

Exploring the potential for achieving the triple bottom-line of sustainability through offsite manufacturing

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Abstract:

Triggered by the rapid depletion of natural resources, sustainability has now becoming a popular topic that has been linked to various aspects of human's life. Given the very scale of the global construction industry, sustainability has emerged as one of the main features in the construction industry including in choosing the construction method such as offsite manufacturing (OSM) in construction. In fact, one of the main advantages of OSM has been expected as its potential to minimise waste as well as higher level of productivity and hence supporting sustainability. However, it has also been reported that despite all its advantages, the uptake of OSM is still considered relatively low in the construction industry. In discussing about sustainability, various scholars have championed the importance of looking into this matter through a more holistic view of sustainability including economical, social and environmental. This is also known as the triple bottom-line of sustainability. This paper presents a review of the current development in analysing the achievement of the triple bottom-line of sustainability throughout the lifecycle of offsite construction projects. The outcomes of this review are expected to unveil various points within the lifecycle of projects delivered with the offsite construction techniques that can be improved to better facilitate the achievement of the triple bottom-line of sustainability in these projects. The findings can be used by practitioners to improve and better justify the implementation of offsite construction techniques and subsequently, further promoting the use of such techniques in the construction industry.

Keywords: construction, sustainability, triple bottom line, offsite manufacturing

Introduction

It has been generally accepted that there are currently increasing demands in the society (including in the construction industry) for sustainability factors to be considered in practices in order to reduce any environmental and social impacts (Azhar *et al.* 2011). Thus, sustainability has become an important decision-making factor in procuring a construction project in the current market place (Schlueter and Thesseling 2009). This 'movement' is understood as the societal needs to be considered in the construction procurement processes (Leinonen and Houvila 2000) and signifies the increase of wider public and communities' influence in the delivery and procurement of construction projects. One of the implications was the potential to implement construction techniques that have been perceived as embodying sustainability, such as the offsite manufacturing (OSM).

Further development of offsite manufacturing (OSM) has been considered one of the most important innovations in construction methods leveraging the advancement of

technologies in construction industry. Being recognised as a construction technique from as early as 1800s, OSM was not really looked into until recently for its potentials in improving efficiency in the process, precision in the products, ability to include various environmental features and hence keeping up with requirements, optimising the use of declining workforce, minimising health and safety risks and to significantly shorten the construction cycles (Steindhart and Manley 2016; Goulding *et al.*, 2015; Khalfan and Maqsood 2014; Schoenborn 2012; Smith 2010). These have earned OSM the term "modern method of construction" since 1990s (Gibb 1999).

With those potential advantages mentioned above, there is a common expectation for OSM to be widely adopted. However, the OSM's uptake in reality has not been as predicted (Rahman 2013). The global research publication looking into OSM has been growing at a relatively steady rate since 1998. But, the actual uptakes in many construction industries have not been inline. For example, a study of the total offsite construction output in the UK between 1998 and 2008 revealed a modest increase between 1998 and 2008 (Taylor 2010). In Australia it was indicated that only 3% of the new housing in Australia utilises prefabrication (Steindhart and Manley 2016). Many researchers and scholars have studied the lower uptake of OSM attempting to understand the reasons behind the lower uptake (e.g. Rahman 2013; Arif and Egbu 2010; Pan *et al.* 2008; CRC Construction Innovation 2007), but there has not been a real consensus among their outcomes.

It is generally accepted that the earlier focus in deciding to implement OSM were mainly the cost and schedule performance of a project (Shahzad *et al.* 2014). In deciding to implement OSM in a more recent time, a number of factors including project costs, time, quality, sustainability, site, project and procurement constraints have impacted the implementation of OSM in a project (Blismas *et al.*, 2005). These identified factors can be generally grouped within the three main groups also known as the triple bottom-line (TBL) of sustainability, namely economic, environmental and social. This paper provides a review of sustainability procurement in the format of a framework that has been developed in this research embodying the triple bottom-line of sustainability (economic, environmental and social) to map the potential ways of achieving the TBL of sustainability in projects implementing OSM.

2. Research methodology

At this early stage of study, the research methodology to be implemented to better understand the potentials for achieving the triple bottom line of sustainability through implementing OSM in construction projects is literature review. In conducting research, literature review has been regarded necessary to understand what already known and written down, relevant to the research (Robson 2013). Thus, it involves systematically identifying, locating, and analysing documents containing information related to the research problem. These documents can include articles, abstracts, reviews, monographs, dissertations, books, other research reports, and electronic media. In this research, the literature review is focused on scholarly journal articles supported by various conference articles as well as scholarly books and book chapters as well as professional industry reports. The review started off with gaining further understanding on offsite manufacturing itself including its terminologies, history, positioning in different sectors and typical lifecycle. This is followed by focusing the review on the triple bottom line of sustainability and identifying the potentials of achieving them through OSM lifecycle.

It is envisaged that further stages of this research to involve case study of real OSM projects. It has been generally accepted that case study approach is a suitable approach to study phenomena within their natural context and setting (Sutrisna and Setiawan 2016; Yin 2014). Thus, the sustainability framework for OSM proposed in the paper can be used as the framework and the unit of analysis in studying the cases. The selection of the cases is beyond the scope of this paper, but it can potentially range from simple residential projects to more complex commercial projects.

3. Offsite manufacturing (OSM)

Off-site manufacturing (OSM) is one of the terminologies used to define a construction technique that involves prefabricating building components, usually done outside the construction site (hence the term “offsite”), followed by installing them into their final position as designed (Blismas and Wakefield 2009; Goodier and Gibb 2004). There are other terms used to describe this construction technique including offsite construction (e.g. Sutrisna *et al.* 2017), off-site prefabrication/production (e.g. Kale and Ardit, 2006) or industrialised building (e.g. Jonsson and Rudberg, 2013; Kamar *et al.* 2011). Although the concept of prefabricating building components itself has been around much longer, it was not until the end of World War II offsite manufacturing (OSM) became popular as a potential solution to the housing shortage at that time. Thus, OSM became the alternative method for shelter provision as quickly as possible within the limited budget (Wolfe and Garfield, 1989). Unfortunately, this situation in OSM’s early implementation has somehow carried over so much so that OSM is known as the ‘Temporary Accommodation’ in the UK for instance or as an off-the-shelf product such as the ‘Lustron House’ in the USA or ‘Beaufort Homes’ in Australia for example.

As the intended lifecycle of the temporary OSM buildings was typically lower (a maximum of 10-15 years), these temporary homes were typically produced with lower quality, made them known as “cheap and nasty” (Duc *et al.* 2014; Goulding and Arif 2013). To make matter worse, it was really hard to customise OSM houses due to their smaller floor space (Gay 1987). Many house builders lost interest in considering OSM when they heard, for example the case of Lustron House in the USA that resulted in more than 10 times additional man-hours to its original estimation (Wolfe and Garfield 1989). It is not unusual for a new technique to experience practical challenges as a part its “growing pains”, but these difficulties have not helped with OSM’s reputation as a preferred solution. Recently, OSM has been also considered carrying-on the traditional subcontracting approach and therefore simply repeating the fragmented practice from the construction industry (Arashpour *et al.* 2018), i.e. simply migrating the onsite activities to an offsite setting but still carrying all the various known issues. Because of that, the adoption of OSM has continued but at a slower pace, i.e. for instance around 20% in Japan, 6% in the UK and about 7% in the US (Goulding and Arif, 2013; HAC, 2011; Taylor, 2009). An exceptions for example is Sweden that managed to implement OSM up to 80% in their residential sector (Duc *et al.* 2014; Davies 2005; Lessing *et al.* 2005).

OSM should benefit from a synergy between manufacturing and construction, where majority of building components can be manufactured in controlled factory environments (Goulding *et al.* 2015). Thus the whole concept is relying on its design to implement planning and processes from the manufacturing sector to achieve the intended benefits. Thus, the building design should enable the construction activities to be conducted in a controlled factory environment to reduce waste generation and therefore resulting in a better cost control and less impact to the environment (Khalfan

and Maqsood 2014; Azhar *et al.* 2011; Gibb 2001). Another example of benefits from the repetitive nature of OSM has also enabled the offsite manufacturers to use semi-skilled or even lower-skilled operatives to reduce the impacts from skilled trades shortage (Nadim and Goulding 2009).

For the potential benefits to be realised, one of the key requirements would be the synchronisation of the activities between the manufacturing and construction sides in an OSM project (Sutrisna *et al.* 2018a). This synchronisation must be carefully planned and take place from the earlier stages of design. This has made the design stage in an OSM project as one of the most important phase in coming up with a solution that bring together various project stakeholders with different interests and facing the high degree of complexity in an OSM project (Bekdik *et al.* 2018). Thus, the relationship between the manufacturing, construction and design industries is very important in successfully implementing the OSM in a project (Goulding and Arif 2013). This relationship is presented in Figure 1.

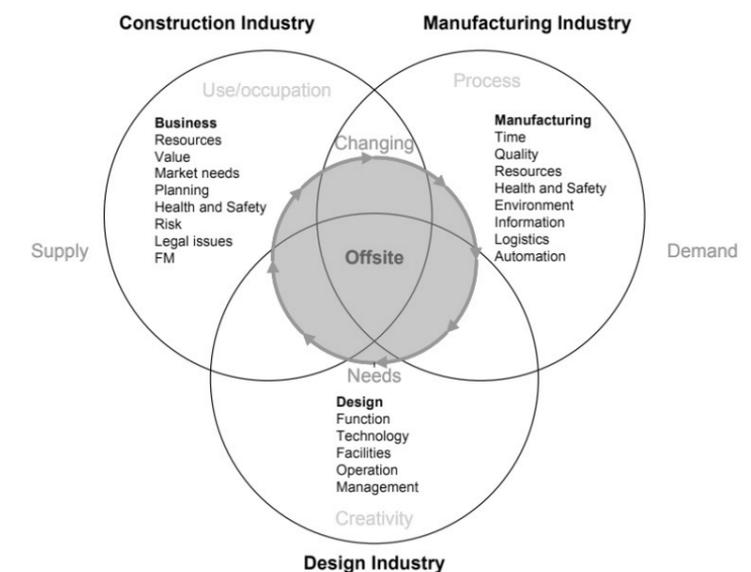


Figure 1. Offsite Manufacturing (OSM) positioning (Goulding and Arif, 2013)

Based on the progressive nature of construction projects, a construction projects’ lifecycle can be presented in a chronological manner using lifecycle frameworks, for example RIBA’s plan of work (Philips, 2000). In terms of OSM’s lifecycle, one of the simplest OSM lifecycle models was the generic OSM lifecycle presented by Sutrisna and Goulding (2018) by dividing up the lifecycle into 4 distinct phases, namely:

- Design,
- Offsite (manufacturing),
- Handling and Transport,
- Site Works and Installation,
- Occupation.

These typical phases will be used in this research to identify the potentials of achieving sustainable procurement through OSM mainly due to its representativeness and ability to simplify the process.

4. The triple bottom line of sustainability in OSM: A proposed framework

The serious impact towards our natural environment has changed societal expectations to demand awareness and considerations by leaders of their practices (Colbert and Kurucz 2007). So much so that sustainability aspect is now considered one of the sources of competitiveness embodied in the principles of procurement management (Savitz and Weber 2006; de Burgos Jimenez and Céspedes Lorente, 2001). Thus, procurement is the vehicle to implement sustainability into practices that extends to the whole supply chains (Meehan and Bryde 2011). A lot of organisations have extended their attention to also look beyond traditional financial performance by embedding environmental and social performance of procurement known as the triple bottom line (TBL) approach (Holloos *et al.* 2012; Birkin *et al.* 2009). Sustainability has now become the new paradigm in many construction industries and one of the most important considerations in delivering and procuring projects (Schlueter and Thesseling 2009). This demonstrates the results from growing pressure from the wider public in delivering and procuring construction projects (Nibbelink *et al.* 2017; Leinonen and Houvila 2000). Sustainable procurement has been used as the generic terminology to describe project's delivery/procurement aligned with the TBL philosophy applying the principles of sustainable development: ensuring a strong, healthy and just society, living within environmental limits whilst promoting good governance (Walker and Brammer, 2009).

3.1. Economical sustainability of OSM

Economical sustainability has been defined as a way to operate that allows delivery with cost benefits and cost savings by embracing a whole-of-life costing way of thinking, impacts of supply chains and sustainability criteria (Zeppel 2014). Whilst this can be impacted by policies, such as landfill levies, carbon taxes and so on (Thomson and Jackson, 2007), this paper focuses on the design, manufacturing and construction processes only. It has been acknowledged that within the total development cost, the construction cost will typically be the most significant component (between 42.8-65.8%) in comparison to other costs such as land, service and finance, government charges and margins (Hsieh *et al.* 2012; Urbis 2011). In procuring and delivering construction projects, the cost associated with material, transportation and labour have been considered the cost drivers that are typically considered in selecting a construction method (Chen *et al.* 2010). There are a large numbers of publications discussing construction cost (Warsame 2006), however the offsite construction cost has not been widely covered.

There have been various discussions from both sides of the argument whether implementing OSM is actually cheaper than constructing with the more conventional onsite construction. A recent investigation on the implementation of OSM technique in the housing sector has revealed that migrating onsite construction activities to be conducted offsite alone may not necessarily result in lower overall construction costs (Sutrisna *et al.* 2018b). Instead, the financial benefits will be realised at the entire supply chain level. The limited demands (volume) as well as the client's requirements for higher degrees of customisation in offsite production has been the main factors found to limit the economic benefits that can be typically expected from a manufacturing operation. Because of these, the design phase of OSM projects holds the main keys in achieving the economic sustainability by optimising the standardisation of the building/structure components with repetitions in production in mind whilst still

allowing a degree of flexibility for clients but based on that standardised components for the subsequent manufacturing process. In terms of manufacturing process, it has been acknowledged that the construction industry needs to adopt higher degree of industrialisation to reduce cost and that prefabrication is the first step in industrialisation (Richard 2005). In transporting the completed modular units, the dimension and weight of the volumetric units to be transported will have to follow the physical limitations of the delivery vehicle as well as complying with the highway authority's requirements (Sutrisna and Goulding 2018; Schoenborn 2012). Existing site condition including the site logistics, access to site or manoeuvring space and/or any obstructions also need to be taken into account in transferring the modular units to ensure smoother site works (Sutrisna *et al.* 2017). At the end of the process, during the occupancy, clients/users will require more economic operation and maintenance.

3.2. Environmental sustainability of OSM

The relatively novel notion of "green procurement" typically refers to environmental considerations enshrined into purchasing policies, programmes and actions to facilitate recycling, reuse and resource reduction (Carter and Carter 1998). A study reported that the implementation of the more conventional onsite construction techniques can produce waste up to 40% from all new products brought to construction site (Smith, 2010). Environmentally sustainable delivery, therefore, should concern with reducing the environmental impacts at every project development phases from the design phase to include the provision of environmentally-friendly construction materials (low embodied energy and renewable materials), application of alternative construction techniques (off-site manufacturing), up to the implementation of eco-design principles (energy efficient and passive-design to reduce/minimise dependency to non-renewable energy sources). Varnäs *et al.* (2009) suggested to incorporate environmental features into a project in the preliminary design, in the tendering for the construction contract and the tendering/considering the building services such as heating, ventilation and air conditioning.

In manufacturing the OSM units as well as subsequent phases, potentials for OSM in addressing environmental considerations have been well documented including the reduction of waste during the manufacturing process itself, minimising the onsite activities and hence reducing the environmental impacts associated to onsite construction processes or even in reducing carbon footprints as a whole (Jaillon and Poon 2014; Azhar *et al.* 2011). Thus, for example by designing the OSM units to optimise transport vehicle capabilities but within the regulations (particularly highway requirements), the minimum transporting cycles can be minimised to limit the carbon footprints from transportation. Another example would be by transferring as many construction activities as possible to be conducted offsite, this will likely shorten the construction time on site and hence minimise pollution, the use of water and energy onsite. At the end of the process, during the occupancy, clients/users will typically require less dependency to non-renewable energy sources to run their building.

3.3. Social sustainability of OSM

The social sustainability has been perceived initially from the corporate social responsibility (CSR) perspective where various social aspects such as employment, labour standard, gender equality, wellbeing, and so on are considered in the whole supply chains (McCrudden 2004). The more recent development of social sustainability includes further aspects including the use of local suppliers and subcontractors,

providing as much information as possible to the local communities through public engagement activities, health and safety in the projects as well as minimising disruptions to the surroundings due to the project activities, such as traffic disruptions or noise pollutions (Sutrisna and Goulding 2018). A relatively recent discourse by Chen *et al.* (2010) discussed one of the main advantages of implementing OSM within the socially sustainable aspects to be the potential to minimise disruptions to the local community that will typically happen in most onsite construction works. Thus, in OSM projects, the manufacturing activities typically take place in a controlled environment and not onsite, hence less disturbance to the site's surrounding. Although, it must be noted that disruptions can still happen during the transporting of the OSM units to site as well as the residual onsite construction activities albeit potentially reduced to minimum.

With the statistic reports of the risks of fatal accidents occurring in the construction industry for instance shown as at least five times of that other sectors, it is not surprising that negative images about the construction industry exist in the society (Arkson and Hadikusmo 2008; Sorrock *et al.* 1993). As another example, the OSM methodology has been perceived as capable of reducing safety risks in construction projects, mainly due to the execution of the majority of these activities in a controlled environment (Khalfan and Maqsood 2014; Pan *et al.* 2008; Gibb 2001). This was found important in improving the image of OSM as well as the construction industry as a whole. A recent study on OSM has reported that in addition to the advantages in term of time, cost and quality, the potentials for health and safety performance of OSM methodology has actually been the main factors for clients in making the decision to adopt OSM in the studied cases (Sutrisna and Goulding 2018). Another example of the potentials for OSM to address the social sustainability aspect is regarding the skills needed in OSM. Typical manufacturing processes, the activities in the factory can be 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 do not need be fully conducted by skilled trades and can also use semi-skilled or lower-skilled operatives instead (Nadim and Goulding 2009). This also addresses the social aspects of allowing employment to local communities even for workers with lower skills or qualifications in construction and provides a training ground to further learn and improve their skills and knowledge (supervised by trained and qualified trades professionals in the factory setting) and hence increasing the potential for their involvement in construction trades.

3.4. The proposed framework

Bringing together all the findings from the literature review discussed above, a framework for achieving the triple bottom line (TBL) of sustainability (economical, environmental and social) by adopting OSM has been developed and presented in Figure 2 below. The framework maps these potentials within the generic OSM project lifecycle discussed in the section 2 above.

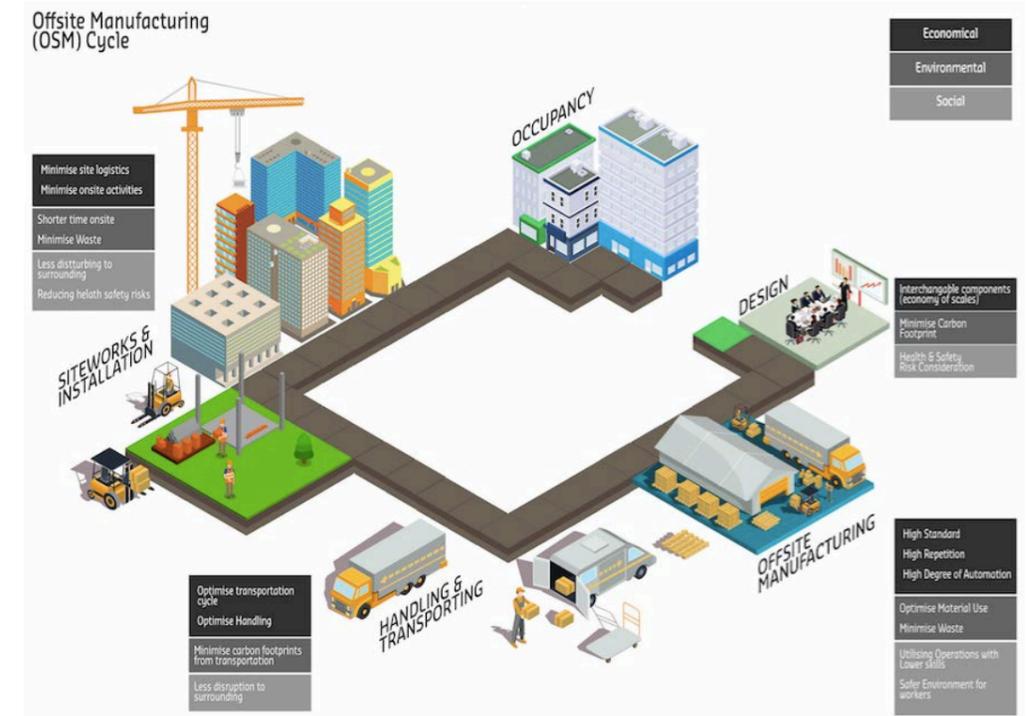


Figure 2. The proposed framework in achieving TBL of sustainability through OSM

4. Conclusion and further research

It has been generally accepted that there are currently increasing demands in the society (including in the construction industry) for sustainability factors to be considered in practices in order to reduce any environmental and social impacts. Thus, sustainability has become an important decision-making factor in procuring a construction project in the current market place. This paper has reviewed offsite manufacturing (OSM) not only as a viable technique in delivering construction projects but also bearing the potentials of achieving the triple bottom line of sustainability. Following this, a framework has been developed to map these potentials throughout the generic lifecycle of OSM.

Further research can be designed to further pursue various directions based on what have been presented in this paper. One of them intended by the authors involves investigating the most appropriate level of prefabrication in a particular project to address the achievement of the triple bottom line (TBL) of sustainability in the most optimum manner. In order to pursue this, real case studies of OSM projects as well as suitable optimisation method to aggregate the TBL of sustainability will be needed. This will be done with the aim to better promote the use of OSM in delivering construction projects.

5. References

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