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Suitability of Modular Technology for House Construction in Sri Lanka: A Survey and a Case Study

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Abstract: Prefabricated volumetric modular building construction is an emerging technology in many countries used to develop the construction industry through its value-added benefits. The adoption of these novel technologies in the Sri Lankan construction industry has been relatively slow compared with other developing countries, delaying the development of the construction industry and the attainment of the added benefits of these technologies. Therefore, this study aims to identify the suitability of modular construction for the Sri Lankan construction industry via a survey and case study. A questionnaire survey was developed and distributed to assess and identify the benefits of implementing the concepts and constraints in Sri Lanka. Then, the construction cost of a proposed single-story house delivered through conventional and modular practices was compared. The survey results showed that introducing a modular concept to the industry is suitable and would benefit the Sri Lankan construction industry. Further, survey participants believed that the economic benefits brought in by modular construction are significantly more important than environmental and social benefits when selecting modular construction. The case study on a single-story affordable modular house showed a 32% reduction in total construction costs and a 36% reduction in labour costs compared to conventional house construction. Further, costs for total modular construction and labour were 32% and 36% less than those of conventional construction costs and labour costs. Moreover, a 16% reduction in embodied energy was observed when compared with conventional construction. Therefore, the modular concept could be used to construct affordable houses and will be cost-effective with the correct choice of material.

Keywords: modular construction; beneficial factors; constraint factors; construction cost; professional readiness; affordable housing

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1. Introduction

The construction industry's productivity needs to catch up to other industries, which are developing their capacity and capabilities by adopting smart and sustainable practices and incorporating AI (artificial intelligence) technologies [1]. Traditional construction faces many problems in efficiency, quality, and sustainability, which will cause decreased productivity [2]. On-site work is also susceptible to external factors like weather and the surrounding environment of the selected construction site [3]. Since the construction industry is highly labour-intensive, productivity depends on labour productivity [4,5]. The advancement of materials, the manufacturing industry, and software development paved the way for the construction industry to change its conventional approach [6]. In recent years, manufacturing and automation concepts have been adapted to increase the construction industry's productivity and have shifted a larger percentage of on-site work to off-site factory environments [7]. With the recent increase in demand for housing, mass production is also required, which can be achieved through automation [8]. The concept of prefabrication comes with the manufacturing of structures, which helps in achieving the newly set goals in the construction industry.

Prefabrication can be categorised into five main categories [9]. Factory-manufactured three-dimensional (3-D) modules with finishes and assembly on-site are used to build the structure in modular (volumetric) construction; two-dimensional (2-D) panel units manufactured in a factory are used for panelised building construction; hybrid (semi-volumetric) construction is a combination of both 2-D panels and 3-D modules; OSM (off-site manufacturing) of sub-assemblies and components is another category, which uses factory-manufactured subassemblies or components, excluding windows, doors, and roof trusses, for on-site construction. The fifth category consists of the structures that cannot be categorised under the other types and those that use innovative construction techniques and structural systems, which are identified as the non-OSM category.

Prefabricated volumetric modular building (PVMB) construction, or modular construction, is one of the off-site construction methods considered in the above categories. Even though the concept was introduced after World War II [10], its share in the construction industry has increased in the last few years [11,12]. The popularity of this construction practice also increased due to the advantages the practice introduces to the industry [13]. This emerging technology has been used for residential and commercial building construction [14]. Structures with repetitive building plans, like housing complexes, apartments, hostels, hotels, hospitals, etc., have been the main adopters of the PVMB approach. Figure 1 shows some modular housing constructions which are also energy efficient [15].

(**a**) (**b**)

Figure 1. Modular houses: (**a**) two-story house [16]; (**b**) single-story house [16].

The PVMB system can be defined as a construction practice wherein most of the on-site work is shifted to factories. In the PVMB system, 3-D modules, or the building units with the structural elements, MEP (mechanical, electrical, and plumbing) services, and finishes are manufactured in the factories and then transported to the required location [17]. To complete the structure, assembly and installation are carried out on-site (refer to Figure 2). The foundations, lateral load-resisting systems (LLRSs), and other construction conventionally constructed on-site have also been the focus of efforts intended to develop and shift to the off-site prefabrication practices, through recent and future research, as these have been identified as the delaying activities in modular construction [18,19]. A modular building system comprises prefabricated units and components (connections) that help the assembly process. Steel, concrete, and timber are the most commonly used materials for constructing modules [20]. Although steel-based modular units and components are the most popular, hybrid modular systems are also available for construction [21–25]. Conventional construction systems, which have yet to receive significant attention, such as masonry walls and foundations, have also been researched and developed for prefabrication in recent years [26].

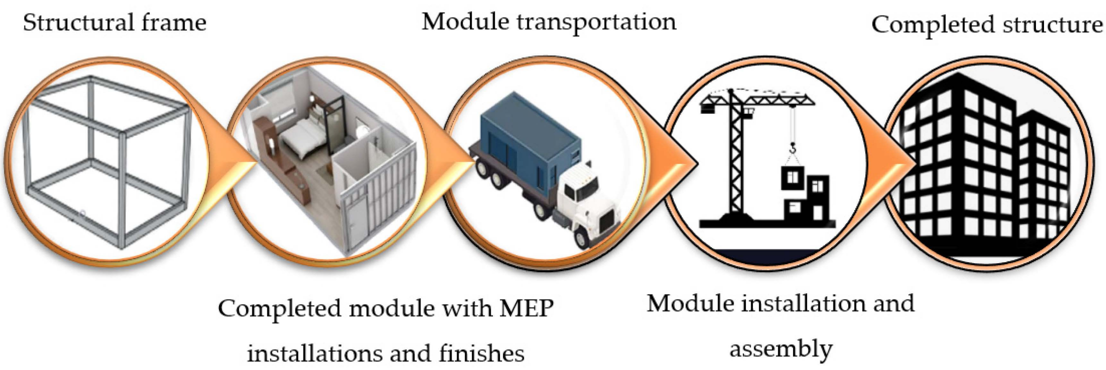


Figure 2. PVMB construction process from factory to site.

The speedy, time-saving construction practice is useful in relocating projects during post-disaster management. These advantages came to light during the COVID-19 outbreak when the need for hospitals with quarantine facilities suddenly increased. Wuhan Huoshenshan Hospital in China is one such construction, built with a capacity of 1000 beds and designed and delivered within seven days [27]. Many developed countries like the USA, Canada, Japan, China, Australia, the UK, and South Korea have adopted this promising technology [23,28]. In contrast, developing countries like India and Bangladesh have been trying to introduce this novel technology to their construction industry during the past few years [29–31]. Regarding the Sri Lankan construction practice, there is a delay in adopting new technologies [32]. The industry adopted panelised construction in the past few decades [33], but the knowledge and expertise about PVMBs are minimal.

Considering the current economic condition and technology in Sri Lanka and the limited research on the introduction of this novel concept to a developing country, and none in the Sri Lankan context, this research intends to study the suitability of modular construction for the Sri Lankan construction industry. Further, this paper studies the factors that hinder the adaptation of PVMB technology in Sri Lanka along with the benefits it would carry to the industry and the current knowledge about this novel technology within the related parties. Considering housing construction, providing affordable and high-quality housing in Sri Lanka and meeting the increasing demand for housing is a continuous challenge. Many half-built houses can be seen due to unstable financial situations. High inflation rates and scarce financial resources in the country discourage time-consuming construction, which will encourage the emergence of productive construction practices. Therefore, this research also presents an affordable housing design with costs and embodied energy considered, compared with conventional construction. The outcomes of this study will be beneficial in identifying the factors that should be addressed when implementing this novel technology in Sri Lanka. Additionally, the findings can be utilised to inform the general public about modular construction, its benefits, and how to address the constraints faced. Furthermore, the designed affordable housing will be beneficial in introducing the modular concept to the industry at a basic level.

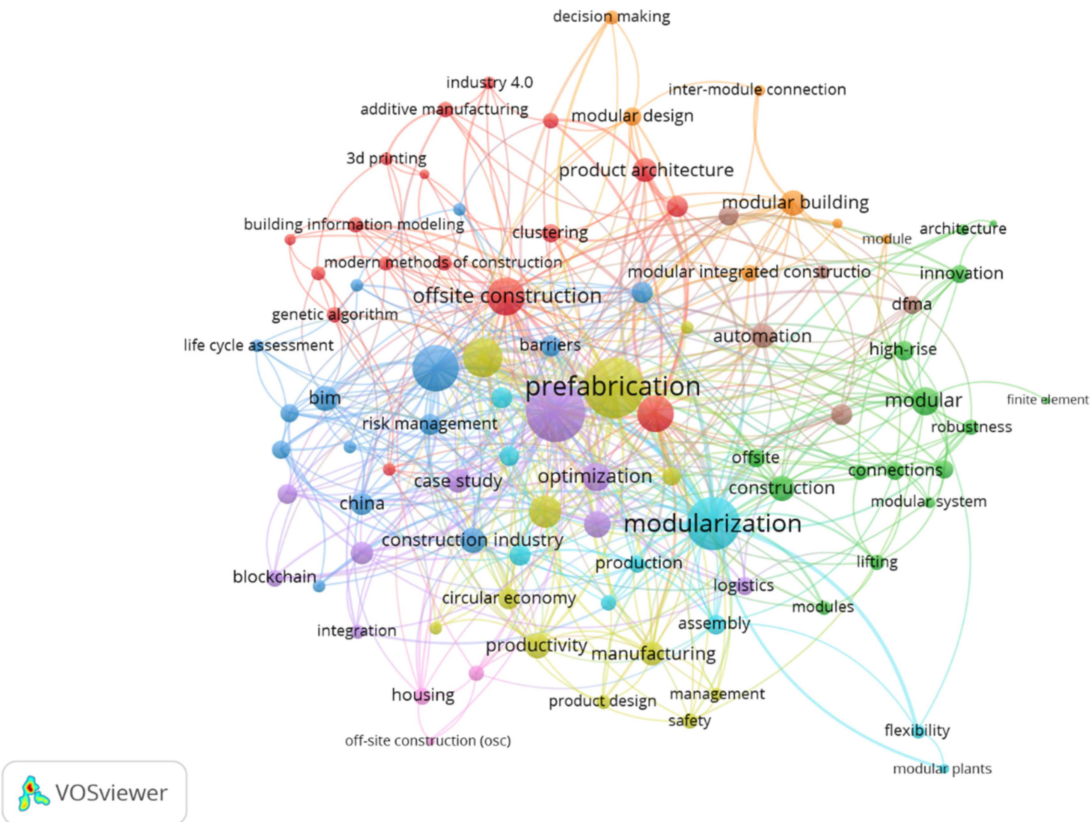
2. Methodology

A detailed literature review was conducted to identify the factors affecting the implementation of modular technology and the effects of modular technology on the construction industry. Scopus and Web of Science (WoS) databases were used to identify the journal articles, and they were narrowed down after we read the abstracts. The search strings in Table 1 were used to identify the related research articles. A network visualisation diagram was created to recognise the fields that are related to the topic. The visualisations were created using VOSviewer software (v.1.6.18), taking the minimum number of keyword co-occurrences as five words. Figure 3a,b show the visualisation diagrams generated for the first search string in Scopus and WoS. The circles representing the keywords are weighted for the occurrence of the keywords.

Table 1. Search strings used and the number of articles found in the Scopus and WoS databases.

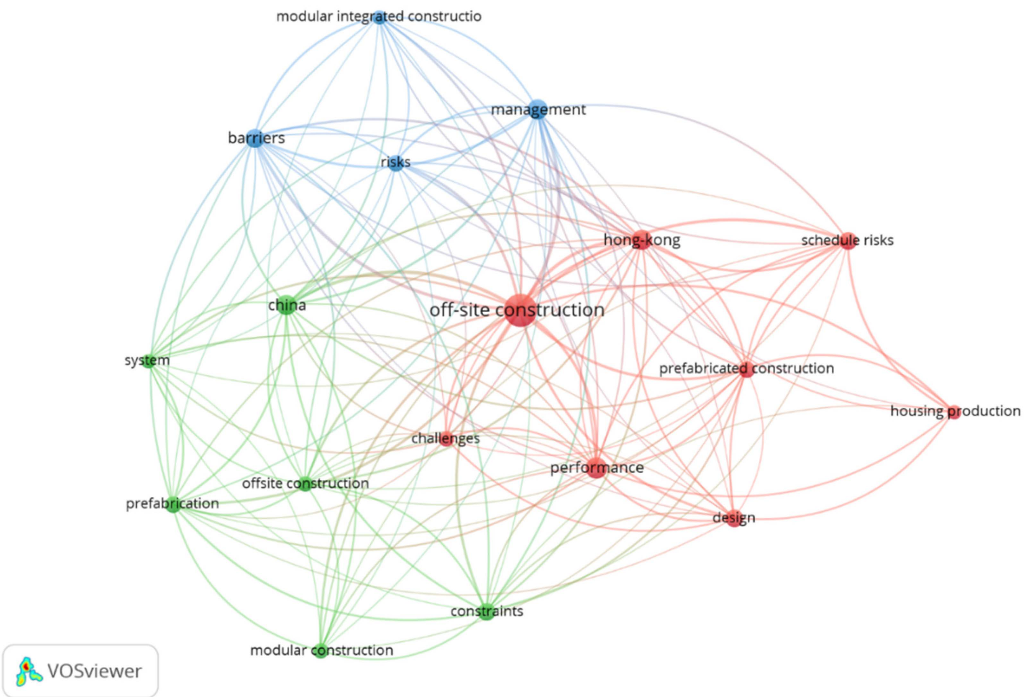
Search String	Database	No. of Articles	Keywords Threshold
(“Modular construction*” OR “Modular building*” OR “Prefabricated buildings*” OR “off-site construction*” OR “offsite construction*”) AND (“benefit*” OR “challenge*” OR “advantage*” OR “disadvantage*” OR “constraint*” OR “risk*”)	Scopus limited to the subject area of “Engineering” and from the year 2000	1498	91
	WoS	32	18
(“Modular construction*” OR “Modular building*” OR “Prefabricated buildings*” OR “off-site construction*” OR “offsite construction*”) AND (“benefit*” OR “challenge*” OR “advantage*” OR “disadvantage*” OR “constraint*” OR “risk*”) AND “developing countr*”)	Scopus limited to the subject area of “Engineering”	14	-
	WoS	1	-

The benefits of adopting modular construction and the constraints facing its adaptation in the context of other developed and developing countries were identified through the literature survey. These identified factors were ranked considering the number of repetitions of each factor. These factors were used for the questionnaire survey design with consideration of the nature of the Sri Lankan construction industry. The questionnaire was validated and then sent to targeted professionals. The data were collected and analysed. This process adopted in this study is described in detail in the following sections (e.g., Section 3.3). After identifying the suitability of modular construction in Sri Lanka, a suitable affordable modular housing unit was developed. Construction materials were chosen considering the availability, affordability with the current economy in the country, and sustainability aspects.



(**a**)

Figure 3. *Cont.*



(**b**)

Figure 3. Network visualisation diagrams: (**a**) Scopus; (**b**) WoS.

3. Suitability of Modular Construction Practice for the Sri Lankan Construction Industry

The suitability of various construction practices in different regions of the world or a country will differ based on the standards and regulations followed, cultural and social aspects in the region, government and political influence, management practices, the economic situation, and the availability of resources. When considering the market share of modular construction in the construction industry in developed countries, it ranges from 5–10%, with an expectant growth to 15–20% by 2030, whereas in developing countries, it is nearly at a level of 0% [34–36]. Therefore, the suitability of modular construction, the benefits it will bring forward, and the constraints faced in its adaptation for a country can be different from the identified factors in the existing literature for other countries. Most of the existing literature covers those aspects faced by developed countries [37–40], while only limited studies focus on developing countries [30,41]. Moreover, Ferrada et al. [42] suggest that industry practitioners' knowledge and experience are the most suitable sources for finding a suitable construction method. Therefore, this research intends to analyse and identify the factors that have a higher impact considering the social and economic aspects of the Sri Lankan construction industry through a questionnaire survey used to collect the ideologies of the field practitioners. The study will also follow similar assessments done in other developing countries about implementing modular construction to identify the factors that will have a major impact on making decisions regarding modular construction.

3.1. Benefits of Modular Construction

The benefits of modular buildings, when compared with conventional construction, can be identified in all sectors, of quality, time, cost, and sustainability. When identifying the beneficial factors, priority was given to studies done in developing countries that have similar economic environments to Sri Lanka [43–45]. The social and environmental factors were identified considering the tropical developing countries that are culturally similar to Sri Lanka, such as India and other South Asian countries [2,46]. One of the main advantages achieved through factory manufacturing is superior quality due to the factory-based production process with human supervision. The percentage of work done in the factory environment is approximately 70%, which can be increased to 90%. The remaining on-site work also will be carried out by skilled, trained professionals [47]. The current high inflation, especially in Sri Lanka, and scarce financial resources encourage speedy construction [45]. When considering construction time, modular technology can reduce conventional construction time by 50–60% [11].

The productivity increase in modular construction is achieved through the concepts adopted in manufacturing, such as assembly line production, lean production, and the specialisation of work. These concepts help in quality control and increase productivity by minimising the waste of material and time, and, hence, will consume less time and cost less [48]. The familiar indoor environment, rather than the site environment changing for every project, will help in increasing the efficiency of labourers. This off-site work is less vulnerable to extremely harsh weather conditions and other external factors. This will be advantageous in temperate climate regions where builders can run the off-site manufacturing in the winter and the on-site construction in the comfortable period [30], and for tropical countries like Sri Lanka with monsoonal rains and intense solar radiation [49].

When considering the cost aspects, quality improvement and time-reducing practices will increase costs due to factory overheads [45]. If proper project planning is executed, the cost will stay the same as the conventional construction. However, with adequate and timely planning, costs can be reduced by planned mass-scale production and mechanised production, which reduce the requirement of labour and material by minimising wastage. These reduced labour requirements will add benefits to countries with labour shortages and higher labour wages [30,43]. Apart from the quality in terms of the time and cost aspects, modular construction shows greater benefits in sustainability when compared with conventional construction methods. Sustainability is one of the main concepts that have drawn the world's attention due to increasing environmental pollution and depletion of natural resources. As the construction industry is responsible for nearly 38% of global CO_2 emissions and 25% of all solid waste, construction should value sustainability more highly [37]. Modular technology addresses the 3-R concept of Reduce, Recycle, and Reuse. PVMBs can reuse the entire modules elsewhere or add extensions to existing buildings. This will be beneficial; instead of occupying half-built houses due to unstable financial situations, people can use modules and their use can be extended in future without many disturbances. It is considered that modular construction can reduce construction wastage by an average of 52% and direct emissions by 43%. This could also help provide a 10–30% cost reduction [50,51]. Since most work is done in off-site factories, disturbance to the environment and the neighbourhood is comparatively low. Moreover, emissions and solid waste disposals can be effectively managed in factories [52]. Therefore, this can be considered an efficient construction practice in highly urbanised or sensitive areas [2]. Considering all the benefits and effects of these factors on a developing country, the most suitable factors were selected for the questionnaire survey.

3.2. Constraints in Adapting Modular Constructions

There will be challenges in introducing new technology to the industry. The literature shows that many obstacles were faced when introducing the PVMBs and developing and sustaining the concept. Similar to the beneficial factors, when identifying the constraints, higher weightage was given to studies done in developing countries that have similar economic, social, and environmental backgrounds to Sri Lanka [2,53,54]. The earlier PVMB designs were limited to selected building layouts and architectural features without significant variations. Prefabricated architecture has also developed, which has introduced much flexibility to complex designs with improved architectural features. Recently, many countries have adopted modular technology in their construction industry to increase productivity and cater to the increasing demand for dwellings. There will be challenges in introducing new technology to the industry. The literature shows that there were many obstacles faced when introducing the PVMBs and in developing and sustaining the concept. The challenges faced by all the countries were similar, but the impacts of the challenges to the introduction or the growth of modular construction in particular countries were different. Moreover, only a limited number of papers studied the challenges a developing country faced when this concept was first introduced to the industry.

Although most developing countries have adopted modular technology to improve their construction industry, there is a delay in adapting it in some countries like Sri Lanka. This is mainly due to a need for more knowledge and understanding of the modular concept and insufficient technological advancement. Although these countries are reluctant to adopt novel technology, it may help provide affordable and high-quality housing. In the Sri Lankan context, census records show that nearly 13% of families need adequate housing, and many half-built houses exist due to unstable financial situations. High inflation rates and scarce financial resources in the country, especially during this economic crisis, discourage time-consuming construction. Therefore, considering these facts, modular concepts will help to address these problems. Although modular construction has many advantages, there are some constraints that hinder the growth of PVMBs and the ability to bring out the best of this construction practice in the industry.

Higher capital costs at the implementation phase, to build the factories with the necessary types of machinery and overhead costs, which cannot be met without the required production output, will have a greater impact on the introduction of the modular construction practice [55]. When the concept is newly introduced, all the infrastructure, including the off-site factories, related machinery and equipment, and improved transport facilities, should be provided. It will only be profitable if the production can exceed the breakeven point. Research in China has shown that the cost increase of PVMBs compared to traditional construction is 26–72% for various projects [11]. Moreover, finding investment in novel construction techniques will be another constraint. Since the decision carries higher risks, it could be challenging to convince the decision-makers to implement the modular technology and for clients to adopt it. It could be difficult to assess the value brought by the modular technology to the project, which will cause unwillingness and reluctance in financiers and insurance underwriters to make funds available and cover the insurance [30]. During the construction process, there will be costs associated with transportation. The road structure should be developed to transport the modules without causing damage to the finishes attached. A traffic management plan should be executed to transport the modules without causing disturbance to the other vehicles and maintain safety [56]. All these requirements are costly and depend on the transport infrastructure and regulations in different countries where the impact of the transportation aspects on modular construction will be different.

A major challenge faced by both countries that are newly adapting the concept and those that are already practising the concept is the need for systematic design guidelines or calculation techniques. The lack of these standard regulations and quality assessment tools and equipment specially designed for the PVMBs will cause reluctance in engineers to produce designs and the public to accept the reliable performance of the structures [30]. There will be difficulties in terms of design complexities due to the need for more understanding of the performance of the structure, which will eventually limit the design variations of the PVMBs [57]. It is required to manufacture the modules with the method of installing them pre-designed on the sites, which will make changes added later on at the site not viable. Therefore, an early design freeze is necessary for modular technology, which is not required in traditional construction [58].

Inadequacy of the capacity, facilities, and experience of the project team, and lack of skilled and experienced labour, will be another barrier when moving to modular construction [30]. The lack of continuous development of professionals and technology in some countries makes them less aware of the new trends in the world [58]. Inadequate or under-developed transport systems and the capabilities of lifting equipment and other tools will also impact the execution of the concept [59]. Low incorporation of the construction industry of computer technology and networking and inefficient coordination among different project teams may lead to design conflicts, such as connectivity and tolerance errors in factory-made components and on-site assembly [60]. There will be health and safety risks associated with modular construction, which must be addressed before implementing the practice [61]. Lack of government support for modular construction also will be a hindrance to adopting modular construction. The government can motivate the contractors by taking various measures. Introducing a systematic approval process for modular construction, offering financial incentives, and promoting research and development and public awareness through pilot projects or training programmes can be considered as a few of them. Not having these support systems will be a constraint when implementing modular construction [62–64]. Considering these constraint factors, the factors suitable for the questionnaire were selected and added.

3.3. Design of the Questionnaire Survey

The factors that were identified as influential for developing countries through the literature survey, from the design and construction perspective, were ranked according to the number of times that they were repeated, and we selected the final 10 beneficial factors and 11 constraint factors. Some factors were intentionally joined, and some were separated, considering their applicability in the Sri Lankan construction industry (Appendix A). Table 2 presents the considered beneficial factors and the references, while Table 3 presents the considered constraint factors and the references. The respondents were asked to rate the factors on a 1–5 scale based on the effects of the factors on the Sri Lankan adaptation of modular construction (1 strongly agree to 5 strongly disagree).

Table 2. Benefits of PVMBs.

	Benefit	**References**
01	Increased productivity	[2,30,43,46,49,56,65,66]
02	The superior quality achieved by the factory-based construction process	[2,30,43,45,56,66]
03	Reduce overall project schedule	[2,43,45,56,66]
04	Less requirement for on-site labour, therefore a solution for the labour shortage	[2,30,43,49,56,65,66]
05	Improve occupational safety and health	[2,43,49,56,66]
06	Less disturbance to the environment and the neighbourhood during construction	[2,43,45,56,66]
07	Economies of scale in production	[45,66]
08	The ability to reuse the elements or extensions to existing buildings	[43,66]
09	Less vulnerable to bad weather	[49,56]
10	Improve the professionalism of the industry	[2]

Table 3. Constraints of PVMBs.

	Constraints	References
01	Higher capital costs	[2,43,53,55–57,60]
02	Lack of capacity, facilities, and expertise of the project team	[30,43,44,53,55–58,60]
03	Lack of trained and skilled labour	[2,30,43,44,55,57,58,60]
04	Fewer opportunities for design variation due to complexities and the inability to make changes on-site (early design freeze)	[30,43,55–58,60]
05	Lack of design standards and quality assessment tools	[30,43,53,55,57,58,60]
06	Inadequate communication and coordination among the project team	[30,55,57,58,60,66]
07	Inadequacy of transport infrastructure in module transportation	[30,43,53,56–58,60]
08	Lack of adequate support from the government	[30,44,55,57,60]
09	Negative impression of the public about modular construction as low-cost and less durable structures	[40,67]
10	The unwillingness of financiers to make funds available and insurance firms to cover the insurance	[30,43,56,60]
11	Difficulties in bringing the industry to a scale that would justify the initial investment in new infrastructure	[57,67]

These beneficial and constraint factors are already identified as benefits and constraints in the literature. Therefore, a one-tailed test was used in choosing the sample size required for the analysis. Past research was followed to identify suitable analysis types for a relatively smaller sample [68,69]. The significance level (Type I error α) was considered 0.05, and the power was taken as 0.8, where the Type II error (β) was set to 0.2 [70]. The effect size (d) was taken as 0.3, considering the differences between the conventional and modular construction as medium [71]. The targeted sample size for these considered values of α, β, and d was 69. Considering all these factors, the questionnaire was prepared, and content validation through expert review following the study by Elangoven et al. [72] and cognitive interviewing were done and distributed through a web link, enabling the online responses to be used to collect information from the respondents [73]. The professions of the respondents, the scales of the company they are working for, their work experience, and their knowledge about PVMBs were collected. The respondents were directed to assess the benefits and constraints of modular construction according to their ideology about the suitability of PVMBs in Sri Lanka. The respondents who were positive about the suitability of modular technology for Sri Lanka were asked to assess the benefits and the suitable construction material for PVMBs. Those who think modular construction is not suitable or are unsure about its suitability were asked to assess the constraints.

4. Survey Results and Discussion

The distribution of the questionnaire survey was carried out following the non-probability sampling technique and the snowball sampling method. Therefore, the exact number of distributions is still being determined. The survey was open for seven months. The participants were selected by considering their profession and experience. Since the study focuses more on residential construction, considering the construction practices in Sri Lanka, influential factors include concerns considering both design and construction aspects together. Therefore, professionals related to both criteria were chosen to distribute the questionnaire. Initially, the questionnaire was distributed to include all the concerned categories. Seventy-two responses were collected, and the questionnaire was kept open to collect more data. Figure 4 shows the number of respondents with their job sectors. Figure 5 shows the understanding of the respondents about the modular concept. The respondents were asked to choose their understanding of modular construction among four criteria. They are as follows: Never heard about the concept (NH), Have heard about the concept (H), Have an adequate understanding of modular construction but no industry experience (AU), and Have an adequate understanding of modular construction and industry experience (E). It shows that even though this questionnaire was distributed among the professionals in Sri Lanka, none of them had any experience related to modular construction. There were ten respondents, which is nearly 14% of the respondents, who had yet to hear about modular construction before they filled out the survey. Therefore, among the participants, only 86% were allowed to go through the entire questionnaire.

Among the participants who knew the modular concept, 79% believed that modular construction practice is suitable for Sri Lanka. Hence, they were assessing the benefits that could be gained through its adaptation. Of all participants, 15% were unsure about the suitability, and 6% of the respondents thought adapting modular technology to the Sri Lankan construction industry was unsuitable. Most of the respondents are consulting or design engineers. Therefore, the constraint section in the questionnaire was assessed by the 21% of the respondents who needed clarification or thought modular construction was not a suitable value addition to Sri Lankan construction.

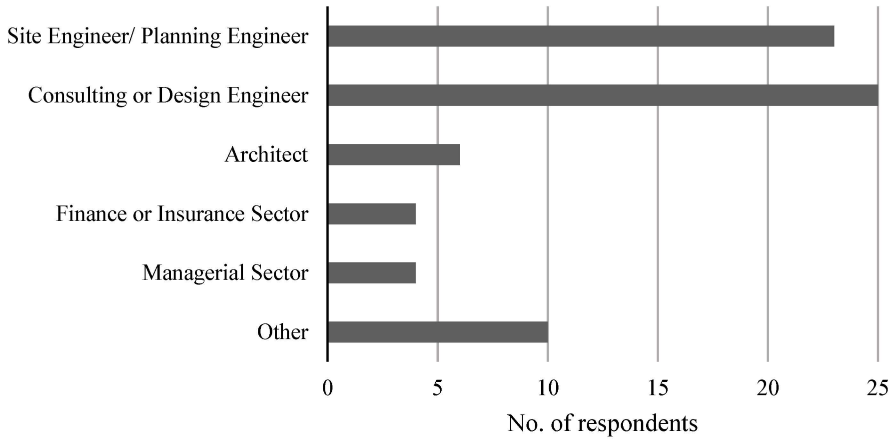


Figure 4. Number of respondents from various job sectors.

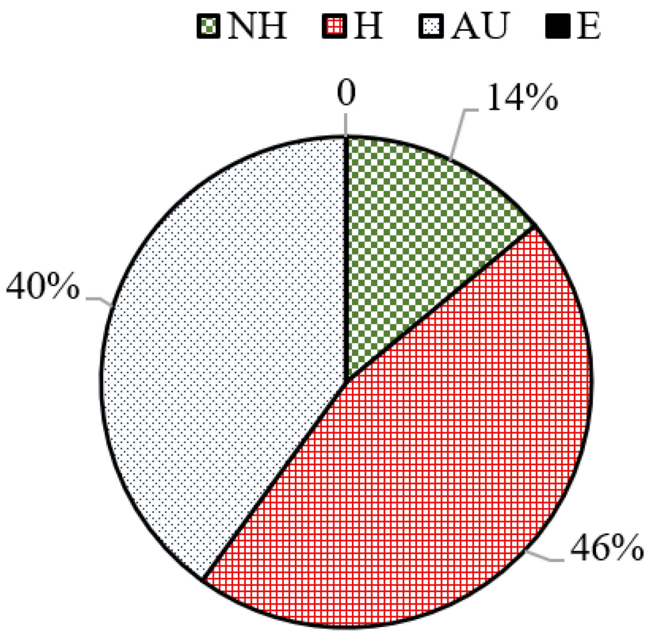


Figure 5. Understanding of the respondents about modular construction.

4.1. Benefits of Adopting Modular Construction

The beneficial factors, which were scaled by the respondents, were analysed to identify the significance of each factor. A P-P probability plot was drawn for all the factors, and it was observed that the data sets were well-fitted to the hypothesis developed, which is "The factors considered are the added benefits of introducing modular construction". Table 4 shows the beneficial factors ranked according to the mean scores, and the standard deviation (SD) of the factors was also calculated. Even though a similar analysis procedure is carried out in this section, since the sample size was reduced to 49, the significance level (α) was increased to 0.1, while the power and the effect were kept the same. A statical sample t-test was conducted to check the importance of each factor, taking the hypothetical mean value as 3.0 for neither agreeing nor disagreeing on the factors presented. For easy reference in the study, the factors were shortened and inserted in the tables with factor numbers below, as shown in Table 4. According to the analysis of beneficial factors in Table 4, it can be seen that all the factors satisfy the confidence level of 99.5%, with all the factors exceeding the t-value of 2.68, which is the critical value. Therefore, it can be concluded that all the considered factors are important benefits that can be achieved by adopting modular construction practices in the Sri Lankan construction industry. "Reduce overall project schedule" was ranked first as the major benefit that can be achieved. The second- and third-ranked benefits are "increased productivity" and "Less requirement for on-site labour, giving a solution for the labour shortage", with similar mean values. "Less vulnerable to bad weather", "The ability to reuse the elements or extensions to existing buildings", and "Improve the professionalism of the industry" were ranked as the last three, indicating these have fewer effects to be considered as benefits gained through modular construction when compared with the other factors. The study gives almost similar results to the study done by Kisi et al. [43], which was done for a developing country, but there, after time and productivity, sustainability was identified as the third most value-added benefit, whereas it was not given much value in Sri Lankan context. Improved occupational safety was identified as the least beneficial factor in that study. Since the construction industry in developed countries is moving towards sustainable construction, similar to economic benefits, socio-environmental benefits also play an important role in decision-making [74]. But considering the economic conditions in developing countries, the industry there pays minimum attention to socio-environmental benefits [75]. From the ranking of the factors, also, it is evident that when a new construction practice is introduced, economic benefits received from its adaptation are prioritised over social and environmental benefits in Sri Lanka. Although these environmental and social beneficial factors can lead to cost savings, participants are more interested in direct cost savings through modular construction. To measure the internal consistency of the factors, Cronbach's alpha test was conducted. The α value obtained was 0.92, indicating an excellent internal consistency among the factors.

Table 4. Significance and ranking of the beneficial factors.

	Benefit	Mean	SD	Rank	Significance (t)
01	Increased productivity	3.94	1.07	2	6.15
02	Superior quality	3.78	1.18	6	4.61
03	Reduce overall project schedule	3.96	1.11	1	5.99
04	Solution for the labour shortage	3.94	1.01	2	6.52
05	Improved safety and health	3.71	0.94	7	5.35
06	Eco-friendliness	3.84	1.05	4	5.59
07	Economies of scale	3.8	0.93	5	5.96
08	Reusability	3.65	1.09	8	4.19
09	Less vulnerable to bad weather	3.51	0.96	10	3.72
10	Professionalism of the industry	3.65	1.07	8	4.27

An ANOVA test with a 90% confidence level (10% significance) was conducted for the data set to check the perception of different subgroups of respondents based on their experience and the job sector [68–71]. Since, in other fields of studies, the years of experience are believed to have effects on different perspectives, the years of experience of the participants were also collected [76]. The responses were checked for the differences in opinion of the group based on their experience, categorising experience as less than five years, 5–10 years, 10–15 years, and more than 15 years. Table 5 shows the mean values and the ranking of factors within each group. The perception of each group of the beneficial factors is also given in the table based on the F-factor $f_{(0.1,4,45),}$ which is equal to 2.08 for the selection. According to Table 5, it can be seen that all the groups with different experiences hold similar opinions on the beneficial factors. Factor 03, "Reduce overall project schedule", ranked among the top three in each group, emphasising its importance. The lesser agreement in the opinions can be seen in factors 10 and 02. The group with more than 15 years of experience disagrees with factor 10, that modular construction increases the industry's professionalism, whereas other groups do not disagree. In factor 02, the professionals with less than 5 years of experience think that is the most beneficial factor, whereas professionals with more than 15 years of experience have ranked it fifth, and others at the far end. To be more certain about the perspective of different groups, it is recommended to collect more survey data.

Table 5. ANOVA test for the groups based on the experience.

Benefit		Mean				Rank				F-Ratio	Opinion
		<5	05–10	10–15	>15	<5	05–10	10–15	>15		
01	Increased productivity	4.1	4.25	3.5	3.5	2	1	5	6	1.05	Same
02	Superior quality	4.14	3.83	3	3.67	1	10	9	5	1.75	Same
03	Reduce overall project schedule	4.1	4.25	3.8	3.83	3	1	1	2	0.49	Same
04	Solution for the labour shortage	4	4.25	3.8	3.33	4	3	1	7	0.9	Same
05	Improved safety and health	3.71	4.08	3.5	3.33	7	4	6	7	0.85	Same
06	Eco-friendliness	3.9	4	3.4	4	5	7	7	1	0.56	Same
07	Economies of scale	3.71	4.08	3.6	3.83	8	4	3	2	0.42	Same
08	Reusability	3.67	3.92	3.6	3.17	9	8	4	9	0.47	Same
09	Less vulnerable to bad weather	3.43	3.92	3	3.83	10	8	10	2	1.55	Same
10	Professionalism of the industry	3.81	4.08	3.30	2.83	6	4	8	10	1.91	Same

Further, the same number of responses was used in the ANOVA test based on the type of job. Since the respondents from other jobs, besides consulting or design engineers (C&DE) and site or planning engineers (SE/PE), are limited, all the remaining jobs were considered a separate group. Table 6 shows the mean values and the ranking of factors within each job sector. The perception of each group on the beneficial factors is also given in the table based on the F-factor $f_{(0.1,3,43)}$, which is equal to 1.91 for the selection. According to Table 6, it can be seen that the differences in perceptions about the beneficial factors between each job sector are greater than those between the groups that are based on experience. In this group, for nine factors, they shared the same opinion, while one carried a different opinion. Similarly to the previous analysis, here also, factor 03 has managed to stay within the first two in importance among the other factors. The factor was ranked second among the consultant/design engineers, while it was identified as the factor that will be most beneficial in the other groups. There was a difference of opinion for factor 10, which also had the least agreement in the previous analysis. Based on this analysis, we advise collecting more data from other industry experts from different sectors for their opinions on modular construction and accurate analysis.

Table 6. ANOVA test for the groups based on the job sector.

Benefit		Mean			Rank			F-Ratio	Opinion
		C&DE	SE/PE	Others	C&DE	SE/PE	Others		
01	Increased productivity	3.76	4.33	3.76	4	2	2	1	Same
02	Superior quality	3.41	4.27	3.71	9	3	3	1.51	Same
03	Reduce overall project schedule	3.94	4.47	3.76	2	1	1	1.83	Same
04	Solution for the labour shortage	4.12	4.13	3.59	1	6	5	1.08	Same
05	Improved safety and health	3.76	4	3.41	6	8	8	1.11	Same
06	Eco-friendliness	3.82	4.2	3.53	2	4	6	1.12	Same
07	Economies of scale	3.59	4.13	3.71	7	5	3	1	Same
08	Reusability	3.71	3.87	3.41	7	10	9	0.48	Same
09	Less vulnerable to bad weather	3.18	3.87	3.53	10	9	7	1.44	Same
10	Professionalism of the industry	3.71	4.13	3.18	4	6	10	2.37	Different

The respondents who thought that modular construction was suitable for the Sri Lankan construction industry were asked to choose or suggest a suitable construction material for the modular structures. Concrete, steel, and timber were given as the options. Figure 6 shows the responses given by the participants. A majority of the respondents (about 67%) think that concrete will be the most suitable construction material for modular structures in Sri Lanka. This is a different opinion from many studies, including the study done by Thirunavukkarasu et al. [77], which suggests that steel would be the most suitable. Nearly 20% of the participants think steel will be the most suitable material. Timber was selected by two respondents as the most suitable material, while four participants suggested other material options. Among them, composite materials were chosen by three participants, while one participant mentioned mud as the most suitable material. Considering all these responses and the response rate to the questionnaire, it can be concluded that a considerable proportion of the professionals have an adequate understanding of modular construction even though they do not have any exposure. Therefore, providing adequate training to the professionals in the country before adopting this technique in the industry will make it possible to attain and secure all these benefits.

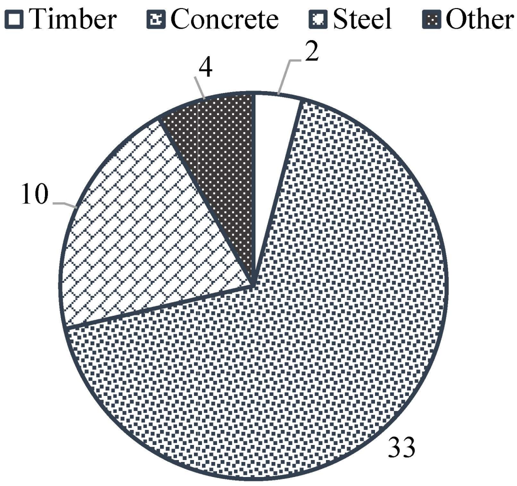


Figure 6. Response on the most suitable modular construction material.

Concrete will be the most suitable option in the Sri Lankan context, when choosing the most suitable construction material, considering domestic production and costs [78]. With the recent failure in the economy and inflation, it is estimated that structural steel prices have increased by about 341% in 2022, while cement prices and reinforcement prices have increased by 156% and 261%, respectively [79]. When considering the tropical climate in Sri Lanka, with heavy monsoonal rains occurring twice per annum, steel and timber would need extra preservation techniques in waterproofing. Although timber is a sustainable option for the hot climate, no developed programmes have been initiated for the sustainable extraction of timber without harming the natural forest cover and ensuring its structural properties. The labour requirement is high for concrete construction, considering the formwork, concreting, and reinforcement laying, considering that the wages for skilled labour for a day in Sri Lanka are nearly AUD 12 (LKR 3000), while the wages in Australia are more than AUD 21 (LKR 5250) per hour [80,81]. Therefore, the cheap labour available in Sri Lanka compared to other countries will not add extra expenses. Although the most suitable options would differ according to the time available for project delivery, the budget, the quality required, and the sustainability considerations, concrete would be the suitable option for most cases. Analysing these beneficial effects of modular construction will aid the perception of the professionals of modular constructions and areas that should be considered in the new industry adaptations. Similarly, analysing the responses on constraints will also provide a similar effect. Therefore, constraints were analysed following a similar methodology in the next section.

4.2. Constraints of Adopting Modular Construction

Among the participants who know the modular concept, 21% assessed the constraints in adapting modular technology to the Sri Lankan construction industry, since they are unsure about its suitability or believe it is not suitable. Even though the data set is very small, the analysis continued because of the very low response rate about the constraint factors, since many participants believe modular technology is suitable for the Sri Lankan construction industry. Here, also, a P-P probability plot was drawn for all the factors, and it was observed that the data sets were well-fitted to the hypothesis "The factors considered are the constraints that hinder the introduction modular construction to Sri Lankan construction". A statical *t*-test was conducted to check the importance of each factor in a one-tailed test. The critical t-value corresponding to a 95% confidence level is 1.78. According to the analysis of constraints in Table 7, it can be seen that only seven factors satisfy the condition and can be categorised as constraints having a significant effect. Two factors, factors 05 and 10, have a very low significance, while the other two factors, 07 and 09, show a negative value, indicating there is no significant importance of those factors. Factors 07 and 09 have mean values less than 3.0, showing that the respondents disagree that these factors will be the constraints in introducing modular technology. The public's negative impression of modular technology can be addressed through proper knowledge sharing and raising awareness. Sri Lanka has developed infrastructure, including a transportation network; if the traffic congestion on the roads can be addressed, modular transport will not be a constraint in implementation. The lack of design standards and quality assessment tools is a problem faced by all the countries that use this technology. Since modular construction has been practised for a few decades in other countries and has constructed many structures, Sri Lanka will have many case studies to use in the adaptation process. Two main constraints identified in the survey are constraints 01 and 08, which are "Higher capital costs" and "Lack of adequate support from the government". In the study done by Akinradewo et al. [30] for developing countries, similar results were obtained, where cost and lack of technical knowledge were identified as the main constraints. In a study done for a developed country by Zhenquan Zhou [55], lack of standards and policy support and insufficient working experience were identified as the main constraints, and a higher capital requirement was not considered a major barrier. From the results, it can be seen that the cost of construction is the main concern in implementing novel technologies in the Sri Lankan economy. To check the internal consistency, here also Cronbach's alpha test was conducted. In the constraints, an α value of 0.76 was obtained, indicating that there is an acceptable internal consistency among the factors.

Table 7. Significance and ranking of the constraints.

	Benefit	Mean	SD	Rank	Significance (t)
01	Higher capital costs	3.92	1.04	1	3.21
02	Lack of capacity, facilities, and expertise of the project team	3.77	1.09	5	2.544
03	Lack of trained and skilled labour	3.85	1.07	3	2.86
04	Early design freeze	3.85	1.21	3	2.51
05	Lack of design standards and quality assessment tools	3.15	1.07	9	0.52
06	Inadequate coordination among the project team	3.54	0.97	6	2.01
07	Inadequacy of transport infrastructure in module transportation	2.77	1.3	11	−0.64
08	Lack of adequate support from the government	3.92	1.32	1	2.52
09	Negative impression as low-cost and less durable structures	2.8	1.07	10	−0.52
10	The unwillingness of financiers to make funds available	3.31	0.85	8	1.3
11	Difficulties of mass production to justify the initial investment	3.54	0.97	6	2.01

Although the ANOVA test was conducted in the previous analysis for the beneficial factors, here, a higher number of constraint factors than the number of responses was observed, meaning it would take more work to arrive at a clear conclusion. Hence, only the mean and rank of the factors of respondents with less and more than 5 years of experience were compared to gain an idea about the perception of the factors based on experience. Table 8 presents the mean and the rank of the factors relative to different age groups. Here, two factors are identified as not having a considerable impact as a constraint on the modular adaptation by both groups. The group with less than five years of experience indicated factors 05 and 09, while the other group indicated factors 07 and 09. To identify the critical constraint factors and to arrive at a more accurate conclusion, another questionnaire survey with only constraints will be required, apart from keeping the survey open, since a majority of the respondents think that adopting modular construction practices in the Sri Lankan construction industry will help them to achieve more potential in the industry.

Table 8. ANOVA test for constraints for the groups based on experience.

	Benefit	Mean		Rank	
		<5	>5	<5	>5
01	Higher capital costs	3.5	4.6	4	1
02	Lack of capacity, facilities, and expertise of the project team	3.75	3.8	1	7
03	Lack of trained and skilled labour	3.63	4.2	2	3
04	Early design freeze	3.63	4.2	2	3
05	Lack of design standards and quality assessment tools	2.88	3.6	10	8
06	Inadequate coordination among the project team	3.38	3.8	6	5
07	Inadequacy of transport infrastructure in module transportation	3.38	1.8	6	11
08	Lack of adequate support from the government	3.5	4.6	4	1
09	Negative impression as low-cost and less durable structures	2.88	2.8	10	10
10	The unwillingness of financiers to make funds	3.38	3.2	6	9
11	Difficulties of mass production to justify the initial investment	3.38	3.8	6	5

A separate analysis was carried out to check current knowledge about modular construction concerning different experiences and job categories. Table 9 shows the understanding of each group with a defined experience range of 72 participants. For easy reference, notations were assigned to the respondents from various ranges of experience. The notations are also given in Table 9. It can be seen that only about 6% of participants from LF belong to the knowledge category NH, while nearly 48% belong to category H and the remaining 45% to AU; for the group FT, nearly 27% belong to category NH, while 41% belong to H. The NH%, relative to the other knowledge fields, is the highest in the experience group FT. When considering the job category, SE/PE and C&DE were considered, and all other job categories were considered as one group due to needing more responses. Table 10 shows the analysis of the extracted data from 72 participants. It is evident that nearly 22% of SE/PE belongs to the category NH and 48% to category H, while the remainder belongs to AU. Regarding C&D, only about 13% belongs to NH, 58% to H, and 29% to AU. Those who have yet to hear about the concept are site engineers or planning engineers. Moreover, 13% of the respondents with an adequate understanding of modular construction are site or planning engineers, and 11% are architects.

Table 9. Understanding of the modular concept respective to experience.

	<5 LF	5–10 FT	10–15 TFN	>15 HF	Total % of Each Knowledge Category
NH	2.78%	8.33%	1.39%	1.39%	13.89%
H	20.83%	12.50%	8.33%	4.17%	45.83%
AU	19.44%	9.72%	6.94%	4.17%	40.28%
E	0.00%	0.00%	0.00%	0.00%	0.00%
Total % of each experience category	43.06%	30.56%	16.67%	9.72%	100.00%

It was observed that even though the questionnaire was distributed among many professionals, the response rate was low. This is due to the need for more understanding of professionals about modular technology. Respondents were asked to comment on their thoughts on modular construction. One participant stated that the requirement for modular construction is limited since Sri Lanka is a small country that can be accessed anywhere within a short time. The inadequate understanding of the modular concept has resulted in these perceptions. It is also required to get more responses to make accurate decisions about the benefits and constraints. Following these results, an affordable low-cost house was developed, neglecting the effects of initial cost in establishing the factories and transportation, the available transport network and facilities, and site locations on the choice of design and the modular practice.

Table 10. Understanding of the modular concept respective to the job sector.

	SE/PE	C&DE	Other	Total % of Each Knowledge Category
NH	6.94%	4.17%	2.78%	13.89%
H	15.28%	19.44%	11.11%	45.83%
AU	9.72%	9.72%	20.83%	40.28%
E	0.00%	0.00%	0.00%	0.00%
Total % of each job sector	31.94%	33.33%	34.72%	100%

5. Proposed Affordable House for Sri Lanka

The planning of the affordable house was carried out considering the regulations set by the Urban Development Authority (UDA) in Sri Lanka [55]. Considering the need for houses to be low-cost, a single-story house with two bedrooms, a bathroom, and a kitchen with dining facilities attached to the living area was designed. In order to have a better internal space arrangement, the modular house was planned as two modular buildings, as shown in Figure 7. The dimensions of the small module are 7.2 m × 2.65 m × 3.0 m, and the larger module is 7.2 m × 2.95 m × 3.0 m. Since the width of the larger module is greater than the maximum permitted width of freight, which is 2.5 m (+0.15 m on each side), it would be required to get special permission from the Road Development Authority (RDA) to transport the module. The dimensions of the house, according to the UDA guidelines, are given in Table 11.

Table 11. Dimensions required according to the UDA guidelines.

	Width (m)	Length (m)
Master Bedroom	2.4	3.6
Bedroom	2.4	3.2
Bathroom	0.9	1.7
Kitchen	1.8	3.2

In the design of this affordable modular housing, special considerations should be given to the cost and the weight of the construction materials. Considering the current economic situation and the scarcity of foreign construction materials, locally available materials were selected, which have added advantages in sustainability aspects. This housing model and details can be used to precisely calculate the cost and feasibility of modular construction in future studies. When considering the cost of housing, mass-scale production will bring out the profits of using modular construction. Hence, this modular house can be used for a housing scheme where several single-story dwellings will be needed. Since the cost-effectiveness of this housing construction should be appropriately considered, the cost of constructing a conventional affordable house was compared with the proposed housing construction.

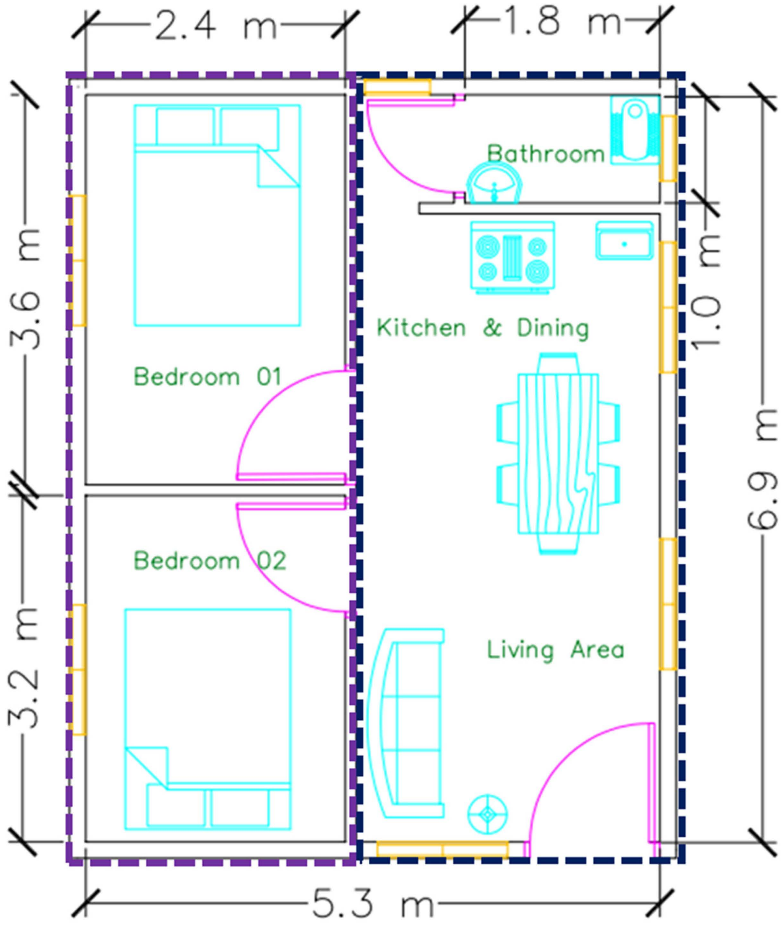


Figure 7. Plan view of the suggested modular housing.

5.1. Modular Housing Construction

The modular housing unit uses a 150 mm raft foundation for the floor, and Expanded Polystyrene (EPS)-based precast panels with 50% recycled content will be used for the walls [82]. Panels of 150 mm thickness will be used for the exterior walls, while panels of 100 mm will be used for the interior walls. Recycled plastic roofing tiles will be used as a roofing material. [83]. Tiles of 8 mm will be used for the designed house. Laminated panels of 50 mm, manufactured by Durra, will be used as ceiling material. Plywood doors and single-panel timber frame windows will be used in the design. Other materials and processes were assumed to be executed in the same way as with the conventional house.

5.2. Conventional Housing Construction

Conventional construction was assumed to be a cement block house with a rendered concrete floor and an asbestos roof with a gypsum ceiling, considering some available construction techniques in Sri Lanka [84,85]. A strip foundation design was adopted for the conventional building [86]. Glazed and panelled timber doors were used in the conventional construction calculation. Some construction materials and procedures were the same for both conventional and modular houses. They were single-plane timber framed windows, sanitary facilities, plumbing and electrical systems, painting, and miscellaneous costs of permits and taxes. Construction materials used for the modular house and some common materials used for conventional construction are shown in Figure 8. The density, embodied energy, and cost of the selected major materials are presented in Table 12.

Table 12. Construction material used for the modular house.

Material	Density	Embodied Energy	Cost (LKR)
Durra panel	350 kg/m^3 [87]	12.6 MJ/m^2 [88]	2760/m^2 [89]
Recycled plastic roofing sheet	725 kg/m^3 [83]	75 MJ/m^2 [90]	1215/m^2 [91]
EPS-based precast panels	738 kg/m^3 [92]	5.8 MJ/kg [93]	3500/m^2 (100 mm) [91] 4500/m^2 (150 mm) [91]
Plywood	700 kg/m^3 [94]	13.0 MJ/kg [93]	1290/m^2 [95]
Glass	2500 kg/m^3 [96]	25.8 MJ/kg [97]	1345/m^2 [95]
Reinforced concrete	2400 kg/m^3 [98]	1.21 MJ/kg [99]	73,133/m^3 [95]
Cement blocks	2100 kg/m^3 [100]	0.6 MJ/kg [99]	95/block (100 mm) [101]
Cement–sand mortar	1540 kg/m^3 [102]	1.21 MJ/kg [99]	7712/m^2 [95]
Asbestos	1500 kg/m^3 [103]	91.3 MJ/m^2 [104]	11,280/m^2 [95]
Gypsum ceiling	940 kg/m^3 [105]	1.8 MJ/kg [106]	5030/m^2 [95]

(**a**) (**b**) (**c**)

Figure 8. Construction material used for the modular house: (**a**) Durra panel; (**b**) recycled plastic roofing sheet; and (**c**) EPS-based precast panels [93].

The prices of conventional construction were solely calculated based on the Building Schedule of Rates (BSR) (2023), which was published by the Western Provincial Council of Sri Lanka [95]. A few assumptions were made in the calculation. The cost for the connections of the modular house was assumed to be 10% of the cost of the module, and factory overheads were assumed to be 20% of the total construction costs [107]. It was also assumed that the house would be assembled within a day on-site, and two days would be needed for the factory assembly of the components. The site of the construction was also assumed to be located within 100 km of the manufacturing sites, and calculations were done for a building at a distance of 100 km. The base cost of transport is LKR 7000 and increases with the distance. Considering the benefits of the process, wastage was also taken into the calculation, where 30% of material waste was assumed for the conventional construction [77], while 50% of the conventional waste percentage (15% of material waste) was assumed for the modular construction [50,51]. Considering the unit prices, the calculated cost of conventional and modular construction with the cost breakdown is provided in Table 13.

This study shows that the conventional house costs LKR 9.46 million (Mn) while the modular house costs LKR 6.41 Mn, which is a nearly 32% cost saving. When the combined cost for the foundation and floor is considered, the two cases do not show any significant differences. However, the cost of wall construction is greatly reduced in modular houses due to the use of pre-cast products and factory assembly. The labour costs also show a 36% reduction in modular construction compared to conventional house construction. It is evident from the results that automation of construction processes will help further gain more advantages in the future with mass production.

Table 13. Cost comparison of modular and conventional houses.

		Conventional Affordable House			Modular Affordable House		
		Cost per Unit (LKR)	Cost per Process (LKR)	Total Cost (LKR)	Cost per Unit (LKR)	Cost per Process (LKR)	Total Cost (LKR)
Foundation	Excavation	3265/m^3 •	35,478	372,767	3265/m^3 •	20,379	620,233
	Rubble masonry	42,658/m^3 •	262,136		-	-	
	Raft concrete	-	-		72,133/m^3 •	450,218	
	Tie beam	2190/m •	75,153		2190/m •	75,153	
	Raft shuttering	-	-		19,106/m^2 •	74,513	
Floor	Concrete	61,530/m^3 •	192,019	562,408	-	-	320,896
	Shuttering for floor slabs	19,106/m^2 •	46,619				
	Rendering	7712/m^2 •	320,896		7712/m^2 •	320,896	
Walls	Interior walls	19,035/m^2 •	548,208	3,186,007	3500/m^2 ••	100,800	654,686
	Exterior walls	25,220/m^2 •	1,520,766		4500/m^2 ••	271,350	
	Plastering and skim coat	12,227/m^2 •	1,089,426		*a 3171/m^2 •	282,536	
	Lintels	2190/m •	27,607		-	-	
Roof	Roofing sheet	11,280/m^2 •	412,549	2,042,807	1215/m^2 ••	44,437	1,691,849
	Timber framework	37,670/m^2 •	1,377,725		37,670/m^2 •	1,377,725	
	Ceiling	5030/m^2 •	183,980		2760/m^2 •••	100,933	
	Roof tie beam	2190/m •	68,552		2190/m •	68,552	
Door and window	Doors	21,618/m^2 •	42,863	94,782	21,618/m^2 •	42,863	94,782
	Windows	22,768/m^2 •	51,919		22,768/m^2 •	51,919	
Painting	Interior	16,275/m^2 •	178,501	279,021	16,275/m^2 •	178,501	279,021
	Exterior	17,920/m^2 •	100,520		17,920/m^2 •	100,520	
Sanitary facilities (bathroom/toilet)		45,360/set •		45,360	45,360/set •		45,360
Plumbing and electrical systems				271,500			271,500
Cost for connections (10% of module cost)				-			409,000
Machinery	Cranes		-	-	11,250/hour •	270,000	1,570,318
	Factory overheads		-		20% total cost	1,272,762	
Transport of modules (round trip)				-	*b 7000 + 800/km		167,000
Labour cost				365,644			233,644
Miscellaneous expenses (permits/taxes)				181,000			181,000
Construction waste		30% of material cost		2,056,450	15% of material cost		599,540
		Total Cost (Million) (LKR)		9.46			6.42

*a Skim coat was applied without plastering. *b Base transport costs were LKR 7000 and LKR 800 was charged for every km. References: • [95]; •• [91]; ••• [89].

The embodied energy of the buildings was also calculated to assess the impact of the chosen materials and the construction using the values presented in previous studies [108–111]. Figure 9 shows the changes in embodied energy of the studied buildings. For the energy calculations, only the major construction processes were compared, and the ability to reuse components in modular construction should have been addressed. Figure 9b shows that the total embodied energy of the conventional building is 97 GJ, while it is only 81 GJ for the modular building, which is 16% less. Therefore, it can be concluded that even though detailed calculations are required to arrive at a solid conclusion, these results imply that when adequate market conditions are met, modular construction practice is suitable for Sri Lankan construction.

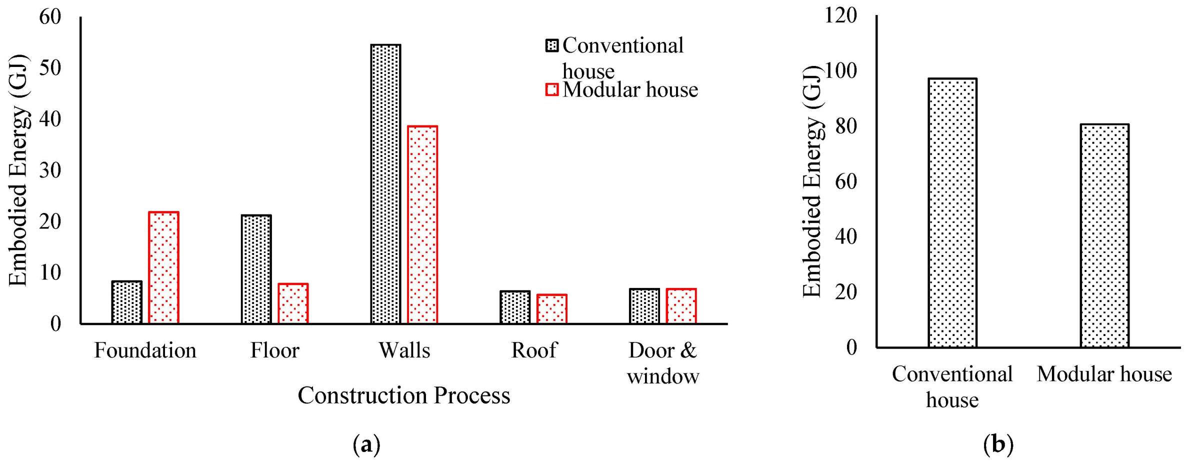


Figure 9. (**a**) Changes in the embodied energy with the construction process; and (**b**) total change in the embodied energy of the considered processes.

The modular housing concept, where the houses are designed to be expanded with the addition of new modules to the existing modules, will be helpful to a country like Sri Lanka. It has been shown that 6.8% of the Sri Lankan population owns no housing [112]. Moreover, there is a considerable amount of half-built houses in the country. These houses are occupied when half-built, with those building it hoping to complete the house while residing in it. Recently, with the economic crisis, sales of many half-built houses were observed due to unstable financial situations coupled with inflation. Therefore, the modular concept and future expandable housing system will be beneficial in these situations. Due to fast constructability, the expansion of the house will be more convenient, without any disturbances to the occupants. Moreover, the high inflation rates and scarce financial resources encourage fast house construction [45].

6. Conclusions and Recommendations

In order to increase productivity and achieve maximum benefits in the construction industry, a number of emerging technologies have been used, and modular construction is one of the most popular concepts in recent times. Although the world has moved forward with adapting this technology, Sri Lanka is lagging in changing the conventional construction procedures to match the emerging novel technologies. A questionnaire survey was carried out to check the experts' ideas on adapting the novel technology to the Sri Lankan construction industry, the benefits that will be achieved, and the constraints that will be faced in the process. Based on the survey results, the following conclusions are drawn.

1. Of the participants, 79% who understand the modular concept believed that the modular construction practice is a novel technology that can be introduced to the Sri Lankan construction industry, and it can be a valuable addition, bringing more benefits.

2. The capability of reducing the overall project schedule, increasing productivity and reducing the requirement for on-site labour, and providing a solution for the construction labour shortage were identified as the top three benefits that will be achieved through the adaption of modular technology, with mean values of 3.96, 3.94, and 3.94 out of 5. Social-environmental factors, less vulnerability to bad weather, reusability of material, and improved occupational safety and health ranked last, indicating that in Sri Lanka, direct economically beneficial factors would be more prioritised than the other social and environmental factors.
3. Results from the questionnaire survey indicated that concrete is the most suitable construction material for modular buildings in Sri Lanka. About 67% of the participants voted for concrete, while about 20% voted for steel as the best material. The cheap labour rates in Sri Lanka compared with the other developed countries and the tropical climate conditions will also justify using labour-intensive concrete modules over using steel or timber modules.
4. Higher capital costs and lack of adequate support from the government were identified as the main constraints that must be faced in adapting modular construction, with a mean value of 3.92 out of 5. Investing in modular construction will be very difficult with the current financial situation. However, with proper fund management and knowledge sharing, it will be possible to develop and expand modular construction to obtain higher profits.
5. In the considered building cases, modular construction shows a 32% reduction in construction costs, a 36% reduction in labour costs, and a 16% reduction in embodied energy when compared with conventional construction. Therefore, modular concepts can be used to construct affordable houses and will be cost-effective with the correct choice of material.

The results presented in this paper can be used in future studies when introducing modular technologies to the Sri Lankan construction industry. Since in Sri Lanka, economic aspects are prioritised over environmental and social aspects, awareness sessions can be held in future for industry professionals and the public to educate them about the importance of the environmental and social benefits of new technologies. Moreover, being a developing country, Sri Lanka rarely uses digital transformation and automation in the construction industry. However, introducing modular technology will also help the industry incorporate and utilise these technologies in the future. More research on the availability of technology, materials, and expert knowledge will be needed before adopting modular construction. Since the study is limited to only design and construction, future research will focus on increasing the profitability of the industry by analysing the perspectives of owners and users of the facilities, financiers, etc. When designing modular buildings, site location, location of the off-site factories, transport infrastructure, availability of materials, and technology should be taken into account in future studies. The questionnaire survey used for this study will be kept open to collect more data and support future studies.

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Nomenclature

Symbols	
AU	Adequate understanding of modular construction but no industry experience
C&DE	Consulting or design engineers
E	Adequate understanding of modular construction and industry experience
H	Have heard about the concept
NH	Never heard about the concept
SD	Standard deviation
SE/PE	Site or planning engineers
Abbreviations	
LLRS	Lateral load-resisting system
OSM	Off-site manufacturing
PVMB	Prefabricated volumetric modular building

Appendix A

The questionnaire survey used in the study is presented.

Adapting Modular Technology for Sri Lankan Construction Industry

Modular construction is a process where buildings are constructed in sections in the factories under a controlled environment and transported to the desired location for the assembly and installation to complete the designed building. 60–90% of the work is completed off-site including architectural finishes and services adapting the lean manufacturing concepts to increase the quality and the productivity.

The novel technology has great potential in changing the traditional construction process due to its fast completion, superior quality, less man-power requirements, and convenience on site.

Please fill out the questionnaire and help us assess the constraints in adapting modular technology in Sri Lanka.

* Required

1. Job Sector

Check all that apply.

Architects	☐
Consulting or Design Engineer	☐
Site Engineer/Planning Engineer	☐
Managerial Sector	☐
Government Regulatory Agency	☐
Finance or Insurance Sector	☐
Other:	

2. Company Size (Number of Employees)

Mark only one box.

Small-sized business: 10–49 employees	☐
Medium business: 50–249 employees	☐
Large-sized business: more than 250 employees	☐

3. Work Experience

Mark only one box.

<5 years	☐
5–10 years	☐
10–15 years	☐
>15 years	☐

4. What is your knowledge about the Modular Construction? *
Mark only one box.

Never heard (Skip to question 9)	☐
Have heard about the concept	☐
Adequate understanding about the modular construction but no industry experience	☐
Adequate understanding and the industry experience	☐

5. Suitability of Modular Construction
Do you think Modular Construction is suitable for Sri Lanka? *
Mark only one box.

Yes (Skip to question 6)	☐
No (*Skip to question 8*)	☐
Not sure (*Skip to question 8*)	☐

Benefits of Adapting Modular Technology

The world has moved to off-site manufacturing from on-site construction in order to increase productivity in the construction industry to cater for the increasing demand for dwellings. Although most of the developing countries have adapted the modular technology to improve the industry there is a delay in adapting that in Sri Lankan construction. Some factors were identified which can be considered as the advantages of adapting modular construction in developing countries.

Please rate the effect of these factors from 1–5 for the Sri Lankan adaptation of modular technology.

1: 0% benefits compared with the traditional construction
2: 25% benefits compared with the traditional construction
3: 50% benefits compared with the traditional construction
4: 75% benefits compared with the traditional construction
5: 100% benefits compared with the traditional construction.

6. Benefits
Mark only one box.

	1	2	3	4	5
Increased productivity					
The superior quality achieved by the factory-based construction process					
Reduce overall project schedule					
Less requirement for on-site labour, therefore a solution for the labour shortage					
Improve occupational safety and health					
Less disturbance to the environment and the neighbourhood during construction					
Economies of scale in production					
The ability to reuse the elements or extensions to existing buildings					
Less vulnerable to bad weather					
Improve the professionalism of the industry					

7. What do you think is the best construction material for the modules in Sri Lankan context? *
Mark only one box.

Concrete (Skip to question 9)	☐
Steel (Skip to question 9)	☐
Timber (Skip to question 9)	☐
Other:	

Constraints in Adapting Modular Technology

The world has moved to off-site manufacturing from on-site construction in order to increase productivity in the construction industry to cater for the increasing demand for dwellings. Although most of the developing countries have adapted the modular technology to improve the industry there is a delay in adapting that in Sri Lankan construction. Some factors were identified that can be considered as the barricades in adapting modular construction in developing countries.

Please rate the effect of these factors from 1–5 for the Sri Lankan adaptation of modular technology.

1: 0% constraints compared with the traditional construction
2: 25% constraints compared with the traditional construction
3: 50% constraints compared with the traditional construction
4: 75% constraints compared with the traditional construction
5: 100% constraints compared with the traditional construction.

8. Constraints

Mark only one box.

	1	2	3	4	5
Higher capital costs					
Lack of capacity, facilities and expertise of the project team					
Lack of trained and skilled labour					
Fewer opportunities for design variation due to complexities and the inability to make changes on-site (Early design freeze)					
Lack of design standards and quality assessment tools					
Inadequate communication and coordination among the project team					
Inadequacy of transport infrastructure in module transportation					
Lack of adequate support from the government					
Negative impression of the public about modular construction as low-cost and less durable structures					
The unwillingness of financiers to make funds and insurance firms to cover the insurance					
Difficulties in bringing the industry to a scale that would justify the initial investment in new infrastructure					

Thank you for taking the time to complete this survey. We truly value the information you have provided.

9. If you have any comments on the survey, please leave a comment below.

____

End of the survey.

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