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Managing information flow and design processes to reduce design risks in offsite construction projects

Abstract

Purpose: Following the increasing need for faster construction, improved quality, and evidence value propositions, offsite construction is increasingly being proffered as a viable contender to 'traditional' construction approaches. However, whilst evidence supports the move towards offsite, its uptake has been lower than expected. Whilst the precise reasons for this seem to be influenced by a number of issues, including contextual drivers and market maturity; some project stakeholders also view offsite as carrying greater risks. This paper reports on the quality of information flow, in particular, the impact and influence of this on design risks in offsite construction projects.

Design/methodology: An existing design risk framework is used as the point of departure for this research. This is further expanded into a specific model for evaluating offsite construction projects design risks, the rubrics of which were informed by two case studies of offsite construction projects in Australia and the UK analysed with a *process-tracing* technique. Whilst these cases were geographically separated, the constructs were aligned to uncover fundamental design information requirements and concomitant risks associated with offsite.

Findings: The findings of the research reported in this paper include the crucial information feeding into the design process emanating from the lifecycle of offsite construction projects, namely design, offsite (manufacturing), handling and transporting, site works and installation and also occupancy. These are contextualised within the four categories, namely client requirements, project requirements, regulation aspects and social aspects and the final outcomes were summarised into a holistic diagram.

Originality/value: Given that the offsite construction has shifted the working paradigm into assigning a significant level of efforts and emphasis at the front end of the construction projects, the importance of its design process and hence design risks management has gone up significantly in construction projects delivered using this technique. This research and paper contributes significantly to the built environment domain by identifying the crucial aspects along the project lifecycle to be considered to minimise the potential occurrence of design risks and hence increasing the confidence of project stakeholders in adopting offsite construction techniques in their projects.

Keywords: design risks, quality of information, offsite construction

Introduction

Responding to the ever-increasing complexity and demanding requirements associated with the design and construction of buildings, many construction professionals are still striving to secure more innovative ways of facilitating the process in order meet client needs and concomitant requirements. Among the many alternatives that have been proffered and subsequently implemented, the transition from on-site to offsite has been recognised as increasingly viable (Goulding and Arif, 2013). Offsite construction has been recognised as a viable construction technique as early as 1800s but has recently attracted more interests typically for its potentials in achieving efficiency and precision, inclusion of environmental features, more optimum use of declining workforce and shorter construction cycles (Goulding *et al.*, 2015; Smith 2010) earning it the term "modern method of construction" since 1990s (Gibb 1999). Its primary technique involves shifting the delivery of core activities offsite, i.e. to be constructed in a controlled environment, followed by transporting these building elements to the project site for installation and finalisation. The superiority of offsite construction techniques have been well documented in extant literature mainly in terms of speed, quality, health and safety, sustainability and life cycle costing (e.g. Khalfan and Maqsood 2014; Pan and Goodier 2012; Blismas *et al.* 2006). It has also been argued that by shifting these construction activities to the offsite environment, constructability can be better envisioned (Gibb 1999) and delivery can be planned to take place in a controlled environment in an attempt to reduce risks in construction projects (Blismas and Wakefield 2009). This resonates with the concepts of Design for Manufacture and Assembly (DfMA) – see Corbett *et al.* (1991).

From a construction perspective, it is generally accepted that risks are almost always inevitable, i.e. they cannot be completely eliminated; and that the success of delivering these projects therefore relies on effective management of the risks (Smith 2003). The structured approach to deal with risks in projects is typically known as risk management – which does not aim to eliminate all risks *per se*, but rather identify appropriate strategies to support project managers in managing these risks (Zou *et al.* 2007; Perry and Hayes 1985). The importance of risk management within the overall project management discipline is demonstrated by its inclusion as one of the nine foci in project management functions (PMI 2013). Whilst risk management typically involves various stages within the lifecycle of a project, design risks are considered most prevalent, yet these have not received sufficient attention compared to other stages (Nibbelink *et al.* 2017). The study also established that the main causes of design risks stem from the quality and completeness of information feeding into the design process. Given this, the accuracy of design information has been considered one of the main requirements for adopting and benefiting from offsite construction (Eastman *et al.* 2008).

Cognisant of these high level challenges, this research aimed to investigate offsite design risks in a greater level of detail, particularly design risks emanating from the quality and completeness of information that the design process relays on. The research was conducted through an evaluation of offsite case studies in the UK and Australia. The rationale behind this was because construction practices in both these countries are ostensibly structurally similar, albeit with a few specific distinctive features (Blismas and Wakefield 2009). The selection of cases from the two construction industries supports the application of *theory-oriented process-tracing* analytical technique, which was adopted for this research. In addition, from a replicability perspective, these two country contexts have mature construction markets that have introduced offsite construction; and have received research attention on offsite construction uptake (Pan *et al.* 2007; Blismas and Wakefield 2009). This paper reports on findings appertaining to the aspects that influence design risks in offsite construction, and also makes specific recommendations for managing these risks.

Offsite construction

Off-site construction terminology has been used to describe a spectrum of construction methodologies that involves the use of prefabricated components - constructed or assembled remotely from the building site prior to installation on the construction site (Goodier and Gibb, 2007). The prefabrication process itself typically involves process in a specialised facility where materials and building systems are brought together to construct a building component or part of a larger final installation (Smith 2010). The extent of use of the prefabricated components is generally used to group offsite construction into non-volumetric offsite construction or volumetric offsite construction (Schoenborn 2012; Gibb 1999). The offsite construction techniques typically includes the use of processed materials and single assembly of particular prefabricated building components such as timber/precast-concrete/steel panels, composite and structurally insulated panels, façade systems and so on. In increasing the extent of offsite prefabrication, further techniques combine various building components ranging from panelised structures that are not forming an enclosed usable space to the modular technique that typically forms an enclosed and completed part of a building such as a complete room or a toilet pod (Schoenborn 2012; Smith 2010). The panelised structures and modular are typically considered volumetric offsite construction that includes the construction and site installation of pods and modules. In some cases, the use of both non-volumetric and volumetric offsite construction components in the same project is referred to as 'hybrid' whilst in other situation the term 'hybrid' refers to the combined use of offsite construction components and in-situ construction in the same project.

The delineation between conventional and offsite construction buildings are considered blurring due to the gradual increase of prefabricated materials and components in conventional projects (Shahzad *et al*. 2014), indicating the increased awareness and appreciation of the benefits of offsite construction in a gradual manner. The benefit of adopting offsite construction mainly stems from its central concept to relocate construction activities from site (in-situ) to be conducted in a controlled environment. This enables offsite construction activities to be better planned to achieve the desired outcomes in the similar manner to processes in manufacturing sector (Barlow *et al*. 2003). Thus, by bringing these construction activities from site into a more controllable environment, it has been argued that safety, efficiency/productivity and quality could all be improved with less waste generated and therefore less impact on the environment (Boyd *et al*. 2013; Gibb 2001). Furthermore, it has been argued that in this controlled environment, there is less influence from the weather conditions (Schoenborn 2012; Lu 2007). Also there is less reliance towards skilled trades due to the possibility of using semi-skilled or lower-skilled operatives, thus reducing dependency towards skilled trades (Nadim and Goulding 2009) made possible by higher degree of standardisation and repetition in a controlled manufacturing environment. Thus, by breaking down the tasks into much simpler tasks, the fabrication process can be carried out by workers with lower skills supervised by skilled or qualified workers. All of these benefits are expected to reduce the uncertainties typically identified in construction sites, and therefore to control risks, particularly construction risks (Gibb 2001). Whilst there are several issues and challenges facing the implementation of offsite construction have also been reported, the conclusions have been that the potential advantages of implementing offsite construction typically outweigh the negatives (e.g. Khalfan and Maqsood 2014; Pan and Goodier 2012; Eastman *et al*. 2008; Pan *et al*. 2007). This forms the premise of this research that there is indeed a need to drill deeper into these issues and challenges to enable construction projects to gain the full benefits from implementing the offsite construction techniques.

The potential benefits of employing offsite construction has earned its reputation as the 'Modern Method of Construction' (MMC), a term coined by the UK Government to describe the use offsite construction techniques, particularly in housing sector (Pan *et al.* 2008; Gibb 1999). Whilst the benefits and superiority of offsite construction against conventional methods of construction have been well documented and published, its uptake has not been as expected (Rahman 2013). An in-depth analysis of the total offsite construction output (value added) in the UK between 1998 and 2008 showed a relatively modest increase from £731 million in 1998 to £1.537 billion in 2008 (Taylor 2010). Only 2% of the value of the entire construction sector (including civil works) in the UK has been attributed to offsite construction work (Gibb and Goodier 2004). Such analysis of offsite construction in the Australian construction industry for example is not readily available (Khalfan and Maqsood 2014; Blismas and Wakefield 2009). However, for illustration purpose, the housing sector in Australia can be used as a 'proxy'. It has been estimated that only 3% of the current new housing market in Australia uses significant prefabrication (Steinhardt and Manley 2016). Whilst many researchers and scholars have strived to understand the reasons behind the low uptake of offsite construction in many construction industries (e.g. Rahman 2013; Nadim and Goulding 2011, 2010; Arif and Egbu 2010; Kelly 2009; Pan *et al.* 2007, 2008; CRC Construction Innovation 2007), many of the findings pointed to the reluctance of the stakeholders to enter into the unknown. More specifically, the low uptake of offsite construction has been linked to the perceived inadequacy in dealing with risks in projects implementing offsite construction methodology in the past (Hassim *et al.* 2009). This informs the premise of this research that there is a need to focus on the risks of offsite construction projects and the most effective ways to manage the risks to further promote the implementation the offsite construction techniques.

Risks in offsite construction projects

In delivering projects, risks have been typically considered inherent parts of the project and therefore must be managed. Project risk management typically 'includes the processes concerned with identifying, analysing and responding to project risks including maximising the results of positive events and minimising the consequences of adverse events' (PMBOK 2013, p.111). Ideally, risk management should not be considered a separate endeavour but 'closely coupled with key project processes such as overall project management, system engineering, configuration management, cost, design/engineering, earned value, manufacturing, quality, schedule, scope and test' (Kerzener 2013, p. 876). In their analysis of risk management application in construction, Edwards and Bowen (1998) observed that the earlier risk management techniques tend to utilise mathematical approaches to risk analysis whilst Hayes *et al.* (1986) marked the shift as one of the earliest attempts to implement the systematic treatment including risk identification, risk analysis and risk control are typically implemented in a chronological manner, hence they are typically in line with the sequences of the project delivery. In order to holistically understand the occurrence, interactions and impact of risks in a project, it has been argued that the project life cycle provides the suitable framework to conduct the risk analysis (Chapman and Ward 2003).

Despite its importance to any project, risks in design phase have not received sufficient attention relative to other stages (Nibbelink *et al.* 2017). In a previous research on risks occurring in offsite construction projects, change in work and defective designs have been regarded the most frequently occurring and therefore need to be managed (Hassim *et al.* 2009). When analysing project risks, Chapman (2001) reported that the design stage as the key strategic stage in a project is subjected to a wide variety of risks so much so that it was found difficult to pinpoint the primary sources of these risks. These traits have characterised design problems and made them considered as "wicked" problems. "Wicked" problems have been considered ill-defined and ill-structured and therefore a lot more difficult to solve (Cross 2007). Further discussion on design problems as wicked problems can be found in various articles including Farrell and Hooker (2013), Buchanan (1992) and Rittel and Webber (1973). When analysing the actual implementation of project risk management, Kutsch and Hall (2010) found that due to the limitation in human's information processing capabilities, the "wicked" problems may be subconsciously ignored by the person responsible for identifying and analysing risks in favour of the "tame" problems due to the fact that the "tame" problems would be more straightforward to be tackled using structured approaches such as the ones used in project risk management methodologies. When looking into the complexity of design risks in construction projects, Nibbelink *et al.* (2017) proposed a credible way to look into design risks through the source of information feeding into the design process. Thus, the main argument was that the quality of the information feeding into the design process is the main determinants of the occurrence and extent of the design risks. After all, the accuracy of design information has been considered one of the main requirements in implementing and capitalising from offsite construction (Eastman *et al.* 2008). This view considers design risks as a product of epistemic uncertainty. Different from aleatory uncertainty that naturally stems from the unpredictable nature of the system and therefore cannot be reduced, epistemic uncertainties stems from the incomplete knowledge about the system under study and therefore conceptually possible to reduce as long as the incompleteness of the knowledge can be resolved (Merz and Thieken 2005; Hora 1996). Thus, the improvement in the quality and completeness of information feeding into the design process, should theoretically reduce the epistemic uncertainty in design process and hence the associated design risks. The simplified framework to analyse the quality of information influencing design risk is presented in figure 1.

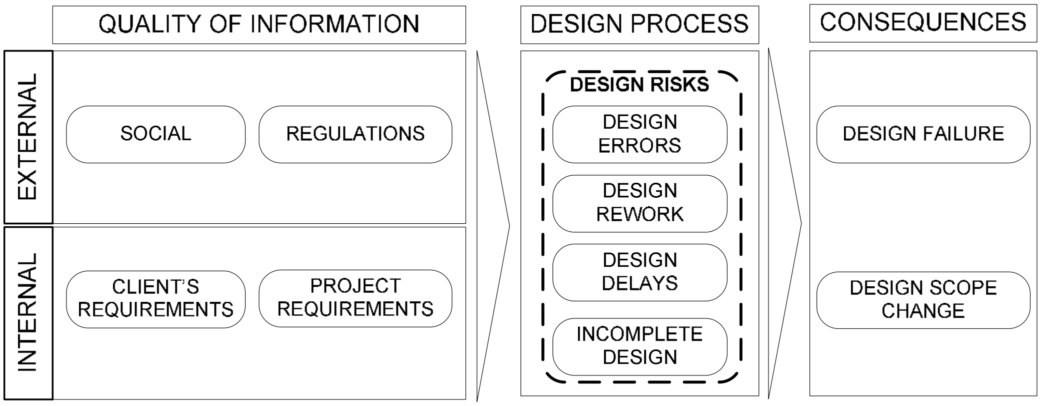

Figure 1. The framework to analyse design risk (adapted from Nibbelink *et al.* 2017)

The suitability of this framework to analyse the quality of information influencing design risks in offsite construction projects is demonstrated by the applicability of its components in offsite construction situation. Acknowledging the centrality of project goals and stakeholder's requirements to the risk management process and the need to incorporate them into design, the quality of information are grouped into client requirements, project requirements and social aspects taking into account the regulatory factors (such as building codes, planning permission and so on). So, for instance, formal project goals at the client's organisational level will be articulated within the client requirements whilst the more practical goals from the internal project team such as time/cost/quality will be contained within project requirements. To balance these, the external "requirements" encompasses social aspects such as aesthetics and other social trends and pressures as well as regulatory requirements are included in the framework. For example public projects will typically bear more external requirements compared to projects in private sector that may put more emphasis on the client requirements and project requirements.

There are further aspects that bring together some of these main triggers, for example environmental sustainability. The increasing demands in the construction industry and beyond for more sustainable practices to reduce environmental impacts (Azhar *et al.* 2011) have positioned environmental sustainability as an important design factor from the perspectives of societal needs, market pressure, regulations and can also manifests in client's and project's requirements (Nibbelink *et al.* 2017; Schlueter and Thesseling 2009; Chapman 2001; Leinonen and Houvila 2000). This is relevant to offsite construction as it has been regarded as a more environmentally sustainable methodology in delivering construction projects (Jaillon and Poon 2014; Tam *et al.* 2005). It must be noted here, however, that this framework was specifically developed to focus on risks specific to the quality of information feeding into the design process and not the risks of the entire design process itself nor the whole project risks.

In offsite construction projects, most of the construction tasks and activities are transferred into an offsite controlled environment – typically a factory-type environment. There are however, residual construction activities still to be conducted on site whilst the building components will have to be transported from the offsite location to the construction site for assembly (Schoenborn 2012; Smith 2010). Therefore, the level of knowledge and quality of information regarding the existing site condition such as the site logistics, access to site or manoeuvring space can be expected to be important considerations in designing offsite construction projects.

In light of the on-going discussion, it can be summarised that there is a real need to minimise design risks in offsite construction projects., particularly the ones stemming from the quality of information Due to its high level of relevance in capturing design risks in these projects, the framework presented in Figure 1 is considered suitable for this research. It is particularly used to structure the data collection and analysis of this research in deriving its findings. Thus guided by the framework for instance, failure to incorporate and integrate any of these sources of information into the design process can be tracked against the likelihood of relevant design risks to occur.

Research methodology

Research methodology is critical aspect in incorporating the research positioning and other integral facets such as sampling, data collection, data analysis, reliability and validity mechanisms and so on, all of which help demonstrate the credibility of the research findings (Holt and Goulding, 2017; Sutrisna and Setiawan, 2016; Mackenzie and Knipe, 2006; Creswell, 2003). The underpinning paradigm of this research falls within the critical realist paradigm. The concept of reality in realism maintains an epistemological stance that human beings have access to reality even though only up to a certain extent (Lomborg and Kirkevold 2003) and the critical realist sharpens this stance by accepting the co-existence of both objective and human-constructed reality (Sutrisna and Barrett 2007).

Case study

In capturing the delivery process in offsite construction projects, a case study was considered the most appropriate way of undertaking this work, given the contextualised boundaries, i.e. both the physical and social dimensions of a phenomenon occur in a specific context (Robson 2011; Miles and Huberman 1994) and these can be captured using case study approach within its natural setting (Yin 2014). Thus, to understand the quality of information feeding into the design process in offsite construction projects, two cases, one in the UK and one in Australia have been selected for this purpose. In terms of the implementation of offsite construction techniques, the construction industry in the UK and Australia have been considered bearing structural similarities mainly due to their commonalities in history, however also with sufficient differences that have emerged over time to warrant separate investigation (Blismass and Wakefield 2009). Whilst both selected cases are school projects with sufficient similarities, the case study in the UK (case A) was originally designed with conventional construction methodology but later delivered with offsite construction methodology. The Australian case study (case B) was planned, designed and delivered with offsite construction methodology from the very beginning. The deliberate selection of the two cases was intended to further highlight the peculiarity of the quality of information feeding into the design process in offsite construction projects. The profiles of the cases are provided in Table 1.

Table 1. The case study profiles

Profile	**Case A**	**Case B**
Project type/scope	New build 2 storey school building	New build 2 storey school building
Floor Area	2,252 m^2	1,979 m^2
Offsite construction type	Volumetric, hybrid	Volumetric, hybrid
Project location	United Kingdom	Australia
Project duration	Oct 2014 – Nov 2015	Apr 2014 – Feb 2015
Project budget	AU$ 9.5 M*	AU$ 5.3 M
Client type	Public school	Independent school

*exchange rate used AU$ 1 = £0.62

Data collection and analysis

The data collection in this research was facilitated through archival study, complemented by clarification discussions with the custodian of the archive, i.e. the offsite construction providers, who assumed the role of the offsite manufacturers as well as the main contractor, i.e. providing a complete package solution to the client. Archival study is considered appropriate for this research to provide evidence of information feeding into design process influencing design risks in offsite construction projects. The adoption of archival analysis reflects the importance of archives in case study research as well as its capability as a standalone method in certain forms of qualitative research (Bowen 2009).

The case study analytical approach taken in this research is defined as *theory-oriented process-tracing*, which has been considered suitable in dealing with multiple interaction effect of the variables within the case (Hall 2013). *Process tracing* typically requires finding diagnostic evidence in the case that can provide the basis for descriptive and causal inference (Collier, 2011). The *theory-oriented process-tracing* approach was implemented in this research by generating numerous interlinked observations within each case to constitute an explanation derived from historical narrative of the case, converted into analytical explanation underpinned by an explicit theoretical form. This particular technique within the *process-tracing* approach is known as the *analytical explanation* (George and Bennett 2005) in which the explanations are deliberately focused on specific points guided by the chosen theoretical underpinning. The theoretical underpinning used was the framework previously developed by Nibbelink *et al.* (2017). Thus, the components of the framework were used as the proposed independent variables that are interlinked to form a causal path leading to the dependent variable, which is the outcome of the case study influenced by the quality of information leading to the occurrence of design risks in the project.

As *process-tracing* is considered one of the small-n analysis techniques, what matters is not the amount of evidence but its contribution to adjudicating among alternative narratives that even a single case may include sufficient salient pieces of evidence (Bennett 2010). Qualitative analysis typically requires the researcher to collate data and interpret meanings emerging from the process (Dey 2003). Thus, the researcher interprets the archival data to conduct the *process-tracing* based on the four main components of the framework. Following the *analytical explanation* technique procedure, a narrative for each group was developed and then transformed into analytical explanation by incorporating the existing body of knowledge (further literature) into the narrative. This is where the clarification of certain matters with the custodian of the archive, i.e. the offsite construction providers, played an important role to form a holistic understanding of "what happened" during the course of the projects. Formal interviews were not considered necessary as this stage of the research to identify the occurrence of design risks on offsite construction projects - based on real-life projects, rather than stakeholders' opinions. It was envisaged that the further stages of this research may involve formal interviews with practitioners but, at this juncture, is beyond the scope of this paper. The structured *analytical explanations* were then mapped into a generic project lifecycle suitable for offsite construction, namely design, offsite (manufacturing), handling and transporting, site works and installation and also occupancy phases to present the findings from this research. The implementation of *theory-oriented process-tracing* in data collection and analysis of the cases is illustrated in Figure 2.

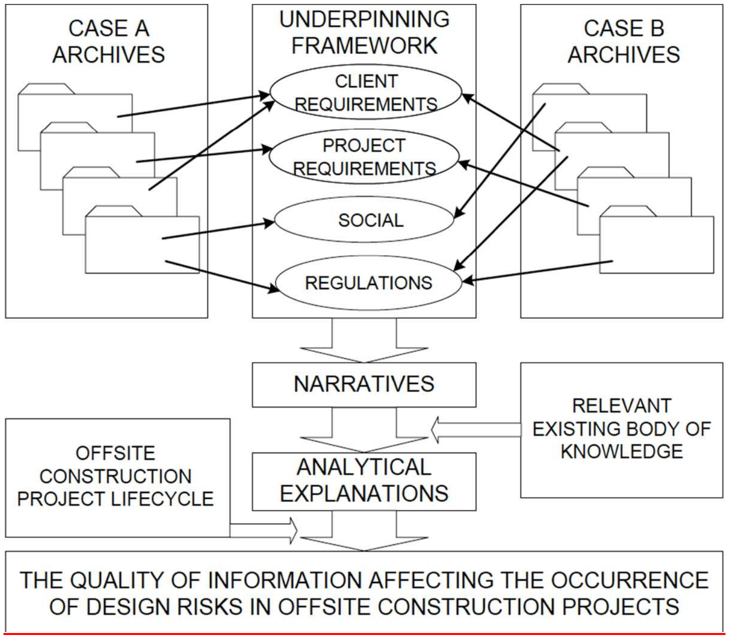

Figure 2. Data collection and analysis in this research

Findings and discussions

Following the implementation of *analytical explanation* of the information feeding into the design process, the findings are presented in the form of analytical discussion as originally emerged from the data analysis stage of this research.

Client requirements

The client requirements were found to be the main factors in designing the studied cases. An idea to develop a project is typically designed as a response to the outcome of looking inwards the client organisation's strengths and weaknesses to identify the needs as well looking outwards by scanning the environment to identify opportunities and/or threats (Burke 2003; Field and Keller 1998). It has been argued that the client requirements are the main components of design requirements (Kamara *et al.* 2000). The school in case A was a new school intended to alleviate the shortage of schools in the area. The project in case A was a new built in a dedicated plot as a part of the plan to progressively adding additional year groups to the school to complete the whole age range by 2019. Thus, time is of essence and the completion time becomes crucial in case A simply because the earlier year pupils already studying in the school's temporary site will need the new facilities when progressing to the subsequent year. As a state-funded community school serving its local residents with clear requirements from the Education Funding Agency (EFA) in designing the project, the client requirements in case A, can be considered straightforward and standardised. Case B on the other hand, is an independent school (both in funding and governance) affiliated with a religious group. The need to construct a new building in case B stemmed out from their rapid growth and the need for a more permanent solution to the initially intended temporary buildings supported by the availability of a 'soft' loan from the religious group. The client requirements in case B, therefore, were comparable to that of commercial clients. Budget and completion time were considered inflexible in both cases due to the limited availability, although even more so in case A. It has been argued that the construction projects are typically derived from the complex needs so much so that the constructed facility should not be seen as an end in itself, but a means to satisfying the business needs of the client (Kamara *et al.* 2000). In both projects (cases A and B), the decision to construct the building mainly using offsite construction techniques was mainly driven by the client's need to lock-in the project cost and its completion time. Informed by these client requirements, the design maximised the use of volumetric offsite construction in both projects.

Subsequent to the design phase, there has not been any evidence of client requirements for the offsite manufacturing stage in both projects (cases A and B). This indicates the client's limited knowledge about the offsite manufacturing process of their projects and hence the lower level of involvement and client's requirements in the process. Thus without fully understanding the process, clients simply perceive that offsite manufacturing process can provide them with better quality products with consistent quality and an expectation that the engineered parts will fit together correctly (Gibb and Isack 2003). There were client requirements to be considered during the handling and transporting phase, mainly related to the access to site and current client's operation. The project in cases B, for instance, took place in existing school premises with existing operations. As the main construction activities were conducted offsite, the bulk of the residual on-site activities (including the installation of the volumetric components) were condensed to occur around the non-term time of the schools (Nov-Feb in case B). The client's operational aspects have been considered crucial inputs to the design requirements and hence the design process (Sterry and Sutrisna 2007).

Client requirements for occupancy that were feeding into the design process include easier and more economic operation and maintenance (cases A and B) and the energy use that had to comply with the low/zero carbon target from the local authority (case A). There has been an increasing demand for more sustainable practices put into place aiming to reduce any adverse environmental impacts (Azhar *et al.* 2011). Representing the social pressure from the wider public and communities (Nibbelink *et al.* 2007; Leinonen and Houvila 2000), these requirements are embodied in policies such as from the local authority in case A to be taken into account in design processes. It can be concluded here that these aspects within client's requirements need to be clearly understood and incorporated into the design phase of offsite construction projects.

Project Requirements

In both projects (cases A and B), it was found that the time-cost-quality triangle was one of the main aspects to be considered during the design phase. Project requirements information that feed into the design process consisted of considerations of aspects relevant to the needs of the projects from design, manufacturing, handling/transporting, installation to occupancy stages. The typical design parameters manifested from the attempt to achieve client's objectives in a project, include cost, time and quality of the project delivery (Bowen *et al.* 2002; Hughes and William 1991). The urgent need to have the constructed building available but with limited financial capabilities (case A) or the need for the timely completion to allow for the client's scope to the quality level desired by the client (case B) have resulted in the decision to adopt offsite construction methods in these projects. Thus by freezing the design at an early stage to enable the subsequent offsite manufacturing construction process to be carried out, higher certainly in terms of time, cost and quality was highly expected. This early interface between design solution and the requirements for manufacturing is required in order to prevent ad-hoc results and conflicted supply chain interest at this early design stages (Jensen *et al.* 2012), where 70–80% of the production overheads are typically determined (Goulding *et al.* 2015).

As procurement represents significant duration in the projects (68 days in case A, 30 days in case B), both offsite manufacturers were fully supported by robust supply chains in manufacturing the volumetric building components, handling/transporting and conducting site works. The supply chain role in an offsite construction project can be mainly considered as the third type as described by Vrijhoeff and Koskella (2000) where the focus is on transferring activities from site to earlier stages of the supply chain. Whilst holding the potentials to benefit of reducing complexities from the on-site phase of the construction, it can potentially shift these complexities into the earlier stage, i.e. design stage (Koskella 2000). Thus, the more holistic view of supply chain has demonstrated the significance of the supply chain towards the design process.

With the underlying assumption that by migrating construction activities to be conducted in a more controlled environment offsite, activities such as the controlling quality and tolerance can be conducted easier, both projects (case A and B) include parts of the building constructed on-site in their projects. Case A was originally designed for a conventional on-site delivery. This has constrained case A from migrating more construction activities to be conducted offsite. Conversely, case B was able to maximise the migration as it was designed for offsite construction from the very beginning. This has enabled case B to be completed comparatively faster relative to case A. Table 2 presents the proportion of activities within the scopes (excluding the hybrid parts) in both projects based on the activity's duration to represent the level of efforts in these activities relative to the rest of the projects.

Table 2. The proportion of activities on the cases

Activities	**Case A**	**Case B**
Procurement	5.3%	2.1%
Offsite activities	43.6%	81%
On-site activities	51.1%	16.9%
Total	100%	100%

By transferring more construction activities into offsite manufacturing environment, the expectation was also to implement higher standardisation for repeatability in the process. This, however, will also depend on the manufacturing capacity including the availability of space, availability of the workers with the right skills and so on. The offsite construction providers in both projects have their own manufacturing facilities with sufficient space available to take on the jobs. The offsite provider in case A mainly uses brick's dimension as the standard in planning and designing building elements and component parts in their volumetric units. The offsite provider in case B, on the other hand, uses the dimension of steel cage structure typical to the local market place to be supplied by steel subcontractors as the standard dimension in designing their volumetric units. In both projects (cases A and B), however, one of the most basic requirements in determining the standard dimension was the capacity of the delivery vehicle. Thus, the dimension (i.e. width, length, height) and weight of the volumetric units to be transported are restricted by the physical limitations of the delivery vehicle (Schoenborn 2012). Whilst there are options available for different transportation vehicle capacities, they have to optimise cost. To optimise the load into the delivery vehicle in combination with the standardisation strategies above, the provider in case A came up with the typical volumetric units up to 14,874 mm in length (with varying widths) whilst the provider in case B opted for units up to 13,100 mm long.

Following the finalisation of transportation choice, the volumetric units will also need to be installed onsite. Therefore, the level of knowledge and quality of information regarding the existing site condition such as the site logistics, access to site or manoeuvring space are also important considerations in designing the volumetric units. The project in case A was delivered on a dedicated plot whilst in case B it was delivered on the existing school premises but both with direct access to main roads. The installation of the volumetric units in case A (56 units) and case B (47 units) both took only 8 days as planned demonstrating their successful executions based on robust planning and design. As hybrid projects, further on-site construction activities were conducted in both projects up to the point of testing and commissioning to ensure fitness for purpose post-handover.

Regulation Aspects

The regulation aspects have been found significant to the design process. Both projects (cases A and B) were found to be fully compliant with regulations. Considerations for regulation aspects extend further from building codes and planning permission. For instance in the UK, this includes the Construction Design Management (CDM) Regulations 2015 that requires project stakeholders to better plan health and safety risks during the project life cycle (HSE 2015). In Western Australia, health and safety regulations to be adhered include, for example, Work Health and Safety (Construction Work) Code of Practice at the federal level and the WA Building and Construction Industry Code of Conduct 2016 (Government of WA 2016) at the state level.

Bearing a significant impact to offsite construction projects, however, is the highway agency regulations. In order to transport the volumetric units from the offsite manufacturing facilities to the project site, these units must be in compliance with the highway authority's requirements (Schoenborn 2012). In Western Australia for example, the Mainroads Western Australia specified maximum dimension of 5.5 m x 5.5 m x 30 m for a long indivisible load before the load is classed as an oversize load that requires a special permit to be applied and it will also require traffic escort where the width of the indivisible load exceeds 5.5 m and the length exceeds 40 m (Mainroads WA 2017). In England, transporting an abnormal load (more than 78.74 tons in weight, 2.9 m in width and rigid length of more than 18.65 m) will require notice with indemnity to Road and Bridge Authority, notice to police and/or application for Highway England Special Order depending on the further classifications based on the weight/width/length (Highway England 2015). From both projects (cases A and B), it was evident that weight and the length of the volumetric units, particularly the width requires a special attention in designing them.

Taking into account the standardisation strategies, the cost optimum choice of the vehicle capacity and the highway authority regulations, the providers in case B designed the width of the volumetric units to be 3,000 mm whilst the provider in case A designed the width of the volumetric units to range between 2,050 mm and 3,600 mm. The relatively higher variability in case A stems from the fact that it was not originally designed to be constructed with offsite construction methodology. Even with varying the width of the volumetric units, it was evident in case A that minor design modifications were necessary including moving the position of doors and windows as well as adding glazing facades in the positions that are now occupied by some columns of the volumetric units. Another example showing the significance of regulations towards the design process of offsite construction projects is the fire design in case B. The strict requirements from the Building Code Australia (BCA) for fire rating and compartmentalisation have resulted in several unplanned iterations in the design process leading to a change into specifying pre-cast concrete columns in the project.

Social Aspects

The research found the health and safety aspects as an overlap between the regulation and the social aspects as was with the carbon footprint/waste/pollution. As previously discussed, the social influence to the design process has been termed as societal needs in design process (Nibbelink *et al.* 2007; Leinonen and Houvila 2000). This "requirements" represents the social pressure from the wider public and communities to be taken into account in contemporary design processes. Both projects (cases A and B) applied very stringent health and safety measures as a deliberate attempt to further promote offsite construction methodology in the eyes of the public. With the existence of negative images about the construction industry in the society, for instance the risks of fatal accidents occurring in the construction industry has been considered at least five times of that other sectors (Arkson and Hadikusmo 2008; Sorrock *et al.* 1993), the offsite construction methodology has been perceived as holding the potential to reduce safety risks (Khalfan and Maqsood 2014; Pan *et al.* 2008; Gibb 2001) and therefore improving the image of the construction industry. It is evident in the both studied cases that in addition to the advantages in term of time, cost and quality, the offsite construction methodology has been sold to the clients with the better potentials for health and safety performance as well as potentially lower carbon footprints and waste. After all, the construction industry and buildings have also been portrayed by the general public as major users of resources in terms of energy and materials (Jaillon and Poon 2010).

The conflict between technical development (offsite construction and prefabrication) and aesthetic have been considered one of the main problems in the post-war public school building in the UK so much so that the design of public schools were considered non-imaginative (Bianco 2013). In case A, there was a need for the offsite construction design to comply with the aesthetics originally designed for a conventional on-site construction. In case B, there was a need for the new building design that blends well with the existing surrounding including existing school buildings in the premises. Whilst the considerations for aesthetic existed in both studied cases, it has been bundled up with client's requirements, project requirements and regulations. Even though, it has been generally accepted that the school facilities impacted on the student's learning process, further research is still needed to better understand the interplay between environment, pedagogical, psychology and social variables in school design (Moore and Lackney 1993).

There are two other social considerations in designing offsite construction, namely the potential disruption to the society and the availability of skills. Matters relevant to the potential disruptions have been mainly covered in the planning permission such as the environmental assessment or permission to the highway agencies as discussed in the previous subsection. For example, in case A the impact assessment of the new school includes a strategy to minimise disruptions to the surrounding by restricting construction activities. This has reinforced the need to implement offsite construction methodology in this project. Whilst operating in construction sectors with continuous skills shortage in the construction sectors, the potential issues with availability of skills in both project (cases A and B) have been alleviated by the use of offsite construction technique, removing the dependency towards skilled trades by breaking down the tasks into much simpler tasks so that the fabrication process can be carried out by workers with lower skills supervised by skilled or qualified workers.

Bringing the findings together

In each of the four groups (client's requirements, project's requirement, social and regulations), various aspects of the quality of information feeding into the design process were found to be interlinked in influencing the design process and the occurrence of design risks. However, it also became evident that these aspects are also interlinked across the different phases of the project as well as between groupings. In order to visualise this in a more holistic manner, the findings have to be presented within the project lifecycle. Due to the progressive nature of construction projects, a construction projects' life cycle can be presented using lifecycle frameworks, for example RIBA's plan of work (Philips, 2000). Therefore, in this research, the findings from the *analytical explanation* process have been mapped into a generic project lifecycle suitable for offsite construction, consisting design, offsite (manufacturing), handling and transporting, site works and installation and also occupancy phases and presented in a diagrammatic format in figure 3. Following recommendation from previous research (Nibbelink *et al*. 2017; Sutrisna and Barrett 2007), the importance of a feedback loop from occupancy back to the design stage is included in the diagram. This diagram can be used by the stakeholders in offsite construction projects as a guideline to analyse these aspects during different project phases and their interrelationship to ensure the provision of and the quality of information to minimise the potential occurrence of design risks in their offsite construction projects.

Limitations of the findings

Whilst the nature of investigation with *process-tracing* as implemented in this research typically requires a single or small-n cases, this research has implemented *process-tracing* in 2 cases in generating the findings and the resulting diagram. Thus, it is acknowledged that further research involving more cases will expand the findings to include different type of projects and clients, different project sizes or different geographical locations/jurisdictions. Nevertheless, the findings reported here provide a solid platform for further expansion of the findings as it unveiled the fundamental requirements of the information feeding into the design process of offsite construction projects and its influence towards the occurrence of design risks.

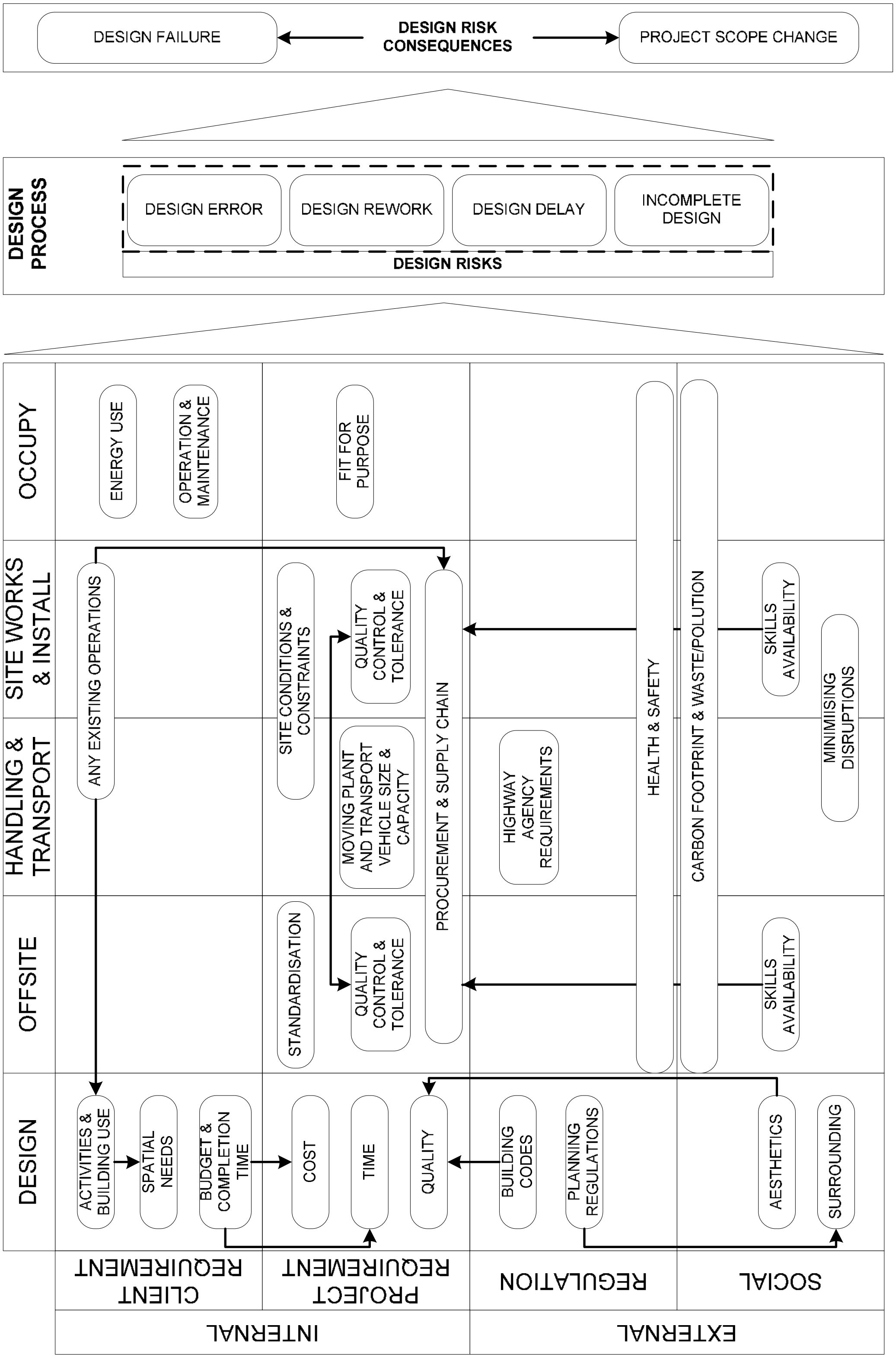

Figure 3. The Quality of information affecting the occurrence of design risks

Conclusion

The offsite construction has been considered holding significant potential to alleviate issues and risks from construction process mainly by migrating many of the construction activities to be conducted in a more controlled environment. When looking into the potential reasons for low uptake, it has been reported that there is perceived inadequate management of risks in offsite construction projects. When zooming into the management of risks, design risks have been considered one of the most prevalent as it can lead to a domino effect to subsequent phases and yet found to be under investigated. This research was then set to investigate the trigger to the occurrence of design risks, focusing on two case studies in the UK and Australia based on a recently reported framework to analyse the information feeding into the design process and their roles in triggering design risks in offsite construction projects.

The findings revealed crucial information feeding into the design process emanating from various subsequent phases of offsite construction project life cycle, namely design, offsite (manufacturing), handling and transporting, site works and installation and also occupancy. One of the salient issues unveiled is the decision to adopt offsite construction techniques in a project at an early stage. In one of the cases, the project was originally designed to be constructed conventionally on site. This has resulted in design changes as the original design did not cater for offsite construction techniques and subsequently resulting on delays in the process. Despite the overall success in delivering this project, it has limited the scope to transfer activities to be conducted off site and necessitated more on-site construction activities that prolonged the delivery process. In designing an offsite construction project, the need to consider activities subsequent to the design process itself has been demonstrated. It became evident that the handling and transporting the volumetric units, the optimisation of lifting equipment, standardisation in manufacturing, transport vehicle capacity and the road/highway regulations significantly influence the occurrence of design risks in offsite construction projects. Other aspects impacting the occurrence of design risks include the occupancy considerations as well as the social aspects of designing offsite construction projects.

Offsite construction continues to demonstrate high levels of innovation and subsidiary value streams. However, to live up to future expectations, a more holistic understanding of risks (especially design risks) is needed. This would help reinforce confidence to adopt offsite construction techniques. The process of managing risks does not exclusively attempt to find a solution for completely eliminating risks; but rather, to be able to identify, plan anticipate and monitor the risk implementation plan. This research reported the first important step towards the development of a holistic understanding for managing offsite risks by analysing the information feeding into the design process. It also provides further evidence for better understanding process roles in triggering design risks. Figure 3 captures the findings of this research; the rubrics of which can purposefully guide offsite construction project stakeholders through the various phases to enable them to focus on explicit information which supports the design process. In doing so, it also provides a vehicle for minimising the occurrence and impact of these design risks on future projects.

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