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EXPLORING OFFSITE CONSTRUCTION FOR THE CONSTRUCTION SECTOR: A LITERATURE REVIEW

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ABSTRACT

The construction sector is one of the largest producers of Gross Domestic Product globally and yet has shown little innovation in the last 20 years. Offsite has been touted as cheaper, faster, higher in quality and more environmentally friendly than onsite construction. The purpose of this paper is to review the current research into offsite construction and determine the barriers to adoption and benefits facing offsite construction. A systematic literature review was undertaken to gather relevant knowledge surrounding the subject matter using a database search of Scopus. It was found that knowledge was the largest barrier to adoption and that transcended multiple stakeholders, from the selection of the appropriate delivery methodology, how to design for optimized fabrication and finally how to interface with the onsite requirements. The benefits are a higher build quality, shorter project duration as both site work and fabrication occur at the same time, improved safety, and less material wastage. The Barriers come from design freezes earlier in the process and inflexible design for customization later in the build.

KEYWORDS

Off-site construction, modular construction, prefabrication, advantages, disadvantages

INTRODUCTION

According to McKinsey report (2020), the construction industry globally represents about $10 trillion annually making the construction industry the largest sector globally accounting for 13% of the worlds spending. The construction sector has demonstrated an average growth of 1% year over year compared to 2.8% growth of the global economy. McKinsey estimates the productivity performance in the construction sector represents $1.6 trillion in potential value added that could be generated by higher productivity. At the same time, the sector has suffered from inefficiencies and persistently low levels of productivity, largely the result of a fragmented supply chain, which still hampers its ability to embrace innovation (Department of Business Innovations and Skills 2013). When looking historically over the construction sector performance has shown a consistent 1% growth over the last 20 years (Mckinsey, 2020). The risks in the delivery of construction projects remain high, it is very typical for projects to run

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over schedule (typically 20% over) and costs (up to 80% over). When combining the high-risk factor with a low profitability, around 5% and that can be less depending on where in the value chain the specific construction company performs, construction companies are frequently the highest hit about insolvency (Mckinsey, 2020).

Based on the low growth and lack of efficiency, the construction industry is open to the risk of disrupters looking to capitalize on the $265m profit pool on the table. That profit pool could be further improved if projects can successfully shed risks. Industrialization in the (1970-1980), globalization (1990 -2000) and digitalization (2010-present) have all been key drivers of change in all other industries. As these drivers hit the construction industry, and are continuing to play a role, it is expected that disruption is likely within this sector (Mckinsey, 2020).

One solution that follows the key drivers to change and presents an opportunity for disruption within the construction sector, is the adoption of offsite construction (Mckinsey, 2020). Goddier and Gibb (2007) define offsite construction as the 'manufacture and pre-assembly of components, elements or modules before installation at their final location'. In a modern context prefabrication or offsite construction, which includes modular construction, refers to the pre-fabrication or fabrication of individual units that are assembled on-site to construct the final building (Jang, Ahn and Rob, 2022) (Marte Gómez *et al,* 2021).

The Prefabrication industry has been under review by different bodies of research and concluded it is faster by 34% cheaper by 19% and a higher quality than conventional construction (Shahzad, Mbachu and Domingo, 2015). A recent study has pointed to offsite construction to improve project efficiency (Steinhardt *et al*, 2016). Industry literature produced by the Modular Building Institute (MBI) touts the benefits of site construction to be further reaching adding to the benefits to include improved worker safety, reduced wastage, and offsets labour shortages (MBI, 2021).

Lou and Guo (2020) found that offsite construction is a complicated system that has multiple stakeholders influenced by different drivers. Inefficacies in design, transportation, storage, manufacturing, building installation and onsite construction all negatively influence construction costs.

The global offsite industry generated $130.4 billion in 2020 with expectation of forecast growth to $235 billion by 2030. As a market share this value places offsite construction at 1.3% (Market wise). Globally the adoption rate varies by region. The market share is very similar within the UK, Australia and the US representing prefabrication as less than 5% of the elements for housing compared to 84% in Sweden, 15% in Japan and 20% in the Netherlands (Cerro, 2021). This is also supported by the Journals reviewed with nine of the twenty-six studies coming from the UK and nine from Australia compared to none from Sweden or the Netherlands indicating that studies into barriers for adoption are not warranted and the value proposition is well established.

Goddier and Gibb (2007) research focused on the construction industry in the UK in 2007, the rate of evolution albeit slow in the construction sector has moved on in the last 15 years it opens up the content to questions regarding relevance today. Cerro (2018) work is more recent and focuses on the United States citing an affordable housing challenge with a lagging supply of homes indicating that adoption rate of innovative practices is still lagging, furthermore Cerro (2018) points to learning from Sweden, Japan and the Netherlands based on adoption rate. Steinhardt *et al*, (2016) researched the structure of the industry and what type of businesses were successful missing the advantages and disadvantages to adoption. Shahzad, Mbachu and Domingo (2015) reviewed 66 completed projects to assess their performance in New Zealand, however, this work did not look at the barriers to adoption. Lou and Guo (2020) only focused on costs for projects in China.

Based on the potential for efficiency gains and risk reduction in an industry that carries such a large profitability this research aims to identify the existing benefits and barriers to offsite

construction to help inform why the adoption rate is so low in some regions and not in others. The construction market value is there and has remained very stable, which also begs the question why disruption is not more prevalent within this sector. Thus, this paper seeks to undertake a systematic review of current literature studies and further answer the following set of research questions:

RQ1. What is the current knowledge surrounding the barriers adoption of offsite construction?
RQ2. What is the current understanding of the benefits to offsite construction?

METHOD

Several types of literature review can be identified in the existing knowledge. According to Clark et al. (2021), narrative review and systematic review are the main types of literature review. When compared with narrative review, systematic review provides comprehensive and rigorous analysis of the existing knowledge on a selected topic (Tranfield et al., 2013). This research method has been used to analyse the existing knowledge on apprenticeship (Daniel et al., 2020) and public private partnership (Tang et al., 2010), among others. In the current research, the systematic review was done in three stages. The initial stage identified the key papers of interest based on a database search of Scopus. The second stage involved limiting relevant and excluding irrelevant information in the search criteria. The final stage was conducted by reviewing the content and analyzing for relevance against the research aims and objectives.

Based on the research questions, a list of key terms was identified for the literature search. The shortlisted terms were further analyzed to identify additional words commonly used in different geographic regions. For example, 'Offsite' is used in the UK as supposed to Malaysia where the use of "Industrialized" is more common. The initial search data set was used as a scoping study to identify other key words that may appear on additional studies that would be otherwise excluded from the search criteria.

The research team decided to remove conference papers due to limited online access. The journal papers included in the study's sample have been peer reviewed and this process validates the findings emerging from those studies. The benefit of secondary research is that the breadth of data available is very extensive compared to a limited primary research approach. By accessing Primary sources, the intent is to access the original research into the field and by focusing on peer reviewed journals the quality will be controlled. The roman emperor and philosopher, Marcus Aurelius had a similar thought when in 160 he said:

"Nothing has such power to broaden the mind as the ability to investigate systematically and truly all that comes under thy observation in life"

Scopus database was selected as it contains the largest abstract database of peer-reviewed literature. With multiple search criteria options it is very useful in identifying the key studies of focus as these primary sources of information are updated on a regular basis. A potential limitation of the study is the use of only Scopus as the research database and may miss some research studies as a result that are available on other databases. The thinking in only selecting Scopus was to limit study duplication and potential over complication of the research data by trying to work through multiple databases simultaneously. Google Scholar was rejected as it is not a database and would not allow for a systematic review of the available literature. The use if Google Scholar would require a labour-intensive manual approach that was rejected as the research method due to the time required and lack of repeatability. Web of science was rejected based on the initial number of studies returning 705 studies compared to 1,963 with Scopus. It was determined that Scopus cast a wider net initially therefore offering a larger research body as a basis.

("offsite construction" OR "off-site construction" OR "off site construction" OR "offsite Manufacturing" OR "off-site Manufacturing" OR "off site Manufacturing" OR "offsite Manufacture" OR "off-site Manufacture" OR "off site Manufacture" OR "offsite fabrication" OR "off-site fabrication" OR "off site fabrication" OR “Prefabrication” OR "Pre-fabrication "OR "Modern Methods of Construction" OR “Lean Construction” OR “Industrialized Buildings” OR ”Modular Construction” OR “Modular Building”) AND (“Barrier” Or “Benefit*”OR “Popular” OR ”adoption”)

The first stage generated a total of 1,963 potentially relevant studies based on the database search. After limiting the results to those available in English, Journal articles and duplicates a total of 238 studies were reviewed by subject area, title. This process was relatively simple to undertake and weeded out several irrelevant studies. For titles that were not as clear or abstracts that answered part of the research focus a more detailed review of the abstracts was required leaving 141 studies. Following the abstract review, a total of 69 studies were deemed to be potentially relevant and required a full text review including introduction, findings and conclusions.

Upon finalizing the screening process, the remaining research left 28 studies that required a full content analysis. Once confirmation against the research aims and objects were confirmed the list was finalized in SCOPUS to create a bibliography. Further data relating to country of origin, guiding themes contained within the literature for (1) benefits of offsite construction (2) Barriers to adoption.

RESULTS

Literature map on the Emerging Themes of Offsite Construction		
Benefits		**Barriers**
Higher quality		**Lack of knowledge of efficient delivery**
Tam et al 2006; Blismas, pasquire & Gibb 2007; Si et al. 2021; Goodier & Gibb 2007; Zhang, Skitmore, Peng. 2014; El-Abidi et al 2019: Li 2020; Goodier et al, 2019: Cerro. 2021		Popovic, Elgh & Heikkinen, 2021; Shahzad, Mbachu, Domingo. 2015: Mossman, Sarhan. 2021; Sutrisna, Goulding, 2019; Jabar et al, 2019: Goodier, 2019
Shorter schedule		**Higher Cost**
Tam et al 2006;Blismas, pasquire & Gibb 2007; Goodier & Gibb 2007; Si et al. 2021; Zhang, Skitmore, Peng. 2014; El-Abidi et al 2019; Shahzad, Mbachu, Domingo. 2015; Peltokorpi et al, 2018; Li 2020: Goodier et al, 2019: Cerro. 2021		Pan, Gibb & Dainty; 2007; Lou and Guo 2020; Blismas, pasquire & Gibb 2007; Goodier & Gibb 2007; Jang, Ahn, Roh. 2022
Reduced costs		**Social Perception**
Tam et al 2006; Saad et al. 2021; El-Abidi et al 2019; Shahzad, Mbachu, Domingo. 2015; Mossman, Sarhan. 2021: Cerro. 2021		Saad et al. 2021; Shahzad, Mbachu, Domingo. 2015
Waste reduction		**Different design process**
Tam et al 2006; Blismas, pasquire & Gibb 2007; Si et al. 2021; Loizou et al 2021: Cerro. 2021		Tam et al 2006; Pan, Gibb & Dainty; 2007; Zhang, Skitmore, Peng. 2014; Popovic, Elgh & Heikkinen, 2021
Health and safety		**Availability of multiskilled labour**
Blismas, pasquire & Gibb 2007; Zhang, Skitmore, Peng. 2014; El-Abidi et al 2019: Goodier et al, 2019		Goodier & Gibb 2007; Zhang, Skitmore, Peng. 2014; El-Abidi et al 2019; Arashpour et al 2014

		Complex supply chain
		Sooriyamudalige et al, 2020

Figure 1. Literature map on the Emerging Themes of Offsite Construction

The benefits and barriers to adoption from the systematic review have been placed to represent the common findings in the Literature Map as shown in Figure 1. There are contrasting views across the study, interestingly the researchers are more aligned on the benefits based on the tighter grouping and more succinct topics when compared with more sporadic points on the barriers to adoption.

RQ1. What is the current knowledge surrounding the barriers to adoption of offsite construction (globally)?

The biggest barriers to adoption are knowledge, higher cost, perception, design, lack of skilled labour and complexities in supply chain.

Knowledge on how to identify the risks of offsite construction and apply the learnings to meet the business objectives is required to increase the rate of adoption (Peltokorpi, 2017). The existing knowledge as it pertains to onsite delivery does not apply in the same way as the entire approach in project execution is different from design, fabrication, transportation, and site installation (Peltokorpi, 2017). Education specifically on the following areas: in first selecting the appropriate delivery methodology based on project goals, design suitable for manufacturing reducing turbulence, robust project execution planning with an understanding on risks mitigation strategies, integration of supply chain earlier in design to reduce the introduction of complexity and lastly procurement strategies to align with project objectives.

Pre-construction requires more upfront skilled labour in design due to the complexities that need to be solved earlier in the process than compared to onsite building (Navaratnam et al, 2019). This is partly driven by the requirement to order long led items earlier in the process and in part due to the design needing to be more complete earlier for design freezes to be in place prior to fabrication.

Supply chain integration focuses on the flow of materials from suppliers to the site on time for the work to commence and providing value across the interrelated business (Sooriyamudalige et al, 2020). In onsite construction this is a well-established process for mature general contractors. Offsite construction however follows a different network, in most cases, of unfamiliar supply chain suppliers in the form of skilled design practitioners, fabricators and installers (Sooriyamudalige et al, 2020). By a conventional site builder to integrate offsite construction it is fair to deduce an entirely new supply chain will be required to deliver the project. First, understanding of the complex supply chain is a barrier to adoption of offsite construction and secondarily the knowledge of how to plan and implement the delivery approach to avoid delays is lacking. Regionality has an impact on the research findings specifically in the complexities in the local supply chain, regulatory processes, and government incentives country to country (Sooriyamudalige et al, 2020; Zhang, Skitmore and Peng, 2014).

Tam et al (2017) found that inflexibility for change in design scored the highest challenge in their study and happened to be derived from previous project experience whereby the design was not frozen and doing so caused the consultant and client team frustration in unmet goals. Design happens earlier in the process for offsite construction and requires an early integration of stakeholders including manufacturers and suppliers all leading to a long lead into the construction process (Pan, Gibb and Dainty, 2007). Changes in design that happen later in the fabrication process can be more costly than conventional construction which may also be linked. Furthermore, understanding some of the barriers to adoption specifically around complex supply chains and lack of knowledge may also be driving costs up in some projects.

Prefabrication is not new and with that comes preconceived ideas of how the building approach will influence the project outcomes based on past experiences and dated connotations from the post war reconstruction (Shahzad, 2015).

RQ2. What is the current understanding of the benefits to offsite construction?

The benefits to offsite construction, that are widely supported, include a reduction in schedule and higher quality. Additionally, a reduction in costs, wastage and improved safety round out the remaining findings.

Pre-fabricated buildings are constructed in controlled environments out of the weather conditions leading to a higher quality of build than compared to onsite construction (Shahzad, Mbachu and Domingo, 2015). Inside fabrication facilities technology can be deployed to increase the accuracy of material processing, reducing waste and improve built quality (Cerro, 2021). Due to the fragmented construction approach with buildings being constructed separately to the site allowing progression of both entities the progress at the same construction times can be reduced if both the manufacturing and the site maintains the as planned schedule (Si et al, 2021). Si et al (2021) goes on to identify a potential contracting strategy to help financially incentivize on time completion, in reality it would be very hard to integrate a new contracting method that is not normalised in the industry.

Shahzad, Mbachu and Domingo (2015) connotes a reduction in cost and schedule savings with conventional construction taking longer than offsite therefore indicating a lower cost for prefabricated buildings. The softer benefits of health and safety appear to be less relevant as a primary driver for winning work based on how larger contracts are awarded and tendered. Safety is perceived as a baseline opposed to a tangible differentiator like faster completion or lower cost.

DISCUSSION

Pan *et al* (2007) interviewed the top 100 performing home builders in the UK and found the majority of stakeholders are satisfied with traditional construction methods and furthermore the drivers for building methodology are tied to the historic considerations for contractors. When considering if a construction scheme will proceed with traditional onsite or prefabrication methods contractors typically make decisions based on schedule, cost, quality, and productivity. Pan *et al* (2007) study did not differentiate between actual stakeholder experiences or if the responses were based on perception. The drivers for decision making are important in understanding which of the benefits, and barriers are most relevant to the broader industry to determine if the barrier is a result of an actual route cause issue that needs to be solved or based on a preconceived perception because the remedies are different for each outcome.

BENEFITS

Schedule efficiencies are gained due to the fragmented delivery whereby the site progresses in the same sequence as conventional methods and the offsite components are manufactured at a factory simultaneously before being put together at site (Arashpour *et al*, 2014). This can result in schedule efficiency over that of site-built projects due to a reduction in time onsite with up to 34% in time savings (Shahzad, Mbachu and Domingo, 2015). ***Shorter schedule*** is thought to be the largest benefit of prefabrication compared with traditional construction (Tuesta *et al,* 2022), this point is supported by nine of the thirteen contractors surveyed by Goodier and Gibb (2007) in their contribution *The research into the future opportunities for offsite in the UK.* Goodier Gibb (2007) used their previous studies in the literature review, this could have led to bias in towards the findings of this later research being influenced by outdated findings and missing current thinking. The incorporation of prOSP (pre curser to Buildoffsite) would help

answer the question as to the future opportunity of prefabrication in the UK construction industry but is unlikely to offer a balanced view due to the pro-offsite nature of the body. The inclusion of a sub section of stakeholders including clients, construction industry, offsite fabricators lend to a triangulation of opinions on the same perceived benefit adding further credibility to the results.

Offsite construction is bound by the same building codes as onsite construction and uses the same certified design professionals in the process. As such assembled buildings are virtually indistinguishable from their on-site counterparts (Chen et al, 2019). On site construction by contrast can experience variable environments with inclement weather conditions challenges with quality forcing rework and labour constraints for specialist trades (Arashpour et al, 2014). Due to offsite buildings being constructed in a factory setting, where the conditions are controlled and the skilled work force is performing repeatable tasks, a consistent and **higher quality** of fabrication can be produced (Jang, Ahn and Roh, 2022). None of the research challenged the quality of the offsite process therefore it may be surmised the body of knowledge agrees that quality is better when factory produced.

Extensive research has been conducted into the **cost impact** of offsite delivery to project budgets. It is reported to reduce costs derived from shorter schedule and more efficient use of labour. However, there can be an increase in material costs, for example the doubling up of interior walls in volumetric deliveries or shipping walls that are then disposed of once the components reach the site. It is expected that even with the increase in material for building completion the cost is offset against material wastage from onsite building due to inclement weather and mistakes. For the cost benefit to be realized the labour on the project needs to be managed effectively and any impacts of material costs to be reduced (Loizou et al. 2021).

It is important to recognize the delivered cost of a project not just the initial price since prefabrication can deliver a higher quality with less wastage and a significant reduction in snags or defects at the close out stage offering a potential lower end cost (Goodier and Gibb, 2006). Modular construction costs in Singapore are reported to be higher than site built concrete construction as much as increase of 8.1% (Jang, Ahn and Roh, 2022), however only one direct comparison was used as a comparison with a steel delivery. If a more robust process was used to evaluate the multiple solutions, there may have been a potentially different outcome for example that case study used would have likely been delivered through wood framing in North America.

Offsite construction, no matter which form, requires a different design approach than compared with traditional methods. The more complex the project and delivery methodology chosen has a direct correlation to the amount of specialized knowledge experts, sub consultants and inextricably the time it takes in predesign **increasing costs** (Navaratnam et al, 2019). Largely these costs can be offset by the time savings when moving into production and a shorter duration of occupancy.

The **environmental** benefits of not using wet construction methods in some forms of prefabrication prove beneficial in diverting waste from land fill. (Cerro, 2021). Global construction activities produce approximately 25% of all solid waste, with 40% of material in landfills as a result of construction activities. (Loizou et al, 2021). To fully understand the environmental benefits of modular, more recent studies have elected to review the full life cycle assessment (LCA) to better determine the impact (Jang, Ahn and Roh, 2022). Life Cycle assessments when using conventional process do not reduce the margin of error to an acceptable level in part due to the complexity and diversity of the supply chain (Aye et al, 2012). This has led to an absence of detailed research in environmental performance to substantiate the environmental benefits as it pertains to prefabrication.

Social sustainability covers the wellbeing people get from the places in which they reside and work. Recent research indicated the offsite construction is a **less hazardous environment**

and is more controllable with a reduction in injuries and less onsite noise (Loizou et al, 2021). The fabrication process can be louder, but this is often in industrial estates having a lower impact on the community. Li et al (2010) argues that due to the size of prefabricated components the risk profile on sites can increase creating a more hazardous environment to work in but does not provide evidence to support or a methodology for the research conducted and does not consider the vertical integration of trades in the precast industry like Steinhardt et al. (2019). Due to less time onsite prefabrication reportedly has less safety risks by default. (Blismas, Pasquire and Gibb, 2007; Zhang, Skitmore and Peng, 2014; El-Abidi et al, 2019; Goodier et al, 2019).

BARRIERS

Tam (2007) found that **inflexibility for change in design** scored the highest challenge and happened to be derived from previous project experience whereby the design was not frozen and doing so caused the consultant and client teams frustration in unmet goals (Tam *et al*, 2007). The research method in this case included a survey based on a literature review to identify the key areas to be graded as benefits and barriers. The author covered a broad base of stakeholders but did not disclose how many of the respondents were represented in the study results making it challenging to assess the validity of the results.

Design happens earlier in the process for offsite construction and requires an early integration of stakeholders including manufacturers and suppliers all leading to a **long lead** into the construction process. (Pan, Gibb, and Dainty, 2007).

A significant choking point in the delivery of offsite construction in China is related to the inefficiency of **Supply chain**. The trades are complex and disjoined in their approach leaving coordination to be challenging. Unlike more developed countries with mature supply chain and standardized construction programs (Zhang, Skitmore and Peng, 2014). Compared to the UK where there is a standardized building system, by comparison, the supply chain limitations inhibit the design community adoption of offsite construction (Pan, Gibb and Dainty, 2007).

Aside from the benefits associated with offsite construction, the industry is still dogged by some of the same challenges as onsite construction, in terms of inefficient prefabrication methodologies. These inefficiencies are caused by dispersed and often **lack the coordination** to prevent work starvation (Arashpour et al, 2014). Most factories are set up in a linear fashion whereby each station is trained to perform one task. When inefficiency is found a bottle neck can be created when oversubscribed tasks take longer to perform than others. The more efficient a building can be constructed in a factory setting the better the flow and less turbulence it generates. Construction by nature contains a high degree of **turbulence**. The degree to which the prefabrication encounters turbulence due to the variation in dimensions, material selections, transportation requirements can degrade the fabrication system (Mossman and Sarhan, 2021).

Offsite construction uses a different supply chain and requires in-depth understanding by **skilled labour** of how the buildings are designed, built, moved and interface with the site. There are a limited number of professionals with this skill set today (Sooriyamudalige et al, 2020).

Si et al (2021) suggests that the challenges faced with **inefficient communication** caused by a fragmented delivery process whereby work and onsite are controlled differently can be resolved by realigning the contract terms whereby if the factory causes a delay they are penalized and where the General contractor allows a production schedule that favors the factory, they are incentivized. This appears to be a complicated solution that most stakeholders will not be familiar with. Where there is a stakeholder lack of understanding this approach may lead to further complications as it doesn't align with traditional construction procurement practices (Daniel et al, 2018).

Perception within the market has a negative impact on the adoption rate whereby past experiences have not been positive or concerns with quality from industry examples in past eras influence decision of today. The lack of flexibility in the design, typically being limited to the builders pre-determined designs (Shahzad, Mbachu and Domingo, 2015) contributes to the decision of conventional builds.

Knowledge Typically Suppliers (30%) believe their customers are not fully educated on the benefits and barriers for offsite construction compared with the designs (73%) and Builders (54%) who believe they are fully aware (Goodier and Gibb, 2007). Traditional construction experience and understanding how the offsite approach of choice works is a knowledge gap that needs to be closed to have a better adoption rate of prefabricated construction (Goodier and Gibb, 2007).

Summary

Global perspectives help to inform the potential benefits and barriers to adoption. The local supply chain, government involvement, knowledge and perceptions all have an impact on the potential outcomes of the project success with an offsite delivery. A gap in the research is: *What knowledge is required effectively to deliver offsite construction in Canada leading to more desirable outcomes?*

CONCLUSION

This research sets out to identify the benefits, and barriers to adoption for offsite construction. Based on the qualitative analysis of this study it can be concluded that efficiency can be improved when the benefits of higher quality and improved schedule are realized when compared to conventional construction. The barriers are largely around design and understanding of how to work within an offsite delivery process whereby design is frozen earlier. When the design is not efficient for the fabricator it impacts the project line flow and has a knock-on impact to cost and schedule. This research found a lack of knowledge, specifically in design for manufacturing, interfacing between onsite and offsite works, understanding the supply chain and how to mitigate the complexities create further barriers to adoption.

The results of this research provide relevant industry stakeholders with the identification of benefits, and barriers to adoption of offsite construction. By understanding the barriers adoptees can effectively plan mitigation strategies to avoid issues with design freezes and potential cost increases. Recognizing the barriers to adoption will inform potential objections from partners that may need to be overcome to progress with an offsite delivery and help to inform new supply chain strategies.

This study was limited to using Scopus database only, as such the use of more databases could have provided richer evidence.

The findings confirm that there is a gap of knowledge in Canada, to better understand the implication from the results a future study could answer questions of; stakeholder knowledge, how to interface effectively between the fabrication and onsite works and what influence the local supply chain complexities have upon the delivery methodology. Based on this evidence it is recommended that an empirical study be conducted in the specific geographical region of Canada to capture the intricacies of local supply chain based on the limited research into this region specifically to interrogate the findings locally. By using a cross section of the industry including design consultants, fabricators, contractors, and customers would better allow to differentiate between lived experience and perception in the study and focus on the knowledge gaps that exist to better provide specific solutions.

REFERENCES

Arashpour, M., Wakefield, R., Blismas, N. and Minas, J., (2015). Optimization of process integration and multi-skilled resource utilization in off-site construction. Automation in Construction, 50(C), pp. 72-80.

Blismas, N., Pasquire, C. and Gibb, A., (2006). Benefit evaluation for off-site production in construction. Construction Management and Economics, 24(2), pp. 121-130.

Cerro, C., (2021). Future of dwelling: the advantages of prefabrication in alleviating the residential crisis. Wit Transactions on Ecology and the Environment, 253, pp. 383-396.

Clark, T., Foster, L., Bryman, A. and Sloan, L. (2021). Bryman's social research methods. Oxford University Press.

Daniel, E. I., Oshodi, O. S., Gyoh, L. and Chinyio, E. (2020). Apprenticeship for craftspeople in the construction industry: a state-of-the-art review. Education+Training, 62(2), pp. 159-183.

Daniel, E.I, Pasquire, C., Dickens, G. and Marasini, R (2018). "Empirical study on the influence of procurement methods on Last Planner® System implementation in construction project." In: Proc. 26 th Annual Conference of the International. Group for Lean Construction (IGLC), González, V.A. (ed.), Chennai, India, pp. 681–690. DOI: doi.org/10.24928/2018/0398 Available at: www.iglc.net.

El-Abidi, K.M.A., Ofori, G., Zakaria, S.A.S., Mannan, M.A. and Abas, N.F., (2019). Identifying and Evaluating Critical Success Factors for Industrialized Building Systems Implementation: Malaysia Study. Arabian Journal for Science and Engineering, 44(10), pp. 8761-8777.

Goodier, C. and Gibb, A., (2007). Future opportunities for offsite in the UK. Construction Management and Economics, 25(6), pp. 585-595.

Goodier, C., Gibb, A., MancinI, M., Turck, C., Gjepali, O. and Daniels, E., (2019). Modularisation and offsite in engineering construction: An early decision-support tool. Proceedings of the Institution of Civil Engineers: Civil Engineering, 172(6), pp. 3-14.

Jang, H., Ahn, Y. and Roh, S., (2022). Comparison of the Embodied Carbon Emissions and Direct Construction Costs for Modular and Conventional Residential Buildings in South Korea. Buildings, 12(1),.

Loizou, L., Barati, K., Shen, X. and Li, B., (2021). Quantifying advantages of modular construction: Waste generation. Buildings, 11(12),.

Lou, N. and Guo, J., (2020). Study on Key Cost Drivers of Prefabricated Buildings Based on System Dynamics. Advances in Civil Engineering.

Marte Gómez, J.A., Daniel, E.I., Fang, Y., Oloke, D. and Gyoh, L. (2021). "Implementation of BIM and Lean construction in offsite housing construction: evidence from the UK" Proc. 29 th Annual Conference of the International Group for Lean Construction (IGLC29), Alarcon, L.F. and González, V.A. (eds.), Lima, Peru, pp. xx–xx, doi.org/10.24928/2021/0122, online at iglc.net.

McKinsey and Company (2020) *The next normal in construction: how disruption is reshaping the world' s largest ecosystem.* McKinsey and Company

Modular building institute (2021) *Permanent Modular Construction Report*. Charlottesville: Modular Building Institute

Mossman, A. and Sarhan, S., (2021). Synchronising off-site fabrication with on-site production in construction. Construction Economics and Building, 21(3), pp. 122-141.

Navaratnam, S., Ngo, T., Gunawardena, T. and Henderson, D., (2019). Performance review of prefabricated building systems and future research in Australia. Buildings, 9(2),.

Pan, W., Gibb, A.F. and Dainty, A.R.J., (2007). Perspective of UK housebuilders on the use of offsite modern methods of construction. Construction Management and Economics, 25(2), pp. 183-194.

Peltokorpi, A., Olivieri, H., Granja, A.D. and Seppänen, O., (2017). Categorizing modularization strategies to achieve various objectives of building investments. Construction Management and Economics, 36(1), pp. 32-48.

Shahzad, W., Mbachu, J. and Domingo, N., (2015). Marginal productivity gained through prefabrication: Case studies of building projects in Auckland. Buildings, 5(1), pp. 196-208.

Si, T., Li, H.X., Lei, Z., Liu, H. and Han, S., (2021). A Dynamic Just-in-Time Component Delivery Framework for Off-Site Construction. Advances in Civil Engineering, 2021.

Sooriyamudalige, N., Domingo, N., Shahzad, W. and Childerhouse, P., (2020). Barriers and enablers for supply chain integration in prefabricated elements manufacturing in New Zealand. International Journal of Construction Supply Chain Management, 10(1), pp. 73-91.

Steinhardt, D., Manley, K., Bildsten, L. and Widen, K., (2020). The structure of emergent prefabricated housing industries: a comparative case study of Australia and Sweden. Construction Management and Economics, 38(6), pp. 483-501.

Sutrisna, M. and Goulding, J., (2019). Managing information flow and design processes to reduce design risks in offsite construction projects. Engineering, Construction and Architectural Management, 26(2), pp. 267-284.

Tam, V.W.Y., Tam, C.M., Zeng, S.X. and Ng, W.C.Y., (2007). Towards adoption of prefabrication in construction. Building and Environment, 42(10), pp. 3642-3654.

Tang, L., Shen, Q. and Cheng, E. W. (2010). A review of studies on public–private partnership projects in the construction industry. International journal of project management, 28(7), pp. 683-694.

Tuesta, R. , Vicuña, M. , Savio, A. A. D. , Palpan, A. , Valle, E. & Quiroz, F. 2022, 'Prefabricated Reinforcement in Construction Using Vdc: Case Study Ovalo Monitor Bridge' In:, *Proc. 30th Annual Conference of the International Group for Lean Construction (IGLC).* Edmonton, Canada, 27-29 Jul 2022. pp 1008-1019

Tranfield, D., Denyer, D. and Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management, 14(3), pp. 207-222.

Zhang, X., Skitmore, M. and Peng, Y., (2014). Exploring the challenges to industrialized residential building in China. Habitat International, 41, pp. 176-184.