Sustainability-Based Barriers to Adopting Offsite Construction in Jordan

Journal:	*Engineering, Construction and Architectural Management*
Manuscript ID	ECAM-04-2025-0601.R2
Manuscript Type:	Original Article
Keywords:	Construction, Architecture, Questionaire survey
Abstract:	

Sustainability-Based Barriers to Adopting Offsite Construction in Jordan

Abstract

Purpose—The paper presents the major barriers to Offsite Construction (OSC) adoption in Jordan from a Triple Bottom Line (TBL) sustainability framework. It also recommends steps to enhance OSC implementation in the Jordanian construction industry.

Design/methodology/approach— A quantitative approach was used to generalise findings and draw conclusions. Exploratory Factor Analysis (EFA) was applied to establish relationships between variables and group them into the proposed components based on 208 valid responses from construction professionals in Jordan. EFA and descriptive statistics using SPSS developed a hierarchy of barriers to OSC adoption.

Findings— The lack of regulations, standards, and incentives, the lack of adequate labourers, and long lead times and time certainty issues were identified as the three most important variables. At the same time, the uncertainty of energy performance was considered the least important variable affecting the Jordanian OSC sector.

Research limitations/implications— Given that the research focused on OSC adoption in the Jordanian construction industry, and the data was collected from Jordan only, the findings are applicable to the Jordanian context only. This exploratory study highlights implications for further investigations into the barriers to OSC adoption in Jordan.

Practical implications— The anticipated outcome is to help practitioners understand the challenges associated with the low adoption of OSC in Jordan. The identified variables and recommendations can guide strategic decisions, including assessments and benchmarking, fostering OSC development in Jordan.

Originality/value— This research identifies barriers to OSC adoption in Jordan and offers unique insights into the variables that hinder OSC uptake from a sustainability perspective.

Keywords: Offsite Construction, Modern Methods of Construction, Prefabrication, Barriers, Sustainability, Jordanian construction industry.

Paper type Research paper

Introduction

The Jordanian construction industry contributes significantly to both the country's social and economic aspects. It employs 68,135 Jordanians and contributed 4.7% of the total Gross Domestic Product (GDP) in 2022, amounting to 261 million JOD (Department of Statistics, 2022; Trading Economics, 2022). However, several problems within Jordan's traditional construction sector cause risks to the industry's three aspects of sustainability: economic, social, and environmental, as they have harmful consequences on natural resources and long-term socioeconomic circumstances. These include the lack of skilled labour and improper use of building materials (Yasin & Rjoub, 2017). Al Assaf (2017) advocated the adoption of sustainable construction methods to enhance the efficiency of the Jordanian construction industry in response to such issues.

OSC is widely acknowledged as a sustainable construction method that addresses the inefficiencies of conventional construction methods. Wuni and Shen (2019) argued that the limitations of traditional methods, including high energy consumption and carbon emissions, are driving the shift towards OSC. In addition, Obi et al. (2023) concluded that OSC's potential for sustainable value creation is vast. Both developed and developing nations are motivated by the benefits of OSC to promote and take the lead in adopting OSC methods. Examples from developed countries include the UK and Australia's promotion efforts, showcasing diverse strategies to promote OSC adoption (Nadim & Goulding, 2011). Meanwhile, Hong Kong's government drives OSC uptake by offering incentives for gross floor area (Tam et al., 2015).

Despite this interest, several countries still need to improve the OSC adoption rates and make the construction sector more sustainable. For instance, Attouri et al. (2022) identified the benefits and barriers to OSC adoption in the French construction sector, where the adoption rate is less than 10%. In Jordan, despite the lack of governmental reports on the status of OSC, it is evident that its adoption

remains minimal (AlBalkhy et al., 2021). These low international adoption rates are likely due to several barriers and challenges, such as design inflexibility (Pan et al., 2007), lack of knowledge and experience (Arif et al., 2012), and lack of environmental awareness (Hu et al., 2019).

Blismas et al. (2005) stated that OSC is impeded by the barriers or the neglect of the benefits. Moreover, Chen et al. (2010) claimed that irrational adoption of OSC leads to change orders, cost overruns, and other significant problems. Although researchers are still looking into the factors that impact the implementation of OSC, a notable gap exists in research concerning OSC in Jordan. Badran et al. (2024) identified the barriers to OSC adoption in Jordan. However, the study did not explore the broader sustainability implications and practical strategies for addressing such barriers. Obi et al. (2023) emphasised that the construction industry has significantly emphasised sustainability to mitigate economic, social, and environmental impacts. Consequently, identifying barriers to OSC adoption in Jordan with a particular emphasis on sustainability considerations becomes crucial for its success. Accordingly, this paper fills the knowledge gap concerning sustainability-based barriers to OSC adoption in Jordan, guided by the TBL theory of sustainability. To achieve this, the paper aims to identify and analyse these barriers and provide practical recommendations, emphasising the importance of addressing them to enhance sustainable practices in the Jordanian construction industry.

Literature Review

Boosting OSC adoption can be achieved through several prerequisites, including the willingness of clients, organisations, and governments (Guribie et al., 2022). Pan et al. (2007) emphasised the importance of the industry's readiness to adopt OSC. While Blismas and Wakefield (2009) asserted that the lack of guidance hinders OSC implementation, the willingness to implement OSC also impacts the decision-making process (Azhar et al., 2013). Agreeing with them, Rahman (2014) found that the construction industry's mindset impacts the willingness to choose OSC, as construction professionals are not trained to think of mass production and modular design paradigms. It can be argued that governments could impact the decision to adopt OSC and enhance OSC promotion through their policies (Mao et al., 2018). In

light of this, it becomes evident that OSC implementation could be promoted through policies, training, and promotion by government agencies and industry bodies.

Barriers associated with OSC are extensively addressed in the existing literature (Attouri et al., 2022; El-Abidi & Ghazali, 2015; Feldmann et al., 2022). For instance, Rahman (2014) found cost-related barriers to be the most influential among 26 validated barriers in the UK and China, including higher initial and total costs. Gan et al. (2018) stressed the significance of influential stakeholders in influencing market and social barriers, including the lack of social acceptance. Nevertheless, the effect of OSC on the environment is considered highly beneficial, and most relevant studies overlooked its environmental barriers. This might be explained by shorter production and construction times when adopting OSC methods (Feldmann, 2022).

Integrating the barriers to OSC with the TBL theory provides a comprehensive understanding of the economic, social, and environmental barriers. Goh et al. (2020) advocated for the TBL theory, stating that it should achieve an optimal balance between the three pillars of sustainable construction. Moreover, the TBL theory was widely employed in construction and OSC-related studies, such as by Kamali and Hewage (2017) in their comparison between modular and traditional construction and Brissi et al. (2021) to cluster the factors affecting the adoption of OSC in the US housing sector. Hence, this holistic approach is crucial to enhancing sustainable practices in OSC and achieving socioeconomic and environmental balance within the OSC industry.

Therefore, this study examines the adoption of OSC in Jordan from the TBL perspective, identifying previously unexplored variables influencing the OSC sector in the country while accounting for the rarely examined environmental barriers. From a synthesis of prior research, 18 barriers were identified and systematically categorised using the TBL theory. These barriers are discussed in the following subsections.

Economic Barriers

Economic barriers focus on cost, productivity, and risk concerns in the OSC industry (Brissi et al., 2021). As the decision to implement OSC is predominantly cost-driven (Blismas et al., 2006), several studies argued that the financial issues of OSC hinder

its adoption, including high initial cost (Nadim & Goulding, 2011), high capital cost (Arif et al., 2012), and cash flow problems (Razkenari et al., 2020). The lack of transportation and storage solutions also increases the cost of implementing OSC. This is attributed to the fact that transportation accounts for 6–11% and sometimes up to 18% of OSC's overall cost (Hong et al., 2018; Lu & Yuan, 2013), in addition to the challenge of locating adequate storage space, particularly in populated areas (Choi et al., 2017).

Design complexities and standardisation issues are also significant economic barriers. OSC process efficiency is impacted by the inability to freeze designs early (Blismas et al., 2005). Pan et al. (2007) maintained that additional management and design considerations result in longer lead times. Rahman (2014) supported this by stating that, in some cases, OSC projects require bespoke designs and freezing designs early to mitigate extensive planning and long lead times. This underscores the importance of thoroughly considering planning and engineering requirements for effective OSC adoption (Wuni & Shen, 2020). Furthermore, the lack of standardisation in some countries is attributed to the lack of design guidance and codes (Gan et al., 2018). Gan et al. (2018) argued that the lack of suppliers, manufacturers, or contractors hinders OSC adoption. This can lead to further logistical and coordination challenges (Pan & Hon, 2020). Bendi et al. (2020) claimed that the availability of OSC manufacturers and suppliers motivates owners to implement it, which affirms the importance of the availability of manufacturing capabilities. Concerning technology, Goulding et al. (2012) emphasised the significance of technology in boosting OSC use. However, the lack of suitable technology and equipment is a significant obstacle to OSC in many nations (Marinelli et al., 2022).

Social Barriers

Social barriers primarily concern the impact of knowledge, quality, labour, and societal issues on the OSC sector (Brissi et al., 2021). Blismas et al. (2006) argued that explaining the added value of OSC to stakeholders is a challenge to OSC adoption. Han and Wang (2018) supported this by declaring that the lack of quality acceptance is an overt barrier in the Chinese OSC industry. However, to enhance OSC adoption, it is essential that all stakeholders share a common optimistic

perspective (Nadim & Goulding, 2011), which is considered a hurdle in countries where the OSC industry is still in its infancy (Bendi et al., 2020). Perspectives on OSC adoption are restricted by scepticism and reluctance to change and innovation. This resistance to change could be explained by the lack of experience and knowledge, with the competency of designers, manufacturers, and contractors' expertise being a crucial success factor (Jung et al., 2021). Although OSC is utilised to improve quality and avoid labour shortages (Jiang et al., 2020), more skilled and educated workers are still needed (Almutairi et al., 2017; Wuni & Shen, 2020). Thus, investing in continuous professional development, training, and collaboration among all parties is essential to overcome change-averseness and ensure successful OSC implementation.

Hwang et al. (2018) affirmed that early collaboration is critical in overcoming barriers to implementing OSC. However, OSC has considerable cooperation challenges because of the fragmentation of the construction industry (Marinelli et al., 2022). The absence of laws and guidelines is another barrier in many countries (Arif & Egbu, 2010; Zhai et al., 2014). Interestingly, some developed countries have successfully overcome this barrier because of their effective strategies and incentives (Oti-Sarpong et al., 2022), with Singapore's explicit policies and legislative encouragement for OSC advancements as an exemplar (Xu et al., 2020).

Environmental Barriers

Stakeholders are still dissatisfied with OSC's environmental benefits (Jayawardana et al., 2023), even though OSC is associated with environmental benefits, such as minimising waste and emissions (Yunus & Yang, 2012). Several barriers that hinder the efforts to achieve these benefits have been identified in past research. For instance, Tam et al. (2007) mentioned a lack of environmental awareness by suggesting that enhancing it will facilitate OSC's future adoption. This is further supported by noting that environmental sustainability awareness affects OSC usage (G. Wu et al., 2019), and its absence impedes green building development (Z. Wu et al., 2019). In addition, the lack of effective waste management strategies hinders OSC adoption as their availability is an OSC key performance indicator (Kamali & Hewage, 2016).

Another environmental challenge is the environmental disruption caused by the transportation of OSC components and materials to the site, leading to congestion and disturbance issues (Jaillon & Poon, 2008), which aggravates by site constraints and access restrictions (Rahman, 2014). The availability of affordable and environmentally friendly materials is also essential (Wuni & Shen, 2020), as it alleviates lead times and high costs. In another study, Wuni and Shen (2020) claimed that OSC's uncertain energy performance is another barrier to its adoption. This supports the argument made by Blismas and Wakefield (2009) that OSC implementation has no impact on Australia's energy ratings.

Overview of the Jordanian Construction Sector and OSC Adoption

Despite the importance of the construction sector in Jordan as one of the key economic drivers, it suffers from productivity degradation and time and cost overruns (Shugran & Ghazali, 2024). Moreover, unlike in developing countries where construction industries benefit from good communication, Jordan's poor communication limit project performance (Suleiman et al., 2023). Persistent financial challenges and cultural resistance further hinder the modernisation and the development of the Jordanian construction sector (Zeadat, 2024). These limitations point to the need for a systemic shift towards more sustainable construction methods like OSC.

OSC is well established for its productivity, efficiency, time, and sustainability advantages (Brissi & Debs, 2023). Although Jordanian strategic plans advocate innovation and OSC to address the challenges in the housing sector (JSF, 2019), the relatively low adoption rate suggests limited effort and commitment from stakeholders. Additionally, several barriers hinder the uptake of OSC in Jordan, including high initial cost and a lack of environmental awareness (Badran et al., 2024). Addressing these challenges requires strategies that balance stakeholder commitment and industry capability to facilitate OSC adoption in Jordan. Therefore, this paper aims to address the gap in knowledge regarding OSC adoption in Jordan, with a specific focus on sustainability-based barriers. Based on the Triple Bottom Line framework, this research will identify and subsequently analyse those economic, social, and environmental barriers that act to impede OSC implementation in Jordan's construction industry. Moreover, this research aims not only to enhance

the understanding of the identified barriers but also to provide practical recommendations for addressing them.

*** INSERT TABLE I HERE ***

Research Methodology

This study follows a positivist epistemology to identify and analyse the sustainability-based barriers to OSC adoption in Jordan. This philosophical position assumes that knowledge can be obtained by rational deduction and quantification. A survey with participants from a variety of stakeholders is the most appropriate approach to draw insightful conclusions about these barriers (Fellows & Liu, 2015). Furthermore, positivism emphasises the use of Likert scale questionnaires to collect quantifiable data, which makes the study quantitative (Dauda et al., 2024). Hence, this research utilised a quantitative approach, enabling precise measurement of the identified variables influencing OSC adoption (Guribie et al., 2022).

After designing the questionnaire, validation was done via piloting before its final distribution. The draft was shared with five respondents from academia and the industry, and a detailed clarification of the research aim was accompanied. ~~Their feedback led to improving the descriptions of the variables~~ This pilot survey was conducted to ensure the relevance and clarity of the questionnaire. Feedback indicated that some items were ambiguous or wordy. For example, separate items addressing long lead times and time certainty were consolidated into a single item to reflect their correlation in practice. Therefore, the item was refined to "Reducing lead times and improving time certainty" to better capture schedule reliability and efficacy. The refinements enhanced the overall flow and clarity of the questionnaire.

Ethical approval for the study was obtained from the relevant institutional committee, and informed consents were secured from all respondents. The questionnaire comprised five sections covering general participant information, economic barriers, social barriers, environmental barriers, and the determinates of OSC adoption. The selection criteria focused on having knowledge or experience in the Jordanian construction sector, and having prior experience in OSC was not mandatory. Similar studies, such as those by Marinelli et al. (2022), chose these requirements based on low OSC adoption rates. Although participants' experience was reported in the

construction industry generally, all participants were familiar with OSC concepts (e.g., precast elements). Therefore, given that OSC in Jordan is still in its infancy, general construction experience served as a reasonable proxy for relevant experience.

A purposive non-probability sampling technique was employed because it was difficult to determine the exact number of construction professionals in Jordan. The snowball sampling technique was used in numerous OSC-related studies due to the global spread and the absence of sampling frames (Guribie et al., 2022; Mao et al., 2018. The impracticability of probability-based approaches in construction research was another factor, which could result in an unreasonably low response rate (Abowits & Toole, 2010). Hence, snowball sampling was the most practical technique to achieve sufficient responses from construction professionals. The questionnaire was administered online to mitigate the biases often associated with in-person surveys. A total of 208 responses were collected from 04/May/2023 to 20/July/2023. The respondents were asked to rate the importance of each indicator in Table 1 on a 5-point Likert scale, ranging from extremely unimportant to extremely important. The demographic profile of the respondents is summarised in Table 2.

***** INSERT TABLE II HERE *****

The data was analysed using SPSS v29. Exploratory Factor Analysis (EFA) was conducted to assess the distribution of the variables among the four proposed factors (i.e., economic barriers, social barriers, environmental barriers, and OSC adoption) as a researcher may determine a specific number of groups based on previous research or theoretical considerations (Hair et al., 2011; Hwang & Choe, 2020; Leeman et al., 2022). Therefore, the researcher forced the number of factors to four and embraced Principal Component Analysis (PCA) and Varimax rotation techniques to perform the analysis. Factor loadings greater than 0.4 indicated significant relationships between the extracted components. Cronbach's alpha, Kaiser-Meyer-Olkin (KMO), and Bartlett Test of Sphericity were employed to assess the reliability of the extracted factors.

Results and Analysis

The four extracted groups in Table 3 explained approximately 65% of the variation. Five variables played multiple roles and contributed to two components, indicating a complex relationship between the foundational concepts. Rahman (2014) attributed the various roles of some barriers to OSC adoption to their interrelations, highlighting the need for a comprehensive and unified approach to address these barriers. Moreover, the five cross-loading variables had communalities above 0.5, leading to disregarding their cross-loading (Kim & Im, 2023). Thus, these variables are not independent but have similarities corresponding with these unique elements.

***** INSERT TABLE III HERE *****

Cronbach's alpha test was performed to assess the reliability of the components. With a minimum value of 0.779, the four components were considered to have acceptable to excellent internal consistency (George & Mallery, 2019). KMO and Bartlett Test of Sphericity were also conducted to examine the correlations among variables and their occurrence (Hair et al., 2018). A KMO value closer to one and the significance of the Bartlett Test of Sphericity indicate that a highly reliable scale is present. The results of these tests are summarised in Table 4.

***** INSERT TABLE IV HERE *****

After the exploratory factor analysis, the descriptive statistics for the variables analysed are presented in Table 5. These results include the number of respondents, as well as the mean and standard deviation. The analysis indicates that the most significant variable is the 'Lack of regulations, standards, and incentives' (mean = 4.09). Additionally, the lowest mean score is 3.77, which indicates that all variables are considered important in the context of OSC in Jordan.

***** INSERT TABLE V HERE *****

Discussion

The literature review and data analysis revealed the key barriers significantly influencing the adoption of OSC. The factor analysis rearranged the 23 variables based on the TBL of sustainability theory into four predefined groups: OSC adoption,

economic barriers, social barriers, and environmental barriers. The 23 variables are grouped as shown in Figure 1.

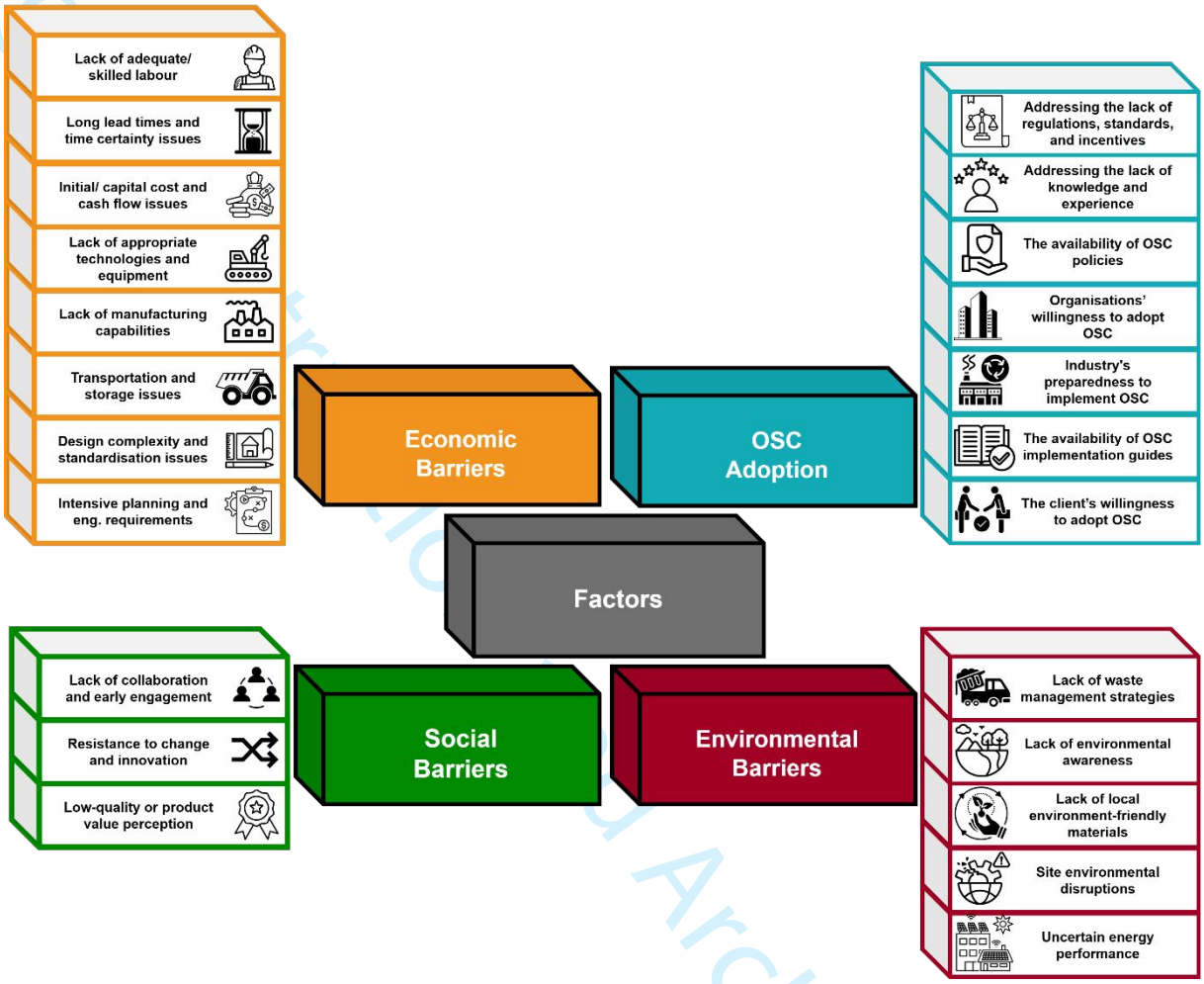

Figure 1: Results of Factor Analysis

Economic Barriers

The first factor, named economic barriers, has eight barriers. The initial/capital cost and cash flow issues barrier is considered a substantial barrier to OSC adoption in Jordan. One reason for this is the interdependency of construction sectors with countries' financial aspects (Dabirian et al., 2023). This is also closely linked to the complexity of decision-making and the extensive planning and engineering requirements. Another economic barrier is the intensive planning and engineering requirements that are intertwined with social barriers and concerns about integration and early engagement of all parties. This is supported by Gibb and Isack (2003), who asserted that OSC might not be effective without the early engagement of the suppliers and design freeze. This means that addressing the economic barriers

requires a comprehensive approach that integrates both economic and social challenges.

Another important economic aspect is the late freezing of design, which is integral to the design complexity and standardisation issues barrier. This is because it can then result in client satisfaction and trust issues. This confirms that freezing design early is a considerable advantage of OSC (Tam et al., 2007). This is crucial in the Jordanian context, as design changes are significantly affected by client requirements and design errors (Gharaibeh et al., 2020). The design time and design freezing sub-variables also correlate with the long lead times and time certainty issues barrier, as OSC has different relationships and concurrencies between construction activities compared to traditional construction methods. Wuni and Shen (2019) reported similar findings when they found that the design variable is highly correlated with time and quality variables. Hence, addressing design-related barriers ultimately leads to more accurate project timelines and improves OSC outcomes.

The lack of manufacturing capabilities also adds to the economic group of barriers. Establishing manufacturing capabilities requires significant investment and evidence of achieving economies of scale. Another reason for the lack of manufacturing capabilities is the lack of appropriate technologies and equipment, as implementing OSC methods requires a sophisticated integration of various technologies and manufacturing techniques (Goulding et al., 2023). In Jordan, this is closely linked to the slow technological adoption, as the country lacks experience and is suffering from high training and software costs (Hyarat et al., 2022). Moreover, transportation and storage issues exacerbate the integration of technologies and manufacturing techniques by restricting the dimensions of the transported elements and the ability to store them. This is particularly common in developing countries, where logistical solutions are more challenging (Jiang et al., 2018). Therefore, investments in advanced technologies and strategic planning are essential for addressing logistical challenges, particularly in developing countries.

Furthermore, although OSC is well-known for addressing labour shortage issues, the lack of adequate labour compounds challenges to adopting OSC. This is because OSC demands more expertise from workers than traditional construction methods (Almutairi et al., 2017). This considerably constraints timelines and productivity rates,

affecting projects' total costs. Hence, adopting a strategic approach to optimising resource allocation and streamlining processes in Jordan's OSC landscape is essential to addressing the economic barriers and enhancing sustainability.

Social Barriers

The second factor, social barriers, included three barriers: quality perception, resistance to change, and collaboration issues confronting the OSC sector. The low-quality or product value perception barrier can be attributed to the negative experience left by previously executed OSC projects that were poorly managed. This negative image from past failures makes it more challenging to assess OSC's superiority, contributing substantially to resistance to change and innovation. Addressing these barriers demands well-defined strategies addressing low-value perceptions and a culture of cooperation (Nadim & Goulding, 2011). Furthermore, the literature review suggested that early collaboration would mitigate several barriers to OSC adoption. For instance, Ezcan and Goulding (2022) revealed that a change in the overall mindset is essential for the sustainability of OSC. This is also consistent with that of Thneibat and Al-Shattarat (2021), who found that client support and team environment are key to value management processes in Jordan. Thus, it is imperative to increase stakeholder cooperation and publicise OSC's quality advantages to increase its adoption.

Environmental Barriers

The third factor constitutes environmental barriers. Addressing these barriers to OSC adoption is critical for sustainable development. In this context, the lack of environmental awareness leads to neglecting sustainable practices. On the other hand, boosting such awareness drives OSC markets to be more mature (Yuan et al., 2022). Also, the lack of waste management strategies leads to increased environmental degradation, worsening the adverse environmental impact of construction. While OSC produces a smaller amount of waste compared to conventional on-site construction (Kamali & Hewage, 2017), inadequate waste management strategies can lead to higher disposal expenses and potential environmental damage. These barriers reflect a wider issue in Jordan, where environmental principles are less emphasised in government construction projects

(Ayoub et al., 2023). Therefore, enhancing environmental awareness and implementing effective waste management strategies are essential steps towards fostering a more sustainable and mature OSC market.

The uncertain energy performance calls into question the long-term sustainability efficiency of OSC projects. This finding is consistent with that of Wuni and Shen (2020), who found that the uncertainties about the energy performance of OSC projects are an important technical barrier. Moreover, while the limited availability of local eco-friendly materials increases emissions and transport costs, it can also contribute to site disruptions during OSC activities. Hence, addressing these barriers provides myriad advantages for the Jordanian construction industry, as it can lead to significant economic and social benefits.

OSC Adoption

The fourth factor is OSC adoption, which covers the variables that affect the mindset of the industry in adopting OSC methods. Interestingly, it is deemed that addressing the lack of knowledge, experience, and the lack of regulations, standards, and incentives is a prerequisite to adopting OSC rather than a barrier. This result provides additional support for the perception that knowledge and experience are essential for the efficient management of OSC projects (Ginigaddara et al., 2023; Jang et al., 2021). By recognising these aspects as foundational prerequisites, stakeholders can focus on enhancing other variables, smoothening a sustainable OSC adoption in the Jordanian construction industry. The importance of addressing the lack of regulations, standards, and incentives is further underlined by being the most crucial variable affecting OSC adoption in Jordan.

The other five variables, namely, the client's willingness to adopt OSC, the organisation's willingness to adopt OSC, the availability of OSC policies, the availability of OSC implementation guides, and the industry's preparedness to implement OSC, are in line with previous results (Guribie et al., 2022). In this context, Goulding et al. (2012) emphasised the need to retrain construction professionals and clients to adopt a fresh mindset. Such a new mindset can maximise the potential of realising OSC's advantages and help overcome the challenges associated with its adoption. This demonstrates that creating a proactive

mindset and empowering both professionals and clients with the requisite knowledge and resources are critical to improving OSC adoption in Jordan. As a result, the benefits of OSC can be realised, positioning the sector better to address associated barriers.

Conclusion

This study aimed to identify the barriers to adopting OSC in Jordan through a sustainability-based perspective, employing the TBL sustainability framework. By collecting data from 208 construction professionals in Jordan and applying EFA, the study refined global variables into four context-specific factors: OSC adoption, economic barriers, social barriers, and environmental barriers. These factors illustrate how the pillars of sustainability are shaping the adoption of the OSC in the Jordanian context. A notable finding is that Jordanian construction professionals view addressing the absence of regulations, standards, and incentives, and the absence of knowledge and experience as essential requirements for OSC adoption rather than barriers to it, underscoring a proactive stance within the industry. Moreover, the statistical analysis revealed that the most crucial variable affecting OSC's adoption was the lack of regulations, standards, and incentives. The second and third most important variables were the lack of adequate labour and long lead times and time certainty issues, respectively. Among other variables, the least essential variable was addressing the uncertainty of energy performance.

The research recognises the importance of addressing economic barriers, given the cost-driven nature of construction industry decisions. The results confirm that the economic barriers are the most prevalent sustainability-based barriers to OSC adoption in Jordan. Hence, optimising resource allocation and implementing value management practices are crucial for addressing these barriers. Also, adopting a new mindset that allows for early collaboration between stakeholders to ensure smooth process coordination is key to realising the advantages of OSC and helping address the barriers to its adoption. Furthermore, enabling a culture of early stakeholder collaboration is essential for improving process coordination and leveraging the benefits of OSC, which supports the social component of the TBL framework.

Overall, this research achieves its aim by providing a clear understanding of sustainability-related barriers to OSC adoption in Jordan and by offering practical insights to improve its uptake. The insights gained from this research should assist Jordanian construction organisations in understanding the fundamental requirements for sustainable OSC adoption. The study significantly contributes to the understanding of OSC adoption, as previous research has not identified these factors within the Jordanian OSC sector. Although the findings of this research are significant, its reliance solely on data collected from Jordan limits the generalisability of these findings. Hence, future studies should expand the research to include various geographical contexts and explore additional factors that may impact OSC adoption across different regions. Such an approach would offer a broader understanding of the challenges and opportunities related to OSC, helping to formulate more effective strategies for promoting sustainable construction practices globally.

References

Abowitz, D. A., & Toole, T. M. (2010). Mixed Method Research: Fundamental issues of design, validity, and reliability in construction research. Journal of Construction Engineering and Management, 136(1), 108–116. https://doi.org/10.1061/(asce)co.1943-7862.0000026

Al Assaf, A. (2017). Enhancing transparency and accountability in the public construction sector in Jordan. Integrity and Anti-corruption Commission. Retrieved from http://www.jiacc.gov.jo/documents/9db9c9fe-1706-4113-a13b-63ffb46202cb.pdf.

AlBalkhy, W., Sweis, R., & Lafhaj, Z. (2021). Barriers to adopting lean construction in the construction industry—the case of Jordan. *Buildings*, *11*(6). https://doi.org/10.3390/buildings11060222

Almutairi, Y., Arif, M., & Khalfan, M. M. A. (2017). Development of implementation strategies for offsite construction techniques in the Kingdom of Saudi Arabia. In *Int. J. Business Competition and Growth* (Vol. 6, Issue 1).

Arif, M., Bendi, D., Sawhney, A., & Iyer, K. C. (2012). State of offsite construction in India-Drivers and barriers. *Journal of Physics: Conference Series*, *364*(1). https://doi.org/10.1088/1742-6596/364/1/012109

Arif, M., & Egbu, C. (2010). Making a case for offsite construction in China. *Engineering, Construction and Architectural Management*, *17*(6), 536–548. https://doi.org/10.1108/09699981011090170

Attouri, E., Lafhaj, Z., Ducoulombier, L., & Linéatte, B. (2022). The current use of industrialized construction techniques in France: Benefits, limits and future expectations. *Cleaner Engineering and Technology*, *7*. https://doi.org/10.1016/j.clet.2022.100436

Ayoub, H., Sweis, G., Abu-Khader, W., & Sweis, R. (2023). A framework to evaluate sustainable construction principles in government building projects: the case of Jordan. Engineering, Construction and Architectural Management, 30(9), 4080–4098. https://doi.org/10.1108/ECAM-01-2022-0040.

Azhar, S., Lukkad, M. Y., & Ahmad, I. (2013). An Investigation of Critical Factors and Constraints for Selecting Modular Construction over Conventional Stick-Built Technique. *International Journal of Construction Education and Research*, *9*(3), 203–225. https://doi.org/10.1080/15578771.2012.723115

Badran, H., Arif, M., Alam, M., Alaqad, M., & Islam, R. (2024, June 26). Barriers to Offsite Construction Adoption in Jordan: An Exploratory Factor Analysis. Transforming Construction with Off-Site Methods and Technologies.

Bendi, D., Rana, M. Q., Arif, M., Goulding, J. S., & Sawhney, A. (2020). An off-site construction readiness maturity model for the Indian construction sector. *Construction Innovation*, *21*(1), 123–142. https://doi.org/10.1108/CI-07-2020-0121/FULL/HTML

Blismas, N. G., Pendlebury, M., Gibb, A., & Pasquire, C. (2005). Constraints to the use of Off-site production on construction projects. *Architectural Engineering and Design Management*, *1*(3), 153–162. https://doi.org/10.1080/17452007.2005.9684590

Blismas, N., Pasquire, C., & Gibb, A. (2006). Benefit evaluation for off-site production in construction. *Construction Management and Economics*, *24*(2), 121–130. https://doi.org/10.1080/01446190500184444

Blismas, N., & Wakefield, R. (2009). DRIVERS, CONSTRAINTS AND THE FUTURE OF OFFSITE MANUFACTURE IN AUSTRALIA. *Construction Innovation*.

Brissi, S. G., Debs, L., & Elwakil, E. (2021). A review on the factors affecting the use of offsite construction in multifamily housing in the United States. In *Buildings* (Vol. 11, Issue 1, pp. 1–23). MDPI AG. https://doi.org/10.3390/buildings11010005

Brissi, S. G., & Debs, L. (2023). Principles for adopting offsite construction in design and construction companies focused on multifamily projects in the USA. Engineering Construction & Architectural Management, 31(11), 4308–4329. https://doi.org/10.1108/ecam-03-2022-0262

Chen, Y., Okudan, G. E., & Riley, D. R. (2010). Sustainable performance criteria for construction method selection in concrete buildings. *Automation in Construction*, *19*(2), 235–244. https://doi.org/10.1016/j.autcon.2009.10.004

Choi, J. O., Chen, X. Bin, & Kim, T. W. (2017). Opportunities and challenges of modular methods in dense urban environment. *International Journal of Construction Management*, *19*(2), 93–105. https://doi.org/10.1080/15623599.2017.1382093

Dabirian, S., Ahmadi, M., & Abbaspour, S. (2023). Analyzing the impact of financial policies on construction projects performance using system dynamics. *Engineering, Construction and Architectural Management*, *30*(3), 1201–1221. https://doi.org/10.1108/ECAM-05-2021-0431

Dauda, J. A., Chavan, N. N., Saka, A. B., Ajayi, S. O., & Oyegoke, A. S. (2024). An appraisal of barriers to digitalisation of construction industry in developing countries: perspective from India. International Journal of Construction Management, 1–13. https://doi.org/10.1080/15623599.2024.2362014

Department of Statistics. (2022). *Department of Statistics | Interactive Database*. https://jorinfo.dos.gov.jo/Databank/pxweb/ar/DOS_Database/

El-Abidi, K. M. A., & Ghazali, F. E. M. (2015). Motivations and Limitations of Prefabricated Building: An Overview. *Applied Mechanics and Materials*, *802*, 668–675. https://doi.org/10.4028/www.scientific.net/amm.802.668

Ezcan, V., & Goulding, J. (2022). Offsite Sustainability—Disentangling the Rhetoric through Informed Mindset Change. *Sustainability, 14*(8). https://doi.org/10.3390/su14084606

Feldmann, F. G. (2022). Towards Lean Automation in Construction—Exploring Barriers to Implementing Automation in Prefabrication. *Sustainability*, *14*(19), 12944. https://doi.org/10.3390/su141912944

Feldmann, F. G., Birkel, H., & Hartmann, E. (2022). Exploring barriers towards modular construction – A developer perspective using fuzzy DEMATEL. *Journal of Cleaner Production*, *367*, 133023. https://doi.org/10.1016/j.jclepro.2022.133023

Fellows, R.F. and Liu, A.M. (2015), Research Methods for Construction, John Wiley & Sons, UK

Gan, X., Chang, R., & Wen, T. (2018). Overcoming barriers to off-site construction through engaging stakeholders: A two-mode social network analysis. *Journal of Cleaner Production*, *201*, 735–747. https://doi.org/10.1016/j.jclepro.2018.07.299

Gan, X., Chang, R., Zuo, J., Wen, T., & Zillante, G. (2018). Barriers to the transition towards off-site construction in China: An Interpretive structural modeling approach. *Journal of Cleaner Production*, *197*, 8–18. https://doi.org/10.1016/j.jclepro.2018.06.184

George, D., & Mallery, P. (2019). *IBM SPSS Statistics 26 Step by Step*. Routledge. https://doi.org/10.4324/9780429056765

Gharaibeh, L. G., Matarneh, S. T., Arafeh, M., & Sweis, G. (2020). Factors leading to design changes in Jordanian construction projects. International Journal of Productivity and Performance Management, 70(4), 893–915. https://doi.org/10.1108/IJPPM-08-2019-0412.

Gibb, A. G. F., & Isack, F. (2003). Re-engineering through pre-assembly: Client expectations and drivers. *Building Research and Information*, *31*(2), 146–160. https://doi.org/10.1080/09613210302000

Ginigaddara, B., Gajendran, T., & Beard, C. (2023). A critical review of quantity surveying education in an offsite construction perspective: strategies for up-skilling. *Construction Innovation*. https://doi.org/10.1108/CI-12-2022-0322

Goh, C. S., Chong, H. Y., Jack, L., & Mohd Faris, A. F. (2020). Revisiting triple bottom line within the context of sustainable construction: A systematic review. In *Journal of Cleaner Production* (Vol. 252). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2019.119884

Goulding, J., Arif, M., Ezcan, V., Rankin, J., & Searle, B. (2023). *CIB Global Report-Revisiting Offsite: A New Capability-Driven Research Roadmap for Offsite Design, Manufacturing and Construction*.

Goulding, J., Rahimian, F. P., Arif, M., & Sharp, M. (2012). Offsite Construction: Strategic Priorities for Shaping the Future Research Agenda. *Architectoni.Ca*, *1*(1), 62–73. https://doi.org/10.5618/arch.2012.v1.n1.7

Guribie, F. L., Kheni, N. A., & Sule, M. (2022). Structural equation modeling of the critical driving forces of offsite construction in Ghana. *Built Environment Project and Asset Management*. https://doi.org/10.1108/BEPAM-03-2021-0051

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2018). *Multivariate Data Analysis: An Overview* (8th ed.). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-04898-2_395

Han, Y., & Wang, L. (2018). Identifying barriers to off-site construction using grey DEMATEL approach: case of China. *Journal of Civil Engineering and Management*, *24*(5), 364–377. https://doi.org/10.3846/jcem.2018.5181

Hong, J., Shen, G. Q., Li, Z., Zhang, B., & Zhang, W. (2018). Barriers to promoting prefabricated construction in China: A cost–benefit analysis. *Journal of Cleaner Production*, *172*, 649–660. https://doi.org/10.1016/J.JCLEPRO.2017.10.171

Hu, X., Chong, H.-Y., Wang, X., & London, K. (2019). Understanding Stakeholders in Off-Site Manufacturing: A Literature Review. *Journal of Construction Engineering and Management*, *145*(8). https://doi.org/10.1061/(asce)co.1943-7862.0001674

Hwang, B. G., Shan, M., & Looi, K. Y. (2018). Key constraints and mitigation strategies for prefabricated prefinished volumetric construction. *Journal of Cleaner Production*, *183*, 183–193. https://doi.org/10.1016/j.jclepro.2018.02.136

Hwang, J., & Choe, J. Y. (2020). How to enhance the image of edible insect restaurants: Focusing on perceived risk theory. *International Journal of Hospitality Management*, *87*, 102464. https://doi.org/10.1016/j.ijhm.2020.102464

Hyarat, E., Hyarat, T., & Al Kuisi, M. (2022). Barriers to the Implementation of Building Information Modeling among Jordanian AEC Companies. Buildings, 12(2), 1–18. https://doi.org/10.3390/BUILDINGS12020150.

Jaillon, L., & Poon, C. S. (2008). Sustainable construction aspects of using prefabrication in dense urban environment: a Hong Kong case study. *Construction Management and Economics*, *26*, 953–966. https://doi.org/10.1080/01446190802259043

Jang, J., Ahn, S., Cha, S. H., Cho, K., Koo, C., & Kim, T. W. (2021). Toward productivity in future construction: mapping knowledge and finding insights for achieving successful offsite construction projects. *Journal of Computational Design and Engineering*, *8*(1), 1–14. https://doi.org/10.1093/jcde/qwaa071

Jayawardana, J., Kulatunga, A. K., Jayasinghe, J. A. S. C., Sandanayake, M., & Zhang, G. (2023). Environmental Sustainability of Off-Site Construction in Developed and Developing Regions: A Systematic Review. *Journal of Architectural Engineering*, *29*(2). https://doi.org/10.1061/JAEIED.AEENG-1420

Jiang, R., Mao, C., Hou, L., Wu, C., & Tan, J. (2018). A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation. *Journal of Cleaner Production*, *173*, 225–234. https://doi.org/10.1016/j.jclepro.2017.06.147

Jiang, W., Huang, Z., Peng, Y., Fang, Y., & Cao, Y. (2020). Factors affecting prefabricated construction promotion in China: A structural equation modeling approach. *PLoS ONE*, *15*(1). https://doi.org/10.1371/journal.pone.0227787

JSF. (2019). The Construction & Housing Sector in Jordan: The Challenge of Demand & Supply Alignment & Financing Mechanisms | October 2019.

Jung, S., Lee, S., & Yu, J. (2021). Identification and prioritization of critical success factors for off-site construction using ISM and MICMAC analysis. Sustainability, 13(16). https://doi.org/10.3390/su13168911

Kamali, M., & Hewage, K. (2016). Life cycle performance of modular buildings: A critical review. *Renewable and Sustainable Energy Reviews*, *62*, 1171–1183. https://doi.org/10.1016/J.RSER.2016.05.031

Kamali, M., & Hewage, K. (2017). Development of performance criteria for sustainability evaluation of modular versus conventional construction methods. *Journal of Cleaner Production*, *142*, 3592–3606. https://doi.org/10.1016/j.jclepro.2016.10.108

Kim, J., & Im, I. (2023). Anthropomorphic response: Understanding interactions between humans and artificial intelligence agents. *Computers in Human Behavior*, *139*, 107512. https://doi.org/10.1016/j.chb.2022.107512

Leeman, T. M., Knight, B. G., Fein, E. C., Winterbotham, S., & Webster, J. D. (2022). An evaluation of the factor structure of the Self-Assessed Wisdom Scale (SAWS) and the creation of the SAWS-15 as a short measure for personal wisdom. *International Psychogeriatrics*, *34*(3), 241–251. https://doi.org/10.1017/S1041610220004202

Lu, W., & Yuan, H. (2013). Investigating waste reduction potential in the upstream processes of offshore prefabrication construction. *Renewable and Sustainable Energy Reviews*, *28*, 804–811. https://www.sciencedirect.com/science/article/pii/S1364032113005881

Mao, C., Liu, G., Shen, L., Wang, X., & Wang, J. (2018). Structural Equation Modeling to Analyze the Critical Driving Factors and Paths for Off-site Construction in China. *KSCE Journal of Civil Engineering*, *22*(8), 2678–2690. https://doi.org/10.1007/s12205-017-1705-4

Marinelli, M., Konanahalli, A., Dwarapudi, R., & Janardhanan, M. (2022). Assessment of Barriers and Strategies for the Enhancement of Off-Site Construction in India: An ISM Approach. *Sustainability*, *14*(11), 6595. https://doi.org/10.3390/su14116595

Nadim, W., & Goulding, J. S. (2011). Offsite production: A model for building down barriers A European construction industry perspective. *Engineering, Construction and Architectural Management*, *18*(1), 82–101. https://doi.org/10.1108/09699981111098702

Navaratnam, S., Satheeskumar, A., Zhang, G., Nguyen, K., Venkatesan, S., & Poologanathan, K. (2022). The challenges confronting the growth of sustainable prefabricated building construction in Australia: Construction industry views. *Journal of Building Engineering*, *48*. https://doi.org/10.1016/j.jobe.2021.103935

Obi, L., Arif, M., Daniel, E. I., Oladinrin, O. T., & Goulding, J. S. (2023). Establishing underpinning concepts for integrating circular economy and offsite construction: a bibliometric review. In *Built Environment Project and Asset Management* (Vol. 13, Issue 1, pp. 123–139). Emerald Publishing. https://doi.org/10.1108/BEPAM-01-2022-0009

Oti-Sarpong, K., Shojaei, R. S., Dakhli, Z., Burgess, G., & Zaki, M. (2022). How countries achieve greater use of offsite manufacturing to build new housing: Identifying typologies through institutional theory. *Sustainable Cities and Society*, *76*. https://doi.org/10.1016/j.scs.2021.103403

Pan, W., Gibb, A. F., & Dainty, A. R. J. (2007). Perspective of UK housebuilders on the use of offsite modern methods of construction. *Construction Management and Economics*, *25*(2), 183–194. https://doi.org/10.1080/01446190600827058

Pan, W., & Hon, C. K. (2020). Briefing: Modular integrated construction for high-rise buildings. *Proceedings of the Institution of Civil Engineers: Municipal Engineer*, *173*(2), 64–68. https://doi.org/10.1680/jmuen.18.00028

Rahman, M. M. (2014). Barriers of Implementing Modern Methods of Construction. *Journal of Management in Engineering*, *30*(1), 69–77. https://doi.org/10.1061/(ASCE)

Razkenari, M., Fenner, A., Shojaei, A., Hakim, H., & Kibert, C. (2020). Perceptions of offsite construction in the United States: An investigation of current practices. *Journal of Building Engineering*, *29*. https://doi.org/10.1016/j.jobe.2019.101138

Shahtaheri, Y., Rausch, C., West, J., Haas, C., & Nahangi, M. (2017). Managing risk in modular construction using dimensional and geometric tolerance strategies. *Automation in Construction*, *83*, 303–315. https://doi.org/10.1016/j.autcon.2017.03.011

Shugran, A., & Ghazali, F. (2024). Understanding the effects of variation orders on construction project success: insights from the Jordanian context. International Journal of Construction Management, 25, 519 - 529. https://doi.org/10.1080/15623599.2024.2337238.

Suleiman, A., Almasaeid, H., Hussein, N., & Abahre, J. (2023). Addressing the Causes and Effects of Poor Communication in the Jordanian Construction Industry: A Study on Improving Project Performance. Civil and Environmental Engineering, 19, 156 - 166. https://doi.org/10.2478/cee-2023-0014.

Sun, Y., Wang, J., Wu, J., Shi, W., Ji, D., Wang, X., & Zhao, X. (2020). Constraints hindering the development of high-rise modular buildings. *Applied Sciences (Switzerland)*, *10*(20), 1–20. https://doi.org/10.3390/app10207159

Tam, V. W. Y., Fung, I. W. H., Sing, M. C. P., & Ogunlana, S. O. (2015). Best practice of prefabrication implementation in the Hong Kong public and private sectors. *Journal of Cleaner Production*, *109*, 216–231. https://doi.org/10.1016/j.jclepro.2014.09.045

Tam, V. W. Y., Tam, C. M., Zeng, S. X., & William, C. Y. N. (2007). Towards adoption of prefabrication in construction. *Building and Environment*, *42*(10), 3642–3654. https://doi.org/10.1016/J.BUILDENV.2006.10.003

Thneibat, M. M., & Al-Shattarat, B. (2021). Critical success factors for value management techniques in construction projects: case in Jordan. International Journal of Construction Management, 23(4), 669–678. https://doi.org/10.1080/15623599.2021.1908933

Trading Economics. (2022, September). *Jordan GDP - 2022 Data - 2023 Forecast - 1965-2021 Historical - Chart - News*. https://tradingeconomics.com/jordan/gdp

Wu, G., Yang, R., Li, L., Bi, X., Liu, B., Li, S., & Zhou, S. (2019). Factors influencing the application of prefabricated construction in China: From perspectives of technology promotion and cleaner production. *Journal of Cleaner Production*, *219*, 753–762. https://doi.org/10.1016/j.jclepro.2019.02.110

Wu, Z., Jiang, M., Cai, Y., Wang, H., & Li, S. (2019). What Hinders the Development of Green Building? An Investigation of China. *International Journal of Environmental Research and Public Health*, *16*(17), 3140. https://doi.org/10.3390/ijerph16173140

Wuni, I. Y., & Shen, G. Q. (2020). Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. In *Journal of Cleaner Production* (Vol. 249). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2019.119347

Wuni, I. Y., & Shen, G. Q. P. (2019). Holistic review and conceptual framework for the drivers of offsite construction: A total interpretive structural modelling approach. In *Buildings* (Vol. 9, Issue 5). MDPI AG. https://doi.org/10.3390/buildings9050117

Xu, Z., Zayed, T., & Niu, Y. (2020). Comparative analysis of modular construction practices in mainland China, Hong Kong and Singapore. *Journal of Cleaner Production*, *245*. https://doi.org/10.1016/j.jclepro.2019.118861

Yasin, B., & Rjoub, A. (2017). Standardization in Construction as a Tool to Reduce Cost of Housing for the Low-Income Families in Jordan. *Journal of Civil Engineering and Architecture*, *11*(2). https://doi.org/10.17265/1934-7359/2017.02.005

Yuan, M., Li, Z., Li, X., Li, L., Zhang, S., & Luo, X. (2022). How to promote the sustainable development of prefabricated residential buildings in China: A tripartite evolutionary game analysis. *Journal of Cleaner Production*, *349*, 131423. https://doi.org/10.1016/J.JCLEPRO.2022.131423

Yunus, R., & Yang, J. (2012). Critical sustainability factors in industrialised building systems. *Construction Innovation*, *12*(4), 447–463. https://doi.org/10.1108/14714171211272216/FULL/HTML

Zeadat, Z. (2024). Implementing Sustainable Construction Practices in the Jordanian Housing Industry. Journal of Sustainable Real Estate. https://doi.org/10.1080/19498276.2023.2298554.

Zhai, X., Reed, R., & Mills, A. (2014). Factors impeding the offsite production of housing construction in China: an investigation of current practice Factors impeding the offsite production of housing construction in China: an investigation of current practice. *Construction Management and Economics*, *32*(1–2), 40–52. https://doi.org/10.1080/01446193.2013.787491

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

Sustainability-Based Barriers to Adopting Offsite Construction in Jordan

Abstract

Purpose—The paper presents the major barriers to Offsite Construction (OSC) adoption in Jordan from a Triple Bottom Line (TBL) sustainability framework. It also recommends steps to enhance OSC implementation in the Jordanian construction industry.

Design/methodology/approach— A quantitative approach was used to generalise findings and draw conclusions. Exploratory Factor Analysis (EFA) was applied to establish relationships between variables and group them into the proposed components based on 208 valid responses from construction professionals in Jordan. EFA and descriptive statistics using SPSS developed a hierarchy of barriers to OSC adoption.

Findings— The lack of regulations, standards, and incentives, the lack of adequate labourers, and long lead times and time certainty issues were identified as the three most important variables. At the same time, the uncertainty of energy performance was considered the least important variable affecting the Jordanian OSC sector.

Research limitations/implications— Given that the research focused on OSC adoption in the Jordanian construction industry, and the data was collected from Jordan only, the findings are applicable to the Jordanian context only. This exploratory study highlights implications for further investigations into the barriers to OSC adoption in Jordan.

Practical implications— The anticipated outcome is to help practitioners understand the challenges associated with the low adoption of OSC in Jordan. The identified variables and recommendations can guide strategic decisions, including assessments and benchmarking, fostering OSC development in Jordan.

Originality/value— This research identifies barriers to OSC adoption in Jordan and offers unique insights into the variables that hinder OSC uptake from a sustainability perspective.

Keywords: Offsite Construction, Modern Methods of Construction, Prefabrication, Barriers, Sustainability, Jordanian construction industry.

Paper type Research paper

Introduction

The Jordanian construction industry contributes significantly to both the country's social and economic aspects. It employs 68,135 Jordanians and contributed 4.7% of the total Gross Domestic Product (GDP) in 2022, amounting to 261 million JOD (Department of Statistics, 2022; Trading Economics, 2022). However, several problems within Jordan's traditional construction sector cause risks to the industry's three aspects of sustainability: economic, social, and environmental, as they have harmful consequences on natural resources and long-term socioeconomic circumstances. These include the lack of skilled labour and improper use of building materials (Yasin & Rjoub, 2017). Al Assaf (2017) advocated the adoption of sustainable construction methods to enhance the efficiency of the Jordanian construction industry in response to such issues.

OSC is widely acknowledged as a sustainable construction method that addresses the inefficiencies of conventional construction methods. Wuni and Shen (2019) argued that the limitations of traditional methods, including high energy consumption and carbon emissions, are driving the shift towards OSC. In addition, Obi et al. (2023) concluded that OSC's potential for sustainable value creation is vast. Both developed and developing nations are motivated by the benefits of OSC to promote and take the lead in adopting OSC methods. Examples from developed countries include the UK and Australia's promotion efforts, showcasing diverse strategies to promote OSC adoption (Nadim & Goulding, 2011). Meanwhile, Hong Kong's government drives OSC uptake by offering incentives for gross floor area (Tam et al., 2015).

Despite this interest, several countries still need to improve the OSC adoption rates and make the construction sector more sustainable. For instance, Attouri et al. (2022) identified the benefits and barriers to OSC adoption in the French construction sector, where the adoption rate is less than 10%. In Jordan, despite the lack of governmental reports on the status of OSC, it is evident that its adoption

remains minimal (AlBalkhy et al., 2021). These low international adoption rates are likely due to several barriers and challenges, such as design inflexibility (Pan et al., 2007), lack of knowledge and experience (Arif et al., 2012), and lack of environmental awareness (Hu et al., 2019).

Blismas et al. (2005) stated that OSC is impeded by the barriers or the neglect of the benefits. Moreover, Chen et al. (2010) claimed that irrational adoption of OSC leads to change orders, cost overruns, and other significant problems. Although researchers are still looking into the factors that impact the implementation of OSC, a notable gap exists in research concerning OSC in Jordan. Badran et al. (2024) identified the barriers to OSC adoption in Jordan. However, the study did not explore the broader sustainability implications and practical strategies for addressing such barriers. Obi et al. (2023) emphasised that the construction industry has significantly emphasised sustainability to mitigate economic, social, and environmental impacts. Consequently, identifying barriers to OSC adoption in Jordan with a particular emphasis on sustainability considerations becomes crucial for its success. Accordingly, this paper fills the knowledge gap concerning sustainability-based barriers to OSC adoption in Jordan, guided by the TBL theory of sustainability. To achieve this, the paper aims to identify and analyse these barriers and provide practical recommendations, emphasising the importance of addressing them to enhance sustainable practices in the Jordanian construction industry.

Literature Review

Boosting OSC adoption can be achieved through several prerequisites, including the willingness of clients, organisations, and governments (Guribie et al., 2022). Pan et al. (2007) emphasised the importance of the industry's readiness to adopt OSC. While Blismas and Wakefield (2009) asserted that the lack of guidance hinders OSC implementation, the willingness to implement OSC also impacts the decision-making process (Azhar et al., 2013). Agreeing with them, Rahman (2014) found that the construction industry's mindset impacts the willingness to choose OSC, as construction professionals are not trained to think of mass production and modular design paradigms. It can be argued that governments could impact the decision to adopt OSC and enhance OSC promotion through their policies (Mao et al., 2018). In

light of this, it becomes evident that OSC implementation could be promoted through policies, training, and promotion by government agencies and industry bodies.

Barriers associated with OSC are extensively addressed in the existing literature (Attouri et al., 2022; El-Abidi & Ghazali, 2015; Feldmann et al., 2022). For instance, Rahman (2014) found cost-related barriers to be the most influential among 26 validated barriers in the UK and China, including higher initial and total costs. Gan et al. (2018) stressed the significance of influential stakeholders in influencing market and social barriers, including the lack of social acceptance. Nevertheless, the effect of OSC on the environment is considered highly beneficial, and most relevant studies overlooked its environmental barriers. This might be explained by shorter production and construction times when adopting OSC methods (Feldmann, 2022).

Integrating the barriers to OSC with the TBL theory provides a comprehensive understanding of the economic, social, and environmental barriers. Goh et al. (2020) advocated for the TBL theory, stating that it should achieve an optimal balance between the three pillars of sustainable construction. Moreover, the TBL theory was widely employed in construction and OSC-related studies, such as by Kamali and Hewage (2017) in their comparison between modular and traditional construction and Brissi et al. (2021) to cluster the factors affecting the adoption of OSC in the US housing sector. Hence, this holistic approach is crucial to enhancing sustainable practices in OSC and achieving socioeconomic and environmental balance within the OSC industry.

Therefore, this study examines the adoption of OSC in Jordan from the TBL perspective, identifying previously unexplored variables influencing the OSC sector in the country while accounting for the rarely examined environmental barriers. From a synthesis of prior research, 18 barriers were identified and systematically categorised using the TBL theory. These barriers are discussed in the following subsections.

Economic Barriers

Economic barriers focus on cost, productivity, and risk concerns in the OSC industry (Brissi et al., 2021). As the decision to implement OSC is predominantly cost-driven (Blismas et al., 2006), several studies argued that the financial issues of OSC hinder

its adoption, including high initial cost (Nadim & Goulding, 2011), high capital cost (Arif et al., 2012), and cash flow problems (Razkenari et al., 2020). The lack of transportation and storage solutions also increases the cost of implementing OSC. This is attributed to the fact that transportation accounts for 6–11% and sometimes up to 18% of OSC's overall cost (Hong et al., 2018; Lu & Yuan, 2013), in addition to the challenge of locating adequate storage space, particularly in populated areas (Choi et al., 2017).

Design complexities and standardisation issues are also significant economic barriers. OSC process efficiency is impacted by the inability to freeze designs early (Blismas et al., 2005). Pan et al. (2007) maintained that additional management and design considerations result in longer lead times. Rahman (2014) supported this by stating that, in some cases, OSC projects require bespoke designs and freezing designs early to mitigate extensive planning and long lead times. This underscores the importance of thoroughly considering planning and engineering requirements for effective OSC adoption (Wuni & Shen, 2020). Furthermore, the lack of standardisation in some countries is attributed to the lack of design guidance and codes (Gan et al., 2018). Gan et al. (2018) argued that the lack of suppliers, manufacturers, or contractors hinders OSC adoption. This can lead to further logistical and coordination challenges (Pan & Hon, 2020). Bendi et al. (2020) claimed that the availability of OSC manufacturers and suppliers motivates owners to implement it, which affirms the importance of the availability of manufacturing capabilities. Concerning technology, Goulding et al. (2012) emphasised the significance of technology in boosting OSC use. However, the lack of suitable technology and equipment is a significant obstacle to OSC in many nations (Marinelli et al., 2022).

Social Barriers

Social barriers primarily concern the impact of knowledge, quality, labour, and societal issues on the OSC sector (Brissi et al., 2021). Blismas et al. (2006) argued that explaining the added value of OSC to stakeholders is a challenge to OSC adoption. Han and Wang (2018) supported this by declaring that the lack of quality acceptance is an overt barrier in the Chinese OSC industry. However, to enhance OSC adoption, it is essential that all stakeholders share a common optimistic

perspective (Nadim & Goulding, 2011), which is considered a hurdle in countries where the OSC industry is still in its infancy (Bendi et al., 2020). Perspectives on OSC adoption are restricted by scepticism and reluctance to change and innovation. This resistance to change could be explained by the lack of experience and knowledge, with the competency of designers, manufacturers, and contractors' expertise being a crucial success factor (Jung et al., 2021). Although OSC is utilised to improve quality and avoid labour shortages (Jiang et al., 2020), more skilled and educated workers are still needed (Almutairi et al., 2017; Wuni & Shen, 2020). Thus, investing in continuous professional development, training, and collaboration among all parties is essential to overcome change-averseness and ensure successful OSC implementation.

Hwang et al. (2018) affirmed that early collaboration is critical in overcoming barriers to implementing OSC. However, OSC has considerable cooperation challenges because of the fragmentation of the construction industry (Marinelli et al., 2022). The absence of laws and guidelines is another barrier in many countries (Arif & Egbu, 2010; Zhai et al., 2014). Interestingly, some developed countries have successfully overcome this barrier because of their effective strategies and incentives (Oti-Sarpong et al., 2022), with Singapore's explicit policies and legislative encouragement for OSC advancements as an exemplar (Xu et al., 2020).

Environmental Barriers

Stakeholders are still dissatisfied with OSC's environmental benefits (Jayawardana et al., 2023), even though OSC is associated with environmental benefits, such as minimising waste and emissions (Yunus & Yang, 2012). Several barriers that hinder the efforts to achieve these benefits have been identified in past research. For instance, Tam et al. (2007) mentioned a lack of environmental awareness by suggesting that enhancing it will facilitate OSC's future adoption. This is further supported by noting that environmental sustainability awareness affects OSC usage (G. Wu et al., 2019), and its absence impedes green building development (Z. Wu et al., 2019). In addition, the lack of effective waste management strategies hinders OSC adoption as their availability is an OSC key performance indicator (Kamali & Hewage, 2016).

Another environmental challenge is the environmental disruption caused by the transportation of OSC components and materials to the site, leading to congestion and disturbance issues (Jaillon & Poon, 2008), which aggravates by site constraints and access restrictions (Rahman, 2014). The availability of affordable and environmentally friendly materials is also essential (Wuni & Shen, 2020), as it alleviates lead times and high costs. In another study, Wuni and Shen (2020) claimed that OSC's uncertain energy performance is another barrier to its adoption. This supports the argument made by Blismas and Wakefield (2009) that OSC implementation has no impact on Australia's energy ratings.

Overview of the Jordanian Construction Sector and OSC Adoption

Despite the importance of the construction sector in Jordan as one of the key economic drivers, it suffers from productivity degradation and time and cost overruns (Shugran & Ghazali, 2024). Moreover, unlike in developing countries where construction industries benefit from good communication, Jordan's poor communication limit project performance (Suleiman et al., 2023). Persistent financial challenges and cultural resistance further hinder the modernisation and the development of the Jordanian construction sector (Zeadat, 2024). These limitations point to the need for a systemic shift towards more sustainable construction methods like OSC.

OSC is well established for its productivity, efficiency, time, and sustainability advantages (Brissi & Debs, 2023). Although Jordanian strategic plans advocate innovation and OSC to address the challenges in the housing sector (JSF, 2019), the relatively low adoption rate suggests limited effort and commitment from stakeholders. Additionally, several barriers hinder the uptake of OSC in Jordan, including high initial cost and a lack of environmental awareness (Badran et al., 2024). Addressing these challenges requires strategies that balance stakeholder commitment and industry capability to facilitate OSC adoption in Jordan. Therefore, this paper aims to address the gap in knowledge regarding OSC adoption in Jordan, with a specific focus on sustainability-based barriers. Based on the Triple Bottom Line framework, this research will identify and subsequently analyse those economic, social, and environmental barriers that act to impede OSC implementation in Jordan's construction industry. Moreover, this research aims not only to enhance

the understanding of the identified barriers but also to provide practical recommendations for addressing them.

*** INSERT TABLE I HERE ***

Research Methodology

This study follows a positivist epistemology to identify and analyse the sustainability-based barriers to OSC adoption in Jordan. This philosophical position assumes that knowledge can be obtained by rational deduction and quantification. A survey with participants from a variety of stakeholders is the most appropriate approach to draw insightful conclusions about these barriers (Fellows & Liu, 2015). Furthermore, positivism emphasises the use of Likert scale questionnaires to collect quantifiable data, which makes the study quantitative (Dauda et al., 2024). Hence, this research utilised a quantitative approach, enabling precise measurement of the identified variables influencing OSC adoption (Guribie et al., 2022).

After designing the questionnaire, validation was done via piloting before its final distribution. The draft was shared with five respondents from academia and the industry, and a detailed clarification of the research aim was accompanied. This pilot survey was conducted to ensure the relevance and clarity of the questionnaire. Feedback indicated that some items were ambiguous or wordy. For example, separate items addressing long lead times and time certainty were consolidated into a single item to reflect their correlation in practice. Therefore, the item was refined to *"*Reducing lead times and improving time certainty*"* to better capture schedule reliability and efficacy. The refinements enhanced the overall flow and clarity of the questionnaire.

Ethical approval for the study was obtained from the relevant institutional committee, and informed consents were secured from all respondents. The questionnaire comprised five sections covering general participant information, economic barriers, social barriers, environmental barriers, and the determinates of OSC adoption. The selection criteria focused on having knowledge or experience in the Jordanian construction sector, and having prior experience in OSC was not mandatory. Similar studies, such as those by Marinelli et al. (2022), chose these requirements based on low OSC adoption rates. Although participants' experience was reported in the

construction industry generally, all participants were familiar with OSC concepts (e.g., precast elements). Therefore, given that OSC in Jordan is still in its infancy, general construction experience served as a reasonable proxy for relevant experience.

A purposive non-probability sampling technique was employed because it was difficult to determine the exact number of construction professionals in Jordan. The snowball sampling technique was used in numerous OSC-related studies due to the global spread and the absence of sampling frames (Guribie et al., 2022; Mao et al., 2018. The impracticability of probability-based approaches in construction research was another factor, which could result in an unreasonably low response rate (Abowits & Toole, 2010). Hence, snowball sampling was the most practical technique to achieve sufficient responses from construction professionals. The questionnaire was administered online to mitigate the biases often associated with in-person surveys. A total of 208 responses were collected from 04/May/2023 to 20/July/2023. The respondents were asked to rate the importance of each indicator in Table 1 on a 5-point Likert scale, ranging from extremely unimportant to extremely important. The demographic profile of the respondents is summarised in Table 2.

***** INSERT TABLE II HERE *****

The data was analysed using SPSS v29. Exploratory Factor Analysis (EFA) was conducted to assess the distribution of the variables among the four proposed factors (i.e., economic barriers, social barriers, environmental barriers, and OSC adoption) as a researcher may determine a specific number of groups based on previous research or theoretical considerations (Hair et al., 2011; Hwang & Choe, 2020; Leeman et al., 2022). Therefore, the researcher forced the number of factors to four and embraced Principal Component Analysis (PCA) and Varimax rotation techniques to perform the analysis. Factor loadings greater than 0.4 indicated significant relationships between the extracted components. Cronbach's alpha, Kaiser-Meyer-Olkin (KMO), and Bartlett Test of Sphericity were employed to assess the reliability of the extracted factors.

Results and Analysis

The four extracted groups in Table 3 explained approximately 65% of the variation. Five variables played multiple roles and contributed to two components, indicating a complex relationship between the foundational concepts. Rahman (2014) attributed the various roles of some barriers to OSC adoption to their interrelations, highlighting the need for a comprehensive and unified approach to address these barriers. Moreover, the five cross-loading variables had communalities above 0.5, leading to disregarding their cross-loading (Kim & Im, 2023). Thus, these variables are not independent but have similarities corresponding with these unique elements.

*** INSERT TABLE III HERE ***

Cronbach's alpha test was performed to assess the reliability of the components. With a minimum value of 0.779, the four components were considered to have acceptable to excellent internal consistency (George & Mallery, 2019). KMO and Bartlett Test of Sphericity were also conducted to examine the correlations among variables and their occurrence (Hair et al., 2018). A KMO value closer to one and the significance of the Bartlett Test of Sphericity indicate that a highly reliable scale is present. The results of these tests are summarised in Table 4.

*** INSERT TABLE IV HERE ***

After the exploratory factor analysis, the descriptive statistics for the variables analysed are presented in Table 5. These results include the number of respondents, as well as the mean and standard deviation. The analysis indicates that the most significant variable is the 'Lack of regulations, standards, and incentives' (mean = 4.09). Additionally, the lowest mean score is 3.77, which indicates that all variables are considered important in the context of OSC in Jordan.

*** INSERT TABLE V HERE ***

Discussion

The literature review and data analysis revealed the key barriers significantly influencing the adoption of OSC. The factor analysis rearranged the 23 variables based on the TBL of sustainability theory into four predefined groups: OSC adoption,

economic barriers, social barriers, and environmental barriers. The 23 variables are grouped as shown in Figure 1.

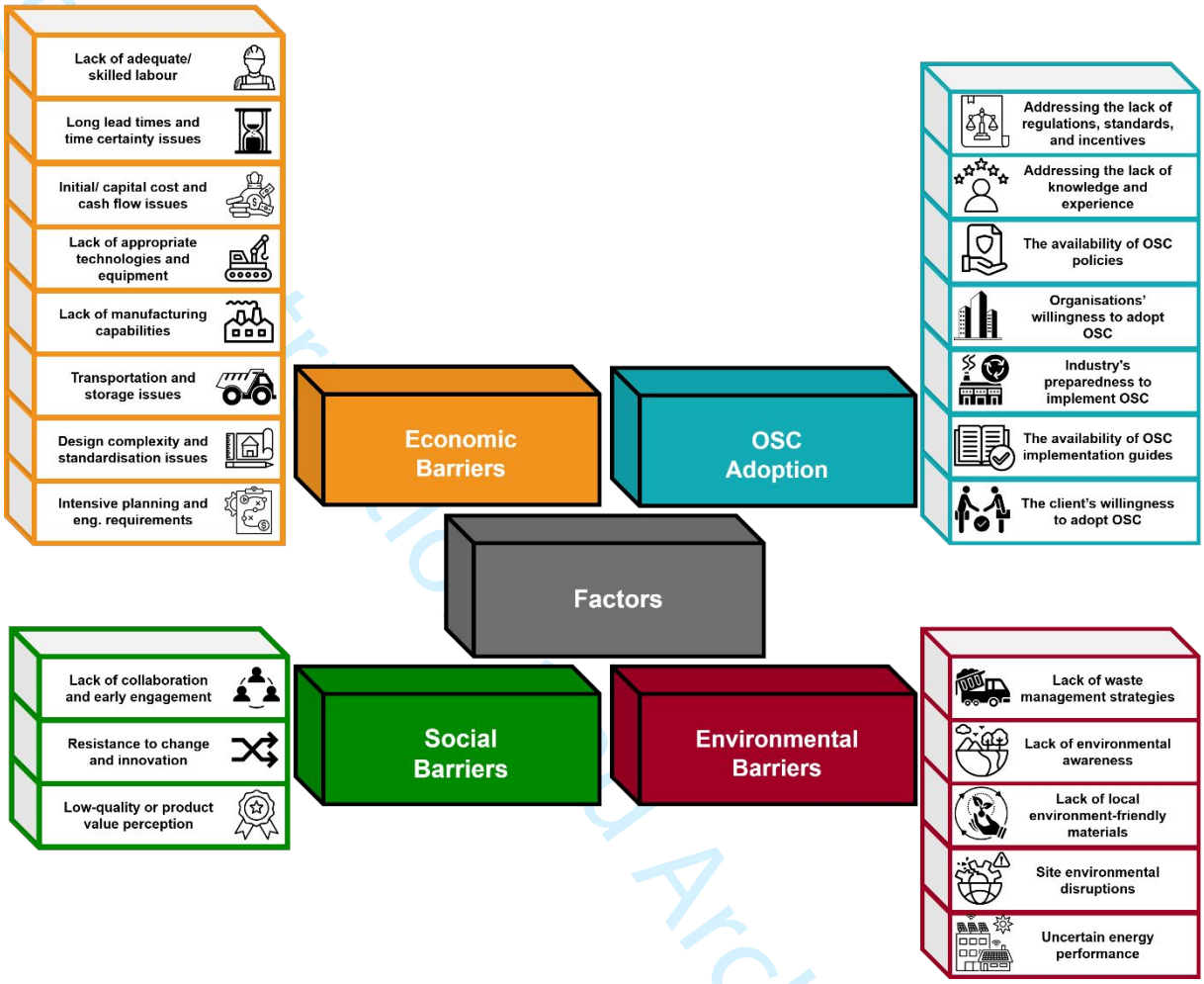

Figure 1: Results of Factor Analysis

Economic Barriers

The first factor, named economic barriers, has eight barriers. The initial/capital cost and cash flow issues barrier is considered a substantial barrier to OSC adoption in Jordan. One reason for this is the interdependency of construction sectors with countries' financial aspects (Dabirian et al., 2023). This is also closely linked to the complexity of decision-making and the extensive planning and engineering requirements. Another economic barrier is the intensive planning and engineering requirements that are intertwined with social barriers and concerns about integration and early engagement of all parties. This is supported by Gibb and Isack (2003), who asserted that OSC might not be effective without the early engagement of the suppliers and design freeze. This means that addressing the economic barriers

requires a comprehensive approach that integrates both economic and social challenges.

Another important economic aspect is the late freezing of design, which is integral to the design complexity and standardisation issues barrier. This is because it can then result in client satisfaction and trust issues. This confirms that freezing design early is a considerable advantage of OSC (Tam et al., 2007). This is crucial in the Jordanian context, as design changes are significantly affected by client requirements and design errors (Gharaibeh et al., 2020). The design time and design freezing sub-variables also correlate with the long lead times and time certainty issues barrier, as OSC has different relationships and concurrencies between construction activities compared to traditional construction methods. Wuni and Shen (2019) reported similar findings when they found that the design variable is highly correlated with time and quality variables. Hence, addressing design-related barriers ultimately leads to more accurate project timelines and improves OSC outcomes.

The lack of manufacturing capabilities also adds to the economic group of barriers. Establishing manufacturing capabilities requires significant investment and evidence of achieving economies of scale. Another reason for the lack of manufacturing capabilities is the lack of appropriate technologies and equipment, as implementing OSC methods requires a sophisticated integration of various technologies and manufacturing techniques (Goulding et al., 2023). In Jordan, this is closely linked to the slow technological adoption, as the country lacks experience and is suffering from high training and software costs (Hyarat et al., 2022). Moreover, transportation and storage issues exacerbate the integration of technologies and manufacturing techniques by restricting the dimensions of the transported elements and the ability to store them. This is particularly common in developing countries, where logistical solutions are more challenging (Jiang et al., 2018). Therefore, investments in advanced technologies and strategic planning are essential for addressing logistical challenges, particularly in developing countries.

Furthermore, although OSC is well-known for addressing labour shortage issues, the lack of adequate labour compounds challenges to adopting OSC. This is because OSC demands more expertise from workers than traditional construction methods (Almutairi et al., 2017). This considerably constraints timelines and productivity rates,

affecting projects' total costs. Hence, adopting a strategic approach to optimising resource allocation and streamlining processes in Jordan's OSC landscape is essential to addressing the economic barriers and enhancing sustainability.

Social Barriers

The second factor, social barriers, included three barriers: quality perception, resistance to change, and collaboration issues confronting the OSC sector. The low-quality or product value perception barrier can be attributed to the negative experience left by previously executed OSC projects that were poorly managed. This negative image from past failures makes it more challenging to assess OSC's superiority, contributing substantially to resistance to change and innovation. Addressing these barriers demands well-defined strategies addressing low-value perceptions and a culture of cooperation (Nadim & Goulding, 2011). Furthermore, the literature review suggested that early collaboration would mitigate several barriers to OSC adoption. For instance, Ezcan and Goulding (2022) revealed that a change in the overall mindset is essential for the sustainability of OSC. This is also consistent with that of Thneibat and Al-Shattarat (2021), who found that client support and team environment are key to value management processes in Jordan. Thus, it is imperative to increase stakeholder cooperation and publicise OSC's quality advantages to increase its adoption.

Environmental Barriers

The third factor constitutes environmental barriers. Addressing these barriers to OSC adoption is critical for sustainable development. In this context, the lack of environmental awareness leads to neglecting sustainable practices. On the other hand, boosting such awareness drives OSC markets to be more mature (Yuan et al., 2022). Also, the lack of waste management strategies leads to increased environmental degradation, worsening the adverse environmental impact of construction. While OSC produces a smaller amount of waste compared to conventional on-site construction (Kamali & Hewage, 2017), inadequate waste management strategies can lead to higher disposal expenses and potential environmental damage. These barriers reflect a wider issue in Jordan, where environmental principles are less emphasised in government construction projects

(Ayoub et al., 2023). Therefore, enhancing environmental awareness and implementing effective waste management strategies are essential steps towards fostering a more sustainable and mature OSC market.

The uncertain energy performance calls into question the long-term sustainability efficiency of OSC projects. This finding is consistent with that of Wuni and Shen (2020), who found that the uncertainties about the energy performance of OSC projects are an important technical barrier. Moreover, while the limited availability of local eco-friendly materials increases emissions and transport costs, it can also contribute to site disruptions during OSC activities. Hence, addressing these barriers provides myriad advantages for the Jordanian construction industry, as it can lead to significant economic and social benefits.

OSC Adoption

The fourth factor is OSC adoption, which covers the variables that affect the mindset of the industry in adopting OSC methods. Interestingly, it is deemed that addressing the lack of knowledge, experience, and the lack of regulations, standards, and incentives is a prerequisite to adopting OSC rather than a barrier. This result provides additional support for the perception that knowledge and experience are essential for the efficient management of OSC projects (Ginigaddara et al., 2023; Jang et al., 2021). By recognising these aspects as foundational prerequisites, stakeholders can focus on enhancing other variables, smoothening a sustainable OSC adoption in the Jordanian construction industry. The importance of addressing the lack of regulations, standards, and incentives is further underlined by being the most crucial variable affecting OSC adoption in Jordan.

The other five variables, namely, the client's willingness to adopt OSC, the organisation's willingness to adopt OSC, the availability of OSC policies, the availability of OSC implementation guides, and the industry's preparedness to implement OSC, are in line with previous results (Guribie et al., 2022). In this context, Goulding et al. (2012) emphasised the need to retrain construction professionals and clients to adopt a fresh mindset. Such a new mindset can maximise the potential of realising OSC's advantages and help overcome the challenges associated with its adoption. This demonstrates that creating a proactive

mindset and empowering both professionals and clients with the requisite knowledge and resources are critical to improving OSC adoption in Jordan. As a result, the benefits of OSC can be realised, positioning the sector better to address associated barriers.

Conclusion

This study aimed to identify the barriers to adopting OSC in Jordan through a sustainability-based perspective, employing the TBL sustainability framework. By collecting data from 208 construction professionals in Jordan and applying EFA, the study refined global variables into four context-specific factors: OSC adoption, economic barriers, social barriers, and environmental barriers. These factors illustrate how the pillars of sustainability are shaping the adoption of the OSC in the Jordanian context. A notable finding is that Jordanian construction professionals view addressing the absence of regulations, standards, and incentives, and the absence of knowledge and experience as essential requirements for OSC adoption rather than barriers to it, underscoring a proactive stance within the industry. Moreover, the statistical analysis revealed that the most crucial variable affecting OSC's adoption was the lack of regulations, standards, and incentives. The second and third most important variables were the lack of adequate labour and long lead times and time certainty issues, respectively. Among other variables, the least essential variable was addressing the uncertainty of energy performance.

The research recognises the importance of addressing economic barriers, given the cost-driven nature of construction industry decisions. The results confirm that the economic barriers are the most prevalent sustainability-based barriers to OSC adoption in Jordan. Hence, optimising resource allocation and implementing value management practices are crucial for addressing these barriers. Also, adopting a new mindset that allows for early collaboration between stakeholders to ensure smooth process coordination is key to realising the advantages of OSC and helping address the barriers to its adoption. Furthermore, enabling a culture of early stakeholder collaboration is essential for improving process coordination and leveraging the benefits of OSC, which supports the social component of the TBL framework.

Overall, this research achieves its aim by providing a clear understanding of sustainability-related barriers to OSC adoption in Jordan and by offering practical insights to improve its uptake. The insights gained from this research should assist Jordanian construction organisations in understanding the fundamental requirements for sustainable OSC adoption. The study significantly contributes to the understanding of OSC adoption, as previous research has not identified these factors within the Jordanian OSC sector. Although the findings of this research are significant, its reliance solely on data collected from Jordan limits the generalisability of these findings. Hence, future studies should expand the research to include various geographical contexts and explore additional factors that may impact OSC adoption across different regions. Such an approach would offer a broader understanding of the challenges and opportunities related to OSC, helping to formulate more effective strategies for promoting sustainable construction practices globally.

References

Abowitz, D. A., & Toole, T. M. (2010). Mixed Method Research: Fundamental issues of design, validity, and reliability in construction research. Journal of Construction Engineering and Management, 136(1), 108–116. https://doi.org/10.1061/(asce)co.1943-7862.0000026

Al Assaf, A. (2017). Enhancing transparency and accountability in the public construction sector in Jordan. Integrity and Anti-corruption Commission. Retrieved from http://www.jiacc.gov.jo/documents/9db9c9fe-1706-4113-a13b-63ffb46202cb.pdf.

AlBalkhy, W., Sweis, R., & Lafhaj, Z. (2021). Barriers to adopting lean construction in the construction industry—the case of Jordan. *Buildings*, *11*(6). https://doi.org/10.3390/buildings11060222

Almutairi, Y., Arif, M., & Khalfan, M. M. A. (2017). Development of implementation strategies for offsite construction techniques in the Kingdom of Saudi Arabia. In *Int. J. Business Competition and Growth* (Vol. 6, Issue 1).

Arif, M., Bendi, D., Sawhney, A., & Iyer, K. C. (2012). State of offsite construction in India-Drivers and barriers. *Journal of Physics: Conference Series*, *364*(1). https://doi.org/10.1088/1742-6596/364/1/012109

Arif, M., & Egbu, C. (2010). Making a case for offsite construction in China. *Engineering, Construction and Architectural Management*, *17*(6), 536–548. https://doi.org/10.1108/09699981011090170

Attouri, E., Lafhaj, Z., Ducoulombier, L., & Linéatte, B. (2022). The current use of industrialized construction techniques in France: Benefits, limits and future expectations. *Cleaner Engineering and Technology*, *7*. https://doi.org/10.1016/j.clet.2022.100436

Ayoub, H., Sweis, G., Abu-Khader, W., & Sweis, R. (2023). A framework to evaluate sustainable construction principles in government building projects: the case of Jordan. Engineering, Construction and Architectural Management, 30(9), 4080–4098. https://doi.org/10.1108/ECAM-01-2022-0040.

Azhar, S., Lukkad, M. Y., & Ahmad, I. (2013). An Investigation of Critical Factors and Constraints for Selecting Modular Construction over Conventional Stick-Built Technique. *International Journal of Construction Education and Research*, *9*(3), 203–225. https://doi.org/10.1080/15578771.2012.723115

Badran, H., Arif, M., Alam, M., Alaqad, M., & Islam, R. (2024, June 26). Barriers to Offsite Construction Adoption in Jordan: An Exploratory Factor Analysis. Transforming Construction with Off-Site Methods and Technologies.

Bendi, D., Rana, M. Q., Arif, M., Goulding, J. S., & Sawhney, A. (2020). An off-site construction readiness maturity model for the Indian construction sector. *Construction Innovation*, *21*(1), 123–142. https://doi.org/10.1108/CI-07-2020-0121/FULL/HTML

Blismas, N. G., Pendlebury, M., Gibb, A., & Pasquire, C. (2005). Constraints to the use of Off-site production on construction projects. *Architectural Engineering and Design Management*, *1*(3), 153–162. https://doi.org/10.1080/17452007.2005.9684590

Blismas, N., Pasquire, C., & Gibb, A. (2006). Benefit evaluation for off-site production in construction. *Construction Management and Economics*, *24*(2), 121–130. https://doi.org/10.1080/01446190500184444

Blismas, N., & Wakefield, R. (2009). DRIVERS, CONSTRAINTS AND THE FUTURE OF OFFSITE MANUFACTURE IN AUSTRALIA. *Construction Innovation*.

Brissi, S. G., Debs, L., & Elwakil, E. (2021). A review on the factors affecting the use of offsite construction in multifamily housing in the United States. In *Buildings* (Vol. 11, Issue 1, pp. 1–23). MDPI AG. https://doi.org/10.3390/buildings11010005

Brissi, S. G., & Debs, L. (2023). Principles for adopting offsite construction in design and construction companies focused on multifamily projects in the USA. Engineering Construction & Architectural Management, 31(11), 4308–4329. https://doi.org/10.1108/ecam-03-2022-0262

Chen, Y., Okudan, G. E., & Riley, D. R. (2010). Sustainable performance criteria for construction method selection in concrete buildings. *Automation in Construction*, *19*(2), 235–244. https://doi.org/10.1016/j.autcon.2009.10.004

Choi, J. O., Chen, X. Bin, & Kim, T. W. (2017). Opportunities and challenges of modular methods in dense urban environment. *International Journal of Construction Management*, *19*(2), 93–105. https://doi.org/10.1080/15623599.2017.1382093

Dabirian, S., Ahmadi, M., & Abbaspour, S. (2023). Analyzing the impact of financial policies on construction projects performance using system dynamics. *Engineering, Construction and Architectural Management*, *30*(3), 1201–1221. https://doi.org/10.1108/ECAM-05-2021-0431

Dauda, J. A., Chavan, N. N., Saka, A. B., Ajayi, S. O., & Oyegoke, A. S. (2024). An appraisal of barriers to digitalisation of construction industry in developing countries: perspective from India. International Journal of Construction Management, 1–13. https://doi.org/10.1080/15623599.2024.2362014

Department of Statistics. (2022). *Department of Statistics | Interactive Database*. https://jorinfo.dos.gov.jo/Databank/pxweb/ar/DOS_Database/

El-Abidi, K. M. A., & Ghazali, F. E. M. (2015). Motivations and Limitations of Prefabricated Building: An Overview. *Applied Mechanics and Materials*, *802*, 668–675. https://doi.org/10.4028/www.scientific.net/amm.802.668

Ezcan, V., & Goulding, J. (2022). Offsite Sustainability—Disentangling the Rhetoric through Informed Mindset Change. *Sustainability, 14*(8). https://doi.org/10.3390/su14084606

Feldmann, F. G. (2022). Towards Lean Automation in Construction—Exploring Barriers to Implementing Automation in Prefabrication. *Sustainability*, *14*(19), 12944. https://doi.org/10.3390/su141912944

Feldmann, F. G., Birkel, H., & Hartmann, E. (2022). Exploring barriers towards modular construction – A developer perspective using fuzzy DEMATEL. *Journal of Cleaner Production*, *367*, 133023. https://doi.org/10.1016/j.jclepro.2022.133023

Fellows, R.F. and Liu, A.M. (2015), Research Methods for Construction, John Wiley & Sons, UK

Gan, X., Chang, R., & Wen, T. (2018). Overcoming barriers to off-site construction through engaging stakeholders: A two-mode social network analysis. *Journal of Cleaner Production*, *201*, 735–747. https://doi.org/10.1016/j.jclepro.2018.07.299

Gan, X., Chang, R., Zuo, J., Wen, T., & Zillante, G. (2018). Barriers to the transition towards off-site construction in China: An Interpretive structural modeling approach. *Journal of Cleaner Production*, *197*, 8–18. https://doi.org/10.1016/j.jclepro.2018.06.184

George, D., & Mallery, P. (2019). *IBM SPSS Statistics 26 Step by Step*. Routledge. https://doi.org/10.4324/9780429056765

Gharaibeh, L. G., Matarneh, S. T., Arafeh, M., & Sweis, G. (2020). Factors leading to design changes in Jordanian construction projects. International Journal of Productivity and Performance Management, 70(4), 893–915. https://doi.org/10.1108/IJPPM-08-2019-0412.

Gibb, A. G. F., & Isack, F. (2003). Re-engineering through pre-assembly: Client expectations and drivers. *Building Research and Information*, *31*(2), 146–160. https://doi.org/10.1080/09613210302000

Ginigaddara, B., Gajendran, T., & Beard, C. (2023). A critical review of quantity surveying education in an offsite construction perspective: strategies for up-skilling. *Construction Innovation*. https://doi.org/10.1108/CI-12-2022-0322

Goh, C. S., Chong, H. Y., Jack, L., & Mohd Faris, A. F. (2020). Revisiting triple bottom line within the context of sustainable construction: A systematic review. In *Journal of Cleaner Production* (Vol. 252). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2019.119884

Goulding, J., Arif, M., Ezcan, V., Rankin, J., & Searle, B. (2023). *CIB Global Report-Revisiting Offsite: A New Capability-Driven Research Roadmap for Offsite Design, Manufacturing and Construction*.

Goulding, J., Rahimian, F. P., Arif, M., & Sharp, M. (2012). Offsite Construction: Strategic Priorities for Shaping the Future Research Agenda. *Architectoni.Ca*, *1*(1), 62–73. https://doi.org/10.5618/arch.2012.v1.n1.7

Guribie, F. L., Kheni, N. A., & Sule, M. (2022). Structural equation modeling of the critical driving forces of offsite construction in Ghana. *Built Environment Project and Asset Management*. https://doi.org/10.1108/BEPAM-03-2021-0051

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2018). *Multivariate Data Analysis: An Overview* (8th ed.). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-04898-2_395

Han, Y., & Wang, L. (2018). Identifying barriers to off-site construction using grey DEMATEL approach: case of China. *Journal of Civil Engineering and Management*, *24*(5), 364–377. https://doi.org/10.3846/jcem.2018.5181

Hong, J., Shen, G. Q., Li, Z., Zhang, B., & Zhang, W. (2018). Barriers to promoting prefabricated construction in China: A cost–benefit analysis. *Journal of Cleaner Production*, *172*, 649–660. https://doi.org/10.1016/J.JCLEPRO.2017.10.171

Hu, X., Chong, H.-Y., Wang, X., & London, K. (2019). Understanding Stakeholders in Off-Site Manufacturing: A Literature Review. *Journal of Construction Engineering and Management*, *145*(8). https://doi.org/10.1061/(asce)co.1943-7862.0001674

Hwang, B. G., Shan, M., & Looi, K. Y. (2018). Key constraints and mitigation strategies for prefabricated prefinished volumetric construction. *Journal of Cleaner Production*, *183*, 183–193. https://doi.org/10.1016/j.jclepro.2018.02.136

Hwang, J., & Choe, J. Y. (2020). How to enhance the image of edible insect restaurants: Focusing on perceived risk theory. *International Journal of Hospitality Management*, *87*, 102464. https://doi.org/10.1016/j.ijhm.2020.102464

Hyarat, E., Hyarat, T., & Al Kuisi, M. (2022). Barriers to the Implementation of Building Information Modeling among Jordanian AEC Companies. Buildings, 12(2), 1–18. https://doi.org/10.3390/BUILDINGS12020150.

Jaillon, L., & Poon, C. S. (2008). Sustainable construction aspects of using prefabrication in dense urban environment: a Hong Kong case study. *Construction Management and Economics*, *26*, 953–966. https://doi.org/10.1080/01446190802259043

Jang, J., Ahn, S., Cha, S. H., Cho, K., Koo, C., & Kim, T. W. (2021). Toward productivity in future construction: mapping knowledge and finding insights for achieving successful offsite construction projects. *Journal of Computational Design and Engineering*, *8*(1), 1–14. https://doi.org/10.1093/jcde/qwaa071

Jayawardana, J., Kulatunga, A. K., Jayasinghe, J. A. S. C., Sandanayake, M., & Zhang, G. (2023). Environmental Sustainability of Off-Site Construction in Developed and Developing Regions: A Systematic Review. *Journal of Architectural Engineering*, *29*(2). https://doi.org/10.1061/JAEIED.AEENG-1420

Jiang, R., Mao, C., Hou, L., Wu, C., & Tan, J. (2018). A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation. *Journal of Cleaner Production*, *173*, 225–234. https://doi.org/10.1016/j.jclepro.2017.06.147

Jiang, W., Huang, Z., Peng, Y., Fang, Y., & Cao, Y. (2020). Factors affecting prefabricated construction promotion in China: A structural equation modeling approach. *PLoS ONE*, *15*(1). https://doi.org/10.1371/journal.pone.0227787

JSF. (2019). The Construction & Housing Sector in Jordan: The Challenge of Demand & Supply Alignment & Financing Mechanisms | October 2019.

Jung, S., Lee, S., & Yu, J. (2021). Identification and prioritization of critical success factors for off-site construction using ISM and MICMAC analysis. Sustainability, 13(16). https://doi.org/10.3390/su13168911

Kamali, M., & Hewage, K. (2016). Life cycle performance of modular buildings: A critical review. *Renewable and Sustainable Energy Reviews*, *62*, 1171–1183. https://doi.org/10.1016/J.RSER.2016.05.031

Kamali, M., & Hewage, K. (2017). Development of performance criteria for sustainability evaluation of modular versus conventional construction methods. *Journal of Cleaner Production*, *142*, 3592–3606. https://doi.org/10.1016/j.jclepro.2016.10.108

Kim, J., & Im, I. (2023). Anthropomorphic response: Understanding interactions between humans and artificial intelligence agents. *Computers in Human Behavior*, *139*, 107512. https://doi.org/10.1016/j.chb.2022.107512

Leeman, T. M., Knight, B. G., Fein, E. C., Winterbotham, S., & Webster, J. D. (2022). An evaluation of the factor structure of the Self-Assessed Wisdom Scale (SAWS) and the creation of the SAWS-15 as a short measure for personal wisdom. *International Psychogeriatrics*, *34*(3), 241–251. https://doi.org/10.1017/S1041610220004202

Lu, W., & Yuan, H. (2013). Investigating waste reduction potential in the upstream processes of offshore prefabrication construction. *Renewable and Sustainable Energy Reviews*, *28*, 804–811. https://www.sciencedirect.com/science/article/pii/S1364032113005881

Mao, C., Liu, G., Shen, L., Wang, X., & Wang, J. (2018). Structural Equation Modeling to Analyze the Critical Driving Factors and Paths for Off-site Construction in China. *KSCE Journal of Civil Engineering*, *22*(8), 2678–2690. https://doi.org/10.1007/s12205-017-1705-4

Marinelli, M., Konanahalli, A., Dwarapudi, R., & Janardhanan, M. (2022). Assessment of Barriers and Strategies for the Enhancement of Off-Site Construction in India: An ISM Approach. *Sustainability*, *14*(11), 6595. https://doi.org/10.3390/su14116595

Nadim, W., & Goulding, J. S. (2011). Offsite production: A model for building down barriers A European construction industry perspective. *Engineering, Construction and Architectural Management*, *18*(1), 82–101. https://doi.org/10.1108/09699981111098702

Navaratnam, S., Satheeskumar, A., Zhang, G., Nguyen, K., Venkatesan, S., & Poologanathan, K. (2022). The challenges confronting the growth of sustainable prefabricated building construction in Australia: Construction industry views. *Journal of Building Engineering*, *48*. https://doi.org/10.1016/j.jobe.2021.103935

Obi, L., Arif, M., Daniel, E. I., Oladinrin, O. T., & Goulding, J. S. (2023). Establishing underpinning concepts for integrating circular economy and offsite construction: a bibliometric review. In *Built Environment Project and Asset Management* (Vol. 13, Issue 1, pp. 123–139). Emerald Publishing. https://doi.org/10.1108/BEPAM-01-2022-0009

Oti-Sarpong, K., Shojaei, R. S., Dakhli, Z., Burgess, G., & Zaki, M. (2022). How countries achieve greater use of offsite manufacturing to build new housing: Identifying typologies through institutional theory. *Sustainable Cities and Society*, *76*. https://doi.org/10.1016/j.scs.2021.103403

Pan, W., Gibb, A. F., & Dainty, A. R. J. (2007). Perspective of UK housebuilders on the use of offsite modern methods of construction. *Construction Management and Economics*, *25*(2), 183–194. https://doi.org/10.1080/01446190600827058

Pan, W., & Hon, C. K. (2020). Briefing: Modular integrated construction for high-rise buildings. *Proceedings of the Institution of Civil Engineers: Municipal Engineer*, *173*(2), 64–68. https://doi.org/10.1680/jmuen.18.00028

Rahman, M. M. (2014). Barriers of Implementing Modern Methods of Construction. *Journal of Management in Engineering*, *30*(1), 69–77. https://doi.org/10.1061/(ASCE)

Razkenari, M., Fenner, A., Shojaei, A., Hakim, H., & Kibert, C. (2020). Perceptions of offsite construction in the United States: An investigation of current practices. *Journal of Building Engineering*, *29*. https://doi.org/10.1016/j.jobe.2019.101138

Shahtaheri, Y., Rausch, C., West, J., Haas, C., & Nahangi, M. (2017). Managing risk in modular construction using dimensional and geometric tolerance strategies. *Automation in Construction*, *83*, 303–315. https://doi.org/10.1016/j.autcon.2017.03.011

Shugran, A., & Ghazali, F. (2024). Understanding the effects of variation orders on construction project success: insights from the Jordanian context. International Journal of Construction Management, 25, 519 - 529. https://doi.org/10.1080/15623599.2024.2337238.

Suleiman, A., Almasaeid, H., Hussein, N., & Abahre, J. (2023). Addressing the Causes and Effects of Poor Communication in the Jordanian Construction Industry: A Study on Improving Project Performance. Civil and Environmental Engineering, 19, 156 - 166. https://doi.org/10.2478/cee-2023-0014.

Sun, Y., Wang, J., Wu, J., Shi, W., Ji, D., Wang, X., & Zhao, X. (2020). Constraints hindering the development of high-rise modular buildings. *Applied Sciences (Switzerland)*, *10*(20), 1–20. https://doi.org/10.3390/app10207159

Tam, V. W. Y., Fung, I. W. H., Sing, M. C. P., & Ogunlana, S. O. (2015). Best practice of prefabrication implementation in the Hong Kong public and private sectors. *Journal of Cleaner Production*, *109*, 216–231. https://doi.org/10.1016/j.jclepro.2014.09.045

Tam, V. W. Y., Tam, C. M., Zeng, S. X., & William, C. Y. N. (2007). Towards adoption of prefabrication in construction. *Building and Environment*, *42*(10), 3642–3654. https://doi.org/10.1016/J.BUILDENV.2006.10.003

Thneibat, M. M., & Al-Shattarat, B. (2021). Critical success factors for value management techniques in construction projects: case in Jordan. International Journal of Construction Management, 23(4), 669–678. https://doi.org/10.1080/15623599.2021.1908933

Trading Economics. (2022, September). *Jordan GDP - 2022 Data - 2023 Forecast - 1965-2021 Historical - Chart - News*. https://tradingeconomics.com/jordan/gdp

Wu, G., Yang, R., Li, L., Bi, X., Liu, B., Li, S., & Zhou, S. (2019). Factors influencing the application of prefabricated construction in China: From perspectives of technology promotion and cleaner production. *Journal of Cleaner Production*, *219*, 753–762. https://doi.org/10.1016/j.jclepro.2019.02.110

Wu, Z., Jiang, M., Cai, Y., Wang, H., & Li, S. (2019). What Hinders the Development of Green Building? An Investigation of China. *International Journal of Environmental Research and Public Health*, *16*(17), 3140. https://doi.org/10.3390/ijerph16173140

Wuni, I. Y., & Shen, G. Q. (2020). Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. In *Journal of Cleaner Production* (Vol. 249). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2019.119347

Wuni, I. Y., & Shen, G. Q. P. (2019). Holistic review and conceptual framework for the drivers of offsite construction: A total interpretive structural modelling approach. In *Buildings* (Vol. 9, Issue 5). MDPI AG. https://doi.org/10.3390/buildings9050117

Xu, Z., Zayed, T., & Niu, Y. (2020). Comparative analysis of modular construction practices in mainland China, Hong Kong and Singapore. *Journal of Cleaner Production*, *245*. https://doi.org/10.1016/j.jclepro.2019.118861

Yasin, B., & Rjoub, A. (2017). Standardization in Construction as a Tool to Reduce Cost of Housing for the Low-Income Families in Jordan. *Journal of Civil Engineering and Architecture*, *11*(2). https://doi.org/10.17265/1934-7359/2017.02.005

Yuan, M., Li, Z., Li, X., Li, L., Zhang, S., & Luo, X. (2022). How to promote the sustainable development of prefabricated residential buildings in China: A tripartite evolutionary game analysis. *Journal of Cleaner Production*, *349*, 131423. https://doi.org/10.1016/J.JCLEPRO.2022.131423

Yunus, R., & Yang, J. (2012). Critical sustainability factors in industrialised building systems. *Construction Innovation*, *12*(4), 447–463. https://doi.org/10.1108/14714171211272216/FULL/HTML

Zeadat, Z. (2024). Implementing Sustainable Construction Practices in the Jordanian Housing Industry. Journal of Sustainable Real Estate. https://doi.org/10.1080/19498276.2023.2298554.

Zhai, X., Reed, R., & Mills, A. (2014). Factors impeding the offsite production of housing construction in China: an investigation of current practice Factors impeding the offsite production of housing construction in China: an investigation of current practice. *Construction Management and Economics*, *32*(1–2), 40–52. https://doi.org/10.1080/01446193.2013.787491

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

Table I: Measurement Items.

Measurement	Key References
Initial/ capital cost and cash flow issues	(Arif et al., 2012) (Razkenari et al., 2020)
Long lead times and time certainty issues	(Zhai et al., 2014) (Bendi et al., 2020)
Lack of appropriate technologies and equipment	(Rahman, 2014) (Marinelli et al., 2022)
Transportation and storage issues	(Choi et al., 2017) (Sun et al., 2020)
Design complexity and standardisation issues	(Zhang et al., 2014) (Navaratnam et al., 2022)
Lack of manufacturing capabilities	(Blismas et al., 2005)
Intensive planning and engineering requirements	(Shahtaheri et al., 2017) (Wuni & Shen, 2020)
Lack of knowledge and experience	(Arif et al., 2012) (Feldmann et al., 2022)
Lack of adequate labour	(Almutairi et al., 2017) (Wuni & Shen, 2020)
Resistance to change and innovation	(Gan et al., 2018) (Bendi et al., 2020)
Low-quality or product value perception	(Han & Wang, 2018) (Marinelli et al., 2022)
Lack of collaboration and early engagement	(Hwang et al., 2018) (Attouri et al., 2022)
Lack of regulations, standards, and incentives	(Arif & Egbu, 2010) (Zhai et al., 2014)
Lack of environmental awareness	(Tam et al., 2007) (G. Wu et al., 2019)
Lack of waste management strategies	(Kamali & Hewage, 2016) (Brissi et al., 2021)
Lack of local environment-friendly materials	(Wuni & Shen, 2020) (Brissi et al., 2021)
Uncertain energy performance	(Blismas & Wakefield, 2009) (Wuni & Shen, 2020)

Site environmental disruptions	(Jaillon & Poon, 2008) (Rahman, 2014)
The client's willingness to adopt OSC	(Azhar et al., 2013) (Guribie et al., 2022)
Organisations' willingness to adopt OSC	(Azhar et al., 2013) (Guribie et al., 2022)
The availability of OSC policies	(Mao et al., 2018) (Guribie et al., 2022)
Availability of OSC implementation guides	(Blismas & Wakefield, 2009) (Guribie et al., 2022)
Industry's preparedness to implement OSC	(Pan et al., 2007) (Guribie et al., 2022)

Note: Guided by the works of Brissi et al. (2021) and Guribie et al. (2022)

Table II: Respondents' Profiles.

Profile	
Nature of Business	
Contractor	78
Consultant	68
Academic	36
Client	12
Manufacturer	8
Other	6
Job Role	
Site Engineer	44
Project Manager	44
Company Manager	40
Other	32
Office Engineer	29
Construction Manager	19
Experience in Construction	
20 years or more	75
15-19 years	13
10-14 years	27
5-9 years	40
0-4 years	53
Total	**208**

Table III: Factor Analysis Results.

Rotated Component Matrix

Label	Component				Communality
	1	2	3	4	
Initial/ capital cost and cash flow issues	0.715				0.667
Long lead times and time certainty issues	0.694				0.591
Lack of appropriate technologies and equipment	0.724				0.65
Transportation and storage issues	0.571				0.523
Design complexity and standardisation issues	0.656				0.626
Lack of manufacturing capabilities	0.59	0.455			0.611
Intensive planning and eng. requirements	0.591	0.401			0.59
Lack of adequate labour	0.585				0.632
Resistance to change and innovation		0.683			0.654
Low-quality or product value perception		0.582			0.613
Lack of collaboration and early engagement		0.775			0.73
Lack of environmental awareness		0.415	0.586		0.687
Lack of waste management strategies			0.701		0.677
Lack of local environment-friendly materials			0.774		0.751
Uncertain energy performance			0.669		0.666
Site environmental disruptions			0.752		0.693
Lack of regulations, standards, and incentives		0.435		0.505	0.627
Lack of knowledge and experience	0.473			0.479	0.569
The client's willingness to adopt OSC				0.73	0.704
Organisations' willingness to adopt OSC				0.735	0.615
The availability of OSC policies				0.715	0.687
The availability of OSC implementation guides				0.633	0.629
Industry's preparedness to implement OSC				0.68	0.707

Notes: Extraction Method: PCA. Rotation Method: Varimax with Kaiser Normalisation. Rotation converged in 7 iterations. Kaiser-Meyer-Olkin Measure of Sampling Adequacy: 0.949. Bartlett's Test of Sphericity: Approx Chi-Square 2976.995, df 253, significance <.001.

Table IV: Cronbach's alpha (α), KMO, and Bartlett Test of Sphericity.

Factor	No. Items	α	KMO	Bartlett Test of Sphericity		
				App Chi	DF	P-value
Economic Barriers	8	0.896	0.912	789.036	28	<0.001
Social Barriers	3	0.779	0.702	169.303	3	<0.001
Environmental Barriers	5	0.885	0.853	551.548	10	<0.001
OSC Adoption	7	0.897	0.906	751.226	21	<0.001

Table V: Descriptive Statistics of Variables.

Variable	Mean	SD
Lack of regulations, standards, and incentives	4.09	1.027
Lack of adequate labour	4.06	1.003
Long lead times and time certainty issues	4.04	0.942
Initial/ capital cost and cash flow issues	4.03	1.044
Lack of appropriate technologies and equipment	4.00	1.052
Lack of manufacturing capabilities	4.00	1.038
Lack of knowledge and experience	3.99	0.993
Lack of collaboration and early engagement	3.97	1.009
Transportation and storage issues	3.96	0.970
Design complexity and standardisation issues	3.96	0.884
The availability of OSC policies	3.95	0.921
Intensive planning and engineering requirements	3.93	1.002
Resistance to change and innovation	3.93	0.943
Organisations' willingness to adopt OSC	3.93	0.862
The availability of OSC implementation guides	3.90	0.963
Industry's preparedness to implement OSC	3.90	1.000
Low-quality or product value perception	3.85	1.046
The client's willingness to adopt OSC	3.85	1.084
Lack of waste management strategies	3.83	0.991
Lack of environmental awareness	3.79	1.118
Lack of local environment-friendly materials	3.79	0.983
Site environmental disruptions	3.78	1.066
Uncertain energy performance	3.77	1.033

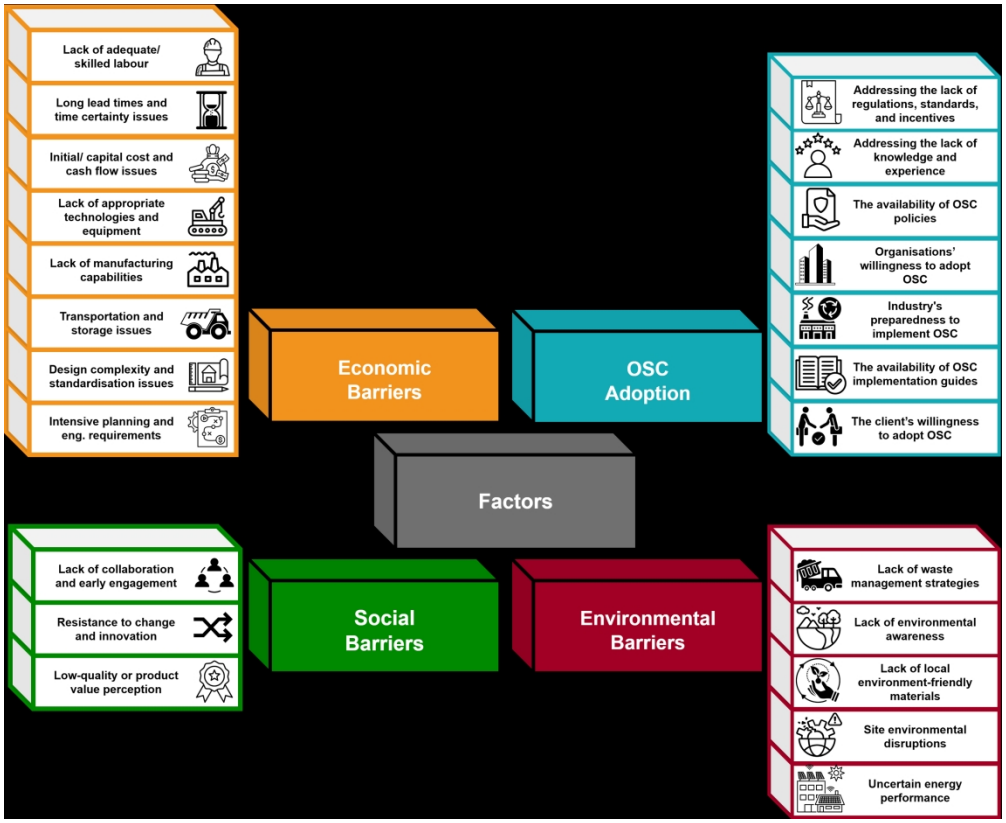

Figure 1: Results of Factor Analysis

561x456mm (150 x 150 DPI)

Authors responses to Reviewers' comments received on 6th December 2025

Manuscript ID ECAM-04-2025-0601.R1

Editor: This reviewer(s) have some important comments that would further improve the quality of the paper and should therefore be addressed within a minor revision.
Authors' response: Many thanks to the Editor and Reviewers for their time and effort in reviewing this study. We trust the revisions made to the manuscript can now justify its publication in this esteemed journal.

Reviewer 1	
Reviewer's Comments	**Authors' Response**
The authors have responded satisfactorily to my comments.	*Thank you. We appreciate your time and constructive feedback, which improved the quality of the manuscript.*

Reviewer 2	
Reviewer's Comments	**Authors' Response**
The revised version of the manuscript has improved. However, further improvement is still required.	*Thank you for your continued review. We have carefully revised the manuscript accordingly to enhance its quality and clarity.*
The authors should describe how the feedback from the five-plot survey was used to improve the questionnaire. Also, they should provide a copy of the questionnaire and a copy of the ethical approval letter.	*Thank you for this constructive comment. We have added the following clarification to the manuscript:* "This pilot survey was conducted to ensure the relevance and clarity of the questionnaire. Feedback indicated that some items were ambiguous or wordy. For example, separate items addressing long lead times and time certainty were consolidated into a single item to reflect their correlation in practice. Therefore, the item was refined to "Reducing lead times and improving time certainty" to better capture schedule reliability and efficacy. The refinements enhanced the overall flow and clarity of the questionnaire." ***(See Lines 234 to 240)***

	Also, the questionnaire is now provided as a supplementary file (The cover letter of the questionnaire has been omitted). *The ethical approval letter has been uploaded separately as a "not for review" document to allow editorial verification while preserving participant and institutional anonymity.*
From the result presented the respondent years of experience in OSC is not clear. It only shows their years of experience in the construction industry. This is confusing and a great concern. Did the author assume everyone in the Jordan construction industry knows OSC? They should explain why the OSC population in Jordan cannot be determined.	*Thank you for this comment. We acknowledge that respondents' experience was reported for the construction industry in general rather than specifically in OSC. This approach follows previous studies, such as Marinelli et al. (2022), which surveyed all construction professionals due to the low adoption of OSC. As noted by Marinelli et al. (2022): "Participants were allowed to complete the survey even if they did not have experience in OSC, as long as they confirmed that they had knowledge of the relevant concept and applications of any kind (e.g., precast elements, volumetric, modular etc). This was considered a reasonable requirement given the very low actual OSC implementation and experience of the sector."* *We did not assume that all respondents have direct OSC experience; however, as construction professionals familiar with the concept of OSC, they can provide their perceptions on the barriers affecting its adoption. Because OSC is still emerging in Jordan, the total population of OSC professionals is not clearly defined, making general construction experience a reasonable proxy for relevant expertise.* *In response, we have added this clarification to the manuscript to improve transparency.* ***(See lines 246 to 252)***

The end. Thank you.

1. General Information

1.1 What is your nature of business in construction? *

☐ Academic ☐ Client ☐ Consultant

☐ Contractor ☐ Manufacturer ☐ Other: ……

1.2 What is your current role in construction? *

☐ Company Manager ☐ Project Manager ☐ Construction Manager

☐ Office Engineer ☐ Site Engineer ☐ Other: ……

1.3 How many years of experience do you have in the construction industry?

☐ 0-4 ☐ 5-9 ☐ 10-14 ☐ 15- 19 ☐ 20 or more

1.4 What is your level of education in construction?

☐ No degree ☐ Diploma ☐ Bachelor's Degree

☐ Master's Degree ☐ Doctoral Degree

1.5 What are the types of offsite construction that you have experience in? (choose all applicable)

☐ None

☐ Components (such as trusses, staircases, columns, and beams)

☐ Panels (such as precast floors, walls, ceilings, and roof panels)

☐ Foldable structures (building panels connected using hinges)

☐ Pods (repetitive parts such as kitchens, bathrooms, and prison pods)

☐ Modules (non-repetitive parts of a whole building)

☐ Complete (modular) buildings

1.6 How important to you is the use of offsite construction in Jordan?

1= Extremely Unimportant, 2= Unimportant, 3= Neither Unimportant Nor Important, 4= Important, 5= Extremely important	1	2	3	4	5

Based on your knowledge/ experience, to *what extent* is the following item important to increase offsite construction adoption in Jordan?

2. Economic-related Barriers						
	1= Extremely Unimportant, 2= Unimportant, 3= Neither Unimportant Nor Important, 4= Important, 5= Extremely important	**1**	**2**	**3**	**4**	**5**
2.1	Addressing initial/ capital cost and cash flow issues					
2.2	Reducing lead times and improving time certainty					
2.3	Providing appropriate technologies and equipment (such as cranes)					
2.4	Having transportation and storage solutions/ plans					
2.5	Addressing design complexity and standardisation issues					
2.6	The availability of manufacturing capabilities (including the ease of supply and delivery)					
2.7	The mitigation of the intensive planning and engineering requirements					
3. Social-related Barriers						
3.1	Having offsite construction knowledge and experience					
3.2	The availability of an adequate/ skilled labour force					
3.3	The acceptance to change and innovation					
3.4	Changing the perception of low-quality/ product value					
3.5	Stakeholders' collaboration and early engagement					
3.6	The availability of governmental regulations, standards, and incentives					
4. Environmental-related Barriers						
4.1	Increasing the focus on/ awareness of environmental sustainability					
4.2	Having effective waste management strategies					
4.3	The availability of local and environment-friendly materials					
4.4	Improving the certainty of energy performance and efficiency					
4.5	Reducing site access environmental disruptions (such as disturbance, noise, and congestion)					
5. Offsite Construction Adoption						
5.1	Client's willingness to adopt offsite construction					
5.2	Construction organisations' willingness to adopt offsite construction					
5.3	The availability of offsite construction policies					
5.4	The availability of guides to implement offsite construction					
5.5	The construction industry's preparedness to implement offsite construction					
6. Offsite Construction Organisational Maturity						
6.1	Accurately informing the staff of a clear and specific offsite construction process					
6.2	Predicting and monitoring the quality of products					
6.3	Having clear organisational roles and responsibilities					
6.4	Having consistent requirements and effective execution strategies for offsite construction					
6.5	The availability of objective and quantitative methods to analyse offsite construction process problems					
6.6	Updating offsite construction data based on previous performance					