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Review

Identification of Impeding Factors in Utilising Prefabrication during Lifecycle of Construction Projects: An Extensive Literature Review

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Abstract: In recent years, the topic of climate change has been increasingly noticed by the public, and carbon emission reduction is one of the primary targets for various industries worldwide. The construction industry has a profound influence in this field, so it is significant to consider what kind of efforts can be made in building projects. Many scholars agree to promote prefabrication technology for construction, but its application still faces several challenges. By undertaking desk research, this paper explores the motivation and barriers to adopting modular techniques in construction projects under the lifecycle analysis. The preliminary information of the literature review is collated from dozens of peer-reviewed academic papers. Under the whole lifecycle thought, the PEST analysis tools also present the analytical results. This research finds that the top five barriers are the attitudinal resistance to using modular constructions, lack of sufficient modular expertise and practice, increasing costs and risks on supply chain management, insufficient government support and policy making, and high design and planning requirements. Moreover, the lifecycle analysis can divide the collated barriers into each stage, and adequate government support can assist in promoting the prefabrication in building projects in financial, legal, and technical aspects. The current findings can facilitate the broader use of prefabrication in building projects, improving the environmental sustainability of stakeholders. The process of proposed desk research can also be considered a referenced pattern for other related studies. More first-hand data should be collected and evaluated in further research to improve accuracy and adapt to the newest research field and industrial situations.

Keywords: prefabricated construction; barriers; building lifecycle; construction management; pest analysis

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1. Introduction

1.1. An Overview of Prefabrication in Construction

Over the worldwide construction industry, there has been a booming trend of exploring the practical application of prefabricated technology in building projects [1–3]. Originating from London, this environmentally friendly technology was applied to housing design in the 19th century [4,5]. Over the past decade, prefabrication has gradually supplanted cast-in-place construction as one of the world's most prominent and pervasive building techniques. Prefabrication requires the production of modules and panels in factories, followed by shipment to the construction site [6]. These completed building components will be artificially joined during the subsequent construction phase to form the building structure [7]. Prefabrication, in other words, is an off-site construction technique. Factory assembly lines produce building elements, which are then transported to the construction site for assembly. Although some building components still rely on the conventional cast-in-situ method [8], fortunately, many building professionals have noticed the importance of promoting modular construction.

1.2. Significance of the Research Direction

A growing number of academics and professionals are realising the significance of sustainable development in both developed and developing nations in light of the complicated issue scenario caused by climate change and resource scarcity. The Sustainable Development Goals (SDGs) were released by the United Nations (UN) to advance the idea of environmental responsibility and sustainability throughout the long-term growth of people [9]. As a result, there has been much discussion in the building industry in the last ten years about energy saving and emission reduction. According to a secondary study by Lachimpadi et al., the worldwide raw material consumption for the building sector is 60%, generating a lot of industrial pollution and waste [10]. For instance, construction activities account for 40% and 33% of the country's total energy consumption in America and Canada [11]. Based on this research, the construction sector should become one motivation for successfully fulfilling the SDGs. However, the current construction projects mainly prefer the cast-in-situ building approach rather than prefabrication. For instance, Li et al. analyse that significant building structures (like bearing members and their combinations) will likely adopt the cast-in-place way [12]. On the other hand, the secondary-important building member could be precast in the assigned factory, which can be counted in the assembly rate of a building project [13]. During the project lifecycle, it is significant to explore what factors promote and impede the use of prefabrication in construction projects. The effective use of prefabrication can improve environmental sustainability.

1.3. Purpose and Scope of Literature Review

Based on the above discussion, this paper explores the impeding factors to adopting prefabrication in construction projects under the lifecycle analysis. Thus, the main research question is: What are the factors and reasons impeding the use of prefabrication in building projects? In order to solve the main research problem, this review paper investigates the major obstacles to using prefabrication in construction projects under the whole lifecycle of a building project by conducting a comprehensive literature study and analysis. Specifically, throughout the whole lifecycle of building projects, the influencing factors are collated by reviewing over 60 academic articles and classified using the political, economic, social, and technological (PEST) analysis. The relevant findings are also classified under the project lifecycle analysis. Thus, answering the main research question, the relevant findings can assist the broad application of modular construction, effectively bringing various benefits to different stakeholder groups. The following sections illustrate the reviewed literature, specific research methodology and flow, research findings and discussion, and conclusion.

2. Literature Review

2.1. Definition and Types of Prefabrication

The terms "prefabricated," "modular," and "off-site" are utilised synonymously within the context of this article without any discernible impact on the substance of the written material. Modular construction is an off-site building process in the specialised lexicon published by Oxford University Press [14]. After the fabrication of panels in industrial facilities and their transportation to the designated site, the subsequent stage in the sequence involves the erection of the edifices. As per the findings of previous research [15], the crucial prefabricated components and standard panels are chosen during the planning phase. The manufacturers responsible for producing the standard panels are allocated in this phase. The constituents above are manufactured off-site and transported to the designated area for ultimate integration. Modular construction relies heavily on prefabrication and assembly as a direct result. Some scholars present a comprehensive account of the essential stages of assembling a modular dwelling, commencing with the transportation phase and culminating in the ultimate dispatch [16]. To a certain extent, the procedure of constructing an edifice using modular elements can be likened to the process of assembling Lego blocks.

2.2. Advantages of Prefabrication in Construction

Choosing the appropriate building methods is one of the effective ways to improve construction projects' sustainability. Specifically, prefabrication can improve the comprehensive performance of construction projects. The sustainability of construction can be categorised into three primary categories: environmental, financial, and social [17,18]. Regarding environmental sustainability, it is evident that prefabricated construction is more sustainable than conventional construction, especially regarding energy consumption and construction waste. According to an environmental impact study, modular construction can effectively reduce energy consumption during construction [7]. Specifically, water, coal, and diesel consumption decreased by 22.48%, 41.02%, and 51.88%, respectively, during the modular building construction. It indicates that renewable and non-renewable energy can be conserved efficiently through prefabricated construction, positively influencing long-term environmental sustainability. In addition, prefabrication has the evident advantage of reducing construction waste. It is generally accepted that construction waste comprises non-recyclable building materials that were damaged during the on-site construction phase and harm environmental sustainability. In the study mentioned above, the waste reduction in modular buildings ranged from 25% to 81%, demonstrating that the prefabrication method significantly improves construction waste reduction [7].

Prefabrication can also reduce and control project costs, contributing to the project's financial viability. In reality, prefabrication is the production of building components in factories [19]. This situation eliminates the need for labour-intensive, cast-in-place procedures, reducing the need for on-site construction personnel. Reducing the quantity of construction employees can significantly reduce project budgets, given that labour is one of the most expensive components of a project. For instance, labour costs in prefabricated constructions were reduced by 25% compared to conventional constructions. Other researchers also report that the factory assembly line can replace 80–90% of on-site construction activities [20]. The valuable construction time is reduced by forty per cent when the prefabricated method is utilised. Time is primarily equal to money in construction projects, so reducing the construction timeline will likely lower the building's worthwhile expenditure. These findings indicate that prefabrication can be used to manage and even reduce the project budget, thereby increasing the financial viability of construction projects [21].

2.3. Importance of Lifecycle Analysis

The collected information mentioned above shows that promoting prefabrication in building projects still faces a few obstacles [22]. Thus, figuring out the barriers to adopting prefabrication in construction projects is essential. However, a construction project has a long-term lifespan, so it is difficult only to consider a single aspect or phase of a building project while analysing the obstacles to using prefabricated technology. Facing such a challenge, the research team agrees to thoughtfully select and review the previous academic and non-academic sources to determine the significant factors that influence the application of modular techniques in construction projects during the project's whole lifecycle. The Project Management Institute (PMI) and many supporters explain that the project lifecycle should be defined as the process from birth to death. As shown in Figure 1, this long-term development process involves six stages, including the conceptual design, decision-making analysis, pre-construction preparation, formal construction and product delivery, operation and maintenance, and the construction of waste and demolition at the end of the building's lifecycle [23,24].

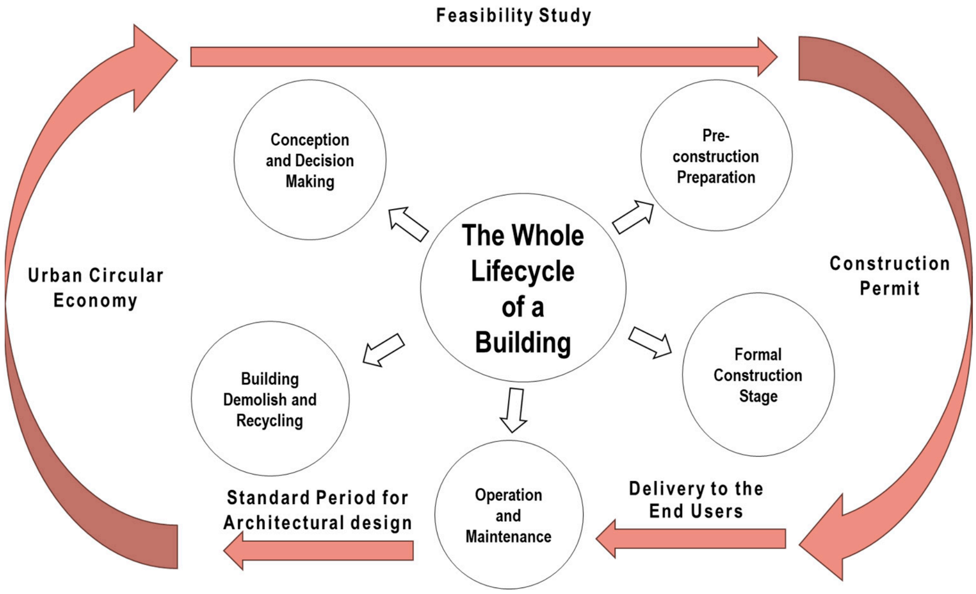

Figure 1. An analysis framework of the building lifecycle.

2.4. Motivation for Adopting Prefabrication

In recent decades, scholars have frequently explored the feasibility of modular architectures. Empirical evidence indicates that modular construction outperforms conventional cast-in-place construction in several categories. The domains encompassing sustainability, safety, cost-effectiveness, and time management are of paramount importance. Using prefabricated buildings can significantly enhance the overall sustainability of a given development endeavour. Modular construction has been identified as a promising approach to mitigate the consumption of basic materials and non-renewable resources, along with the generation of harmful greenhouse gas emissions and construction waste [7,25]. The outcomes above can be attributed to the flexibility and recyclability of the abovementioned construction technique. This pioneering construction technique can also enhance the safety of on-site construction operations, thereby constituting an added benefit of its implementation. According to the research conducted by Fard's research team, modular buildings can significantly decrease the count of fatalities [26]. This situation is due to a notable decrease in the number of staff members currently present at the worksite. Modular construction represents a building technique that mitigates risks to construction workers, thereby reducing potential health hazards [7]. Furthermore, modular construction can enhance the management of schedules and budgets in construction endeavours. Modular construction entails the construction of a structure in distinct sections, as opposed to a simultaneous construction of the entire system. Lawson, Ogden, and Bergin have conducted a thorough case study, illustrating that implementing off-site building techniques can effectively reduce costs and manage construction schedules [27].

Modular construction has been increasingly recognised by scholars and professionals in the industry as a superior alternative to the traditional cast-in-place approach in recent times. The improvement in sustainability, safety, and project management is particularly noteworthy. Using prefabrication techniques in construction can considerably improve the eco-friendly attributes of buildings in comparison to traditional construction methods [25]. Modular construction presents itself as a sustainable substitute for conventional building techniques. A research team performed a case study that evaluated and compared traditional approaches' energy consumption, material utilisation, and waste generation with modular techniques while maintaining identical conditions [7]. For instance, using modular construction techniques may lead to a decrease of up to 20% in the consumption of unprocessed materials and other non-renewable resources in contrast to the cast-in-place procedures. Implementing prefabrication techniques in construction projects has been shown to improve their environmental sustainability by decreasing the utilisation of inefficient construction materials and minimising greenhouse gas emissions [7].

Modular construction can enhance environmental sustainability and safety measures on traditional construction sites. The authors accomplished this task by referring to the 2012 dataset furnished by the Bureau of Labour Statistics of the United States. It can be inferred that the construction industry in the United States is among the most hazardous sectors, given that it registers the highest number of fatalities and injuries, accounting for nearly 20% of the total incidents [26]. A study conducted by Wu et al. in 2019 suggests that incorporating modular structures can significantly decrease the total workforce and on-site activity, resulting in around a 30% reduction in injuries [28]. Based on their comprehensive case studies, some scholars have agreed that in-factory manufacturing and on-site assembly are comparatively safer than on-site construction [26]. Nevertheless, it has been found that on-site construction presents the most significant peril. Implementing comprehensive training programmes and properly utilising personal protective equipment (PPE) can effectively mitigate the occurrence and gravity of pertinent hazards across all stages of construction [29].

Moreover, it is widely acknowledged that the amount of time allocated towards constructing initiatives is equivalent to financial investment. One of the benefits of a shortened timeframe is evident. A reduced schedule can effectively manage construction expenses, facilitating adherence to the estimated budget [30]. A research group has analysed three distinct building scenarios and determined that using off-site construction methodologies may reduce costs by approximately 33% [27]. The phenomenon above can be attributed to the fact that a decrease in workforce size can lead to significant cost reductions concerning expenditures related to human resources.

2.5. Hindrances of Utilising Prefabrication

Zhai, Reed, and Mills observe that modular construction still entails certain risks in the building project process despite its numerous advantages over conventional cast-in-place methods [31]. The hazards are the primary disadvantages of utilising modular construction methodology. A research group conducted a second-hand study using a systematic literature review approach [32]. That review analysed 39 selected articles to identify potential concerns that may arise during the construction of modular houses. The research team identified the top five most common hazards associated with modular buildings. Managing multiple stakeholders, delays in component shipment, increased initial budgets, and insufficient supply chain integration contribute to project management's complexity. Luo's research team interviewed specialists in the construction industry to examine the current status. These potential hazards can be mitigated by refraining from falling into these pitfalls [33]. Numerous scholars researching identical or closely related fields have cited or demonstrated these results, and the explanations of the typical hindrances are presented in detail as follows [34–37].

1. The intricacies involved in managing stakeholders.

The PMI has identified stakeholder management as a pivotal component that significantly enhances the likelihood of project success [23]. As a result, this particular segment has been incorporated into the fifth iteration of the expert compendium. The management of stakeholders in modular building projects can be perceived as a multidimensional challenge due to varied cognitive processes, unregulated behaviour, and intricate communication networks [38]. A modular construction project typically involves the participation of various stakeholders, including sponsors and developers, management professionals, on-site construction teams, planning and design groups, suppliers, manufacturers, deliverers, safety supervisors, end-users, construction site neighbours, and insurance companies [39]. Project participants often establish personalised goals and objectives, which drive their pursuit of diverse rewards. Consequently, the interests of stakeholders have the potential to be in conflict. The modular construction methodology necessitates the consideration of inter-manufacturer, delivery, and supplier coordination [40]. The stakeholder groups mentioned above are responsible for pre-manufactured constituents' production and subsequent placement. The complexity of stakeholder management is directly proportional to the number of stakeholders involved. Stakeholder complexity may give rise to communication difficulties, which have been identified as a significant determinant of the efficacy of lean construction management [41].

2. A significant initial investment is required.

Although modular construction has been proven more time-efficient than traditional building techniques, the initial expenses of this pioneering approach are considerably greater than those of alternative construction alternatives. Modular structures generally incur an initial cost of 20% higher than cast-in-place technologies [41]. The modular construction initiative in China would incur additional costs per square meter due to the design and prefabrication phase [37]. The situation could stem from the other prerequisites that off-site construction mandates before the commencement of a project. The high upfront expenses linked to modular technology could dissuade construction developers or intensify the economic hazards of overseeing such endeavours. As a result, mitigating risks is a pressing concern that modular advocates must tackle. The proposed measures encompass the identification of distinct enterprises specialising in the production of prefabricated building panels, the implementation of mandatory training programmes for construction personnel tasked with the assembly of such structures, and the deployment of appropriate equipment. Studies with comparable objectives have been conducted in various countries, including Korea, China, Malaysia, and Singapore [42–46].

3. Insufficient instances and practical experience from the real world

One of the significant areas for improvement in modular designs is the need for practical illustrations and proficiency [37]. In several industrialised nations, the total number of practical applications of modular construction still needs to catch up in conventional cast-in-place projects, based on their systematic survey and case study [27]. Employing prefabricated buildings is a relatively new and innovative idea in numerous underdeveloped and economically disadvantaged countries [16]. Consequently, the regional construction sector needs more practical instances of off-site construction to acquire knowledge. Hwang, Shan, and Looi agree that construction workers and other pertinent stakeholders in developing nations and regions may need to be qualified to execute similar modular projects owing to their inadequate knowledge, techniques, and essential skills, including on-site assembly and in-factory fabrication [47]. The absence of practical instances and familiarity with modular constructions in several emerging economies, including Malaysia and mainland China, poses a substantial hazard [10,35].

4. Apprehensions of the established schedule

Although modular construction has the potential to reduce project duration compared to traditional building methods, it is essential to note that this innovative technology is not immune to schedule-related challenges. Two factors contributing to delays are personnel needing to meet the site's eligibility requirements and the absence of connectivity between the transportation and supply chain management systems. These two factors are responsible for the total duration of the delays. Ji et al. have identified project completion delays as a significant impediment to the progress of modular construction [15]. The research team's findings indicate that inadequate work skills and knowledge are the primary factors contributing to delays in modular building projects. The research team has concluded that the prevalent challenge faced during such projects is the structural interconnections among the system components. Additionally, the implementation of modular construction may result in potential transit delays. The existing management system poses a challenge in ensuring the accurate transportation of materials from manufacturers to construction sites [36]. Inadequate supply chain integration can harm the prompt delivery of modular structures [40]. The optimal distribution of crucial resources within modular construction remains a persistent challenge, particularly concerning allocating resources among construction teams, suppliers, and manufacturers.

2.6. External Environment of Using Modular Constructions

Given the current research circumstances, it is imperative to undertake a comprehensive inquiry into the external environment of using modular construction. The strengths, weaknesses, opportunities, and threats (SWOT) analysis encompasses four key domains: opportunities, risks, advantages, and disadvantages [48]. Through the application of this analytical tool, an evaluation of the external environment of using modular construction is conducted, which mainly assesses the benefits and drawbacks of this construction method. A SWOT analysis of prefabrication in building projects is illustrated in Figure 2. The advantages and disadvantages of prefabrication are discussed in previous parts. Regarding the opportunity part, the Industrial 4.0 period promotes modular constructions, improving the working efficiency and project scope accuracy [49]. The worldwide promotion and effective implementation of SDGs can also be a positive factor in facilitating the use of prefabricated buildings, which can reduce the environmental impact on the negative side [50]. Moreover, the threat of using prefabrication requires consideration of other construction methods, which have similar functions for completing construction projects. For instance, the cast-in-situ method is not an environment-friendly building approach, but it is a mature and traditional way in which social acceptance is high. At the same time, 3D printing technology is limited to the building height, but it can improve cost efficiency and reduce the project timeline to some extent [51,52].

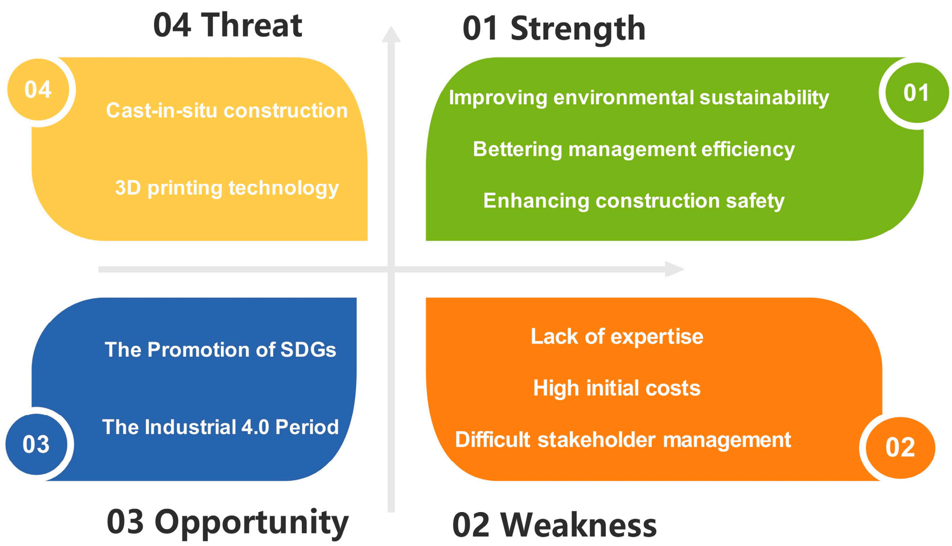

Figure 2. A preliminary SWOT analysis of using prefabrication in building projects.

2.7. The GAP Analysis of Previous Research

There still needs to be a gap between the previous research and the current situation. Although some researchers have investigated the barriers to using modular constructions, exploring the current findings using the lifecycle analysis is essential. It can provide a wider horizon of analysing what kind of barriers can impede the use of modular constructions from the conception design (the initial stage of the whole project lifecycle) to the demolition and recycling of the prefabricated buildings (end of the whole project lifecycle). Specifically, the PEST analysis can divide the identified factors into the political, economic, social, and technological aspects [53,54], which can better understand the research findings. These classified factors should also determine whether they impede prefabrication use during the construction project's lifecycle and in which stage.

3. Research Methodology

3.1. Research Flow and Search Strategies

This paper mainly explores the research topic based on an extensive literature review. By studying a few academic papers focusing on the engineering management topic [28,55,56], the specific process of this research is elaborated, as shown in Figure 3. The study relies on desk research, and the information is collated from academic journals, conference proceedings, official news, technical reports, and other convincing sources. This desk research will be developed by following the steps explained above. The first step is to search the online school library, Google Scholar, Scopus, and Science Citation Index to preliminarily investigate hundreds of theme-related papers. Then, the researcher elaborately refined the selections by setting more accurate keywords and prioritising reputable publications and more recent published years (the total number of selected articles is over 60). After that, PEST analysis is essential to summarise the research findings from different aspects more comprehensively and clearly. Using the PEST analytical tool, the identified barriers can be grouped into political, economic, social, and technological aspects, which can determine possible solutions in further investigations. The proposed research findings should be convincing and comprehensive for other secondary research in the relevant construction study field.

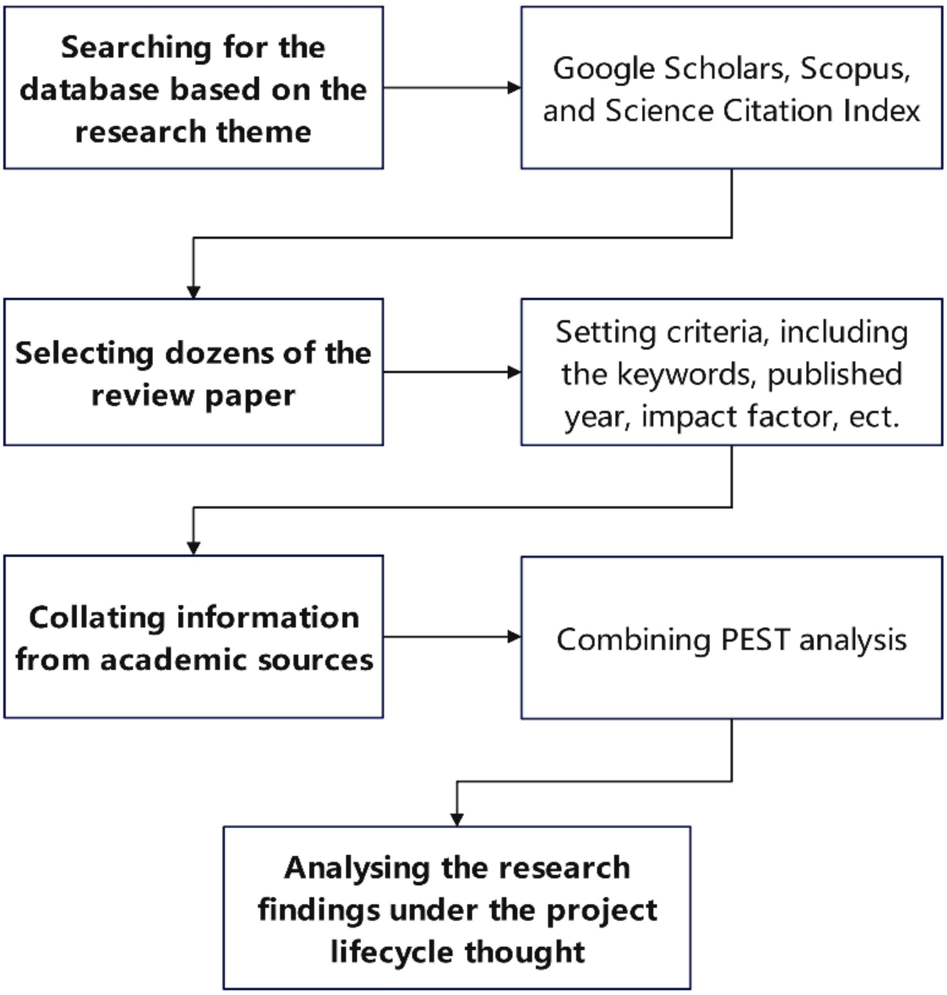

Figure 3. The structure of the proposed research flow.

3.2. Inclusion and Exclusion Criteria for Studies

The initial step is to search for the database to ensure the proposed research project's feasibility. Over 100 peer-reviewed papers are selected by searching the research theme (separately search barriers and prefabrication, building project, PEST analysis, and project lifecycle). However, it is essential to ensure that the information collected from the papers is reliable (should be indexed by reputable databases). The preliminary search must also exclude papers published over 20 years (most refined articles are published within the past ten years) or without the peer-reviewed process before publication. The limitation of years can satisfy the requirements of the research timeline and is encouraged to be published in the past five years, improving the accuracy of research findings. After the preliminary study of the dozens of literature, it is essential to refine the selected papers. The refined papers should include at least three keywords or synonyms according to previous keyword settings, such as prefabrication, barriers, construction project, building project lifecycle, literature review, and PEST analysis. Refined by keyword searching and abstract analysis, the preliminary academic papers are reduced and refined to around 60 articles, providing more convincing and comprehensive information.

3.3. Information Extraction and Analysis Process

Combining PEST analysis is essential to analyse the research findings (the identified barriers to using modular constructions) from political, economic, social, and technological sides. This step explores the impeding factors of preliminarily using prefabrication in building projects. The preliminary selected papers can theoretically explore and explain the expertise, solidifying the research framework and knowledge. It can also be evidence that the selected research topic is one of the hot-spot directions for construction management study areas. After that, the collated data and information from the selected articles support the presentation of research findings using the PEST analysis under the project lifecycle thought. There are no limitations for research regions, but it is essential to summarise the findings and classify the barriers by PEST category. Notably, the impeding factors collated from the refined papers should only conclude that the same hindrances occurred twice or more, and the times of occurrence decide the importance of identified barriers. This consideration can reduce previous studies' contingency, accuracy, and objectiveness. The lifecycle evaluation figure can consolidate the findings widely.

4. Research Findings

Reviewing the screened papers identifies the relevant barriers to using prefabrication in building projects, as shown in Table 1. In summary, the impeding factors to utilising prefabrication vary across different regions, and they encompass issues related to knowledge, adaptability, funding, stakeholder management, transportation, governmental assistance, market maturity, quality control, and design conflicts. Understanding these factors is crucial for overcoming challenges and promoting the successful implementation of prefabrication in construction projects. As shown in Table 1, many research groups have investigated the impeding factors of adopting modular buildings. However, specific research has not narrowed the topic based on the project's whole lifecycle analysis. In other words, an extensive literature review should consider the impeding factors from a broad perspective. It generally includes the stage of conception and decision-making, feasibility study and pre-construction preparation, formal construction and delivery to the end-users, operation and maintenance, and building demolish and recycling based on the circular economy concept.

Table 1. The obstacles to adopting modular buildings in various locations.

Study Areas	Researchers and Reference	Impeding Factors of Using Prefabrication
Worldwide	Tam et al. [57]	The process of familiarising with established methods Modular designs display limited adaptability to modification
	Wuni and Shen [58]	The understanding of construction-related information The particular situations that are unique to the industry Insufficient project funding The emergence of technical deficiencies
	Wuni, Shen, and Mahmud [32]	The intricacy involved in effectively managing stakeholders Transportation delays of components Escalation of initial budgets Inadequate governmental assistance
	Ham and Raymond [59]	Building industry awareness and culture Stakeholder cooperation methods
	Tsz et al. [60]	Transportation network capacity
	Chourasia, Singhal, and Manivannan [61]	Insufficient anti-seismic performance tests Inadequate practice of joint connections and building project designs
	Zhao et al. [62]	Schedule issues and related organizational management risks
	Chen [63]	Transportation delays and related issues Lack of sufficient practice in modular construction Technical limitations to different project types
	Han, Wang, and Kang [64]	Customer preference and other stakeholder management issues
	Laovisutthichai, Lu, and Xue [65]	Design simplification of building structure Limited and immobilised dimension
	Zolghadr, Gharaie, and Naderpajouh [66]	Economic justifiability Acceptance of prefabricated buildings
	Gan et al. [67]	Practical market demand Higher project initial cost Concerns regarding the aesthetic performance of modular buildings
Europe	Martin et al. [68]	Attitudinal resistance to using prefabrication buildings
	Lawson, Ogden, and Bergin [27]	The logistical organisation and coordination of the panels
	Pan and Sidwell [69]	The exorbitant expenses associated with transportation
	Martin et al. [70]	Uncertainty of bid price Resistance to transition from traditional approach to prefabrication
	Pan, Parker, and Pan [71]	Problematic interfaces and relevant design issues Ineffective management, organisation, and communication
	Ribeiro, Arantes, and Cruz [72]	Low levels of research and development Inadequate accredited authorities to certify the modular panels The industrial resistance to change in construction approaches
	Agha et al. [73]	Exorbitant land costs Insufficient available land Extra transportation expenditures
	Feldmann, Birkel, and Hartmann [74]	Attitudinal acceptance of the building industry and market
	Agapiou [75]	Cost-related requirements Supplying capacity of modular construction suppliers End-users preference for building project types

Table 1. *Cont.*

Study Areas	Researchers and Reference	Impeding Factors of Using Prefabrication
America	Fard et al. [26]	Potential hazards regarding the transfer of structural component
	Polat [76]	Insufficient ability of experts specialised in modular systems
	Regner [77]	The changing awareness of adopting prefabrication buildings Increasing knowledge of applying the modular building approach
	Cruz, Grau, and Bilec [78]	Budgets and timeline constraints Unclear regulations and requirements Conflicts on current industrial specifications
	Paliwal et al. [79]	The issues of logistical transportation and supply chain management
Chile	Ortega, Mesa, and Alarcón [80]	Insufficient governmental assistance Inadequate value chain integration in the initial stage of a project Difficult stakeholder management Resistance to new building technology
Australia	Khalfan and Maqsood [81]	The absence of effective leadership A possible shortage of modular manufacturers Governmental provision of incentives is deemed inadequate
	Zhang et al. [82]	Inadequate standardisation of local modular constructions Insufficiently skilled labours Imperfect connection design Insufficient automated manufacturing systems Accessibility of construction site
New Zealand	Shahzad et al. [83]	Conflicts between building designs and practical construction Escalation of initial budgets Supply chain management issues Acceptance level of using prefabrication in building projects
	Nesarnobari, Shahzad, and Jelodar [84]	Misconception on modular construction Lack of required skills Ineffective communication management Lack of adjustable designs based on the site situation Need for governmental support.
China	Zhang et al. [46]	The inadequacy of shortage areas Challenges with implementing changes in design and planning
	Gan et al. [17]	Insufficient modular expertise is a notable limitation The prevalence of traditional methods
	Hong et al. [85]	The increased cost intensity associated with prefabrication The level of maturity exhibited by the domestic market
	Jiang et al. [25,37]	Complex stakeholder engagement The implementation of industry guidelines and regulations
	Luo et al. [33]	Inadequate management of prefabrication systems Inadequate quality control The building standards are incomplete
	Mao et al. [41]	Insufficient governmental assistance The upfront expenses are substantial Be accustomed to utilising conventional construction methods
	Wu et al. [28]	The standardisation of local policies and market practices The perspective of businesses The building exhibits technical deficiencies
	Xiahou et al. [29]	The metamorphosis of conventional industry

Table 1. *Cont.*

Study Areas	Researchers and Reference	Impeding Factors of Using Prefabrication
China	Zhai, Reed, and Mills [31]	Uncertainties on the structural reliability Social desire and market availability
	Chiang et al. [35]	Poor water resistance of buildings Greater proficiency requirements for labour The rising prices of conveyance
	Jaillon and Poon [86]	Design conflicts that arise among stakeholders
	Luo et al. [40]	The management of intricate supply chains
	Sun et al. [87]	Room for improvement in industrial regulation and standards Insufficient publicity on prefabrication technology
	Wang et al. [88]	Relevant building standards still need to be improved Escalation of initial budgets Supply chain management issues Deficiency of using information technology Conflicts of using different Management modes appropriately
	Zhou et al. [89]	Complex stakeholder management Inadequate practical skills Demands on manufacturing capacity of modular panels
Singapore	Hwang, Shan, and Looi [47]	The design and planning necessitate elevated standards The intricate project management coordination
	Xu, Zayed, and Niu [45]	The provision of governmental assistance The formulation of policies by the state
Malaysia	Amin et al. [43]	The absence of specialised knowledge or skills The adjusting phases in marketplaces The expanding caseload
	Al-Aidrous et al. [90]	Financial consideration and anxiety Inadequate policy support Technical and design limitations Management-related concerns
Pakistan	Pervez et al. [91]	Inadequate capacity for manufacturing modular components Conflicts between the design and construction Inadequate practical experience and skills
Lebanon	Hamzeh et al. [92]	The underdeveloped techniques for prefabrication
Korea	Lee and Kim [42]	The upfront expenses are high The ability of corporations to use modules
	Shin et al. [93]	Technological acceptance level
South African	Kenny et al. [94]	Inadequate understanding of modular buildings Aesthetic attraction and appreciation Product flexibility and beliefs
Libya	Ammari and Roosli [95]	Supply chain management issues Governmental support and interventions Financial burden
Egypt	Ali et al. [96]	The awareness of overall sustainable success
	Ali et al. [97]	Conflicts between the design and construction Increasing initial expenditure Transportation delays of modular panels Acceptance level of innovative building approach
	Ibrahim, Hamdy, and Badawy [98]	Policy barrier factors Attitudinal acceptance of the innovative building approach
	Ali et al. [99]	Attitudinal resistance to using prefabrication buildings Lack of relevant knowledge and technical deficiency

Table 1. *Cont.*

Study Areas	Researchers and Reference	Impeding Factors of Using Prefabrication
Nigeria	Akinradewo et al. [100]	Stakeholders' concern about value management Building industrial practices need to be improved
	Bello et al. [101]	Governmental provision of incentives is deemed inadequate The absence of specialised knowledge or skills Inadequate capacity for producing modular panels

By excluding the relevant factors figured out only once, the statistical data of the major barrier occurrence in each article are concluded in Figure 4. A PEST analysis aims to classify the external factors as political, economic, social, and technological aspects, outlining a clear analytical result of collated barriers [102]. Specifically, the political barriers involve insufficient government support and policy making (11 times) and incomplete building standards, guidelines, and specifications (8 times). The economic obstacles are increasing costs and risks on supply chain management (16 times), higher initial costs of the modular construction project (8 times), and project finance burden and its economic justifiability (7 times). As for the social aspect, attitudinal resistance to using modular constructions (18 times), the complexity of stakeholder engagement and management (10 times), and insufficient modular manufacturers (8 times) are significant contributions. Moreover, the technological factors include but are not limited to a lack of sufficient modular expertise and practice (17 times), high requirements of design and planning (11 times), and technical deficiencies of the modular building (10 times). Based on the data statistics, the top five barriers are determined and ranked from No. 1 to No. 5 as the attitudinal resistance to using modular constructions (the social aspect), lack of sufficient modular expertise and practice (the technological factor), increasing costs and risks on supply chain management (the economic obstacle), insufficient government support and policy making (the political barrier), and high requirements of design and planning (the technological aspect). The complexity of stakeholder engagement and management has been presented 10 times, which has the same situation as the technical deficiencies of the modular building. Based on the findings from Table 1, political factors can make contributions for both developed and developing regions or countries. It can be inferred that underdeveloped regions should focus on the technological aspects, while developed regions should pay more attention to the social acceptance level of promoting new construction methods. This PEST analysis is well-rounded because the identified top barriers refer to all aspects, including political, economic, social, and technological factors. In other words, promoting prefabrication in building projects can be seen as a comprehensive issue instead of only focusing on a single analytical aspect. Meanwhile, these collated impeding factors should be analysed further for more profound insight.

Although Figure 4 classifies and ranks the significant obstacles in sequence, dividing these barriers into different stages according to the building project lifecycle is also essential. Under critical consideration, the research teams put the influential factors (identified in the proposed PEST analysis) into a project lifecycle analysis (considering the analysis from Figure 1), as elaborated in Figure 5. In terms of the horizontal axis in Figure 5, the whole lifecycle of modular construction projects generally includes the conceptual design and decision-making analysis (stage one), pre-construction preparation (stage two), formal construction and product delivery (stage three), operation and maintenance (stage four), and construction of waste and demolition (stage five). As for its vertical axis, it considers the statistical data collated from Figure 4. The major identified barriers are marked in Figure 5 throughout each stage during the modular building lifecycle. It can be seen that each building lifecycle stage faces different promoting barriers.

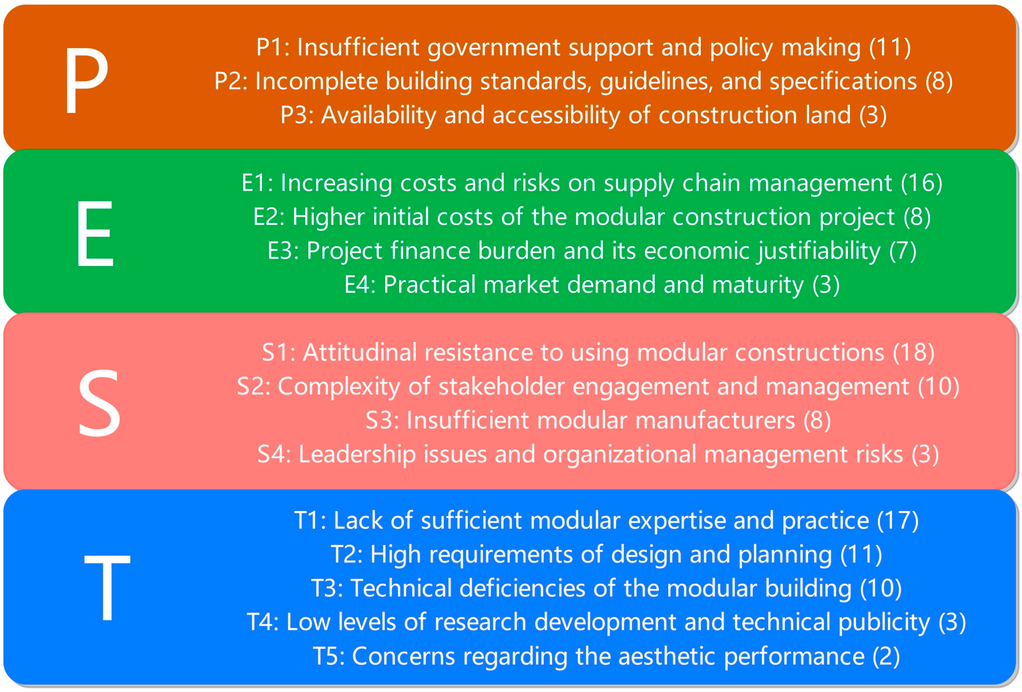

Figure 4. A PEST analysis of the obstacles to using prefabrication in building projects. The number in bracket means the statistical frequency based on the extensive literature review.

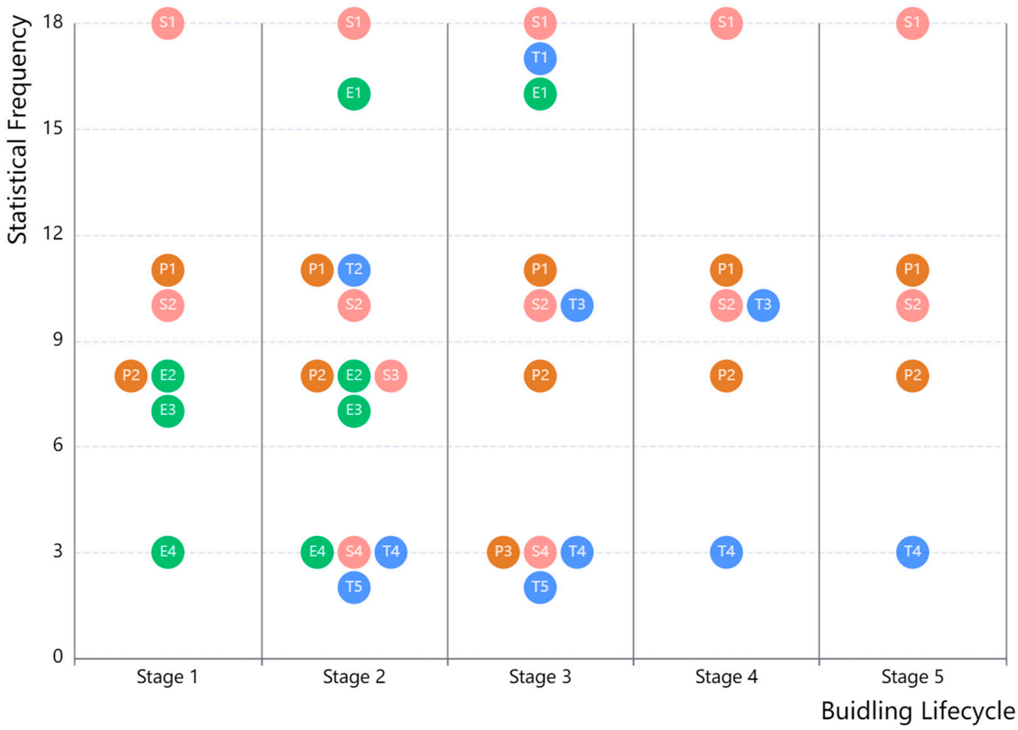

Figure 5. Main obstacles to using prefabrication in building projects under the project lifecycle.

As shown in Figure 5, insufficient government support and policy making (P1), incomplete building standards, guidelines and specifications (P2), attitudinal resistance to using modular constructions (S1), and complexity of stakeholder engagement and management (S2) exist during the whole lifecycle of prefabricated construction projects. This figure also indicates that the most frequent hindrances are likely related to attitudinal resistance to using modular constructions (S1), lack of sufficient modular expertise and practice (T1), and insufficient government support and policy making (P1). Based on these two groups of analysis, it can be inferred that effective government support can efficiently motivate prefabrication in building projects. In other words, if building professionals, environmentalists, or project developers promote prefabrication in building projects, one of the significant factors is how to cooperate with the government and apply for official legal, financial, and technical support. Further research can be investigated by verifying and modifying the current research findings and devising relevant solutions to tackle stubborn obstacles.

On the other hand, the attitudinal resistance (S1) to using modular constructions could have an interdependent relationship with the complexity of stakeholder management (S2), such as the habituation of traditional methods and the misconception of new building technology. A successful building project needs to narrowly satisfy the cost, quality, and schedule criteria, which are the minimum requirements for assessing the project performance. On the other hand, an excellent and successful project should satisfy the purposes of different stakeholder groups. This is why stakeholder management's complexity is frequently a major barrier during the project lifecycle. For example, in the project decision-making stage, some developers, especially those who have succeeded in traditional cast-in-situ building projects, are likelier to insist on this conventional construction approach instead of prefabricated constructions. Many construction labourers habituating to adopting the cast-in-place method in building projects are probably reluctant to accept the use of modular buildings, which will cause negative effects on the building quality and budgets during the preparation and formal construction stages. In addition to these two stakeholder groups involved in different lifecycle phases, end-users (sometimes also called the consumers in the building market) have safety concerns regarding the long-term safety issue of building projects. Thus, this situation at the conceptual design or operation stages causes the customer to prefer using mature technology rather than choosing prefabricated buildings.

A lack of sufficient modular expertise and practice (T1) can also increase the systematic risks of project quality during the formal construction stage and even other aspects of assessing the project's lifecycle. This issue is linked to the technical deficiencies of the modular building (T3) and can cause higher expenditure on prefabricated building projects (E2). Technical deficiencies, especially in underdeveloped countries, are likely to elevate the requirements of design and planning, which can influence the project process at the conceptual stage for experienced developers or during the decision-making analysis based on a comprehensive feasibility study. Meanwhile, increasing costs and risks on supply chain management (E1) during the pre-construction stage should also consider the inadequate manufacturing capacity (S3) and other schedule-related problems. More importantly, insufficient government support and policymaking need to be considered during the whole building lifecycle process due to its influence on various stakeholder groups. Thus, effective governmental assistance and stakeholder management are significant in promoting the adoption of modular construction projects.

5. Discussion

This paper considers the impeding factors of using modular constructions under project lifecycle thinking. Through an extensive literature review, attitudinal resistance to using modular constructions, lack of sufficient modular expertise and practice, increasing costs and risks on supply chain management, insufficient government support and policy making, and high requirements of design and planning are currently defined as the top five barriers. These research findings can assist the supporters and promoters of prefabrication buildings in figuring out effective solutions to typical barriers. Promoting the suitable adoption of prefabrication buildings can bring many intangible benefits for construction stakeholders and tangible benefits for the economy. It can improve the sustainability of the local environment and economic recycling. Besides this, there needs to be more effective government support and complex stakeholder engagement in the project's whole lifecycle of prefabricated buildings. It emphasises the importance of governmental support for developing a modular building project. In other words, local government will likely play a significantly positive role in facilitating modular building use, even in different countries and regions. Thus, it is necessary to enhance cooperation with local governments while promoting this sustainable building approach for construction, especially in developing countries and regions. The research findings can improve the effectiveness and efficiency of promoting modular constructions aligned with the SDGs and vision of corporate social responsibility. Such a situation can improve the sustainability of the environment, society, economy, and technology while constructing buildings. Meanwhile, this paper can enrich the study on the barriers to using off-site building approaches from a literature review perspective. Specifically, the research process could be cited as a pattern for similar studies, providing an extensive analysis of relevant literature and research topics.

Although this paper has many benefits in either practical engineering applications or academic research in similar study areas, there still needs to be more room for improvement in this research. For one thing, this paper needs to consider collating the secondary information based on a bigger data collection, which can widely consider the research findings. A multi-criteria decision analysis could also be adopted for analysing first-hand data collection in further research, which can validate the study more effectively and improve the accuracy of the study results. For example, it is essential to ensure transdisciplinary collaboration and seek advice from official organisations which can share up-to-date data and suitable approaches to verification. Meanwhile, the identified top barriers, in some situations, have interdependent relationships with each other. For instance, supply chain management issues, one of the major impeding factors in this paper, may influence project finance burden (one of the economic factors). Considering project lifecycle analysis, governments could also be regarded as a typical stakeholder group, which can also affect the stakeholder management of a modular building project. Based on this situation, a multi-criteria analysis approach and fuzzy analytical method may be adopted for dealing with first-hand data and bigger secondary figures in further research, which can outline a clearer system boundary for this presented analysis.

6. Conclusions

Under the Industrial 4.0 period and the implementation of SDGs globally, the increasing adoption of prefabrication in building projects is a significant trend in the construction sector. This paper investigates the impeding factors to utilising prefabrication in construction projects under the lifecycle analysis. By undertaking an extensive study of the literature, the most mentioned barriers from the literature review are the attitudinal resistance to using modular constructions, lack of sufficient modular expertise and practice, increasing costs and risks on supply chain management, insufficient government support and policy making, and high requirements of design and planning. In addition, ineffective government support and complex stakeholder engagement are two major factors that affect the project's lifecycle. The comprehensive promotion of prefabricated technology in construction heavily relies on governmental assistance in financial, legal, and technical aspects. Thus, official organisations and departments worldwide should take more responsibility for promoting modular constructions if this environmentally sustainable building approach is a driving force in achieving SDGs. If humans can figure out a smooth pathway for facilitating prefabrication in more building projects, this modification will likely bring more advantages to internal and external stakeholders. Moreover, first-hand research and the adoption of the multi-criteria decision analysis should be developed to verify and modify the current research findings, ensuring their accuracy and appropriateness.

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References

1. Cheng, Z.; Tang, S.; Liu, H.; Lei, Z. Digital Technologies in Off-site and Prefabricated Construction: Theories and Applications. *Buildings* **2023**, *13*, 163. [CrossRef]
2. Liao, F.; Pan, H.; Zhang, J. April. Application of BIM technology in the design of prefabricated architecture. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *760*, 012005. [CrossRef]
3. Zhang, Y. Research on the application of prefabricated building system under the background of rural revitalization. *Fresenius Environ. Bull.* **2021**, *30*, 8917.
4. Herbert, G.; Herbert, G. *Pioneers of Prefabrication: The British Contribution in the Nineteenth Century*; Johns Hopkins University Press: Baltimore, MA, USA, 1978; Volume 19.
5. Lasner, M.G. Architecture's Progressive Imperative: Housing Betterment in the 19th and 20th Centuries. *Archit. Des.* **2018**, *88*, 14–21. [CrossRef]
6. Zhou, Z.; Syamsunur, D.; Wang, X. The implication of using modular construction projects on the building sustainability: A critical literature review. *Adv. Urban Eng. Manag. Sci.* **2022**, *1*, 422–427.
7. Cao, X.; Li, X.; Zhu, Y.; Zhang, Z. A comparative study of environmental performance between prefabricated and traditional residential buildings in China. *J. Clean. Prod.* **2015**, *109*, 131–143. [CrossRef]
8. Philip, A.M.; Kannan, M.R. Constructability assessment of cast in-situ, precast and modular reinforced concrete structures. *Mater. Today Proc.* **2021**, *45*, 6011–6015. [CrossRef]
9. Bexell, M.; Jönsson, K. Responsibility and the United Nations' sustainable development goals. In *Forum for Development Studies*; Routledge: Abingdon, UK, 2017; Volume 44, pp. 13–29.
10. Lachimpadi, S.K.; Pereira, J.J.; Taha, M.R.; Mokhtar, M. Construction waste minimisation comparing conventional and precast construction (Mixed System and IBS) methods in high-rise buildings: A Malaysia case study. *Resour. Conserv. Recycl.* **2012**, *68*, 96–103. [CrossRef]
11. Kamali, M.; Hewage, K. Development of performance criteria for sustainability evaluation of modular versus conventional construction methods. *J. Clean. Prod.* **2017**, *142*, 3592–3606. [CrossRef]
12. Li, J.; Wang, L.; Lu, Z.; Wang, Y. Experimental study of L-shaped precast RC shear walls with middle cast-in-situ joint. *Struct. Des. Tall Spec. Build.* **2018**, *27*, e1457. [CrossRef]
13. Almashaqbeh, M.; El-Rayes, K. Optimising the prefabrication finishing level in modular construction. *Can. J. Civ. Eng.* **2021**, *48*, 1534–1540. [CrossRef]
14. Gorse, C.; Johnston, D.; Pritchard, M. *A Dictionary of Construction, Surveying, and Civil Engineering*; Oxford University Press: Oxford, UK, 2012.
15. Ji, Y.; Qi, L.; Liu, Y.; Liu, X.; Li, H.X.; Li, Y. Assessing and prioritising delay factors of prefabricated concrete building projects in China. *Appl. Sci.* **2018**, *8*, 2324. [CrossRef]
16. Knaack, U.; Chung-Klatte, S.; Hasselbach, R. *Prefabricated Systems: Principles of Construction*; De Gruyter: Berlin, Germany, 2011.
17. Gan, X.; Chang, R.; Zuo, J.; Wen, T.; Zillante, G. Barriers to the transition towards off-site construction in China: An Interpretive structural modeling approach. *J. Clean. Prod.* **2018**, *197*, 8–18. [CrossRef]
18. Zhou, Z. The Obstacles to Promoting the Modular Building Project: A Tentative Assessment of the Literature. *Technol. Innov. Eng. Res.* **2022**, *6*, 1–6.
19. Astrachan, I.-D. Modular Construction as a Post COVID-19 Design Alternative. Building Enclosure. Available online: https://www.proquest.com/docview/2753552558?_oafollow=false&pq-origsite=primo&sourcetype=Trade%20Journals (accessed on 16 March 2024).
20. Navaratnam, S.; Ngo, T.; Gunawardena, T.; Henderson, D. Performance review of prefabricated building systems and future research in Australia. *Buildings* **2019**, *9*, 38. [CrossRef]
21. Almashaqbeh, M.; El-Rayes, K. Minimising transportation cost of prefabricated modules in modular construction projects. *Engineering. Constr. Archit. Manag.* **2022**, *29*, 3847–3867. [CrossRef]
22. Jin, H.; Qu, X.; Liu, B.; Liu, C. Examining the success drivers and barriers of modular building projects using qualitative comparative analysis. *Int. J. Constr. Manag.* **2022**, *24*, 601–609. [CrossRef]
23. Edition, P.S. *A Guide to the Project Management Body of Knowledge*; Project Management Institute: Newtown Square, PA, USA, 2018.
24. Blackwell, W. *Code of Practice for Project Management for Construction and Development*; The Chartered Institute of Building: London, UK, 2014.

25. Jiang, R.; Mao, C.; Hou, L.; Wu, C.; Tan, J. A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation. *J. Clean. Prod.* **2018**, *173*, 225–234. [CrossRef]
26. Fard, M.M.; Terouhid, S.A.; Kibert, C.J.; Hakim, H. Safety concerns related to modular/prefabricated building construction. *Int. J. Inj. Control Saf. Promot.* **2017**, *24*, 10–23. [CrossRef]
27. Lawson, R.M.; Ogden, R.G.; Bergin, R. Application of modular construction in high-rise buildings. *J. Archit. Eng.* **2012**, *18*, 148–154. [CrossRef]
28. Wu, H.; Zuo, J.; Yuan, H.; Zillante, G.; Wang, J. A review of performance assessment methods for construction and demolition waste management. *Resour. Conserv. Recycl.* **2019**, *150*, 104407. [CrossRef]
29. Xiahou, X.; Yuan, J.; Liu, Y.; Tang, Y.; Li, Q. Exploring the driving factors of construction industrialisation development in China. *Int. J. Environ. Res. Public Health* **2018**, *15*, 442. [CrossRef]
30. Taghaddos, H.; Hermann, U.; AbouRizk, S.; Mohamed, Y. Simulation-based multiagent approach for scheduling modular construction. *J. Comput. Civ. Eng.* **2014**, *28*, 263–274. [CrossRef]
31. Zhai, X.; Reed, R.; Mills, A. Factors impeding the off-site production of housing construction in China: An investigation of current practice. *Constr. Manag. Econ.* **2014**, *32*, 40–52. [CrossRef]
32. Wuni, I.Y.; Shen, G.Q.; Mahmud, A.T. Critical risk factors in the application of modular integrated construction: A systematic review. *Int. J. Constr. Manag.* **2022**, *22*, 133–147. [CrossRef]
33. Luo, L.Z.; Mao, C.; Shen, L.Y.; Li, Z.D. Risk factors affecting practitioners' attitudes toward the implementation of an industrialised building system: A case study from China. *Eng. Constr. Archit. Manag.* **2015**, *22*, 622–643. [CrossRef]
34. Cheng, C.; Shen, K.; Li, X.; Zhang, Z. Major barriers to different kinds of prefabricated public housing in China: The developers' perspective. *ICCREM* **2017**, *2017*, 79–88.
35. Chiang, Y.H.; Chan, E.H.W.; Lok, L.K.L. Prefabrication and barriers to entry—A case study of public housing and institutional buildings in Hong Kong. *Habitat Int.* **2006**, *30*, 482–499. [CrossRef]
36. Han, Y.; Wang, L. Identifying barriers to off-site construction using grey DEMATEL approach: Case of China. *J. Civ. Eng. Manag.* **2018**, *24*, 364–377. [CrossRef]
37. Jiang, L.; Li, Z.; Li, L.; Gao, Y. Constraints on the promotion of prefabricated construction in China. *Sustainability* **2018**, *10*, 2516. [CrossRef]
38. Gorod, A.; White, B.E.; Ireland, V.; Gandhi, S.J.; Sauser, B. (Eds.) *Case Studies in System of Systems, Enterprise Systems, and Complex Systems Engineering*; CRC Press: Boca Raton, FL, USA, 2014.
39. Gan, X.; Chang, R.; Wen, T. Overcoming barriers to off-site construction through engaging stakeholders: A two-mode social network analysis. *J. Clean. Prod.* **2018**, *201*, 735–747. [CrossRef]
40. Luo, L.; Qiping Shen, G.; Xu, G.; Liu, Y.; Wang, Y. Stakeholder-associated supply chain risks and their interactions in a prefabricated building project in Hong Kong. *J. Manag. Eng.* **2019**, *35*, 05018015. [CrossRef]
41. Mao, C.; Shen, Q.; Pan, W.; Ye, K. Major barriers to off-site construction: The developer's perspective in China. *J. Manag. Eng.* **2015**, *31*, 04014043. [CrossRef]
42. Lee, J.S.; Kim, Y.S. Analysis of cost-increasing risk factors in modular construction in Korea using FMEA. *KSCE J. Civ. Eng.* **2017**, *21*, 1999–2010. [CrossRef]
43. Amin, M.M.; Abas, N.H.; Shahidan, S.; Rahmat, M.H.; Suhaini, N.A.; Nagapan, S.; Rahim, R.A. November. A review on the current issues and barriers of Industrialised Building System (IBS) adoption in Malaysia's construction industry. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *271*, 012031. [CrossRef]
44. Xu, W.; Yang, X.; Wang, F.; Chi, B. Experimental and numerical study on the seismic performance of prefabricated reinforced masonry shear walls. *Appl. Sci.* **2018**, *8*, 1856. [CrossRef]
45. Xu, Z.; Zayed, T.; Niu, Y. Comparative analysis of modular construction practices in mainland China, Hong Kong and Singapore. *J. Clean. Prod.* **2020**, *245*, 118861. [CrossRef]
46. Zhang, W.; Lee, M.W.; Jaillon, L.; Poon, C.S. The hindrance to using prefabrication in Hong Kong's building industry. *J. Clean. Prod.* **2018**, *204*, 70–81. [CrossRef]
47. Hwang, B.G.; Shan, M.; Looi, K.Y. Key constraints and mitigation strategies for prefabricated prefinished volumetric construction. *J. Clean. Prod.* **2018**, *183*, 183–193. [CrossRef]
48. Benzaghta, M.A.; Elwalda, A.; Mousa, M.M.; Erkan, I.; Rahman, M. SWOT analysis applications: An integrative literature review. *J. Glob. Bus. Insights* **2021**, *6*, 55–73. [CrossRef]
49. Gallo, P.; Romano, R.; Belardi, E. Smart Green Prefabrication: Sustainability Performances of Industrialized Building Technologies. *Sustainability* **2021**, *13*, 4701. [CrossRef]
50. Ogunmakinde, O.E.; Egbelakin, T.; Sher, W. Contributions of the circular economy to the UN sustainable development goals through sustainable construction. *Resour. Conserv. Recycl.* **2022**, *178*, 106023. [CrossRef]
51. Gunawan, I. Construction Productivity Analysis of Precast and Conventional Cast-In-Situ Projects: A Case Study in Malaysia. *J. Manag. Eng. Integr.* **2009**, *2*, 62.
52. Sanjayan, J.G.; Nazari, A.; Nematollahi, B. *3D Concrete Printing Technology: Construction and Building Applications*; Butterworth-Heinemann: London, UK, 2019.
53. Dalirazar, S.; Sabzi, Z. Strategic analysis of barriers and solutions to development of sustainable buildings using PESTLE technique. *Int. J. Constr. Manag.* **2023**, *23*, 167–181. [CrossRef]

54. Sammut-Bonnici, T.; Galea, D. PEST Analysis. Wiley Encyclopedia of Management. Available online: https://onlinelibrary.wiley.com/doi/abs/10.1002/9781118785317.weom120113 (accessed on 16 February 2024).
55. Zhou, Z. The hindrances of using modular constructions in Sichuan Province of China: A comprehensive literature review. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *676*, 012090. [CrossRef]
56. Pan, W.; Yang, Y.; Pan, M. Implementing modular integrated construction in high-rise high-density cities: Perspectives in Hong Kong. *Build. Res. Inf.* **2023**, *51*, 354–368. [CrossRef]
57. Tam, V.W.; Tam, C.M.; Zeng, S.X.; Ng, W.C. Towards adoption of prefabrication in construction. *Build. Environ.* **2007**, *42*, 3642–3654. [CrossRef]
58. Wuni, I.Y.; Shen, G.Q. Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. *J. Clean. Prod.* **2020**, *249*, 119347. [CrossRef]
59. Van der Ham, M.; Opdenakker, R. Overcoming process-related barriers in modular high-rise building projects. *Int. J. Constr. Manag.* **2023**, *23*, 1779–1789. [CrossRef]
60. Tsz Wai, C.; Wai Yi, P.; Ibrahim Olanrewaju, O.; Abdelmageed, S.; Hussein, M.; Tariq, S.; Zayed, T. A critical analysis of benefits and challenges of implementing modular integrated construction. *Int. J. Constr. Manag.* **2023**, *23*, 656–668. [CrossRef]
61. Chourasia, A.; Singhal, S.; Manivannan. Prefabricated volumetric modular construction: A review on current systems, challenges, and future prospects. *Pract. Period. Struct. Des. Constr.* **2023**, *28*, 03122009. [CrossRef]
62. Zhao, Y.; Chen, W.; Yang, Z.; Li, Z.; Wang, Y. Analysis on risk factors related delay in PCPs. *Eng. Constr. Archit. Manag.* **2023**, *30*, 4609–4644. [CrossRef]
63. Chen, C. Advantages and barriers of modular construction method in constructing buildings. *Proc. Inst. Civ. Eng.-Smart Infrastruct. Constr.* **2023**, *176*, 75–84. [CrossRef]
64. Han, Y.; Wang, L.; Kang, R. Influence of consumer preference and government subsidy on prefabricated building developer's decision-making: A three-stage game model. *J. Civ. Eng. Manag.* **2023**, *29*, 35–49. [CrossRef]
65. Laovisutthichai, V.; Lu, W.; Xue, F. Modular construction: Design considerations and opportunities. In *Proceedings of the 25th International Symposium on Advancement of Construction Management and Real Estate*; Springer: Singapore, 2021; pp. 1351–1361.
66. Zolghadr, A.; Gharaie, E.; Naderpajouh, N. Barriers to innovation in the housing sector: Economic justifiability of offsite construction for housebuilders. *J. Build. Eng.* **2022**, *52*, 104490. [CrossRef]
67. Gan, X.-L.; Chang, R.-D.; Langston, C.; Wen, T. Exploring the interactions among factors impeding the diffusion of prefabricated building technologies: Fuzzy cognitive maps. *Eng. Constr. Archit. Manag.* **2019**, *26*, 535–553. [CrossRef]
68. Martin, H.; Garner, M.; Manewa, A.; Chadee, A. Uncovering the Barriers to Widespread Adoption of Modular Construction-the Role of Technology Diffusion. *SSRN Electron. J.* 2023. [CrossRef]
69. Pan, W.; Sidwell, R. Demystifying the cost barriers to off-site construction in the UK. *Constr. Manag. Econ.* **2011**, *29*, 1081–1099. [CrossRef]
70. Martin, H.; Garner, M.; Manewa, A.; Chadee, A. Validating the Relative Importance of Technology Diffusion Barriers–Exploring Modular Construction Design-Build Practices in the UK. *Int. J. Constr. Educ. Res.* **2024**, 1–21. [CrossRef]
71. Pan, W.; Parker, D.; Pan, M. Problematic interfaces and prevention strategies in modular construction. *J. Manag. Eng.* **2023**, *39*, 05023001. [CrossRef]
72. Ribeiro, A.M.; Arantes, A.; Cruz, C.O. Barriers to the adoption of modular construction in Portugal: An interpretive structural modeling approach. *Buildings* **2022**, *12*, 1509. [CrossRef]
73. Agha, A.; Shibani, A.; Hassan, D.; Zalans, B. Modular construction in the United Kingdom housing sector: Barriers and implications. *J. Archit. Eng. Technol.* **2021**, *10*, 236.
74. Feldmann, F.G.; Birkel, H.; Hartmann, E. Exploring barriers towards modular construction—A developer perspective using fuzzy DEMATEL. *J. Clean. Prod.* **2022**, *367*, 133023. [CrossRef]
75. Agapiou, A. Barriers to offsite construction adoption: A quantitative study among housing associations in England. *Buildings* **2022**, *12*, 283. [CrossRef]
76. Polat, G. Factors affecting the use of precast concrete systems in the United States. *J. Constr. Eng. Manag.* **2008**, *134*, 169–178. [CrossRef]
77. Regner, A.J. Understanding Adoption Barriers to Widespread Use of Prefabrication in United States Construction Industry. Doctoral Dissertation, University of Wisconsin—Stout, Menomonie, WI, USA, 2023.
78. Cruz Rios, F.; Grau, D.; Bilec, M. Barriers and enablers to circular building design in the US: An empirical study. *J. Constr. Eng. Manag.* **2021**, *147*, 04021117. [CrossRef]
79. Paliwal, S.; Choi, J.O.; Bristow, J.; Chatfield, H.K.; Lee, S. Construction stakeholders' perceived benefits and barriers for environment-friendly modular construction in a hospitality centric environment. *Int. J. Ind. Constr.* **2021**, *2*, 15–29. [CrossRef]
80. Ortega, J.; Mesa, H.A.; Alarcón, L.F. The interrelationship between barriers impeding the adoption of off-site construction in developing countries: The case of Chile. *J. Build. Eng.* **2023**, *73*, 106824. [CrossRef]
81. Khalfan, M.M.; Maqsood, T. Current state of off-site manufacturing in Australian and Chinese residential construction. *J. Constr. Eng.* **2014**, *2014*, 164863. [CrossRef]
82. Zhang, Z.; Tan, Y.; Shi, L.; Hou, L.; Zhang, G. Current state of using prefabricated construction in Australia. *Buildings* **2022**, *12*, 1355. [CrossRef]

83. Shahzad, W.M.; Reddy, S.M.; Kahandawa, R.; Rotimi, J.O. Benefits, constraints and enablers of modular offsite construction (MOSC) in New Zealand high-rise buildings. *Eng. Constr. Archit. Manag.* 2023, *ahead-of-print*. [CrossRef]
84. Nesarnobari, S.; Shahzad, W.; Jelodar, M.B. The status quo of prefabricated housing: An investigation into New Zealand construction sector. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1101*, 042014. [CrossRef]
85. Hong, J.; Shen, G.Q.; Li, Z.; Zhang, B.; Zhang, W. Barriers to promoting prefabricated construction in China: A cost–benefit analysis. *J. Clean. Prod.* **2018**, *172*, 649–660. [CrossRef]
86. Jaillon, L.; Poon, C.S. Design issues of using prefabrication in Hong Kong building construction. *Constr. Manag. Econ.* **2010**, *28*, 1025–1042. [CrossRef]
87. Sun, H.; Fang, Y.; Yin, M.; Shi, F. Research on the restrictive factors of vigorous promotion of prefabricated buildings in Yancheng under the background of "Double Carbon". *Sustainability* **2023**, *15*, 1737. [CrossRef]
88. Wang, Q.; Shen, C.; Guo, Z.; Zhu, K.; Zhang, J.; Huang, M. Research on the barriers and strategies to promote prefabricated buildings in China. *Buildings* **2023**, *13*, 1200. [CrossRef]
89. Zhou, Z.; Syamsunur, D.; Wang, L.; Kit, A.C. Exploring the feasibility of using modular technology for construction projects in island areas. *J. Infrastruct. Policy Dev.* **2024**, *8*, 3424. [CrossRef]
90. Al-Aidrous, A.H.; Shafiq, N.; Rahmawati, Y.; Mohammed, B.S.; Al-Ashmori, Y.Y.; Baarimah, A.O.; Alawag, A.M. Major blocking factors affecting the application of industrialized building system. *Ain Shams Eng. J.* **2023**, *14*, 102151. [CrossRef]
91. Pervez, H.; Ali, Y.; Pamucar, D.; Garai-Fodor, M.; Csiszárik-Kocsir, Á. Evaluation of critical risk factors in the implementation of modular construction. *PLoS ONE* **2022**, *17*, e0272448. [CrossRef]
92. Hamzeh, F.; Abdul Ghani, O.; Saleh Bacha, M.B.; Abbas, Y. Modular concrete construction: The differing perspectives of designers, manufacturers, and contractors in Lebanon. *Eng. Constr. Archit. Manag.* **2017**, *24*, 935–949. [CrossRef]
93. Shin, J.; Moon, S.; Cho, B.H.; Hwang, S.; Choi, B. Extended technology acceptance model to explain the mechanism of modular construction adoption. *J. Clean. Prod.* **2022**, *342*, 130963. [CrossRef]
94. Kenny, D.W.; Ayesu-Koranteng, E.; Amoah, C.; Adeniran, A. The use of prefabrication in building. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1101*, 042012. [CrossRef]
95. Ammari, A.M.; Roosli, R. A Review of Prefabricated Housing Evolution, Challenges, and Prospects Towards Sustainable Development in Libya. *Int. J. Sustain. Dev. Plan.* **2024**, *19*, 1181. [CrossRef]
96. Ali, A.H.; Kineber, A.F.; Elyamany, A.; Ibrahim, A.H.; Daoud, A.O. Identifying and assessing modular construction implementation barriers in developing nations for sustainable building development. *Sustain. Dev.* **2023**, *31*, 3346–3364. [CrossRef]
97. Ali, A.H.; Kineber, A.F.; Elyamany, A.; Hussein Ibrahim, A.; Daoud, A.O. Exploring stationary and major modular construction challenges in developing countries: A case study of Egypt. *J. Eng. Des. Technol.* 2023, *ahead-of-print*. [CrossRef]
98. Ibrahim, A.; Hamdy, K.; Badawy, M. Overall Barriers to The Prefabricated Construction Industry: A Fuzzy-SEM. *Res. Sq.* 2023; *preprint*. [CrossRef]
99. Ali, A.H.; El-Mahdy, G.M.; Ibrahim, A.H.; Daoud, A.O. Towards the adoption of modular construction in residential projects in Egypt: Benefits, barriers, and enablers. In *Construction Industry Development Board Postgraduate Research Conference*; Springer International Publishing: Cham, Switzerland, 2022; pp. 72–81.
100. Akinradewo, O.; Aigbavboa, C.; Aghimien, D.; Oke, A.; Ogunbayo, B. Modular method of construction in developing countries: The underlying challenges. *Int. J. Constr. Manag.* **2023**, *23*, 1344–1354. [CrossRef]
101. Bello, A.O.; Khan, A.A.; Idris, A.; Awwal, H.M. Barriers to modular construction systems implementation in developing countries' architecture, engineering and construction industry. *Eng. Constr. Archit. Manag.* 2023, *ahead-of-print*. [CrossRef]
102. Lu, W.; Chen, K.; Xue, F.; Pan, W. Searching for an optimal level of prefabrication in construction: An analytical framework. *J. Clean. Prod.* **2018**, *201*, 236–245. [CrossRef]