

A PESTEL Analysis of Problems Associated with the Adoption of Offsite Construction: A Systematic Literature Review [†]

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Abstract

Offsite construction (OSC) is fragmented and involves a complex network of stakeholders in all the stages such as planning, design, legal approval, site preparation, modular manufacturing, transportation, storage, and onsite installation. The barriers include complexity of the process; lack of awareness; supply chain challenges in capacity and knowledge; cultural perception; lack of viable business process models or solutions; scarcity of skills in design/manufacturing/construction and lack of government regulations and legislation. This study, therefore, categorises the barriers according to political, economic, social, technological, environmental, and legal (PESTEL) analysis. The PESTEL analysis aims at providing organisations a comprehensive list of all the external barriers against the adoption of offsite construction. A wholistic list of all the barriers and understanding the barriers will help them to improve the overall productivity and contribute to the economy metrics. Utilising popular databases, including Scopus, Web of Science, and Google Scholar, a systematic literature review of 56 papers relevant to OSC adoptions in the construction industry research was conducted. From the review, the barriers to the adoption of OSC in the construction research and relevant organisations reports were identified. The research shows that countries such as Australia, UK, China, Hong Kong, Singapore, and New Zealand have been the top countries in which papers on OSC were published. A relationship analysis shows that political barriers amounting to 5 out of the 101 barriers identified having the most causal effects on the low adoption of OSC.

Keywords: offsite construction; modular construction; modular integrated system; industrialised building; barriers; challenges; obstacles; risks; barriers



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1. Introduction

OSC adoption is still small because of the complexity of the process; lack of awareness; supply chain challenges in capacity and knowledge; cultural perception; lack of viable business process models or solutions; and scarcity of skills in design/manufacturing/construction and lack of government regulations and direction. In addition, there is a complex need for accuracy and integration of the operation of all stakeholders at the right time to onsite locations [1]. This study provides organisations the

external barriers against the adoption of offsite construction. A wholistic list of all barriers and understanding the barriers will help them to improve the overall productivity and contribute to the economy metrics [2].

PESTEL analysis is a management framework and diagnostic tool used to analyse and understand external factors that can impact strategies and influence business decisions. The outcome of the analysis helps to understand external factors which impacts upon organisation's strategy and influence business decisions. The study informs organisations of the external barriers against the adoption of OSC [3]. PESTEL analysis is an important market and environmental analysis tool used to support decision-making. It is a strategic management technique used as an external analysis tool when conducting market research in business but is also used by organisations to manage different projects strategically [4].

Performing a political, economic, social, technological, environmental, and legal (PESTEL) analysis of the barriers, the study attempts to facilitate an in-depth understanding of the barriers of adopting the use of offsite construction processes. Data are collected through literature reviews, government reports, and reports from various stakeholders.

The study informs organisations of the external barriers against the adoption of offsite construction. The PESTEL analysis aims at providing organisations a comprehensive list of all barriers against the adoption of offsite construction. A wholistic list of all the barriers and understanding the barriers will afford them to improve overall productivity and contribute to the economy metrics [2].

Government and construction organisations require a holistic approach to solve barriers facing the construction industry to improve the overall productivity and contribute to the economy. There is limited understanding of the barriers to the adoption of OSC on process improvement and we address them in a holistic way using all metrics [2]. To address the knowledge gaps, this paper explores the nature of the barriers to the adoption of offsite construction and identify the major themes and how they affect the decisions of organisation to adopt the method. The PESTEL themes are developed for use by all the stakeholders of the offsite construction industry to assess the dynamic business environment. Ref. [5] avers that strategy development should take a dynamic and wholistic view of the interactive factors of the macro business environment. External factors pressurise individual organisations to make decisions [3]. Such factors are uncertainties that affects the political, legal, social, economic, and technological decisions of an organisation [6] and consequently shifted management decisions to the adoption of OSC. The classification using PESTEL will capture the external environmental factors that militate the use of OSC. PESTEL analysis is a strategic management technique used as a tool to analyse market research in business and is also adopted by organisations to strategically manage projects [3].

Political factors include political stability, bilateral relationship, and tariff and taxation policies [7]. The economic factors include interest rate, inflation and exchange rate, and employment rate [7]; social factors include population, attitude to work, and attitude towards retirement and leisure [8]; technological factors refer to innovation and new product development; and environmental factors include the effect of activity on global warming, attitude towards green products, recycle activities, and environmental taxes. The legal factors are related to competition law, employment law, consumer law, and health and safety laws. It is important for companies willing to adopt offsite construction to understand all the macro-environments using PESTEL to make tangible decisions [9,10].

2. Methodology

A systematic literature review is a transparent and structured process to identify, evaluate, and synthesise published evidence on a topic to appraise their quality [11]. It is adopted for rigour in identifying details of articles related to each category of the research

themes and justifying future design research in the area. SLR captures all research areas in a comprehensive and transparent manner, making it reproducible by other researchers. It is a comprehensive method that captures the relevant literature by systematically searching multiple databases to avoid gaps and bias in the study [12].

This systematic literature review was guided by the PRISMA Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) review method. A total of 56 articles from the Scopus and Web of Science databases were selected for the review. The review builds on the works of other authors who have worked on the subject and include all the other external entities and environmental barriers that impede the adoption of offsite constructions by organisations. The study therefore aggregates all the barriers to the adoption of offsite construction and classify them based on political, economic, social, technological, environment, and legal (PESTEL) method of analysis. This method of categorization will be more focused and target on the actual clusters of barriers that are identifiable.

2.1. Search Strategy

For this systematic search, studies were selected from three electronic databases, Scopus, Web of Science, and Google Scholar, because of their volume of journals and papers on offsite construction [13]. Boolean operators, truncations, and wildcards were used for combining and excluding words, to search for terminologies with similar meanings, and to include words with spelling deviation to search the databases. The method ensured focused and productive results during the search.

A combination of terms was used in the search using the following keywords: Offsite construction, Offsite production, offsite manufacture, prefabrication, modular construction, Industrialised Buildings/Construction, Modular Integrated Systems, Modular Integrated Building systems, Systems Building, modern methods of construction, Industrialised Buildings/Construction, barriers, challenges, obstacles, risks, barriers.

2.1.1. Search Words and Search String

Additional manual search for studies was performed using Google Scholar for articles missed from the two search engines. Thereafter, the records were screened and duplicated, and non-related records were excluded from analysis.

The title, abstract, keyword, authors' names, journal names, and year of publication of the identified records were exported to an NVivo 15 and MS Excel spreadsheet. The record was screened for titles and their abstracts were studied. Papers and records not clearly on the subject were discarded. Then an eligibility assessment of the papers was carefully performed by cautiously screening the full texts of the remaining papers. At this stage, papers with doubtful contents were put to another independent reviewer for authentication. All the papers that were to some extent explicit and without any prior assumptions on the relevance of the literature were selected [14] (Table 1).

Table 1. Search words and search strings.

Scopus	((offsite construction) OR (Offsite production) OR (offsite manufacture) OR (prefabrication*) OR (modular construction*) OR (Industrialised Buildings/Construction) OR (Modular Integrated System*) OR (Modular Integrated Building system*) OR (Systems Building*) OR (modern methods of construction) OR (Industrialised Building*)) AND (barriers OR challenges OR obstacles OR risks OR barriers))
Web of Science	((“Offsite construction” OR prefabrication* OR “Offsite production” OR “offsite manufacture” OR “modular construction*” OR “Industrialised Buildings Construction” OR “Modular Integrated System*” OR “Modular Construction*” OR “Modular Integrated Building system*” OR “Modular integrated construction*” OR “Systems Building*” OR “modern methods of construction” OR “Industrialised Building*”) AND (barriers OR constraint* OR problem*))

2.1.2. Selection and Inclusion of Relevant Articles

The selection criteria were based on the PRISMA Statement [15]. The search mainly focused on the existing literature on offsite constructions and all its various nomenclatures with no geographical exclusions. The search span was from year 2000 to 2023. All articles before 2000 were excluded from the search.

The search mainly focused on journal articles and all other sources were excluded. A total of 164 journal articles were extracted at this stage. To maintain the quality of this review, all duplications were thoroughly checked and deleted. Abstracts of the articles were carefully read and analysed to ensure quality and relevance to the study. The next exclusion criterion was to limit the study to papers published in the English language only. All non-English language papers were excluded from the study. After the filtration of duplicate records, 77 more articles were removed from the study. A total of 87 articles were selected after assessing each article that passed the inclusion criteria.

In the end, 56 articles were considered to have met the criteria and were considered adequate for this study. Refs. [13,16,17] have used fewer articles (23, 16, and 17, respectively) in the construction, engineering, and management (CEM) research papers. Thereafter, a careful evaluation of each paper was carried out and only relevant articles were included in the study (Figure 1).

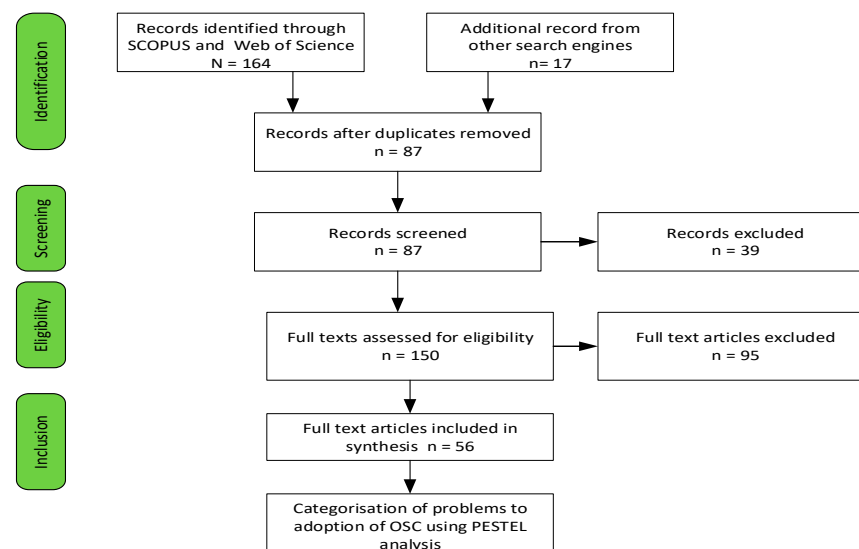


Figure 1. Flowchart of the methodological approach used in this paper.

3. Results and Review

3.1. Annual Trend of Publications

The annual publication trend on the barriers to the adoption of offsite construction by researchers between 2005 and 2023 is shown in Figure 2. In total, 56 research articles were published on the barriers to adoption of offsite construction across the six categories of PESTEL. As shown in the figure, there was a low interest of researchers in the offsite construction between 2005 and 2015. There were no publications in the years 2008–2010 and 2016–2017, while in 2005–2006 and 2011–2013 there were single publications. However, they thereafter showed more interest in the adoption of offsite constructions globally with the number of publications increasing from 2018 through to 2023, with 2022 having the most publications with 25% of the publications in this review.

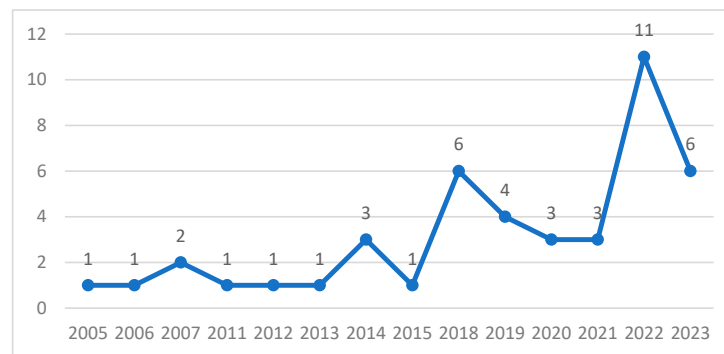


Figure 2. Annual publication trends on barriers to adoption of offsite construction from 2005 to 2023.

3.2. Most Contributing Countries in Offsite Construction Studies

Adoption of offsite construction varies from country to country. Some countries have partially accepted the method, while others have embraced the method and its applications [18]. The construction method has been accepted in many countries including Hong Kong, Spain, Australia, Singapore, China, the United Kingdom, and the United States [19]. Offsite construction shared a large percentage of construction markets in many developed countries such as Germany, Sweden, and Japan. Germany is well-established in the offsite construction market; between one fifth and one eighth of all dwellings are constructed with prefabricated parts [20]. In Sweden, approximately 84% of detached houses have used OSC. In Japan, the percentage of prefabricated new detached or semi-detached houses was approximately 15% in 2015 [21]. However, in Australia between 3 and 4% of new building constructions are prefabricated [22].

Australia's adoption of offsite construction has been fairly low due to the perception that modular homes are second best, and this perception could be swayed by innovation and designs [23,24]. Recently, a few construction companies and governments in Australia have developed interest in offsite construction with the resultant modular construction and offsite construction representing 3% of the AUD 150 billion construction industry and it was predicted that by 2021 nearly 10% or AUD 15 billion of the total construction industry will be shared by offsite construction [25].

Figure 3 shows that there is a surge in interest by researchers in offsite construction with Australia (24.5%), the United Kingdom (17%), China (17%), China (Hong Kong) (9.4%), and New Zealand (7.5%) having the most publications. This shows an interest in the Asian countries in offsite construction, while the United Kingdom still continues to maintain its interest in the method of construction. In Australia, various governments are investing and actually using modular construction as a method to accelerate the delivery of infrastructure to schools and healthcare [26].

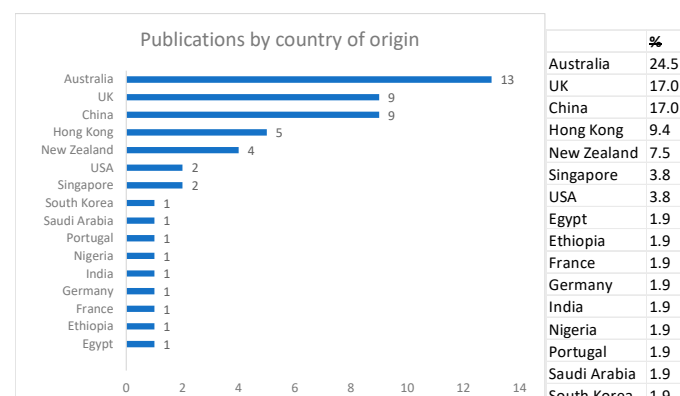


Figure 3. Geospatial distribution of the included publications. Source: [27].

The construction industry is a significant contributor to the Australian economy, accounting for 8.1% of the gross domestic product (GDP) [28]. Furthermore, offsite construction has economic and social benefits for the Australian construction industry. However, the industry faces challenges such as a shortage of skilled labour and increasing material costs [29]. Offsite construction has the potential to address these challenges by reducing the need for skilled labour and minimising material waste. In addition, offsite construction can lead to faster construction times and reduced project costs, resulting in cost savings for developers and investors [30].

3.3. Prominent Research Outlets of Barriers to Adoption of Offsite Construction

Academics are always eager to publish results of their research in high-ranked scholarly journals and research outlets to make a great impact in the literature and disseminate their knowledge on the subject [31]. Table 2 shows the leading and impactful academic journals of offsite constructions. The journals with large publications, *Journal of Cleaner Production*, *Buildings*, and *Construction Management and Economics* are highly ranked journals, and they deal solely with construction management and buildings and production. All leading journals in offsite construction are high quality Q1 journals with high impact factor. The *Journal of Cleaner Production* has the most publications and an impact factor of 11.1. Akomea-Frimpong, Kukah, Jin, Osei-Kyei and Pariafsai [13] used articles published in Q1 and Q2 journals or any reputable conference recognised among the construction research community. Such journals and conferences must extensively cover the topic under discussion and contribute to further research and practice [32,33].

Table 2. Journal distribution of included studies.

Journal	Number of Articles	Quality	Impact Factor
1. Journal of Cleaner Production	9	Q1	11.1
2. Buildings	5	Q1	3.8
3. Construction Management and Economics	5	Q1	3.04
4. Engineering, Construction and Architectural Management	3	Q1	4.1
5. International Journal of Construction Management	3	Q1	4.5
6. Architectural Engineering and Design Management	2	Q1	2.9
7. Construction Innovation	2	Q1	3.8
8. Habitat International	2	Q1	5.2
9. Journal of Architectural Engineering	2	Q1	2
10. Journal of Management in Engineering.	2	Q1	7.4
11. Sustainability	2	Q1	3.9

4. Classification of Barriers to the Adoption of Offsite Construction

Many authors have written on the barriers confronting the adoption of offsite construction; identified complexity of the process; lack of awareness; supply chain challenges in capacity and knowledge; cultural perception; lack of viable business process models or solutions; and scarcity of skills in design/ manufacturing/ construction [29]. Other barriers identified are the need for accurate and real-time information sharing about the progress of work and integration of the operation for the supply of components at the right time to onsite location [1].

Political factors include political stability, bilateral relationship, and tariff and taxation policies. The economic factors include interest rate, inflation and exchange rate, employment rate; social factors include population, attitude to work, attitude towards retirement and leisure; technological factors refer to innovation and new product development; and environmental factors include the effect of activity on global warming, attitude towards green products, recycle activities, and environmental taxes. The legal factors are related to competition law, employment law, consumer law, and health and safety laws. It is important for companies willing to adopt offsite construction to understand all the macro-environments using PESTEL to make tangible decisions [10].

Based on this perspective, this study examined political, economic, social, technological, environmental, and legal (PESTEL) barriers. PESTEL analysis is an important market and environmental analysis tool used to support decision-making. It is a strategic management technique used as an external analysis tool when conducting market research in business but is also used by organisations to manage different projects strategically [4].

4.1. Political Barriers

Government regulations affect a company's ability to operate and its ability to be profitable and successful. Obstacles against the adoption of OSC include standards/legislations, building codes, planning permission, and regulations by the government [8]. Government jurisdictional differences between states and territories in countries like Australia and the USA make a unified policy on the use of OSC a problem [7]. Including the lack of codes and standards are major limitations to OSC adoption, lengthy consultation and approval processes by the government also consume time and incur a cost [34] (Table 3).

Table 3. List of political barriers.

No	Barriers	Citation
1	1.1 Absence of government incentives and subsidies	Correia, Sutrisna and Zaman [8];
	1.2 Inadequate policies and regulations	Gan, Chang and Wen [7]; Zhang,
	1.3 Lack of technical guidance and information	Lee, Jaillon, and Poon [34]; Lin,
	1.4 Lack of modular design codes and standards	Lyu, Yang and Tivendale [21];
	1.5 Regulatory authorities not yet included in planning regulations	Darlow et al. [35].

Other barriers include the provision of wide roads which in effect affect the transportation of heavy and bulky fabricated components from the manufacturer to the site [7,34]. Darlow, Rotimi and Shahzad [35] opined that local legislations need to allow the size specifications of manufactured products to be covered by local legislation or otherwise manufacturers may not be able to transport their goods from factory to site when bulky and heavy items are to be transported [7].

4.2. Economic Barriers

Economic factors such as interest rates, inflation, and credit availability to offsite manufacturers and assemblers influence the client/end-user adoption of OSC. Though OSC may reduce cost in the long run, the high initial cost in the early part of project implementation is a major impediment [34]. Also, banks and mortgage lenders are risk averse to OSC because there are higher capital costs and few examples of completed OSC buildings [35–37].

The market for OSC is small; builders are not ready to rush into a big capital investment required [37]. There is no financial certainty for the construction cost and time and the perception of quality and sustainability in the industry is also a concern [35]. In addition, the upfront payments to manufacturers is new to the industry [37]. The cost of equipment

needed from offsite manufacturers is high and it is hard to justify financial support from the banks [7]. OSC is a manufacturing approach which needs a high capital to set up [38] as opposed to the common traditional method that requires low capital and utilises the client's funds [36] (Table 4).

Table 4. List of economic barriers.

No	Barriers	Citation
2	2.1 High initial cost.	Zhang, Lee, Jaillon and Poon [34]. Correia, Sutrisna, and Zaman [8]. Abdul Nabi and El-Adaway [39]. Nadim and Goulding [36]. Darlow, Rotimi and Shahzad [35]. Gan, Chang, Zuo, Wen and Zillante [37]. Gan, Chang and Wen [7]. Rahman [38]. Hong et al. [40]. Goodier and Gibb [41]. Sutrisna, Cooper-Cooke, Goulding, and Ezcan [42].
	2.2 High total cost.	
	2.3 Higher capital costs.	
	2.4 Affordability.	
	2.5 Economies of scale.	
	2.6 Flexibility funding.	
	2.7 Insurance.	
	2.8 Market analysis.	
	2.9 Limited understanding of OSC business model.	
	2.10 Limited market demand.	
	2.11 Lack of incentives.	
	2.12 Challenges in securing financial supports.	
	2.13 Materials and labour costs are also higher.	
	2.14 Supply chain is fragmented and involves a complex web of stakeholders.	
	2.15 Defects in OSC projects are expensive to rectify.	
	2.16 Limited knowledge of the associated cost in the entire supply chain of OSC.	
	2.17 Difficulty in objectively ascertaining the value-added benefits of OSC.	
	2.18 Business case development.	
	2.19 Cash flow change.	
	2.20 Increased transportation and logistics considerations.	
	2.21 Expensive long-distance transportation for large and heavy loads.	

Manufacturers may need to charge higher to meet the cost of production [38]. OSC is believed to be costlier than the traditional method and the decision to adopt OSC is based on cost rather than value [40,41]. The additional costs of highly skilled workers, design changes, and initial investment in new machinery, fabricating moulds, and factories, as well as special requirements for crange, transportation, and logistics processes were emphasised [38,40].

4.3. Social Barriers

The people element is one of the most important hinderances to the adoption of OSC [36]. Companies assess social factors such as growth rates, attitudes of people towards a product, and market trends to understand how the needs of the consumers are formed or what motivates them to make a purchase decision. Building houses is different from building cars; several millions of the same model cars can be manufactured but manufacturing buildings or houses needs flexibility and accommodation of the customised designs of various clients [43]. The reluctance of clients and contractors to adopt OSC is attributed to poor understanding of OSC and difficulties in ascertaining the benefits of the method [8]. They view OSC as expensive and only a remedy for the barriers of the construction industry [44]. Stakeholders' perceive that a reduction in construction time in OSC projects results in low-quality products and if a structure is built faster using OSC, will affect the cost, quality [8], aesthetic performance, and the durability will be poor [7]. The protection of the traditional method and conservative culture in the industry in relation to risk aversion and the reluctance to innovation, and public perception that OSC is only for low-income social housing, is reported to militate against its use [37] (Table 5).

Table 5. List of Social barriers.

No	Barriers	Citation
3	3.1 Inclined towards the traditional building method.	Nadim and Goulding [36]. Arif, Goulding and Rahimian [43]. Correia, Sutrisna and Zaman [8]. Blismas, Pasquire and Gibb [44]. Gan, Chang and Wen [7]. Gan, Chang, Zuo, Wen and Zillante [37].
	3.2 Decision-making process to implement OSM in their project.	
	3.3 Uninformed perceptions of stakeholders.	
	3.4 Poor attitude of the construction industry towards innovation.	
	3.5 Scepticism on OSC benefits over traditional construction.	
	3.6 Limited OSC experience and knowledge.	
	3.7 Inexperience or limited knowledge of OSC.	
	3.8 Risk averse in technological investment.	
	3.9 Limited understanding of the technology.	
	3.10 Fewer trained and skilled contractors and technicians with specialisation in OSC.	
	3.11 Poor monotonous architecture and impaired outlook.	
	3.12 Concerns about the adaptability of OSC projects.	
	3.13 Lack storage space on site.	
	3.14 Conservative industry culture.	
	3.15 Resistance from client.	
	3.16 Mindset of the industry (cultural barriers).	
	3.17 Poor public acceptability.	
	3.18 Clients suspicious about performance but build at good location for higher price.	
	3.19 Market protection from traditional suppliers	
	3.20 Not suitable for small projects.	
	3.21 Contractual risks and disputes.	
	3.22 Lack of evidence of successful OSM projects.	
	3.23 Risk due to minimal amount completed.	

Construction is highly fragmented, offsite construction require pre-project planning and early participation of all stakeholders. It is highly challenging to develop a high level of integration and collaboration among several stakeholders [43]. Organisational barriers include the management, process, knowledge, and business model of the organization. Manufacturers' lack of adequate finance and resources for quality control procedures in the production of OSP and the lack of knowledge and expertise of the organisation and insufficient qualified and skilled workers are obstacles to factory manufacturing of building components [7].

4.4. Technological Barriers

Technological innovations can affect business negatively or positively. The introduction of new technology and services may be difficult for some markets to adapt and adopt. Government spending and support for a new technology is to be analysed before a company dabbles into its adoption. Technological innovations brought about by OSC is a benefit [8]. However, unlike cars, buildings need to be flexible in design to accommodate the varied needs of clients. Therefore, only a reasonable level of mechanisation could be implemented for manufactured construction [43]. The construction industry is customised, and the manufacturing process has to incorporate a flexible design to accommodate design changes. The involvement of many parties in OSC is required; all stakeholders should be involved in the project from the design stage [8]. OSC lacks economies of scale within the market as demand is low compared to high capital requirement [35] (Table 6).

Other barriers include poor manufacturing capacity [7]; quality and aesthetic performance [45]; lack or shortage of skills in designers [25]; and new technologies [36], suppliers, contractors, professionals, and labour [21,36,46]. Technological requirements may also include the use of BIM for enhancing the design process [47] and supply chain integration [48].

Table 6. List of technological barriers.

No	Barriers	Citation
4	4.1 Design for manufacture.	Correia, Sutrisna and Zaman [8]. Arif, Goulding and Rahimian [43]. Nadim and Goulding [36]. Darlow, Rotimi, and Shahzad [35]. Gan, Chang and Wen [7]. Kamali and Hewage [45]. Li, Luther, and Mills [25]. Lin, Lyu, Yang, and Tivendale [21]. Polat [46]. Nawari [47]. Babič et al. [48].
	4.2 Design freeze.	
	4.3 Lack of experience in OSC design, production, and delivery.	
	4.4 Inflexible for design change.	
	4.5 Quality barriers.	
	4.6 Low IT integration in the industry.	
	4.7 Levels of industrialisation/mass production.	
	4.8 Dimensional coordination/standardisation.	
	4.9 Long design time impaired aesthetics impaired quality.	
	4.10 High fragmentation in the industry.	
	4.11 Inter-manufacturer rivalry and market protection.	
	4.12 The need for additional project planning and design efforts.	
	4.13 Limited capacity of existing manufacturers.	
	4.14 Reluctance of manufacturers to innovate and change to OSC.	
	4.15 Barriers with lightweight construction.	
	4.16 Poor manufacturing capacity.	
	4.17 OSC compliance.	
	4.18 Limited capacity of logistics to transport larger modules to job site.	
	4.19 Lack of expertise and/or economy of scale.	
	4.20 Lack of OSC experiences in terms of installation.	
	4.21 Failure to comply with regulations and standards relevant to the industry.	
	4.22 Non-compliance of building services elements onsite OSC commissioning.	
	4.23 Lack of regulatory process and policy constraints, particularly in compliance and legislations.	
	4.24 Patented technology hinders technology transfer.	
	4.25 No standardised forms of contract.	

4.5. Environmental Barriers

The current emphasis on Sustainable Development Goals (SDGs) is actually pressuring the stakeholders of offsite construction. Environmental factors are external forces that potentially affected organisation's performance [6]. Manufacturers, therefore, have to upskill their operations to reduce waste and other goals. Manufacturing awareness is required to manage their processes and align them with the onsite schedules to leverage potential environmental benefits [43] (Table 7).

Table 7. List of environmental barriers.

No	Barriers	Citation
5	5.1 Reducing waste generation.	Rajeh, Tookey and Rotimi [6]. Arif, Goulding and Rahimian [43]. Pan, Gibb, and Dainty [49]. Blismas, Pendlebury, Gibb, and Pasquire [50]. Nahmens and Ikuma [51]. Elnaas et al. [52].
	5.2 Construction process can be conducted in a controlled environment.	
	5.3 Save cost and time to the site operation.	
	5.4 Environmental pollution reduction (air, dust control, water, and noise).	
	5.5 Energy efficiency.	
	5.6 Environmental performance.	
	5.7 Health and safety.	
	5.8 Supply chain.	
	5.9 Sustainability.	
	5.10 Transportation/logistics.	
	5.11 Transportation restrictions due to rules and regulations.	

There are concerns about the impacts of offsite construction materials and processes on the environment. Offsite construction manufacturers are limited by practices and selection of sustainable materials, inefficient energy emissions, waste management, and lifecycle assessment [49,50]. Carbon footprint may increase due to inefficient transportation and logistics. They therefore need to train their personnel in promoting sustainability [51] and

safe and healthy environment for workers [52]. Environmental factors have been linked to the social trends in the acceptance of OSC because of the sustainability advantages of reducing environmental impacts by reducing waste and overall carbon footprints of the buildings. Moving production of construction components to the factories away from construction sites reduces onsite pollution, dust control, water pollution, and noise pollution [8].

4.6. Legal Barriers

Legislation is important for the adoption of OSC, and a lack of it constitutes barriers to its adoption [35,37]. Another external factor against the adoption of offsite construction are government standards/legislations such as building codes, planning permission [9] that is needed to complete the project. In some countries such as Australia, the jurisdiction to legislate on offsite construction is different between states [8]. Also, Germany has 16 different codes for every federal state [53]. This makes the business operations of contractors difficult across states. However, in countries like Singapore, the central government makes laws and policies that drive the practices and helps to increase the adoption of offsite construction and fulfil its potential as an alternative to the traditional building construction [42]. The lack of building design codes and regulations and approval processes for offsite construction is also a barrier to adoption of offsite construction by stakeholders [21,54] (Table 8).

Table 8. List of legal barriers.

No	Barriers	Citation
6	6.1 Policy process/organisation procurement.	Darlow, Rotimi and Shahzad [35]. Gan, Chang, Zuo, Wen and Zillante [37]. Zhai, Reed, and Mills [9]. Correia, Sutrisna, and Zaman [8]. Sutrisna, Cooper-Cooke, Goulding, and Ezcan [42]. Mao, Shen, Pan and Ye [54]. Lin, Lyu, Yang and Tivendale [21]. Feldmann, Birkel and Hartmann [20].
	6.2 Regulation.	
	6.3 Risk.	
	6.4 Complex code compliance and inspection process.	
	6.5 Few codes and standards available.	
	6.6 Lack of guidance and information.	
	6.7 Non standardised forms of contract.	
	6.8 Failure to comply with regulations and standards relevant to the industry.	
	6.9 Non-compliance of building services' elements and energy efficiency.	
	6.10 Regulatory authorities: not yet included in planning regulation.	
	6.11 Lack of incentives.	
	6.12 Lack of regulatory process and policy constraints.	
	6.13 Patented technology hinders the technology transfer.	
	6.14 Low standardisation.	
	6.15 Inadequate policies and regulations.	
	6.16 Non-existence of regulations to support OSC and offsite logistics scheduling.	

In countries where the laws are available, they are too rigid and cumbersome, leading to a long and complicated approval process [20]. Another point of concern is the procurement process for buildings, which is tedious in length and favours the traditional construction. A revision of the procurement system to facilitate the Design for Manufacturing and Assembly (DfMA) can be the key to automation of building construction and adoption of OSC [35].

5. Further Analysis

The lists of barriers and their references are contained in the journal articles on offsite construction reviewed in the study. A conceptual framework was developed based on the combination and consolidation of all barriers and their relationships and interactions. The PESTEL themes are interrelated with one another. For example, the environmental theme aspects are interrelated to political and legal, and the theme of new construction

technologies and methods concerns both technological and environmental aspects of the PESTEL framework. Social and economic themes are also interrelated.

Ref. [34] stated that links have been established between environmental factors with social factors. For example, the adoption of OSC because of the sustainability advantages includes reducing environmental impacts by reducing waste and overall carbon footprints of the buildings. Moving the production of construction components to the factories away from construction sites reduces onsite pollution, dust control, water pollution, and noise pollution and increases safer working conditions [55]. The environmental reasons has been adduced for the designing and constructing buildings, and essential factors in formulating policies, codes, and planning permissions and consideration for funding provision of funding [56].

The interrelationship analysis tool is used to quantify the relationships between factors and classify the potential causal barriers and drivers of adoption of offsite construction. The interrelations among the barriers shown in Figure 4 as “in” and “out” in each cluster of barriers. The weighted score of each theme are the number of “ins” and “outs” arrows on the drawing [57].

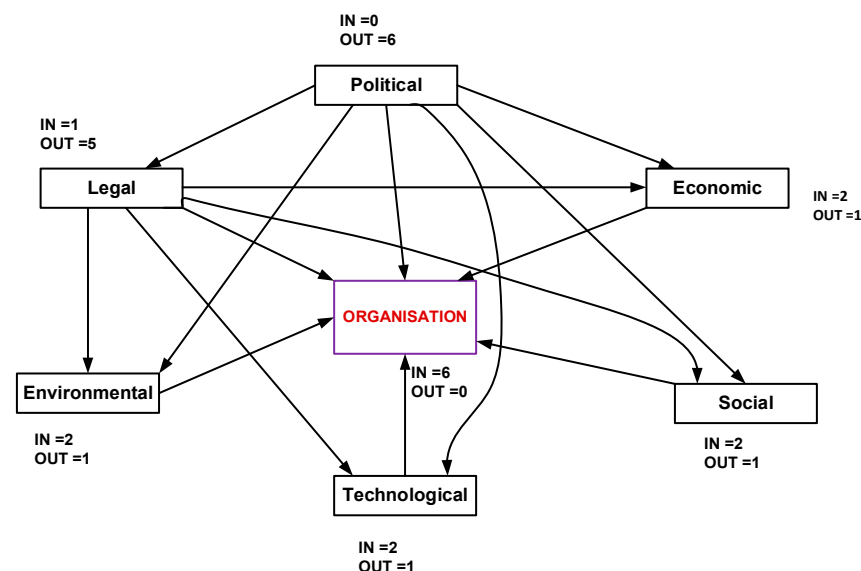


Figure 4. Interrelationship diagram of the barriers.

From the interrelationship analysis, political and legal barriers are observed to have the most causal (outs) effects (6 and 5, respectively) on the adoption of offsite construction while the organisation is mostly affected by all the variables (6 ins). This shows that for the organisation to find solution to the barriers, the political and legal variables of the barriers have to be the focus. If both are addressed, then all other variables would have been solved. These two variables are driven by the government through laws, policies, guides and support to the methods by its adoption by the various governments.

In the past few years, offsite construction has gained more attention in the academia, industries, and institutions [24]. The recent works by academia, industries, and institution such as has increased the confidence in the use of the method especially in the public service sectors. Various governments in Australia are investing and actually using modular construction as a method to accelerate the delivery of infrastructure to schools, housing, and healthcare [58]. State governments such as Queensland plan to build one million homes by 2046 with the establishment of production facilities to streamline design and smooth delivery of modular housing products [59]. The New South Wales government has also led the push for modular buildings to address homelessness by establishing a AUD 224m

package to boost housing supply. The package includes AUD 70m for new and \$35m for maintenance to existing social, and AUD 35.3m for housing services for Indigenous people and families. A total of AUD 20m is reserved for supported housing for mental health, AUD 15m to boost homelessness services, and AUD 11m to fund emergency temporary accommodation [60]. The Victoria government's Permanent Modular Schools Program (VPMS) has delivered more than 100 modular school buildings [61]; Ref. [62]. Organisations such as CIOB reported that despite all the barriers faced by Australia because of the vast geographical and climate challenges, the country operates a multiple three-layered system of government which makes decision-making complex and fragmented. However, there are successful implementations of offsite construction across Australia [63].

The Chinese government invested more than USD 1 trillion into the building and construction industry. In 2022 it also established the Special Economic Zone's (SEZ) new relaxed policies on bank loans that offer special incentives such as tax breaks and providing a conducive environment for the growth of offsite construction. The China offsite construction market is expected to grow from USD 16.26 billion in 2023 to USD 24.92 billion by 2030 [64].

Sweden is a global leader in offsite construction with over 80% of the country's overall housing market. This was made possible by the government support of the industry with a well-trained workforce; knowledge of the methods of offsite production; customer needs satisfaction; and environmental knowledge of green building [65].

The government of Singapore established a special fund, the Public Sector Construction Productivity Fund (PSCPF), to promote the use of modern technologies and pay up to 70% of the cost of training. The fund is also available to promote workforce skills, research, education, and training [66].

6. Identified Gaps and Limitations

6.1. Geographical Limitations

The paper reveals that the research on the barriers to the adoption of offsite construction is mostly concentrated in the developed economies. This may be due to the technological advancement of those countries and their governments' interest in the development of the method. However, there is a need by researchers in developing/underdeveloped countries to show interest in the support for the offsite method of constructing buildings. This is very important because of the shortage of adequate houses for their populations. Offsite construction, having been proved to be cheaper in the long run and environmentally friendly, is most likely to solve their barriers.

6.2. Issues Gap

Though the barriers to the adoption of offsite construction are exhaustively discussed, the issue of waste management, the health and safety of the workers, and mental health are not considered in this paper. There is also a need for further research on the financial aspect of the barriers. The governments of various countries have to show more interest in the method by enacting laws and policies that support the method. One policy could be the promotion of the method by some governments to deliver infrastructural and building projects. Governments can also support manufacturing companies willing to manufacture offsite products by giving them tax waivers for a few years and guarantee loans from banks [35].

6.3. Methodological Limitations

The methods used in the papers under review include questionnaire survey, interview and collection of secondary data. There has not been any data on other stakeholders

like private developers and corporate business owners. Data has not been collected from government adopters of OSC. However, there has been an increase in the number of offsite manufacturers and contractors in Australia [67]. Collecting data across all stakeholders will further shed light on the barriers and therefore help in finding solutions to the low adoption by these categories of users.

7. Conclusions

Given the fragmented, conservative, and slow adoption of innovation and technology of the construction sector, interestingly there is a global shift in the adoption of OSC as different countries and organisations are pursuing the method for various reasons. This paper classified the barriers using PESTEL approach.

The research reviewed existing studies and drew the interrelationships of the PESTEL classifications utilising a systematic literature review method. Based on the content analysis, the review identified 112 barriers of OSC. For a better understanding, the paper collated the barriers as political (5), economic (22), social (33), technological (25), environmental (11), and legal (16). This will form the basis for further research and in choosing the focus of analysis.

However, the three themes with most barriers are not actually the most important. The two most important are political and legal. Solving these causal barriers will solve the other interrelated ones (Figure 4). The developed framework can therefore be used by organisations to develop strategies to reduce or completely eradicate the barriers and find lasting solutions to adoption of offsite construction.

Further, the review is limited to 56 relevant papers that are available in Scopus and World of Science databases. It was also limited by the papers available to industrialised world with very few papers from underdeveloped countries in Africa and South America, and therefore could not draw a general global conclusion in the paper.

7.1. Policy Implications

Having established that the two main barriers are political and legal, this study will influence the formulation of policies and enactment of relevant laws to support the adoption of offsite construction. In years to come, various governments will need to adopt offsite construction as a very good method for delivering infrastructures and buildings to their populace. The increasing demand for new houses for a growing and poor population of these states and countries [65]. Local legislations can improve the adoption of offsite construction. Rigid legislations and regulatory frameworks hinders the adoption of offsite construction in New Zealand construction industry [68]. In Portugal, lack of awareness, data, and accredited organisations were identified to certify the quality of manufactured components and policies defining the most suitable projects for the adoption of OSC. All stakeholders actively involved in the various stages of OSC should engage in more research and development conducted in the industry and the development of value-based evaluation methods for comparison of traditional and OSC. The curriculum and research directions of training and research institutions should be improved to stimulate modular thinking in the curriculum structure of engineering degrees.

7.2. Practice/Practical Implications

The findings of this research will assist all stakeholders of offsite construction to improve the technological and economic aspects as identified by this research to improve production and reduce the overall costs of buildings by accessing low-risk financing to support their businesses [13]. The knowledge and understanding created by this research will create awareness and understanding of the barriers among the stakeholders. Develop-

ers will be aware to seek for low-interest finances for their business. The government will be triggered to enact laws and policies that supports the adoption of the method. Banks, insurance, securities, mortgage companies, and other financial institutions will be guided to design models that will encourage the issuance of credits, subsidies, and low-interest loans to developers according to the developed policies and laws [69]. It will also ginger the government to increase people's confidence in the method by adopting the method in their various building projects [59–61,64,70].

7.3. Further Research

Understanding OSC requires efforts at studied at the country levels, as different countries prioritise different aspects of the methods due to their economic development. There exists a gap by government and other stakeholders in legal, regulatory issues, and green practices [71]. The outcomes of this paper provide the stakeholders of OSC with the external barriers/barriers to the adoption of OSC. It also gives the interrelationship between the barriers so the stakeholders can focus on the barriers that are dominant. OSC is gaining relevance among researchers globally, the issues surrounding its adoption needs to be addressed and resolved by all to improve its acceptability.

The result of this study reveals external factors affecting the organisations in adopting OSC. Further studies are required to focus on the internal barriers militating against the adoption of OSC. The internal factors could be categorised using PESTEL or any other method of analysis.

Lastly, the results of this study showed limited research were conducted on the subject in emerging economies such as Africa and South America (Figure 3) where the advantages of OSC could be harnessed for developing the regions. Future studies could concentrate on Africa and South America to make data available for global analysis of the barriers.

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