally planned, the new payment term has helped to reduce the impact towards the offsite construction provider. There was not any data available, however, on how the implementation of this new payment terms impacted on the company's competitiveness in the market place. The majority of the engineering, certification, permit, fees cost items occur in the earlier part of the project whilst the onsite construction activity cost occur right after that, all through the remaining of the project duration. By far, the payment for the offsite manufactured volumetric units is a single point of expenses that dramatically impacted on the cash flow. Therefore, the term of payment to be agreed with client should take into account these major cost/expenses 'points' during an offsite construction project.

Conclusion

Offsite construction has been hailed as a potential solution for alleviating the housing imbalance in Western Australia. This was mainly due to the perceived superiority of offsite construction compared to conventional onsite house building methods. Additional benefits included the delivery of higher quality products with high level of standardisation, shorter delivery time and less reliance towards the increasingly reduced availability of skilled trades. Despite these benefits, the uptake of offsite construction has been lower than expected. Looking into the roots causes of this low uptake, one of the main reasons was found to be the reluctance of the supply side actors, i.e. the house builders, to adopt a relatively 'unfamiliar' building method, where they were worried about unfamiliar costs and cash-flow streams for delivering offsite construction projects. This is exacerbated by the limited availability of cost information regarding offsite construction projects, particularly residential projects. This research was set to address this matter and shed light on this discourse by focussing on three embedded case studies of residential projects implementing offsite construction techniques in Western Australia. Whilst the studied cases are quite unique in terms of their design and location, they can be considered 'representative' of typical practices, level of demand, level of manufacturing's standardisation and automation of offsite house building in Western Australia.

The findings reported here provide important insight for house builders intending to implement offsite techniques. Three emerging themes pertinent to the cost relevant matters of residential offsite construction projects emerged in this research. Firstly, the findings confirmed that the overall cost of delivering a residential project with offsite construction techniques is generally higher than the cost of delivering a residential project using conventional onsite method (theoretical estimation). Whilst the general rules of thumb are to shift as many construction activities into offsite controlled environment, the findings from the studied cases have provided evidence that migrating 71-73% building elements into offsite construction execution in residential projects did not significantly reduce the overall cost compared to theoretical baseline. Whilst acknowledging the potential for higher degree of standardisation in the offsite house's designs to further capitalise from the repetitive nature of manufacturing process that may reduce production cost, in many cases the cost benefits from implementing the offsite construction may not be directly quantifiable for a single project in isolation but in the longer term the entire supply chain should benefit from this so-called "modern method of construction". Secondly, the findings also revealed that the onsite construction activity portion of an offsite construction residential project (also known as the "residual onsite activities") could still expose the project towards uncertainties whilst the offsite-manufactured parts of the projects may not be necessarily immune to the cost variance. As a low level of standardisation and automation was found in the case study, upgrading the level of industrialisation in the manufacturing process can potentially reduce the cost variance, but such investment will require a certain level of production volume to justify the financial investment (achieving "economies of scale"). Notwithstanding this, the uncertainties can also impact on the process of transferring the manufactured volumetric units to its final position on site. This has highlighted the importance of preliminary site investigation to increase the likelihood for smooth transfer. The third strand concerns with the cash flow of residential offsite construction projects. In order to minimise the exposure to a negative cash flow situation, the offsite construction providers should negotiate or set up a payment term that takes into account the major points when significant cost can be expected to occur as identified in this paper.

With the view to facilitate a wider adoption of offsite construction techniques in WA, Australia and beyond, further research will be needed to further investigate the cost aspects discussed above. The findings of the research reported in this paper present a foundation for further research on residential housing projects. A further investigation to realise the benefits of implementing offsite construction methods for the entire supply chain is needed. Other directions for further research include: establishing the optimum level of standardisation and manufacturing automation balanced against the volume of production required to achieve the economies of scale; determining the optimum level of site investigation needed to support a smooth transfer process from the offsite manufacturing facilities to the final position on site; evaluating the maturity of the offsite manufacturing supply chain; capturing the experiences from previous projects implementing offsite construction techniques in order to compile a repository for wider dissemination. In terms of cash flow management of offsite construction housing projects, determining the balance between payment terms to minimise the risks of exposure to negative cash flow but maintaining competitiveness in the market place at the same time is another direction for further investigation. Until sufficient development towards these aspects have been achieved, it is likely that myths, beliefs and reluctance around cost related matters will continue to hinder the uptake of offsite construction techniques as the modern method of construction.

Acknowledgement
The authors would like to acknowledge the support from Ausco Modular in providing the case study datasets for this research.

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