

Article

Potential of Modular Offsite Construction for Emergency Situations: A New Zealand Study

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Abstract: Natural disasters cause significant adverse social and financial impacts by damaging homes and infrastructure. These disasters also need a quick and immediate solution to post-disaster housing problems, to provide temporary housing services for short-term disaster relief and reconstruction of lost and damaged houses for complete recovery. Reconstruction of new permanent housing for disaster victims is one of the most time-consuming post-disaster activities. However, time is a vital consideration that should be minimized for the reconstruction of houses for affected populations. Modular offsite construction technology has the potential to enhance the post-disaster housing reconstruction process due to its intrinsic characteristics of time-efficiency. This study aimed to assess the potential of the modular offsite construction method as an approach that could promote the design and construction process of post-disaster reconstruction in New Zealand in emergencies. An extensive literature review has been carried out to evaluate the features of the modular construction method, which can add value to the post-disaster recovery phase. To evaluate the suitability and viability of modular offsite construction for post-disaster reconstruction and to find substantial obstacles to its implementation, feedback was collected and evaluated using the multi-attribute methodological approach by performing a national survey of construction industry experts in New Zealand. Semi-structured interviews with New Zealand experts were then followed to confirm and validate the questionnaire findings. The findings indicate that modular offsite construction technology is a viable solution for providing housing in emergencies or during post-disaster reconstruction in New Zealand, with its time-efficiency and ability to overcome the challenges of the current traditional method by its specific advantages. Reduced need for onsite labor, overcoming local labor resource constraints affected by the disaster, and enhanced productivity due to a controlled environment are the advantages of the modular offsite technology, which are discussed in this research.



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Keywords: modular offsite construction; disaster; emergency; post-disaster; New Zealand

1. Introduction

The negative social and financial consequences of natural disasters are becoming more severe as population centers expand. In recent years, the desecration of houses and infrastructure has resulted in numerous deaths and refugees [1]. Several scholars have described and researched the disaster from multiple viewpoints. Ghannad et al. and Smith et al. [1,2] characterized the disaster as an unforeseeable incident that claimed a substantial number of people and caused severe property damages. According to the Federal Emergency Management Agency (FEMA): (1) mitigation, (2) preparedness, (3) response, and (4) recovery are the four phases of a disaster [3]. Government agencies must act swiftly and effectively in the aftermath of catastrophes to address post-disaster housing concerns and provide enough funding for both temporary housing for short-term disaster relief and restoration of destroyed homes for full reconstruction [4].

The immediate difficulty for construction management following a catastrophic disaster is the immediate reconstruction of destroyed homes and facilities. On the other

hand, the recovery and reconstruction phase, which involves quickly supplying houses for impacted people, is the most critical and time-consuming post-disaster stage [5]. After a disaster happens, accommodations need to be provided within a short period of time as an immediate housing relief response. The construction of new buildings will take years, using conventional construction techniques. In an emergency response, time will be insufficient to satisfy building requirements which is the most important aspect, and thus quicker construction technology is needed [6]. This process may take up to five years or longer, up to 10 years [7], depending on the magnitude of the catastrophe. Undoubtedly, it takes a very long time for communities and individuals to recover their usual livelihoods. Time is also a crucial factor in the rebuilding process to minimize the effect on people [4,8].

There are certain commonalities among emergency construction projects that need to recover quickly, including: (1) constrained construction timelines [9], (2) a shortage of resources, and (3) high stakeholder expectations [10,11]. Time is, therefore, crucial in the rehabilitation and construction projects' effort to avoid future disastrous social and economic effects, delays, and overruns in impacted areas. Among all new technologies, modular offsite construction is increasingly gaining popularity as a method to tackle the challenge of time in post-disaster recovery [5,8,12–14]. It is a viable modern approach that dramatically increases the construction of a dwelling unit in a shorter period [8]. Modular construction, as a highly time-efficient and holistic approach, could solve several common issues of existing post-disaster reconstruction strategies of permanent housing [6]. Modular offsite construction is driven by a number of time-related factors, including its short construction time supported by automation, parallel manufacturing activities taking place simultaneously [15], reduction in overall product delivery time [16], accelerated return on investment [17], shorter planning and design time [18], fewer weather disruptions due to controlled factory settings [19]. Therefore, time-efficiency is an inherent characteristic of modular offsite construction, which offers great potential for it to be a desirable strategy for post-disaster housing reconstruction [20].

Although modular offsite construction has many advantages, there are some challenges to implementing this method too. Several studies investigated transportation concerns, contractor's early commitment, inadequate incentives and regulations, high capital cost, and lack of standards as some of the challenges that the construction industry will face using this method [21–26]. The challenges associated with modular offsite construction have been identified in some other countries. However, in the New Zealand context, there is not much research conducted to specifically understand the issues and challenges associated with the uptake of modular offsite construction [27,28]. As a result, it is necessary to identify the challenges which impede the implementation of modular offsite construction to mitigate the consequences. It is pertinent to note that the construction industry in New Zealand faces some unique challenges, mainly due to the small size of the industry, lack of economies of scale, skill shortage, and remoteness of New Zealand from the rest of the world leading to lack of innovation adoption in the industry.

In the case of emergency response, the modular offsite approach may provide certain advantages since the construction of a structure from pre-assembled blocks or pods is feasible. Modular pods are manufactured in offsite warehouses and then delivered to the construction site for simple and faster assembly [12,29]. The positive experiences of using this method in other countries as a response to fast recovery after different kinds of emergency situations have made modular offsite construction to be a desirable strategy. Government and industry always seek to figure out solutions for the wellbeing of people in any situation, and New Zealand is no exception. In New Zealand, the construction industry contributes significantly to the country's economy. Housing shortage challenges, along with other disasters, put New Zealand in a rough condition. Since the need for housing provision was high, the use of offsite construction was chosen to address the need for residential and other buildings [30–32].

The Christchurch post-earthquake rebuild was responsible for the majority of construction sector work in the South Island of New Zealand. Further, it is observed that the

frequency of natural disasters that occur in New Zealand is comparatively high. Lying on the boundary of two great and slowly shifting tectonic plates, New Zealand does get earthquakes and other natural calamities. Therefore, applying a method that could help the industry to build faster and safer is necessary. It should be noted that, despite the significant rise of modular offsite studies in New Zealand [27,28,32,33], only a few studies looked at modular offsite construction as a response to emergencies. Therefore, this paper explored the viability and understanding of modular construction-based post-disaster reconstruction and recovery, identified the competitive characteristics of modular construction to accelerate and meet the housing demands during an emergency or disaster recovery process, and the challenges for modular offsite construction after the disaster in New Zealand. The research objectives are developed as follows:

- To investigate the potential of modular offsite construction in emergency response in events such as earthquakes and other natural disasters in New Zealand.
- To determine the features of modular offsite construction that might help provide housing in emergencies.
- To identify the challenges that the construction industry can encounter with the adoption of modular offsite construction for emergency response in New Zealand.

The hypothesis for this research is:

- There is sufficient potential for modular offsite construction implementation in New Zealand in case of any disaster or emergency.
- There are positive features of modular offsite construction that gain the required attraction in New Zealand as an emergency solution
- There are challenges for modular offsite construction applications in New Zealand which require attention in advance.

2. Background

2.1. Disaster and Emergency Responses

According to Fitz [34], a disaster is ‘an event concentrated in time and space, in which a society or one of its subdivisions undergoes physical harm and social disruption, such that all or some essential functions of the society or subdivision are impaired.’ There are several research institutions and agencies across the world which have concerns regarding the prevention, preparedness, mitigation, response, and relief stage of disaster management. It has been shown that disasters may be divided into three categories: (1) natural, (2) artificial, and (3) hybrid [35]. No matter what kind of disaster happens, the important aspect is post-disaster management. Many organizations, including the government, architects and designers, non-government organizations (NGOs), and others, have undertaken a variety of efforts in response to the tragedy through a variety of post-disaster recovery initiatives [36].

Whenever a large number of dwellings are destroyed or left untenable as a result of a disaster, a huge number of people become homeless and in need of a safe place to reside [37]. Housing and infrastructure (e.g., roads, electricity, ports, etc.) are included in post-disaster rebuilding. Both are essential concerns, although several studies have mostly focused on housing restoration following a disaster that leaves many victims. The terms “shelter” and “housing” have been used to categorize two different types of homes [38]. The shelter provides temporary housing until the victims can find permanent housing. “Housing,” on the other hand, refers to a permanent abode that meets all standards, including physical, social, and administrative infrastructure. In other words, shelters are offered as a short-term solution to the relief process, and permanent housing must be provided in the long run to allow disaster-affected populations to resume normal livelihoods [8].

The post-disaster housing restoration process has comparable obstacles to conventional housing projects, as well as various additional challenges owing to their unique condition. Many recent catastrophes’ post-disaster recovery procedures have been documented by the parties involved, and it is useful to analyze them. This analysis demonstrates that crucial problems have become more widespread and may necessitate an inventive solution [1,4,5].

Forcael et al. [39] stated that 373 natural disasters occurred in the year 2014, the majority of them weather-related. These calamities claimed 296,000 lives and cost about 110 million dollars to approximately 208 million people directly or indirectly. For example, the 1999 Turkey earthquake destroyed an estimated 380,000 structures; the February 2011 Christchurch earthquake damaged over 100,000 buildings, and almost 10,000 residences faced destruction, forcing residents to flee their homes [40]. In order to meet the alarming situation of huge numbers of temporary housing in a short period of time, the most common alternative is to make use of the effectiveness and manufacturing capacity given by industrialized buildings [41].

2.2. Modular Offsite Construction

Modular offsite construction has been described using several terminologies, including offsite fabrication (OSF), offsite manufacture (OSM), pre-assembly, and prefabrication [42]. Offsite construction, a concept adopted from the manufacturing sector, is a building method in which the main characteristic is the relocation of most operations from an onsite location to a more controlled offsite manufacturing environment, which can give greater benefits than the more traditional methods [43,44]. It is a huge advancement in the construction industry since the construction procedures for finishing projects are completely modified [23].

By using the offsite construction method, the elimination of waste generation, shipping, time, electricity, and greenhouse gas emissions is simpler to achieve than the conventional construction method [45]. Modular offsite construction has offered an answer to the global challenges of house building and emergency recovery, primarily by reducing onsite activities that are typically dependent on weather conditions and highly dependent on specialized trades, while shorter construction time has become the norm due to housing shortages [46,47].

This strategy has been frequently employed to rescue lives impacted by different disasters such as global warming, earthquakes, and virus outbreaks by providing immediate and temporary refuge. In today's uncertain environment, modular construction enables rapid and effective reactions, allowing a higher number of lives to be saved. When compared to traditional building methods, the use of offsite modules is more efficient when rapid construction is required, allowing for the coverage of large regions and the provision of medical treatment to those in need [14,20,40,48].

In 1806, the first offsite constructed home arrived in New Zealand. It was built in a factory and brought to the country. Individual dwelling package sets, however, were delivered from the United Kingdom to New Zealand by 1833 [49]. Early in the 1920s, the New Zealand Railway Department was the country's major builder of offsite constructed dwellings. The Frankton plant built offsite houses, which were then shipped to the North Island site for assembly [50]. The demand for housing in New Zealand is now increasing dramatically due to the population increase. This need is being met by utilizing offsite construction, which has a relatively good time efficiency. Modularization of the building sector is crucial in New Zealand for increasing efficiency [31,51]. The modular offsite construction approach was employed in the construction of the University of Auckland Elam Hall of Residence; consequently, the difference in efficiency and productivity can be noted when compared to the conventional procedure [52,53]. Despite the growing attention to offsite construction in New Zealand, it still needs more investigation through applying this method in case of emergency.

2.2.1. Modular Offsite Construction Advantages

The construction industry benefits from offsite construction in many ways. A large and growing body of literature has investigated this method's advantages [22,24–26,54–60]. Table 1 presents the advantages of applying modular offsite construction from the literature. There are five categories of advantages resulting from the literature, including time management, financial, quality, management, and standards [19,29]. An improvement in time production from 30% to 50%, a decrease in project costs to 20%, a reduction in material consumption to

90%, and an increase in health and safety due to the regulated working conditions, which is higher than the conventional construction are some of the key advantages [32,61,62].

Table 1. Modular Offsite Construction Advantages.

Categories	Modular Offsite Construction Advantages	References
Time Management	Increased construction pace	[63,64]
	Onsite working hours are reduced	[17,56]
	Time intervals are shorter	[16,25,59]
Financial	Savings on expenses	[17,63,64]
	Provide low-cost mass housing	[64–66]
Quality	Error reduction	[67]
	Enhanced component customisation	[54,68]
	Improving productivity and performance	[27,56,65]
	Building regulations compliance	[69]
Management	Optimize the building process	[65,70]
	Improved command and precision	[65,71]
	Reduce skill shortages in specific areas	[71–73]
	Refresh traditional manufacturing areas	[74]
	Fewer transactions and interfaces for onsite management and coordination	[65,74]
	Reduce to the adjacent services	[20,59]
	Integration of third-party components and systems that is efficient	[54,60]
	Fewer site overhead and traffic congestion	[56,65]
Sustainability	Mitigation of environmental impacts	[56,60]
	More material reuse and recycling	[59,60]
	Produce factory-tested and approved items	[65,68,74]
	Improved indoor environment control	[56,60]
	Promotes health and safety	[56,60,64,75]
	Labour-intensive activities reduction	[57,59]

2.2.2. Modular Offsite Construction Challenges

Despite the advantages mentioned in the previous section, several issues, such as increased planning and design efforts, transportation concerns, and lack of standards and logistics, have hampered the adoption of offsite construction [24,25,58]. Other studies noted the lack of competent and professional labor or instructional programs, as well as project management expertise and poor comprehension and ignorance of advantages, as additional difficulties [21,26,60]. Despite the ability of offsite construction to lower overall project cost [17,26,63,64], a larger initial capital expenditure may be necessary [21,26,76]. Table 2 presents the challenges associated with the uptake of modular offsite construction.

Table 2. Modular Offsite Construction Challenges.

Categories	Factors	References
Technological	Transportation concerns	[22,23,25,64]
	Inferior imports	[21,55,64]
	Inventory control challenges	[21,55,58,64]
	Rigid for last-minute design modifications	[21,55,58,64]
	Inadequate artistic performances	[26,55]
	Quality issues	[23,77]
	Increased planning and design efforts	[23,26,77]
	Absence of acceptable size and repetition options	[25,56]
	Risk brought on by doubt	[57,58]
	Early commitment from contractors	[57,58]
Human Resource	Training for current professionals and courses for new entrances	[58,64]
	Inadequate incentives	[21,25]
	Lack of competent and professional labour	[21,26]
	Poor comprehension and ignorance	[26,60]
	Manufacturers' inability to increase prefabrication effectiveness	[22,58]
	Manufacturers' resistance to innovation and change	[55,58]
Operational procedures	No standardized design	[21,58]
	Lack of logistics	[24,25]
	Lack of standards	[24,58]
	Intense emphasis on lowest bid price	[24,58]
Financial	High capital expenses	[26,57]
	Larger initial capital expenditure	[21,26,76]
	Transportation costs spanning large distances are high	[55,58]
	Having trouble implementing economies of scale	[26,57]
Managerial	Loss of control in the supply chain and on the job site	[26,56]
	Small market demand	[24,58]
	Difficult Management	[24]
	Inadequate regulations	[24,58,75]
	Extensive collaboration/dialogue amongst project participants	[26,58]
	Project procurement lacking management expertise	[57,58,75]
	Regulatory specifications	[57,58]
Organizational	Inappropriate business strategy and insufficient investment	[22,58]
	Inadequate manufacturing capacity	[33,58,59]

2.3. Modular Offsite Construction Emergency Responses-Case Studies

Modular offsite construction is regarded as one of the significant technologies that are now upending the construction industry [78]. It has demonstrated significant advantages and chances to overcome many of the difficulties faced by the construction sector [79]. During the most recent COVID-19 outbreak, there were numerous well-known success

stories for the utilization of offsite construction techniques. This approach enables the possibility of working numerous shifts, improving labor management, and controlling social isolation circumstances in addition to other health and safety criteria [47,80]. The section that follows has a review of three case studies based on the existing literature.

2.3.1. Wuhan Leishenshan Hospital

Leishenshan Hospital (Figure 1) was established as a result of an urgent need in order to treat individuals afflicted with the brand-new COVID-2019 outbreak [14]. Engineers and architects have employed modular offsite construction solutions to lighten the burden and speed up the project. A basic modular component made of steel was used to provide a variety of functions necessary to host a day to day operations in complete isolation [20]. Compared to the two Huoshenshan hospitals, the Wuhan Leishenshan hospital is larger.



Figure 1. Wuhan Leishenshan Hospital [20].

Leishenshan hospital had to be operational in just two weeks, although a hospital of its size would typically take 3 to 5 years to build. Even yet, construction took about as long as at Huoshenshan Hospital. More than 1500 pieces of machinery and equipment were deployed with more than 10,000 workers during the height of the building's development. The short timeline and difficult challenges are the major obstacles to the Leishenshan hospital's development. It must be finished and delivered in more than ten days, as an infectious disease hospital with 1500 beds and a total building area of 79,000 m². The building work for the whole year was condensed into more than ten days. Therefore, the utilisation of industrialized, prefabricated, and modular composite structures was essential for project construction [14,20,80].

2.3.2. Huoshenshan Hospital

Wuhan Huoshenshan COVID-19 Hospital (Figure 2) was built in just ten days (from 23 January 2020 to 2 February 2020) [81]. The designers adopted offsite construction technology to avoid time-consuming in situ construction work. Moreover, the implementation of digital technologies such as building information modeling (BIM) cannot be overlooked [82,83]. Rapid construction, large scale, and low cost are three essential features of this approach. Such as the Leishenshan hospital, the solution to the emergency circumstances needed modular offsite construction [53]. The building process model has sped and encouraged the integration of modular components into emergency construction throughout the world, resulting in a unique design strategy for combating the COVID-2019 virus. A preliminary study has revealed a shortage of supporting materials in modular hospital design, emphasizing the significance of more research [14].



Figure 2. Wuhan Huoshenshan Hospital Building Layout [84].

2.3.3. UK Nightingale Hospital Exeter

A critical care unit was built at a conference center (Figure 3) in East London in 57 days in response to an unmet demand for critical care beds in London during the first wave of the coronavirus disease 2019 (COVID-19) pandemic in late March 2020 [85]. The renovation of a repurposed retail unit into a hospital was doubled in size with the addition of 1700 m² of modular structures for services such as the pharmacy, staff welfare, catering, utility rooms, and patient transfer. Because of modular offsite construction, the program for this new 116-bed hospital was lowered from about 12 months to only one month during the pandemic, which could not have been accomplished with a regular contractual manner of working [80,86]. Hiring modular housing is a quick, flexible, and cost-effective solution for healthcare providers to expand capacity or shift services, especially on confined hospital campuses. The concept also provides greater flexibility to trusts since the facilities may be deconstructed and withdrawn if local requirements alter [80,85].



Figure 3. UK Nightingale Hospital Exeter © Stride Treglown/Tom Bright [87].

The procedure becomes parallel in the case studies mentioned above, greatly reducing the construction time. The use of offsite modular can best fulfill the requirements and truly address the benefits of offsite buildings of “brightness, fast, efficiency, and environmental protection when considering the purpose and urgent construction period requirements of the new epidemic emergency conditions. The experience of these case studies throughout

the world is likely to give significant knowledge to other nations and areas such as New Zealand in the fight against any emergency.

3. Methods

In order to achieve the research objectives, a mixed method approach (Figure 4) was adopted in this study, where quantitative and qualitative methods are used in a complementary manner. No matter which discipline, the foundation of all academic research efforts is building on and connecting it to the existing body of knowledge. This job is getting harder and harder as the construction knowledge is expanding at a faster rate while yet being interdisciplinary and scattered [88]. Given the nature of this activity, a more pertinent research strategy, such as a literature review, is required. A more general definition of a literature review is a method of gathering and summarising prior research that is methodical. Literature review, as an efficient and well-executed research methodology, establishes a solid platform for knowledge expansion and the facilitation of theory building [89,90]. A literature review can address research topics with a power that no one study has by incorporating the conclusions and points of view from numerous empirical findings [91].

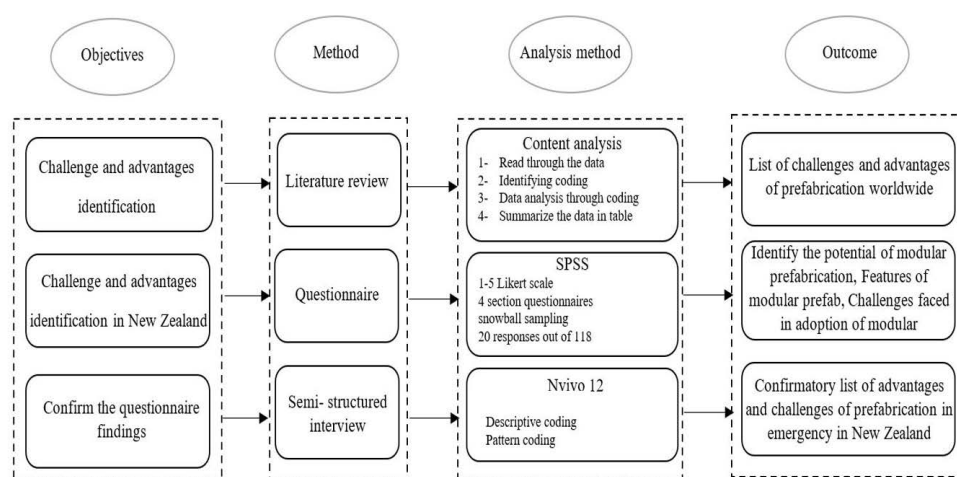


Figure 4. Research Design and Implementation Process.

Thorough literature reviews of the challenges and advantages of adopting offsite construction have been identified. It enables a comprehensive review of past studies on the topic [92–94]. The data gathered at this step assist the authors in developing the questionnaire for the following stage. In order to generate reliable findings from enormous amounts of literature, content analysis was used [95]. This is followed by a four-section questionnaire survey to obtain expert opinions on the level of agreement.

The questionnaire for this study is focused on the objective of discovering an appropriate way to use modular offsite construction technologies for emergency response in New Zealand. It has been noted that the frequency of natural catastrophes in New Zealand is relatively high. As a result, one of the most time-consuming post-disaster restoration efforts is the construction of new permanent homes for catastrophe victims. However, time is an important concern that should be reduced while rebuilding dwellings for impacted populations. Modular offsite construction technology is a potential option for enhancing the post-disaster reconstruction process due to its intrinsic characteristics of time-efficiency.

The questionnaire is prepared in four sections. Questions are formulated in the form of closed-ended and open-ended questions to elicit the views of specialists in the field. The parts are as follows:

Section I: Potential of modular offsite construction in emergency response in events such as COVID-19 and other disasters in New Zealand.

Section II: Features of modular offsite construction and its aid in emergency responses.

Section III: Challenges faced in the adoption of modular offsite construction for emergency response.

Section IV: Demographic background.

The questionnaire was designed with 5-point Likert-scale questions that allowed participants to express their degree of agreement with the statements delivered. The Likert scale method data are analyzed using modes, medians, and frequency [96–98]. A snowball sampling approach was used to identify professionals with extensive knowledge and competence in the use of modular offsite construction in disaster response [23,24]. Only 20 replies were obtained from a total of 118 experts who were members of OffsiteNZ and were invited to participate in the survey.

Finally, as with the other qualitative data collection, semi-structured interviews with eight offsite construction specialists from academia and business in New Zealand were conducted to validate the findings of the previous stage. The experts have been chosen from different disciplines to achieve a comprehensive perspective on the topic. The data and analyses provided by the interviews are thorough and complimentary. However, variations in data collection, processing, and interpretation approaches, questionnaires and semi-structured interviews are frequently utilized in mixed-method research to yield confirmatory results [99]. The interviews provided details on the challenges and advantages of modular offsite construction applications in an emergency in New Zealand. Eight interviews were performed to confirm the questionnaire findings.

Nvivo 12 was used to analyze the interview transcripts, and it has previously been utilized for qualitative data analysis in much other research [100,101]. In order to discover trends throughout the interviews, the qualitative coding procedure was performed repeatedly. The study team used descriptive coding to help shape the originally obtained data and analyze the data's fundamental subjects. Theoretical saturation defines the number of interviewers as the point at which more interviews cease to yield additional insights for the specific objective of the study [102]. Table 3 contains information about the interviewees. Interviews were developed with key questions supported by follow-up questions for maximum tangibility and comprehension of replies [103].

Table 3. Interviewees details.

Participant	Professional Role	Experience of Offsite Construction
R1	Engineer/Researcher	5 years (Research on offsite construction)
R2	Engineer/Researcher	5 years
R3	Project Manager	20 years (New Zealand construction industry)
R4	Offsite Manufacturer	3 years (CEO of manufacturing company)
R5	Manufacturer	8 years (Involved in more than 30 offsite projects)
R6	Offsite Designer	7 years
R7	Manufacturer	6 years
R8	Project Planning Engineer	3 years (3 years of offsite specific experience)

4. Results

Following the data analysis procedure, the findings of this research are presented in the form of an analytical discussion in this section. This section comprises the survey and interview responses regarding the potential use of modular offsite construction in providing housing in emergencies, the features of modular offsite, and the challenges faced in using modular offsite construction technology in providing housing in emergencies. The findings of the survey for each research objective are followed by the interview findings with New Zealand experts in the field of modular offsite construction. The demographic profiles of the research participants were also analyzed for the related interpretation of the analyzed data.

4.1. Survey-Demographic Profile of Participants

From the targeted population, twenty responses were received for the study. The twenty response was received from Architects (12%), Consultants (18%), Engineers (20%), Planning/Design/Construction professionals (6%), Prefab manufactures (6%), Project managers (29%), and superintendent (6%). Further, the inputs obtained from the individuals associated with their organizations were also added to balance the viewpoints. The role of survey participants in their respective organizations is shown in Figure 5. The input received was, therefore, primarily from the engineers and project managers engaged in the construction industry in New Zealand. While not substantially biased as to the inclusion of vital factors, the results of the analysis and the findings may be influenced by the main responses of engineers and project managers to their own value. In this context, the observations and assumptions are viewed.

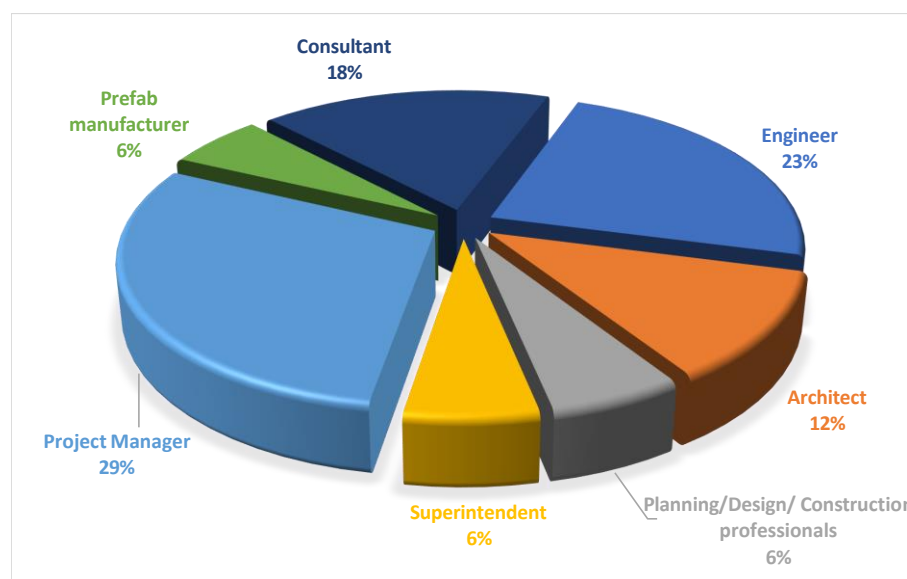


Figure 5. Participants' Demographic Information.

Survey participants, as mentioned before, were member of OffsiteNZ, which is the leading membership organization of offsite construction professionals in New Zealand. After excluding the student members and other irrelevant members from the membership directory of OffsiteNZ, 118 members of the organization were invited to participate in the Anonymous online survey. The requests to participate in the survey were sent to them via email. By the cut-off date, 20 responses were received.

The length of experience of survey participants in their respective fields of specialization is summarized in Figure 6. This figure indicates that the largest of the survey participants (63.16%) have worked actively in the offsite construction industry for more than 5 years. This figure contributed to the credibility of the reviews and the subsequent results, as most responses came from experienced industry operators, thanks to their rich expertise, knew a great deal about the issues of the industry and could thus provide reliable feedback on the subject.

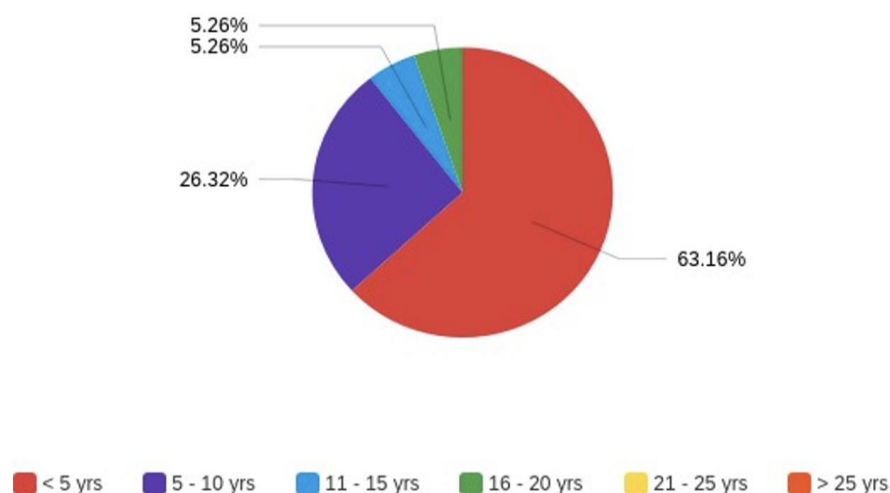


Figure 6. Experience of Survey Participants.

4.2. Results and Discussion of Research Objectives

The first objective of this study was to identify the potential of modular offsite construction in emergency response in events such as earthquakes and other natural disasters in New Zealand. The second objective was to determine the features of modular offsite construction that might help provide housing, and the third objective was to identify the challenges encountered by the offsite sub-sector of the construction industry. Based on the outcomes obtained from the questionnaire survey and interviews, the following section provides the results of the analysis for each of the three objectives.

4.2.1. Section I: The Potential of Using Modular Offsite Construction to Address/Provide Housing Needs in Emergencies

The statements posted in Section I of the questionnaire survey are shown below with the answers provided by the participants (Table 4). There were nine questions posted for Section I. Table 4 shows the participant's point of view regarding every significant possible factor, and the Likert scale rating was used with values from 1 to 5 (SA (Strongly agree) = 5; A (Agree) = 4; M (Moderate) = 3; D (Disagree) = 2; SD (Strongly disagree) = 1. A "No Idea" NI option was also provided to the participants to avoid any bias in the findings. Statistical analysis of the data obtained from the survey was carried out to determine the mean value (MR) for all the responses. The factors that have an MR value of 2.5 or more are regarded as significant factors. In three of the questions, the factor is more than 2.5, which therefore indicates that the potential use of modular offsite construction to provide housing in emergencies in New Zealand is possible with the current resources but requires more attention.

The three most significant potential factors derived from the survey, indicated by MR over 2.5, have been discussed in this section first. These include modular offsite houses are readily available in the local construction market to meet disaster/emergency response, modular offsite houses are structurally designed to withstand seismic interference in times of disaster/emergency, and modular offsite houses are a less expensive housing option for users (e.g., cheaper to procure) in times of disaster/emergency (Table 4). According to the literature, good structural performance, fire resistance, and lightweight qualities of modular components turned the modular offsite into a great option for building emergency facilities [27,56,104].

Table 4. The potential of using modular offsite construction to address/provide housing needs in emergencies (e.g., earthquakes).

The Potential of Using Modular Offsite Construction to Address/Provide Housing Needs in Emergencies (e.g., Earthquake)	Level of Agreement ¹							
	SA	A	M	D	SD	NI	MR	SD
Modular offsite houses are readily available in the local construction market to meet disaster/emergency response	15%	25%	15%	35%	5%	5%	3.05	1.36
Modular offsite houses are structurally designed to withstand seismic interference in times of disaster/emergency	10%	45%	20%	10%	0%	15%	2.90	1.51
Modular offsite houses are a less expensive housing option for users (e.g., cheaper to procure) in times of disaster/emergency	15%	30%	35%	15%	0%	15%	2.70	1.19
Modular offsite houses can be easily transported from one location to another in times of disaster/emergency	25%	45%	15%	10%	5%	0%	2.25	1.09
Modular offsite houses can be reused in multiple disaster occurrences	30%	40%	20%	0%	5%	5%	2.25	1.30
Modular offsite houses provide a comfortable indoor environment in times of disaster/emergency	40%	40%	10%	0%	0%	10%	2.10	1.45
Mass modular offsite housing production is possible to meet the high demand for housing/shelter in times of disaster/emergency	30%	30%	40%	0%	0%	0%	2.10	0.83
Using Modular offsite technology helps in avoiding time fluctuation as well as material and labor costs	30%	35%	30%	5%	0%	0%	2.10	0.89
Modular offsite houses are produced faster to meet emergency housing needs in times of the disaster/emergency	45%	40%	15%	0%	0%	0%	1.70	0.71

¹ Level of agreement of constraint statement: SA (Strongly Agree) = 5; A (Agree) = 4; M (Moderate) = 3; D (Disagree) = 2; SD (Strongly Disagree) = 1; NI = No Idea; MR = Mean Rating; SD = Stranded Deviation.

Cost-cutting opportunities for the client and main contractor are provided by the usage of modular offsite construction throughout the project. The manufacturing industry's lower labor costs and less reliance on on-site trained workers are the leading causes of this. Additionally, this method allows for cost savings within the contractor's preliminary budget due to the shortened construction schedule it achieves [17,63–65].

Although previous studies mentioned the speed of production in times of emergency as a significant potential [16,25,63,64], the findings of this research showed in the New Zealand emergency situation. This factor is not one of the most important modular offsite potentials.

The participants believed that using modular offsite technology to provide housing in emergencies is fast compared to the traditional method of construction in New Zealand. The intrinsic characteristics of modular construction, including a waste reduction in construction, reduced labor, cost-efficient, time efficiency, health and safety standards, quality and health and safety control, and noise and dust reduction, make it the most appropriate approach for post-disaster housing rehabilitation. By adapting to the new technology over the conventional method of construction during the post-disaster phase, such as earthquakes, permanent housing solutions can be provided much faster to the disaster-struck area. Although two New Zealand experts believe there are many advantages of an offsite system that could be beneficial for the recovery phase of the post-disaster (R1 and R2), one of them mentioned there is no significant fluctuation in cost compared with conventional methods (R7).

The modular offsite houses can be easily moved from one location to another. Further, the modules can be easily removed from the main structures. They can be moved to other locations for future reuse or relocation, leading to reduced construction waste generation. This benefit has been confirmed through the experts' interviews (R6 and R7). Hence from the survey received from the industry experts and the characteristics of the modular structures, there is a high potentiality in using modular offsite technology to provide housing in emergencies or during post-disaster scenarios in New Zealand.

4.2.2. Section II: The Features of Using Modular Offsite to Address/Provide Housing Needs in Emergencies

The statements posted in Section II of the questionnaire survey are shown below (refer to Table 5) with the answers provided by the participants. There were 11 questions posted for Section II. Table 5 shows the participant's points of view regarding every significant possible factor. The features that made modular offsite construction more attracted seem to be significant with MR above 2.5.

Table 5. Features of modular offsite construction that help in emergency response.

Features of Modular Offsite Construction That Help in Emergency Response	Level of Agreement ¹							
	WHC	HC	MC	LC	NC	NI	MR	SD
Modular offsite construction is affordable compared to conventional methods during post-disaster events.	10.53%	36.84%	31.58%	21.05%	0%	0%	5.63	0.93
Weather independent: Modular offsite buildings are constructed in an enclosed temporary and weather-controlled factory.	21.05%	21.05%	21.05%	26.32%	5.26%	5.26%	2.89	1.41
Simple onsite expansion: To meet growing needs at a later date.	21.05%	21.05%	15.79%	42.11%	0%	0%	2.79	1.20
Reduced onsite construction hazard: Construction sites come with a certain hazard level, but because most of the construction process happens in factories, the onsite construction hazard is reduced significantly.	21.05%	31.58%	31.58%	0%	5.26%	10.53%	2.68	1.49
Controlled production: High-quality assurance under controlled production	26.32%	47.37%	21.05%	5.26%	0%	10%	2.65	0.83
Smarter: Modular offsite buildings are produced with the same materials, same building standards, and architectural specifications as traditional construction	26.32%	15.79%	42.11%	5.26%	5.26%	5.26%	2.63	1.35
Flexibility and reuse: Modular offsite buildings are movable and flexible, where they can be dismantled, refurbished, and move to another location for new use.	15.79%	26.32%	42.11%	10.53%	5.26%	0%	2.63	1.04
Modular offsite construction can be an immediate disaster relief solution	36.84%	21.05%	26.32%	10.53%	5.26%	0%	2.62	1.21
Customizable: Modular offsite buildings are more easily customized to suit 'user's needs.	16.67%	22.22%	22.22%	27.78%	11.11%	0%	2.54	0.89
Speed up project schedule: Faster and efficient factory processes replace the slow unproductive site activities	42.11%	21.05%	31.58%	0%	5.26%	0%	2.52	1.10
Sustainable: Controlled production reduces waste and energy dissipated	15.79%	52.63%	15.79%	5.26%	5.26%	5.26%	2.47	1.27

¹ Level of agreement of constraint statement: SA (Strongly Agree) = 5; A (Agree) = 4; M (Moderate) = 3; D (Disagree) = 2; SD (Strongly Disagree) = 1; NI = No Idea; MR = Mean Rating; SD = Stranded Deviation.

The affordability of modular offsite construction compared to conventional methods during post-disaster events stands on top of the factors in Table 5 with MR 5.63. Modular offsite affordable houses have been considered in other studies, which confirms that this method could be an option in many situations, such as emergency responses [105,106]. This is followed by weather-independent nature due to a controlled factory environment [107,108] and simple onsite expansion with MR 2.89 and 2.79, respectively. Assaad et al. [80] offered a brief discussion of how building a container isolation ward would be a rapidly scalable modular strategy to increase isolation capacity during the COVID-19 pandemic. The statement confirms the finding of this study and shows that modular offsite construction has the flexibility to be expanded whenever there is more capacity required.

From the survey response, it is evident that all participants trusted that the modular offsite could be used to provide faster housing. Interview findings also confirm the fact that

the speed of the construction increases through this method (R1, R2, R4, R5, and R6). The literature also confirmed that the time reduction in this method would be a vantage point in case of emergency and, compared to conventional building, can reduce project delivery time by between 30 and 50 percent [25,56,72]. The features of modular offsite construction have been identified to tackle the challenges faced during the post-disaster recovery process. Some features are time efficiency, which makes it more fit for post-disaster reconstruction compared to the traditional in-situ method. On the other hand, the speed of availability of the components will provide the post-disaster facility as they are produced (R3, R4, R7, and R8).

Further, both survey and interview findings show that the flexibility of modules of different shapes and sizes can vary to fulfill transportation limitations (R3 and R5). The modular offsite technique's long-term cost benefits are 43% higher [4]. Moreover, it reduces the demand for labor and unwanted resources onsite. The interviewees all confirmed that modular offsite construction could be a good solution for emergency response in case of natural disasters (R1–R8). Previous studies and experiences from different countries also indicate a positive response to applying modular offsite construction in case of emergency [14,47,80,85].

The modules can be connected in only a matter of time. This includes the preconstructed roofs, facades, and walls. It also has the potential to provide work for disciplines from various platforms, such as governmental and non-governmental institutions, and for contractors to produce better results when working together in the event of a crisis. This outcome is contrary to that of the interviewees who mentioned difficulty in collaboration between government and private parties (R3 and R4). However, such a desired practice is not possible in onsite construction. Since the housing modules are performed in a highly controlled environment, the quality of the material will be much higher, which ensures the final product is more structurally stable, reliable, and sustainable. The mass production facility will have more reliable quality checks when compared to the onsite construction as it will have high-pressure working conditions, especially during the post-disaster scenario.

So, based on the survey responses received, it is derived that the features of the modular offsite construction will help during post-disaster reconstruction.

4.2.3. Section III: Challenges Faced in the Adoption of Modular Offsite Construction for Emergency Response

Table 6 contains the statements posted in Section III of the questionnaire survey, along with the answers provided by the participants. There were nine questions posted for Section III; Table 6 presents the participant's point of view regarding the challenges faced by the construction industry in using modular offsite construction for post-disaster reconstruction. All challenges investigated through the survey are known as significant in this study with MR above 2.5. to mitigate these challenges, the New Zealand construction industry needs to act before happenings of any emergency happens.

In accordance with the response received from the survey questionnaire, even though there are greater merits found in the use of modular offsite construction for providing houses in emergencies, there are certain contests faced while implementing. The bottleneck faced during the post-disaster reconstruction was shortages of resources and modules, in other words, non-readiness of offsite manufacturing for such mass productivity. The result from interviews also confirms that the low capacity of the offsite industry comprised mainly SME manufacturers, there is a possibility that they might not have able to cater to the required demand in the emergency (R1, R4, R5, R7, and R8). In the literature, inadequate manufacturing capacity is one of the challenges which have an adverse impact on implementing modular offsite construction. This challenge could be worsened even in case of emergency and disaster [33,58,59]. One of the interviewees mentioned that the logistic channels should grow in New Zealand as adequate transport infrastructures will be required when using modular offsite construction during emergency response (R5).

Table 6. Challenges associated with modular offsite construction for emergency response.

Challenges Faced in Adoption of Modular Offsite Construction for Emergency Response	Level of Agreement ¹							
	WHE	HE	ME	LCE	VLE	NI	MR	SD
Ambiguous responsibility for handling call-backs (e.g., for repairs) for modular units.	21.05%	15.79%	15.79%	10.53%	26.32%	10.53%	3.37	1.72
Standard unit design plans do not accommodate climatic differences e.g., Climate differences between North and South NZ.	21.05%	21.05%	26.32%	15.79%	15.79%	0%	2.84	1.35
Integrating modules onsite can have challenges e.g., mismatch between completion of units and onsite prepared work.	26.32%	26.32%	21.05%	10.53%	5.26%	10.53%	2.74	1.58
Lack of government policies that support modular offsite housing in times of disasters/emergencies.	21.05%	42.11%	10.53%	15.79%	0%	10.53%	2.63	1.49
Transporting modular units to the development site is challenging, e.g., damaged units and transportation costs.	21.05%	42.11%	10.53%	10.53%	10.53%	5.26%	2.63	1.46
Non-readiness of the offsite industry for mass housing production in times of disaster/emergency in NZ.	31.58%	31.58%	21.05%	10.53%	5.26%	0%	2.62	1.16
Difficulty in finding trade contractors to do onsite assembly of modular units due to small contract size and lack of familiarity with modular housing.	21.05%	31.58%	31.58%	10.53%	0%	5.26%	2.53	1.23
Offshore supply of modular units may be impossible in times of disasters/emergencies.	26.32%	36.84%	10.53%	15.79%	5.26%	5.26%	2.53	1.43

¹ Level of agreement of constraint statement: SA (Strongly Agree) = 5; A (Agree) = 4; M (Moderate) = 3; D (Disagree) = 2; SD (Strongly Disagree) = 1; NI = No Idea; MR = Mean Rating; SD = Stranded Deviation.

Natural disasters of a larger magnitude can sweep away local productivity and can cause supply chain issues leading to disrupted transportation. Further, while transporting the modules or modular units to the development or construction site, any damage can be caused to the modular units leading them to be defective. The cost of transportation is also another factor to be considered and importing from offshore will also be challenging. During the interviews, different aspects of transportation were stated too. One of the experts mentioned the difficulties with large items (R1 and R7). Transportation concerns, the absence of acceptable size of the prefabricated components, and the lack of logistics confirm the importance of logistics and infrastructure channels before any unforeseen situation [24,25,56,64].

The others stated that due to the road damage, and internal transportation will be hard (R2 and R3). Finally, the emergency may affect the transportation of the components (R3). The other challenging factor will be the climate. The standard unit design plan does not include the changing climate factor between the North and South Islands in New Zealand. During the interview, the lack of government policies that support offsite construction was mentioned as a factor to be considered for an emergency. This factor may arise from other challenges, such as poor comprehension and ignorance, resistance to change, and small market demand, which have been identified through the literature review process [24,26,55,58]. The expert believed that because the designing and planning stages require more time and in emergencies, it makes the situation harder. However, as the repetitive nature of the components, the design of prefabs can be considered before any emergency (R1, R2, and R6). This is consistent with the findings of a case study conducted by Hwang et al. [25], who highlighted the significant difficulties and efforts required for the timing and planning of modular offsite construction supply. One of New Zealand's biggest problems is planning-related, especially when there aren't enough standards in place. Though these challenges are faced in the use of modular offsite construction, it is

still proved to be a much outstanding approach compared to the conventional method for meeting the housing demand in emergencies.

Other challenges, such as difficulties in finding the contractors and integrating modules onsite can have challenges, e.g., the mismatch between the completion of units and prepared onsite work, and standard unit design plans do not accommodate climatic differences, e.g., climate differences between North and South NZ are not mentioned through the literature. It seems that these challenges are specifically related to the New Zealand construction industry, which needs more attention. Based on the survey response received from Section I and Section II, as shown in Tables 4 and 5, it is evident that the industry experts confirm the potential and features of modular offsite construction in New Zealand. Along with addressing the areas of challenges (Table 6), such as lack of skilled personnel and inefficiencies in planning, communication, and coordination for post-disaster reconstruction housing modular offsite construction technology ingenious approach to meet the demand in New Zealand.

5. Conclusions

The key objective of this study is to understand if the modular offsite construction method can be used for post-disaster reconstruction in New Zealand and by adopting this technology, how government can prevail from unexpected circumstances caused due to natural disasters. Lying between two tectonic plates, New Zealand is deemed to get unexpected natural disasters without any warning Christchurch earthquake that occurred in 2011 is one of the real-time examples, causing many people to lose their homes and damage their properties.

Content analysis for the literature review process helped authors to figure out the groups of challenges and strategies which may affect the modular offsite construction implementation. Technological, human resource, operational procedures, financial, managerial, and organizational are the six groups of challenges identified through the literature review. Time management, financial, quality, management, and sustainability are the five groups of advantages extracted from the literature. Both these categories made a database for the next step of the data collection.

The six constraints that were identified from the literature review set the background for this study. With the help of the mean value rating obtained from the survey circulated to the industry experts, the major factors that are obstructing the use of modular offsite construction technology for providing post-disaster housing are identified as follows lack of skilled personnel and resources, inefficiencies in planning, communication, and coordination, time efficiency, funding, resilience, and sustainable supply chain or transportation.

It is evident from the literature review that many countries have faced the same situations and needed to build a permanent housing solution after a disaster. They have also used offsite construction technology in the past to overcome the difficulties when using modular construction. The demand was met in a matter of months or days. However, with the conventional method, it will be years.

The great advantage of using modular offsite structures for post-disaster construction is that in reconstruction, it is directed as one solution provider as it effectively reduces the reconstruction time. Most of the industrial experts and pioneer researchers in the field of offsite technology state that modular offsite construction can be used by planning effectively to overcome the factors affecting the use of offsite construction in providing housing in emergencies.

This study has helped in establishing the various factors that are affecting the use of modular offsite construction to provide housing in emergencies in New Zealand. It also suggests that by overcoming the challenges faced when implementing or providing housing in emergencies, modular offsite construction technology can be used smoothly and rapidly to meet the demand. The findings also established that, although there are

challenges to using modular offsite construction, the New Zealand construction industry has its own potential to implement this method in case of emergencies.

The defined hypothesis has been answered through various data collection methods in this research. The first hypothesis was, there is sufficient potential for modular offsite construction implementation in New Zealand in case of any disaster or emergency. The results of this study showed that the three most significant factors for modular offsite construction are the availability of modular offsite houses in the local market of New Zealand, high quality of structural design, and affordable housing options.

The second hypothesis refers to the feature of modular offsite construction, which made this method a useful solution in New Zealand for an emergency. Although there are many advantages to this method, its affordable method compared to conventional construction, its controlled manufacturing environment, and its ability to expand are the most significant factors. In addition, the last hypothesis is related to the challenges of implementing modular offsite construction, which also has been confirmed by the findings of this study.

The funding for a post-disaster recovery process can be tough. To meet the funding required, government and NGO sponsors can play a vital role in overcoming this constraint by funding post-disaster recovery and reconstruction. It is important that if such an unexpected circumstance occurs, the government should be prepared for the worst to smoothen the recovery period. Hence a pre-disaster response plan should be devised to deploy modular offsite construction technology. Further, the government and construction industry need to collaborate to carry out the work seamlessly, resulting in providing faster housing solutions in the event of emergencies in New Zealand. The developments of automated and robotic prefabrication, which helps speedy onsite assembly and delivery in New Zealand, should be considered as well.

The findings of this study have established that the New Zealand construction industry to foresee the benefits of using modular offsite construction in response to the building demands that are generated in emergencies. Industry practitioners understand the challenges that are likely to be faced by the construction industry in the adoption of modular offsite construction and how these challenges can be tackled. Future studies can investigate more aspects of modular offsite construction, such as structural systems, technologies, and materials that will be suitable for this system. More research in this area will promote the realization of modular offsite construction projects and the preparedness of the construction industry to provide an efficient response in case of emergencies.

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