
# MODULAR OFFSITE CONSTRUCTION (MOSC) FOR HIGH-RISE BUILDINGS: A NEW ZEALAND STUDY


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# MODULAR OFFSITE CONSTRUCTION (MOSC) FOR HIGH-RISE BUILDINGS: A NEW ZEALAND STUDY


## Abstract

**Purpose:** The ascendancy of modular offsite construction (MOSC) over traditional construction methods is well known. Despite the known potential of this construction approach, its adoption is minimal in New Zealand construction industry. This article investigates the potential benefits of using MOSC for delivery of high-rise buildings in New Zealand, underlying factors responsible for its low uptake, and the measures that can facilitate its improved uptake.

**Design:** This study utilised a mixed research approach. An empirical questionnaire survey was carried out with New Zealand construction industry professionals with expertise in MOSC. Survey data were analysed using statistical analysis techniques. Semi-structured interviews were carried out with subject matter experts to get further insights and expand the survey findings. Interview data were analysed using thematic analysis.

**Findings:** Study identified benefits of MOSC, thus establishing potential of its uptake for high-rise building construction. Constraining factors were investigated, most pronounced being low level of skills in construction industry to design, manufacture and integrate supply chain of MOSC, high initial investment, high cost of importing modules, and negative perception about offsite manufactured buildings. This study also highlighted the enablers to improve uptake of MOSC. These enablers included; loan and mortgage policies to suit MOSC paradigm, building regulations to support OSC industry, increased support from the government, and awareness and acceptance of standardised building designs among the clients.

**Originality:** Originality of this paper harps from little to no research carried out to investigate use of modular offsite construction for high-rise buildings in New Zealand context.


**Keywords:** Modular Buildings, Modular Construction, New Zealand, Offsite Construction (OSC), Prefabrication.

## 1. Introduction

New Zealand construction industry practices are dominated by traditional construction methods, with considerably low levels of innovation and technological advances (ITA, 2020). This applies to all construction industry sectors, including the offsite construction (OSC) market. Darlow *et al.* (2020) reports a small market share of offsite construction and lag in innovation and the use of technology in New Zealand. Nuja (2019) confirms that OSC in New Zealand is still infancy with only 10% market share. Panelised OSC is the most used variant in offsite construction in New Zealand (Sooriyamudalige *et al.*, 2020). While panelised OSC refers to the assembly of pre-built exterior and interior panels of a building on project site, MOSC refers to the assembly of pre-built three-dimensional volumetric units also known as pods or modules (OffsiteNZ, 2013). Arif *et al.* (2013)

noted that MOSC has a leading edge over panelised OSC due to its potential to enhance project performance with most negligible cost impact.

MOSC supersedes traditional construction practices by minimizing requirement of onsite works, as they are almost completed three-dimensional modules, ready to be assembled on project site (OffsiteNZ, 2013). Innovative like automation can easily be integrated into manufacturing process, adding further efficiencies like quick completion and improved quality (Neelamkavil, 2009). Automation reduces labour cost and also improves working conditions while enhancing productivity of process and improving quality control (Zavala, 2016; Burgess *et al*., 2013). Many economies like Germany, Singapore, Japan, Sweden, and USA have already benefited from these aspects of MOSC and set a precedence for others to follow (Matsumura *et al.,* 2019; Mitchell and Hurst, 2009; Rippon, 2011; Balaguer, 2003). MOSC is widely tried and tested for low rise buildings, but the full potential of this system still needs to be realized for high-rise buildings. Benefits of MOSC are optimized when used in high-rises due to stacking of repeatable modules, which significantly reduces the project completion time (Thai *et el*., 2020; Jellen and Memari, (2013). New Zealand's first MOSC building was completed in 2012, this fourteen-storey building containing 468 modules saved 8% in cost but still failed to promote MOSC culture in country (Burgess *et al.*, 2013). Most of the MOSC in the country is limited to installing modular bathroom and kitchen pods. This study, therefore, set out to achieve the following objectives:

- Establish benefits of MOSC for high-rise buildings in the New Zealand.
- Identifying factors constraining the adoption of MOSC for high-rise buildings in New Zealand,
- Investigate the enablers of MOSC for high-rise buildings in New Zealand.

## 2. Literature Review

### *2.1. MOSC: A Leading Edge*

MOSC also known as prefabricated prefinished volumetric construction (PPVC) and modular integrated construction (MiC) is the most effective form of offsite construction (Jellen and Memari, 2013; Pan and Hon, 2020; Thai *et el*., 2020; Li and Samarasinghe*,* 2020). Manley (2008) and Lee *et al.* (2012) defined MOSC as a method of construction in which individual standalone modules are assembled to form a large structure. These modules are mounted side-by-side, end-to-end, or stacked, allowing for a wide range of styles and designs in the architectural aspects of the buildings (Ganiron and Almarwae, 2014). Ribeiro *et al*. (2022) document that MOSC is the most sophisticated offsite construction method. Various researchers have documented many benefits of MOSC. MOSC is an efficient way of construction that reduces the environmental impact and makes project management easier (Akinradewo *et al*. (2021). MOSC has the potential to reduce project costs, project duration, construction waste, and noise pollution (Haas *et al*., 2000; Song *et al*., 2005). This construction approach can enhance the overall quality of the project, improve labour productivity and optimise the environmental performance (O'Connor *et al.* 2014). Ferdous *et al*. (2019) further narrate this system of faster project delivery offers better predictability of project completion targets while requiring fewer workers on site and offering sustainability benefits like less waste generation and optimisation of resources. Mortice (2019) observed that MOSC allows 70% to 95% of all the work to be completed in factories before the modules are transported to the project site. However, Akinradewo *et al*. (2021) argue that the extent of modularization in structure largely depends on the skills and expertise of the project teams.

### *2.2. MOSC for High-Rise Buildings*

The most common application of MOSC so far is in low rise buildings, and despite its vast benefits, its share in high-rise buildings is meager. It is reported that less than 1% of high-rise buildings are constructed using MOSC (Thai *et al*., 2020). With right ingredients, MOSC is a futuristic approach, and this approach is continuously evolving and innovating. Depending on assembly method, MOSC can be categorized in three ways in which the three-dimensional modules are assembled to form a structure namely core, podium, and infilled frame systems. Core assembly requires all modules to be assembled around one central core constructed of concrete or steel (Srisangeerthanan *et al.*, 2020). In podium assembly, modules are placed on top of podium, which acts as a building foundation (Lawson and Ogden, 2008). Core and podiums are widespread approaches of MOSC in USA and Europe, whereas infilled frame method is more common in Asian countries. In this approach, modules are inserted between columns and beams (Lawson, 2016; Lawson and Ogden, 2008).

Despite known benefits of MOSC, like time-saving, cost-saving, defects reductions, waste minimization, lower health and safety risks, and improved environmental performance, uptake of MOSC is low in many countries (Rahman, 2014). Hong Kong, Japan, Netherlands, Singapore, UK, and USA are among few countries that realized the potential of MOSC for high-rise buildings, but many other countries, including New Zealand, still have to make this move (Hwang *et al*., 2018; Darlow *et al*., 2022). Considering how slowly MOSC has been adopted (Shahzad *et al*., 2015; OffsiteNZ, 2013), there is still a long way to go before New Zealand can fully reap MOSC benefits (Sooriyamudalige *et al.*, 2020).

#### *2.2.1. Benefits of MOSC*

MOSC offers promising benefits to all project stakeholders, most importantly reduction in project schedule, leading to cost savings and productivity improvement (Loizou *et al.*, 2021). Sutrisna *et al*. (2020) and OffsiteNZ (2021) observed 20%-50% reduction in project completion time resulting from manufacturing of structural components in factory settings that are supported by streamlined processes and use of machines. MOSC offers sustainability benefits like, less construction waste and and potential for recycling and reusing building components (Loizou *et al*., 2021; Jang *et al*., 2022; Kamali and Hewage, 2016). Chauhan *et al*. (2022) noted that MOSC not only minimizes project cost, but whole lifecycle cost for MOSC is much lower. MOSC also reduces greenhouse gas (GHG) emissions. Kim (2008) predicted a 4.6% reduction of energy consumption and 3% reduction of greenhouse gas emissions for 50-year life cycle of MOSC projects.

MOSC extends health and safety benefits, as it requires fewer workers on site. MOSC minimises requirement of working on scaffolding (Pahuja and Shahzad, 2022). Workers mostly work in factory environments and are not exposed to harsh weather. Due to standardisation most activities carried out by these workers are in repetitive manner (Kamali and Hewage, 2016). Since manufacturing is done in factory, quality and construction environment is well regulated, resulting in better quality outputs (Chen and Samarasinghe, 2020). MOSC is acknowledged for the possibility of conducting early seismic tests on structural elements of a building to understand its seismic behaviour, reducing design defects and ensuring good quality of buildings (Jellen and Memari, 2013).

### *2.2.2. Constraints to the Adoption of MOSC*

Despite known benefits, uptake of MOSC is low (Taylor *et al.*, 2015), this low uptake is linked to some restrictions and difficulties that constrain uptake of MOSC by industry. Most important constraints to its adoption is capital expense of offsite production facilities (Juan *et al*., 2019; Luo *et al*., 2015; Xue *et al*., 2018). Although innovation is essential to increased productivity performance, adopting innovation comes at a hefty cost (Pan *et al*., 2012; Li *et al*., 2014). Offsite manufacturing has a capital cost that is 10–20% higher than traditional construction, according to Chan *et al*. (2010). Mao *et al*. (2017) notes that higher cost of MOSC is attributed to several factors that are unimportant in conventional construction approach, like cost of skilled labour, machinery, factory setup, operation and maintenance, and depreciation. Need for professionals, workers' training, and need of ample storage makes it very costly to adopt (Xue *et al*., 2018; Steinhardt *et al.,* 2013).

Lack of expertise and training in design among architects is a major barrier to adoption of MOSC (Schoenborn, 2012). Clearly, design drawings developed for MOSC are more comprehensive. Offsite drawings should, for instance, more realistically depict links and locations. To guarantee appropriate locking, interfaces between two components must be designed accurately. Building Information Modelling (BIM) guide (GSA, 2007) advises that use of BIM should begin during procurement. A clear expectation of level of detail and participation of project stakeholders should be included in contract. Designers must receive training to develop projects that make best use of factory technology; this entails maximising replication of parts that can be produced by available equipment (Schoenborn, 2012).

Local laws are important to OSC and might hinder its growth (Patel, 2016). New Zealand building sector is subject to strict regulations. Resource Management Act (RMA), Building Act, and Building Code are few examples of regulatory compliance (Kennerley, 2019). These regulations prevent OSC from being adopted since it requires extensive consultation and approval procedures involving time and money. Historical quality issues with offsite and perception like temporary, low quality, and inexpensive construction continue to hinder its uptake (Kennerley, 2019; Shahzad, 2016). For MOSC, installation at construction site, and shipping from off-site venue, careful transportation planning is required (Bell, 2018). From an economic perspective, manufacturers aim to design modules to maximum allowable transportation size. However, method of transportation and process have weight and measurement restrictions, and they can be expensive and challenging (Onori and Martinez, 2008). Most significant issue facing MOSC is societal acceptance of its products. According to (McGraw-Hill Architecture, 2011), main justification offered by sector for not utilising modularization in their projects was that the architect failed to specify a modular construction method. It is crucial to have a clear definition of modular systems. Cost of the project and timelines may have a significant influence due to its austere character (White *et al.*, 2015). A drawback, in view of construction professionals, is requirement for extensive cooperation before and during construction, and additional project planning and design (Hwang *et al*. 2018).

### *2.2.3. Enablers of MOSC*

ITA (2020) states that New Zealand policymakers understand that MOSC adoption, , industrialization, and automation are necessary to fix low productivity issues of building sector. Hence it is critical to understand enablers of MOSC to promote its use. Some research has been conducted to understand factors that can enable uptake of MOSC. One major factor is high capital cost, which can be offset by utilizing MOSC in large scale projects. High-rise structures and terraced dwellings are examples of repetitive ongoing work that ensure return on investment. Continuity of work makes MOSC highly feasible. BIM, visualisation, and simulation of building production, could be potential drivers to encourage the uptake of MOSC (O'Connor *et al.*, 2014; Dimyadi and Amor, 2013).

Bertram *et al.* (2019) documented seven factors that can drive the construction sector to adopt MOSC, including: regulations, material access, supply chain, labour dynamics, quality perception, local site constraints, and consolidated and continuous demand. They elaborated that quality certifications, warranties, and buildings standards can help in enabling uptake of MOSC but demand is the most important factor, and all other factor are relevant demand of MOSC in the market high and contineous. MOSC for high-rise buildings can increase workers' overall safety and well-being, by eliminating working at heights for longer durations and under harsh weather (Pahuja and Shahzad, 2022). Use of MOSC also reduces cost associated with labour and injuries, according to Juan *et al.* (2019). CIDB report (2013) recommends increasing investment in R&D and providing subsidies to offsite sector of construction industry.

## 3. Methodology

This study endeavours to identify benefits MOSC for high-rise buildings, constraints to its uptake and measures that can enable the enhanced use of MOSC. Methodology of this study was designed, consisting of four phases, starting with critical review of relevant literature to establish context and study need. Critical review of existing literature both qualitative and quantitative information is regarded as attested approach of providing theoretical underpinning to an investigation (Deng *et al.*, 2014, Lu *et al.*, 2015, Sylvester *et al.*, 2015). Paré *et al.* (2015) reinforces robust literature review to outline knowledge gap. In second phase, online questionnaire survey was developed, pre-tested and administered to collect quantitative data from professionals with experience in offsite construction to elicit study objectives. Questionnaire survey is a valid tool to gather insights from subject matter experts (Azhar *et al.* 2013). In third phase, semi-structured interviews were conducted to collect qualitative data (Dejonckheere and Vaughn, 2019). Interviews provided more in-depth insight into the MOSC. In last phase, data analysis was carried out.

### *3.1 Questionnaire Survey - Data Collection and Analysis*

A questionnaire survey was developed and pre-tested (Sekaran, 2016) by construction professionals. Respondents were asked to provide their opinion on perceived benefits of MOSC in high-rise buildings, factors constraining its uptake, and measures that can enable improved uptake of this technology. Close-ended question utilised a five-point Likert-scale (1) strongly disagree, (2) disagree, (3) somewhat agree, (4) agree, and (5) strongly agree, to obtain insight of participants (Bryman, 2016). Members of OffsiteNZ (industry organisation for offsite construction) were invited to participate. For 118 requests sent out, 23 usable responses were received. Cronbach's Alpha value of 0.98 indicated the questionnaire used has high level of internal consistency and hence is a reliable data collection tool (Taber, 2018). Statistical Package for Social Sciences (SPSS) based factor analysis was conducted to determine mean rating values for various measurement factors included in survey, following recommendations of Siregar *et al.*, (2017). Mean rating (MR) values helps established the rankings of measurement factors MR > 2.5 is regarded as a significant contributor and MR < 2.5 is unimportant factor.

Demographic characteristics of the survey participants showed responses were received from engineers (25%), project managers (25%), offsite manufactures (25%), quantity surveyors (19%), and architects (6%). Major responses from engineers, project managers, and offsite manufacturers to their own value may have an impact on the analysis's findings, even when they are not significantly biased in terms of the inclusion of important criteria. Figure 1 provides an overview of survey respondents' experience in field of offsite construction. Their experience and knowledge contributed to the legitimacy of the research outcomes.

Figure 1: Survey participants' offsite construction experience

### *3.2 Semi-structured Interviews - Data Collection and Analysis*

This study was able to gain valuable information from practitioners through semi-structured interviews. It is established that qualitative research puts an emphasis on observations that are otherwise hard to quantify (Glesne, 2016; Potter, 2015). Interviews were open-ended, allowing for more inclusive results (Barriball and While, 1994) that can test reliability and validity of survey findings (Rabionet, 2011; DeJonckheere and Vaughn, 2019). Use of semi-structured interviews is a common and well established approach of yielding confirmatory results (Harris and Brown, 2010). Interview was designed with key questions supported by follow-up questions for maximum tangibility and comprehension of replies (Chen and Partington, 2014). All transcripts were sent back to interviewees for verification to augment data reliability.

To analyse the interview transcripts, Nvivo 12 was used, which is widely endorsed for qualitative data analysis (Kordestani *et al*., 2018). Descriptive coding was utilised to help shape the original data, obtained data, and analyse the data's fundamental subjects. Theoretical saturation defines the number of interviewers as the point at which more interviews cease to yield additional insights (Glaser and Strauss, 2017). Table 1 contains information about the interviewees.

Table 1: Details of interview participants

This pool of experts has provided the breadth of knowledge and necessary expertise as recommended by Ochieng and Price (2010).

## 4. Results & Discussion

Findings of this research are presented in this section as an analytical discussion based on data analysis. This section contains survey and interview responses corresponding to study objectives: (i) benefits of MOSC in high-rise buildings, (ii) constraints to uptake of MOSC for high-rise buildings, and (iii) MOSC enablers for high-rise buildings in New Zealand. Results of interviews with New Zealand professionals in MOSC field are presented after survey results for each study objective.

### *4.1. Benefits of MOSC for High-rise Buildings in New Zealand Context*

Statements posted in this section of questionnaire are presented below with answers provided by participants (Table 2). Participants' point of view was understood by carrying out statistical analysis of survey data by calculating mean rating (MR) value for all responses. Factors with MR value of 2.5 or more are regarded as the significant. Results indicate that there are many benefits of using MOSC for high-rise buildings in New Zealand.

Table 2: Benefits of MOSC for construction of high-rise buildings

MOSC has the ability to enhances aesthetic appearance of high-rise buildings. This finding is supported by Neelamkavil (2009) who noted use of automation and sophisticated design software can create pleasant looking modular buildings. MOSC can enhance durability of high-rise buildings due to the potential of carrying out prototype testing for modular structures (Jellen and Memari, 2013). Study participants believed that MOSC implies a higher quality end product. They also noted that MOSC has the potential to offer good quality indoor environment in buildings. It is recognised that MOSC reduces overall construction cost of high-rise buildings. Similar observations are made by OffsiteNZ (2021) for OSC in general. The participants disagreed that MOSC can offer easy design solutions, and constructability. Contrary to literature findings, participants did not agree to the notion of faster construction. This can be due to longer lead time require for planning and design of modular buildings.

Interviewees gave some excellent insights based on their comprehensive knowledge and expertise in MOSC sector of New Zealand construction industry. All interviewees agreed that MOSC has potential to reduce project cost. Cost benefits are not limited to project life cycle but it is deemed that whole of building life cycle will have lesser cost. Additionally, everyone agreed that OSC is a time efficient approach of construction, as many activities are taking place concurrently and standardised design can reduce the time required to get building consent. The fact that, MOSC is a faster method of construction, also helps achieving the cost savings for the project. Respondents noted that one part of MOSC can be very expensive that is transportation of large sized modules, but this cost doesn't override the overall cost saving of using MOSC.

There are a number of environmental benefits associated with using MOSC for high-rise buildings. Most of work is done remotely in factory setting so the disruption to local community, environment and traffic is minimal. Another benefit is opportunity for construction industry to upskill and learn advanced technologies.

### *4.2. Constraints to Adoption of MOSC in New Zealand*

During survey, factors constraining the uptake of MOSC were categorised into six broad categories (Table 3): (i) design process, (ii) regulations, (iii) cost/investment, (iv) industry and market culture, (v) supply chain and procurement, and (vi) skill. Seven constraints were examined related to design process, analysis showed that unless offsite manufacturers are involved in the project from its inception, this approach might not be beneficial. Need of extra effort during the design of MOSC for high-rise buildings and the requirement of sophisticated OSC design software to achieve design efficiencies were the next most important constraints. These findings align with Mydin *et al.*, (2015) who investigated offsite construction for Malaysia. Inflexibility imposed by MOSC methodology prevents design changes after project commencement. Design changes are exceedingly expensive and nearly impossible. Jaillon and Poon (2010), also assert that using MOSC to satisfy customer requirements prevents design modifications at any later stage.

Table 3: Constraints to adoption of MOSC for high-rise buildings

MOSC is a tightly collaborative process that is moderately dependent on adequate teamwork and cooperation over the entire life cycle, including planning, designing, manufacturing, transport, and assembly. Lack of an integrated workflow between OSC manufacturers and contractors' results in mismatched design assumptions on the job site. According to Sun *et al*., (2020), who compares MOSC with traditional construction, due to a lack of information sharing, the MOSC technique is met with numerous challenges as a result of the fragmented stakeholder group.

Survey data analysis of regulatory constraints showed negligible impact on the adoption of MOSC in New Zealand with MR values less than 2.5. The New Zealand construction industry's regulations, according to Becker (2005), do not encourage innovative construction methods; rather, they place more emphasis on the safety of tenants and building users than on the methods used for construction, even though this is not thought to be a problem that should be taken seriously.

Impact of constraints under the category of cost/investment on low adoption of MOSC in the New Zealand building industry revealed that high expense of importing modular components made overseas is the most significant factor, followed by the overall high cost of MOSC compared to conventional techniques due to the requirement of huge upfront investment. Cost involved in transportation for MOSC is significantly more than for other forms of OSC and what it accounts for in conventional construction, particularly where the distance is greater. These results are consistent with a related study (Chen & Samarasinghe; 2020) which found that contractors saw MOSS projects as more expensive than traditional construction projects. Gibb and Isack (2003) and Phillipson (2003) also agrees with the same notion.

Survey responses about industry and market related constraints highlight that most significant factor inhibiting the application of MOSC poor perception about this technology among the clients and other stakeholders. Negative stigmas about offsite construction from bad experiences in past are noted to be second most critical barrier. These findings are supported by a New Zealand study (Chen and Samarasinghe; 2020) that recorded clients' perceptions of modular structures are mainly to blame for the industry's slow adoption. Furthermore, despite MOSC's efficiency having been demonstrated, the contractors continue to be more self-assured and use traditional construction techniques (Durdyev and Ismail, 2019). Building procedures have become more difficult because of recent developments, according to Mbachu (2008). Therefore, it is impossible to put offsite building into effect by adding fresh advancements to the typical contractor's way of thinking. According to Tam *et al*. (2007), the creation and implementation of OSC call for a high level of technological and resourceful innovation including integrated supply chain. The most important barrier to the current low adoption of MOSC is the apparent lack of project control during onsite operations without effective supply chain management. Second-most important restraint in this category shows how difficult it is for new suppliers to enter the market because incumbent suppliers are supported by both industry stakeholders and the public. These constraints are backed up by Scofield *et al*. (2009) and Chen and Samarasinghe (2020).

A synopsis of skills related constraints pointed out lack of MOSC skills and expertise as major impediment. This is caused by low levels of training and reluctance to adopt new technologies and skills. New Zealand's emphasis is on education and training for current traditional methods rather than new inventive concepts for the future in the construction industry. The second biggest barrier was determined to be a lack of industry-related research and development (R&D) concerns. Survey participants viewed the lack of research and development in the MOSC field as having an effect on the uptake and acceptance. This is consistent with Bell (2018) finding, that funding for research and development through government and industry grants is required to assess and analyse MOSC products for their superiority.

Interviewees were interviewed about the use of modular building construction (MOSC) in high-rise buildings in New Zealand. Results from interviews indicate that offsite sector of New Zealand construction industry is constrained by a multitude of barriers. Fragmented nature of construction industry makes it difficult to develop a coherent supply chain that can optimise delivery of MOSC.

Participants had a consensus of views that inflexibility to change design combined with complex design requirements of MOSC for high-rise buildings compared to traditional construction process. Lack of innovation in MOSC design process like limited or no use of building information modelling (BIM) is also a reason for longer design period. Achieving customized designs with modular offsite method is hard, whereas customers prefer unique and bespoke designs. This will either require a cultural change where clients have acceptance of standard designs or modular industry will have to evolve to meet clients' desire of unique designs for their buildings. New Zealand also needs regulations that are tailor made to suite MOSC paradigm. Interviewees mentioned that MOSC can reduce the overall project cost, but the initial capital cost involved in setting up offsite manufacturing facilities can be very high. Lack of volume and demand does not justify the huge capital investment require to set up such facilities. However, with increasing pipeline of project in New Zealand, MOSC might establish sooner than expected. MOSC is being hampered by the formerly negative reputation of modular construction and the notion that they are utilised as temporary structures. Poor level of skills and training is another limiting factor. here is a need to develop capacity and capability of modular offsite construction in New Zealand to promote use of this technology and reap its benefits. Finally, interviewees added that lack of financial support from government, like subsidies for importing equipment and machinery also discourage the sector from adopting MOSC.

### *4.3. Enablers of MOSC in New Zealand*

Enablers of MOSC for high-rise construction are presented in Table 4. Fair finance and mortgage conditions for modular offsite construction have highest mean rating of 3.32 when compared to all other enablers. Government support for offsite sector of construction industry is another significant enabler. New regulations and standardization for MOSC is likely to encourage adoption of modular offsite construction. Bathtiarizadeh *et. al.* (2019) pointed out the vague regulations are offsite construction are limiting its uptake.

Table 4: Enablers of MOSC for construction of high-rise buildings

Interviews confirmed that support to businesses through loans, mortgages, and financial assistance is mandatory to promote use of MOSC in New Zealand. This is particularly true for large-scale high-rise buildings as many businesses don't have the capacity. Collaboration and cooperation of New Zealand organisations with international organisations can foster the sector's capacity and capability. Experts believe that MOSC need to be marketed more to correct the wrong perceptions attached this technology. Local councils and government organisations also need to show better acceptance of MOSC. For success of this technology innovative procurement like early contractors' involvement (ECI) needs to be implemented.

## 5. Conclusion

This study explores the benefits, barriers, and enablers of MOSC for delivery of high-rise buildings in New Zealand. Study findings have clearly outlined the advantages of this system that can be availed in case of high-rise construction. MOSC is disadvantaged by high upfront investment on offsite manufacturing unit but at project level MOSC offer cost saving. Modular offsite construction (MOSC) can produce high-rise buildings with an excellent aesthetic appearance and indoor environment for the building dwellers. MOSC is a time-efficient approach as many activities are taking place concurrently, and standardised design can reduce the time required to get building consent. MOSC also offers my sustainability related benefits like less waste generation, low air and noise pollution levels. Many barriers constrain the uptake of Modular Offsite Construction (MOSC) in New Zealand. Lack of supply chain integration and fragmented nature of the industry also impact MOSC uptake. High upfront investment to set up an OSC factory and high cost of importing modules from other countries. Lack of regulations that suit MOSC, shortage of skills, poor market perception, reluctance of industry to adopt innovation, and lack of financial support secure loans and mortgages impede the uptake of MOSC in New Zealand. This study finding has highlighted some enablers of MOSC, key enabler is support to OSC businesses through loans, mortgages, and financial assistance. This, combined with marketing the benefits of MOSC, developing the capacity and capability of the sector, and government support in mandating MOSC for pipeline projects, can bring a change in the construction sector where project stakeholders will feel encouraged to adopt MOSC. Findings of this study are likely to support construction industry and policymakers to take the right steps in the right direction to benefit from MOSC for large-scale and high-rise buildings. A limitation of this study is its focus on offsite construction professional. Future studies can involve the participation of other stakeholders in the supply chain of MOSC to expand the perspective viewpoints.

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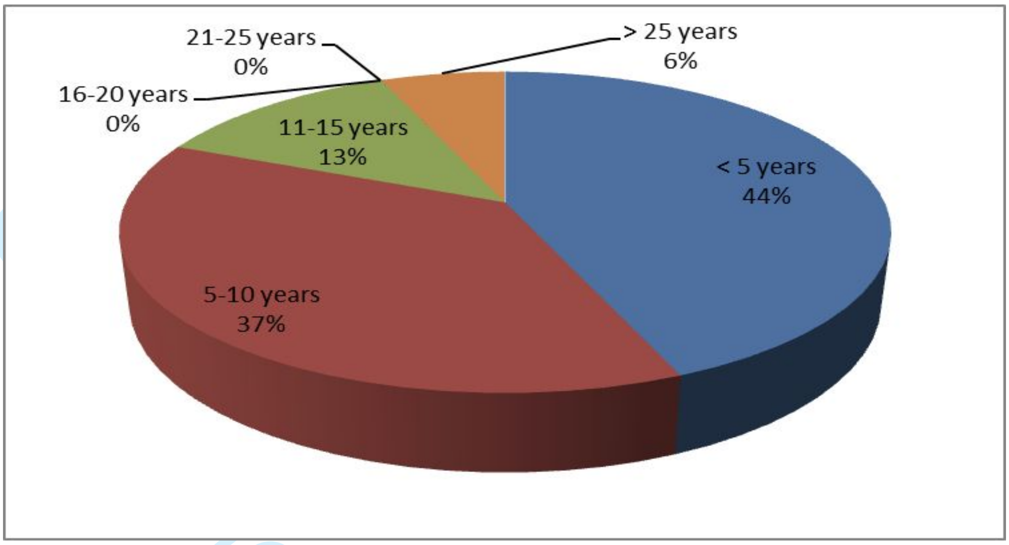

Figure 1: Survey participants' offsite construction experience

Table 1: Details of interview participants

| Interview Participant | Role | Offsite Construction Experience |
|---|---|---|
| A | Engineer | 5 years |
| B | Engineer/Researcher | 5 years |
| C | Project Manager | 20 years |
| D | Manufacturer | 8 years |
| E | Project Manager | 3 years |
| F | OSC Designer | 11 years |
| G | Manufacturer | 6 years |
| H | Engineer | 5 years |

Table 2: Benefits of MOSC for construction of high rise buildings

| Benefits of modular offsite construction | [1]Level of Agreement (percentage of participants) | | | | | Mean Rating |
|---|---|---|---|---|---|---|
| | SA (5) | A (4) | SwA (3) | D (2) | SD (1) | |
| Modular offsite construction enhances the aesthetic appearance in high rise buildings | 11.11 | 33.33 | 27.78 | 27.78 | 0.00 | 2.72 |
| Modular offsite construction increases the structural durability of high-rise buildings | 10.53 | 47.37 | 21.05 | 15.79 | 0.00 | 2.63 |
| Higher quality product is achieved with modular offsite construction | 16.67 | 38.89 | 27.78 | 5.56 | 5.56 | 2.61 |
| Modular offsite construction increases the indoor environment quality of buildings | 5.26 | 42.11 | 42.11 | 10.53 | 0.00 | 2.58 |
| Modular offsite construction accommodates installations of more services in high rise buildings | 11.11 | 44.44 | 22.22 | 22.22 | 0.00 | 2.56 |
| Modular offsite construction reduces the construction cost of high-rise buildings | 23.53 | 29.41 | 17.65 | 29.41 | 0.00 | 2.53 |
| Modular offsite construction increases the ease of design in case of high-rise buildings | 27.78 | 16.67 | 38.89 | 16.67 | 0.00 | 2.44 |
| Modular offsite construction reduces the amount of rework in high rise buildings | 16.67 | 38.89 | 38.89 | 5.56 | 0.00 | 2.33 |
| Modular offsite construction reduces impact of weather conditions during construction | 31.58 | 36.84 | 26.32 | 5.26 | 0.00 | 2.05 |
| Modular offsite construction increases the constructability in high rise buildings | 38.89 | 33.33 | 16.67 | 11.11 | 0.00 | 2.00 |
| Modular offsite construction increases the construction speed for high rise buildings | 47.37 | 21.05 | 21.05 | 10.53 | 0.00 | 1.95 |

[1]Level of agreement of constraint statement: SA (Strongly Agree) = 5; A (Agree) = 4; SwA (Somewhat Agree) = 3; D (Disagree) = 2; SD (Strongly Disagree) = 1

Table 3. Constraints to adoption of MOSC for high-rise buildings

| Design process related constraints | [1]Level of Agreement (percentage of participants) | | | | | Mean Rating |
|---|---|---|---|---|---|---|
| | SA (5) | A (4) | SwA (3) | D (2) | SD (1) | |
| Advantages are possible if offsite manufactures are involved in designed at the outset. | 5.88 | 47.06 | 23.53 | 17.65 | 5.88 | 2.71 |
| MOSC requires extra project design endeavors which could affect any time saving advantage. | 23.53 | 17.65 | 35.29 | 17.65 | 5.88 | 2.65 |
| Lack of sophisticated software for MOSC design | 17.65 | 35.29 | 17.65 | 23.53 | 5.88 | 2.65 |
| After project commencement modular offsite does not allow design changes | 11.76 | 47.06 | 11.76 | 29.41 | 0 | 2.59 |
| Additional project planning required for high rise modular offsite buildings | 23.53 | 47.06 | 5.88 | 11.76 | 5.88 | 2.47 |
| Lack of integrated processes between offsite manufacturers and contractors leading to mismatch of design assumptions on site. | 29.51 | 29.41 | 17.65 | 23.53 | 0.00 | 2.55 |
| Sophisticated architectural and engineering design of modular offsite construction | 23.53 | 47.06 | 29.41 | 0.00 | 0.00 | 2.06 |

| Regulations related constraints | 1Level of Agreement (percentage of participants) | | | | | Mean Rating |
|---|---|---|---|---|---|---|
| | SA (5) | A (4) | SwA (3) | D (2) | SD (1) | |
| Certified crane operators (H&SE Act 1992) with proper training for site operations | 25.00 | 31.25 | 25.00 | 12.50 | 0.00 | 1.32 |
| Strenuous, restricted, costly regulations are applied to offsite construction processes | 25.00 | 18.75 | 37.50 | 37.50 | 0.00 | 1.21 |
| Ambiguities in the ownership of modular components manufactured offsite | 12.50 | 25.00 | 31.25 | 31.25 | 6.25 | 1.14 |
| Limited regulatory support (e.g. standards and codes) for modular construction | 18.75 | 31.25 | 43.75 | 6.25 | 0.00 | 0.86 |

| Cost/investment related constraints | [1]Level of Agreement (percentage of participants) | | | | | Mean Rating |
|---|---|---|---|---|---|---|
| | SA (5) | A (4) | SwA (3) | D (2) | SD (1) | |
| High cost of importing modular components manufactured offshore | 17.65 | 35.29 | 23.53 | 17.65 | 5.88 | 2.59 |
| Offsite construction is often recognized as more expensive compared to conventional method | 18.75 | 37.50 | 12.50 | 31.25 | 0.00 | 2.56 |
| High transportation cost of modules to sites | 11.76 | 47.06 | 29.41 | 5.88 | 5.88 | 2.47 |
| Complex handling of large sized components | 18.75 | 50.00 | 6.25 | 25.00 | 0.00 | 2.38 |
| Complex transportation planning of modules | 11.76 | 52.94 | 23.53 | 11.76 | 0.00 | 2.35 |

| Industry and market culture related constraints | [1]Level of Agreement (percentage of participants) | | | | | Mean Rating |
|---|---|---|---|---|---|---|
| | SA (5) | A (4) | SwA (3) | D (2) | SD(1) | |
| Offsite manufactured buildings are still treated as poor and low quality buildings. | 5.88 | 41.18 | 35.29 | 17.65 | 0.00 | 2.65 |
| Negative stigma in the application of offsite techniques in the past may limit acceptance. | 23.53 | 41.18 | 17.65 | 11.76 | 0.00 | 2.51 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Market with low level of formal skills is not ready for modular offsite construction | 25 | 31.25 | 31.25 | 6.25 | 6.25 | 2.38 |
| Issues with and poor perceptions of non-traditional construction and materials have led to a risk-adverse industry | 25 | 43.75 | 31.25 | 0.00 | 0.00 | 2.06 |
| Reluctance to change from traditional approach by key stakeholders may restrict industry-wide adoption of modularisation | 52.94 | 29.41 | 11.76 | 5.88 | 0.00 | 1.71 |

| Supply chain and procurement constraints | [1]Level of Agreement (percentage of participants) | | | | | Mean Rating |
|---|---|---|---|---|---|---|
| | SA (5) | A (4) | SwA (3) | D (2) | SD (1) | |
| Apparent loss of project control during onsite operations. | 5.88 | 29.41 | 29.41 | 5.88 | 17.65 | 3.35 |
| Stiff opposition from traditional suppliers against new entrants to modular construction business may limit supply capacity and large-scale adoption. | 23.53 | 41.18 | 17.65 | 5.88 | 5.88 | 2.47 |
| Lack of a framework for supply chain management of modular offsite construction in New Zealand | 37.50 | 18.75 | 18.75 | 18.75 | 6.25 | 2.38 |
| Difficult quality assurance requirements for modular components | 31.25 | 18.75 | 37.50 | 12.50 | 0.00 | 2.31 |
| Complex supply chain logistics involved in modular offsite construction | 29.41 | 29.41 | 29.41 | 11.76 | 0.00 | 2.24 |
| Modular offsite requires firm control of supply chain which involves high risks especially in relation to international logistics & supply arrangements. | 12.50 | 62.50 | 18.75 | 6.25 | 0.00 | 2.19 |
| Industry capacity to supply diverse varieties of modular offsite products is limited | 29.41 | 35.29 | 23.53 | 11.76 | 0.00 | 2.18 |

| Skills related constraints | [1]Level of Agreement (percentage of participants) | | | | | Mean Rating |
|---|---|---|---|---|---|---|
| | SA (5) | A (4) | SwA (3) | D (2) | SD (1) | |
| Low formal skill levels of labour to understand the interface and designs in MOSC | 29.41 | 35.29 | 11.76 | 0 | 17.65 | 2.59 |
| Dearth of research and development on Modular offsite construction | 29.41 | 23.53 | 29.41 | 5.88 | 11.76 | 2.47 |
| Limited modular offsite project experiences in the NZ construction industry | 17.65 | 52.94 | 11.76 | 11.76 | 0.00 | 2.41 |
| Limited expertise of designers and manufacturers in modular construction | 20.00 | 40.00 | 40.00 | 0.00 | 0.00 | 2.20 |
| Lack of modular offsite contractors in NZ | 29.41 | 41.18 | 17.65 | 11.76 | 0.00 | 2.12 |
| Limited formal education on MOSC in NZ | 41.18 | 29.41 | 17.65 | 11.76 | 0.00 | 2.00 |

[1]Level of agreement of constraint statement: SA (Strongly Agree) = 5; A (Agree) = 4; SwA (Somewhat Agree) = 3; D (Disagree) = 2; SD (Strongly Disagree) = 1

Table 4: Enablers of MOSC for construction of high rise buildings

| Factors enabling adoption of modular offsite construction in high rise buildings | [1]Level of Agreement (percentage of participants) | | | | | Mean Rating |
|---|---|---|---|---|---|---|
| | SA (5) | A (4) | SwA (3) | D (2) | SD (1) | |
| Fair loan and mortgage conditions for offsite projects | 15.79 | 21.05 | 21.05 | 10.53 | 21.05 | 3.32 |
| Favorable (new) building regulations supporting all forms of offsite construction | 0 | 42.11 | 36.84 | 21.05 | 0.00 | 2.79 |
| Increased client demand for customized buildings | 21.05 | 31.58 | 21.05 | 10.53 | 10.53 | 2.74 |
| Increased government support for offsite sub-sector of construction industry | 15.79 | 26.32 | 42.11 | 15.79 | 0.00 | 2.58 |
| Increased level of innovation required for modular offsite construction | 26.32 | 36.84 | 15.79 | 15.79 | 0.00 | 2.42 |
| Increasing population relative to land availability (High density population) | 21.05 | 31.58 | 36.84 | 10.53 | 0.00 | 2.37 |
| Adequate housing provision | 21.05 | 31.58 | 36.84 | 10.53 | 0.00 | 2.37 |

[1]Level of agreement of constraint statement: SA (Strongly Agree) = 5; A (Agree) = 4; SwA (Somewhat Agree) = 3; D (Disagree) = 2; SD (Strongly Disagree) = 1