# *Prefabricated Construction in Sri Lanka: A Proposed Adoption Strategy and a Pilot Case Study from Sustainability Perspective*

Jayawardana, Janappriya, Jayasinghe, JASC, Sandanayake, Malindu, Kulatunga, Asela K and Zhang, Guomin (2023) Prefabricated Construction in Sri Lanka: A Proposed Adoption Strategy and a Pilot Case Study from Sustainability Perspective. Engineer: Journal of the Institution of Engineers, Sri Lanka, 56 (1). pp. 71-80. ISSN 1800-1122

ENGINEER - Vol. LVI, No. 01, pp. [71-80], 2023
© The Institution of Engineers, Sri Lanka
DOI: http://doi.org/10.4038/engineer.v56i1.7562

# Prefabricated Construction in Sri Lanka: A Proposed Adoption Strategy and a Pilot Case Study from Sustainability Perspective

**J. Jayawardana, J.A.S.C. Jayasinghe, M. Sandanayake, A.K. Kulatunga and G. Zhang**

**Abstract:** Prefabricated construction (PFC) has increasingly been recognised as a viable construction solution that has the potential to address the typical issues of conventional construction. Portability, quick fixing ability, less labour intensity, a massive potential for quality, productivity enhancements, and environmental savings are some of the most highlighted benefits of PFC. Developed nations and other industrialised regions have been applying these construction methods more successfully compared to developing economies such as Sri Lanka. Sri Lanka is slow in adopting PFC because of some inherent barriers. Thus, this study aims to strengthen the case for shifting to PFC in Sri Lanka. Firstly, the current status of the PFC in the Sri Lankan context is described, including the barriers to adoption. Subsequently, an adoption strategy is proposed using the learnings from successful countries. This adoption framework discusses in-depth strategies/ initiatives to overcome current barriers to adopt prefabrication in construction projects. Finally, a pilot case study is carried out to assess the potential of PFC from a sustainability perspective. The results show that PFC has potential time savings and slight improvements in greenhouse gas (GHG) emissions than traditional construction in the selected case studies. Reduced times have a huge positive impact on sustainability by cost savings and environmental benefits from less on-site waste and emissions from fuel and electricity usage of construction machines. The outcomes of this study can influence construction industry stakeholders, including government and academia, towards escalating the use of prefabricated technologies to maximise sustainability and project-specific benefits.

**Keywords:** Prefabricated construction, Modular construction, Time and cost, Sustainability, Sri Lanka

## 1. Introduction

The construction industry, an ever-expanding industrial sector, is the primary contributor to around 30-40% of global GHG emissions [1-3] and about 40% of energy consumption [4-6]. The architecture, engineering, and construction (AEC) industry is increasingly focusing on innovative modern methods of construction (MMC) to address the existing sustainability concerns in conventional construction [7]. PFC has evolved over the last decades as an alternative to MMC to provide high time and cost savings and environmental savings. PFC produces prefabricated/modular components in an off-site manufacturing facility (Figure 1) and afterwards transports, erects, and assembles these manufactured components on the in-situ construction site [8].

Even with the highly researched benefits of the PFC, particularly in developing countries, PFC adoption is slower compared to developed countries [9]. In the Sri Lankan context, precast component technology was introduced, by Dr. A.N.S. Kulasinghe [10], from the mid-20th century onwards. Despite precast bridge beams

***Mr.J.Jayawardana,*** *Student Member of IESL, B.Sc.Eng. (Hons)(Peradeniya), Research (split PhD) Student, Faculty of Engineering, University of Peradeniya, Sri Lanka, and School of Engineering, RMIT University, Australia.*
*Email:janappriyalj@eng.pdn.ac.lk*
*http://orcid.org/0000-0002-5307-4017*
***Eng.(Dr.)J.A.S.C. Jayasinghe,*** *AMIE(SL), PhD (Tokyo) M. Eng. (AIT), B.Sc.Eng. (Hons)(Peradeniya), Faculty of Engineering, University of Peradeniya, Sri Lanka.*
*Email:supun@pdn.ac.lk*
*http://orcid.org/0000-0003-1054-9358*
***Dr.M.Sandanayake,*** *PhD (RMIT), B.Eng. (First Class Hons) (Calicut), College of Engineering and Science, Victoria University, Australia*
*Email:malindu.sandanayake@vu.edu.au*
*http://orcid.org/0000-0003-4303-7279*
***Eng.(Prof.)A.K. Kulatunga,*** *AMIE(SL), PhD (Sydney), B.Sc.Eng. (Hons)(Peradeniya), Faculty of Engineering, University of Peradeniya, Sri Lanka.*
*Email:aselakk@eng.pdn.ac.lk*
*http://orcid.org/0000-0002-9241-3149*
***Prof.G. Zhang****, PhD (Queensland), MTEM (Chongqing), B.Eng. (Hons)(Chongqing), School of Engineering, RMIT University, Australia.*
*Email:kevin.zhang@rmit.edu.au*
*http://orcid.org/0000-0002-3503-7431*

prefabrication never came to the major construction market as a main construction technology. In the last two decades, there were several ground-level necessities that arose for the rapid completion of built environments in Sri Lanka due to Post Tsunami construction in the South and Eastern coastal belt in 2004 and Post Civil War construction in the North and East in 2009. However, this technology did not reach the limelight in Sri Lanka, even with the historical learnings showing many merits of using such technology in similar context to the rest of the world. One major scare related to prefabricated buildings is the stability against lateral loads that arise from natural disasters such as earthquakes. On a positive note, Sri Lankan geographical position favours the lack of these lateral loads, which solidifies the applicability of PFC to Sri Lanka.

**Figure 1 – Prefabricated (Modular) Component under Manufacturing in the Factory (Greenfab, Seattle) (Source: [11])**

However, some attention started directing towards these PFC technologies in the last decade by a small set of construction organisations. It is imperative to promote these construction methods in Sri Lanka to address some growing issues such as diminishing workforce, strict time constraints, requirements to comply with environmental standards, and demand for more quality. In other words, increased PFC adoption has a significant potential to enhance the long-term sustainability of the Sri Lankan construction industry. Hence, this study aims at 1. Investigate the current status of PFC in Sri Lanka, 2. Derive learnings from developed economies and propose an adoption strategy for Sri Lanka, 3. Conduct a pilot case study to evaluate the potential of PFC in terms of environmental performance and time and cost factors. The time parameter is selected considering the indirect influence on cost and environmental implications such as operating equipment and vehicle emissions. Moreover, the cost of wall finishing and total GHG emissions are selected as the sustainability indicators. Considering the focus is to conduct a pilot case study, these three indicators will be used to demonstrate the potential of PFC on sustainability.

## 2. Current Status of Prefabricated Construction in Sri Lanka

### 2.1 Overview

Sri Lanka, a developing economy, is significantly lagging in adopting PFC technologies compared to other developed and industrialised economies. In the Asian region, as similar developing economies, China, and Malaysia have shown a different trajectory compared to Sri Lanka in terms of the adoption of PFC. They have been progressing fairly well in promoting, adopting, and supporting PFC, particularly in the last two decades [12, 13]. India is not performing up to the level of China and Malaysia; however, they have taken some initiatives towards adopting smart construction technologies such as PFC to solve the growing housing shortages [14].

Moreover, Sri Lanka does not own a satisfying market share of prefabrication methods in the construction industry [15-17]. An external business opportunity related to market expansion could be explored in countries like the Maldives as they have ideal requirements to go for modular construction due to constraints such as space. However, growing number of construction organisations in Sri Lanka have started their work on PFC projects. Nonetheless, tremendous efforts will be required to take this construction method to mainstream and stabilise the application. The same commitment will be needed to increase the prefabrication rates by moving into sophisticated volumetric construction methods.

### 2.2 Current Status of Prefabricated Construction

The progress is presented with the discussions held for the research and from the information from secondary sources such as official websites.

*1. Precast Concrete Components*

One of the pioneers in PFC in Sri Lanka produces precast wall panels based on technology from ELEMATIC Finland. This precast wall panel system has proven to save 80% on labour, 40% less weight, five times faster than blockwork, and zero cost of plastering [18]. Furthermore, this construction company produces pre-stressed concrete floor systems, precast bridge beams, box units, drain units, cover slabs and precast paving blocks and slabs. Figure 2 shows an intermediate stage of a recent housing project completed by this organisation using their prefabricated components. Moreover, a Government Hostel Project in Sri Lanka has built around 25 hostels using prefabrication technology by the same organisation (Figure 3). They are currently producing and testing concrete modular units (prefabricated prefinished volumetric construction) for housing as their latest research and development activity in the PFC domain.

**Figure 2 - Mount Clifford Residencies Homagama, a Six-storey Prefabricated Building in Sri Lanka (Source: [19])**

**Figure 3 - Ediriweera Sarachchandra Hall, University of Peradeniya, Peradeniya (Source: [20])**

Notably, a local prefabrication solution provider delivers light wall panels manufactured with fly ash and rigifoam as secondary material constituents. The use of a byproduct (fly ash) and waste output (rigifoam) has potentially reduced the environmental load from these wall panels. On top of that, it supports circularity by incorporating waste products into the prefabrication process. Moreover, other organizations work on prefabricating bridge components (Figure 4) [21, 22] and other components such as piles, , and box culverts with precast concrete technology.

*2. Prefabricated Steel-based Solutions*

A leader in offering modular construction solutions in Sri Lanka worked on delivering Convertainers (Container conversions) primarily for temporary and less load applications (Figure 5). This modular approach is getting trendy due to the portability of modular shipping units. Convertainers offer a wide range of prefabricated modular construction solutions through shipping containers such as – site office units, quarantine units, medical units, laboratory units, and retail/shop units, among many other applications [23]. Moreover, this organisation works on fabricating steel buildings for all kinds of steel construction and fabrication requirements. Higher guarantees in quality, cost-effectiveness and low completion times are some prominent advantages of these Prefabricated Steel Buildings [24].

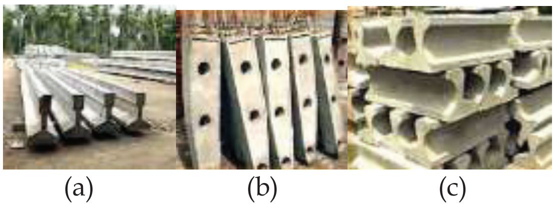

**Figure 4 - Prefabricated Bridge Components: (a) Pre-Stressed Beams, (b) Uprights and (c) Bridge kerbs (Source: [22])**

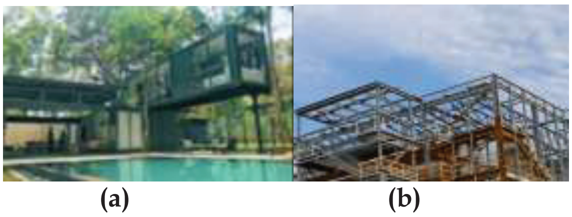

**Figure 5 - Modular Solutions: (a) Convertainers and (b) Prefabricated Steel Buildings (Source: [23, 24])**

### 2.3 Critical Barriers

The current section will present the barricades slowing the growth and adoption of PFC technologies in Sri Lanka. As a developing economy with less industrialised construction and manufacturing sectors in Sri Lanka, shifting into MMC, such as PFC, presents significant challenges. These barriers are described under the following subtopics. The inputs from discussions and the literature were explored to come up with the context of barriers.

*1. Cost-related complications*

Cost complications are a significant barrier to adopting PFC in Sri Lanka. Hong et al., 2018 discovered high initial capital establishment costs in PFC as a critical challenge in developing countries for the uptake [25]. The infrastructure, technology, machines, and layout required for PFC at the start of an off-site plant demand high costs. Moreover, complexities and high costs associated with transportation are other cost-related issues that most developing countries [26, 27], such as Sri Lanka, face when adopting PFC technologies.

*2. Government policies, regulations, and support*

Sri Lanka lacks support from the government in creating policies, regulations, and incentives to motivate the shift to PFC. Government should take leadership to promote prefabricated buildings by initiating building projects such as residential apartment buildings, hospitals, schools, hostel accommodations, etc. Moreover, the government should lay mandatory requirements in construction projects to enable the PFC.

*3. Societal acceptance*

Distrust and resistance to adopting prefabrication technologies by construction companies and the public is a massive barrier in the Sri Lankan context. Notably, the pre-stressing and assembly process has created a great sense of insecurity in public perception. Uthpala and Ramachandra., 2015 have identified public perception and poor awareness as primary barriers to promoting PFC in Sri Lanka [15]. The reluctance of people to shift from familiar conventional construction to PFC is fuelled by beliefs such as low quality, high stress, and less long-term durability of prefabricated components.

*4. Experienced and skilled labourers/ experts*

The off-site factory manufacturing process of prefabricated components requires subject-specific expertise and knowledge of workers and management. Deficiencies in transferring and originating these aspects in the Sri Lankan context are barricading the confidence shifting into PFC methods. Moreover, the lack of available consultancy of prefabrication construction experts is another difficulty that is slowing the uptake.

*5. Technical capacity and innovation*

A primary challenge in Sri Lanka is the slow rate of technological evolution compared to developed and industrialised nations. Overall, lack of research and development (R&D) initiatives within the construction sector can be seen. Most organisations prefer to stay in their comfort zone without taking risks to explore innovation. Regarding prefabrication-related research, the lack of fundamental testing and other technology for these components has stood against the progression. The shortfall of government support to adopt these technical strategies through ground-breaking research is clearly visible. Government not taking the upper hand in aiding construction organisations and R&D institutes to benchmark technological innovation is a major barrier that hinders effective adoption.

*6. Lack of country-specific life cycle databases*

Nation-based life cycle data of construction-related activities has the potential to help and give insights into decision-making. The lack of construction databases specific to Sri Lanka has become a barrier to promoting PFC. The proven sustainability benefits of PFC techniques by research studies conducted by other nations should be verified in Sri Lanka using sustainability assessments. Project-specific indicators such as quality control, reduction of delays, efficient construction, and waste minimisation could be used. Moreover, economic, environmental, and social indicators can be employed to assess comprehensive sustainability performance. Consequently, the decision-makers would have a benchmark to compare conventional construction and PFC. Hence, significant efforts are needed to develop country-specific life cycle data.

## 3. Proposed Adoption Strategy for Sri Lankan Context with Learnings from Successfully Adopting Countries

Sri Lankan construction industry and academia can use learnings from the countries adopting PFC technologies successfully. Subsequently, they could develop goals, strategies, and actions to reinforce the adoption of PFC. Figure 6 shows the strategies/initiatives to address the existing main barriers to PFC adoption in Sri Lanka.

Trying to obtain economic support from the government at the fundamental stage of adoption is one potential option construction companies have to reduce the cost-related complications. However, it will not be that straightforward considering the economic strength and other conditions from the government side. A proper long-time strategy, vision, and mission have the potential to persuade financial aid from donor institutions. Small scale prefabricated component production may take a considerable time to cut off the high initial capital establishment costs. Thus, planning for the potential mass-scale output of these units should be decided at the initial stages to accommodate capital resources.

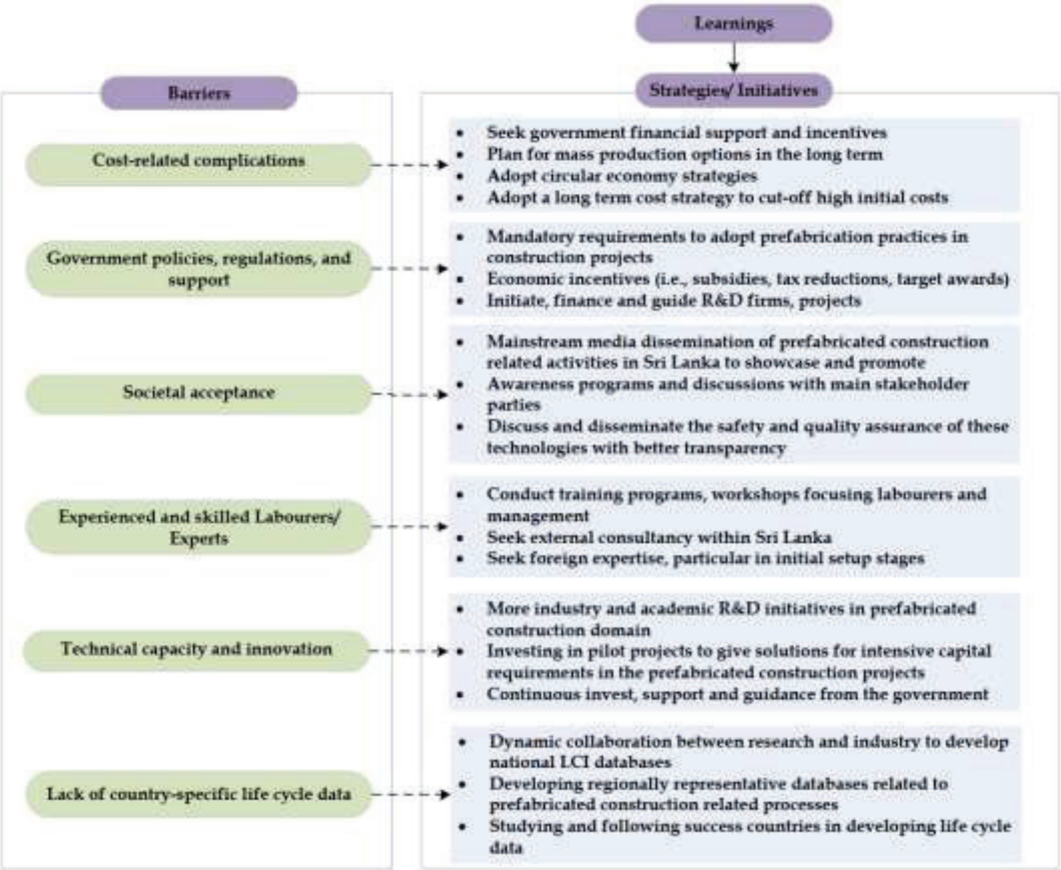

**Figure 6 - Adoption Strategy for Sri Lankan PFC**

Moreover, as an evolving strategy, particularly in European Union (EU), circular economy strategies such as 6R concepts have huge potential to address high initial capital costs. For example, using recycled materials, reusing materials, and using by-products such as fly ash to cover certain portions of cement are common circular economy solutions to reduce initial material costs. Overall, construction organisations should have a long-term cost strategy to address the cost-related complications in PFC. They can seek consultancy and learnings from other countries that have managed these complications proficiently over time. The construction developers could use some findings from cost assessment-based research to understand the accurate picture of cost variations in traditional construction and PFC [28]. Furthermore, more cost assessments are required to benchmark the cost breakdowns in conventional and PFC.

The government should play a central role in promoting and adopting PFC technologies in Sri Lanka. Creating and passing policies and regulations and giving economic incentives should be their key activities in this role. Mandating the use of a certain percentage of prefabrication technologies in construction projects has the push to promote and adopt. This regulation may not apply to every large to a small-scale construction project. However, for starters, the government could themselves start applying this regulation to their construction projects as a guiding example. Subsequently, this regulation can be passed to large to medium-scale construction projects. More importantly, this effort will be a starting point for standardising PFC in Sri Lanka. Moreover, the government should support construction companies with economic incentives to encourage them to adopt PFC [29]. On top of that, it is crucial to reinforce the R&D effort by initiating, guiding, and funding these firms for consistent research and innovation.

As discussed in Section 2.3, social acceptance is a critical barrier that construction organisations should cross with the backup from the government to adopt these modern methods of construction. The mainstream media (i.e., newspapers, television, radio, etc.) could be used to share the crucial breakthroughs, progress points, and other awareness of PFC to reach society. Clients, project engineers, suppliers, and contractors are the main stakeholder parties that should be convinced of this method of construction in the initial stages of a project. Discussion and awareness sessions would be supported to cross this barrier.

Moreover, it is imperative to convince the stakeholders about the quality and safety of these prefabrication methods to overcome the reluctance. Organisations leading PFC could carry out load experiments and other relevant experiments on these components and disseminate the assurance results to these parties to reinforce their trust. On top of that, they can collaborate with academic and other R&D bodies (e.g., universities, and government units) to do more advanced and comprehensive assessments on prefabricated components. This approach will support the validation of their experiments and, in the long term, the continuous improvement of the prefabrication processes. Moreover, this discussion highlights the need for standard authorities for certifying these tests and experiments.

Experience and unique skills for applying these construction methods are lacking factors in the Sri Lankan context. Conducting training programs and workshops for construction workers that will be committed to prefabricated activities and respective management initially as well as periodically will be an excellent strategy to overcome the barrier. Knowledge of the potential new technology could be shared along with hands-on training with the process. As a second strategy, for example, if a construction organisation looking to adopt prefabricated methods does not have experts within its organisation, it could seek external expertise and consultancy within Sri Lanka. However, in the worst case, if any consultancy is not reachable within Sri Lanka, the construction firm could plan for expertise from other countries.

Increasing technical capabilities and innovation pave a solid basis for adopting modern methods of construction such as PFC. As a developing nation, Sri Lanka lacks a considerable deal of R&D for progression in technological growth in the construction industry. More academic and industry research collaborations are required to bridge this gap. Notably, the reluctance of construction organisations to share data and information has resulted in sluggish and incomprehensive research studies without definite conclusions. Industry and academia should be more open to these misunderstandings and should try to work collaboratively, respecting and trusting others, for the betterment of the nation. Moreover, government should take primary responsibility in investing, guiding, and supporting industry and academia in this regard.

Comprehensive sustainability assessments, such as life cycle assessment (LCA), life cycle costing (LCC), and social-LCA (S-LCA), have the potential to benchmark and evaluate these construction techniques to generate improvement options and alternatives. To carry out sustainability assessments, nation-wise and sector-wise life cycle data are highly demanded. Sri Lanka does not have a nation or sector-wise database for construction life cycle data. However, some individual research has been carried out in recent years, where synthesising these data would be essential and valuable in developing national databases. To start with, research studies should at least look for region-wise life cycle data availability. Moreover, researchers/ academia and other parties related to life cycle inventory development could focus on success stories of countries with comprehensive databases developed for the construction sector. Japan is a prime example in this context, which has advanced data accessibility in construction that has gained true potential in prefabricated related research [30].

## 4. Pilot Case Study Analysis

The case study will be demonstrated using two cases. The case study base is a conventional building (CB) from Sri Lanka. The aim of the case study is to showcase the potential of PFC in terms of time and cost savings and environmental performance.

### 4.1 Case 01: Time and Cost Factor

This case considers a hypothetical scenario where the masonry walls of the CB are replaced by precast wall panels. Typically, to complete 1m$^2$ of conventional masonry brickwork is estimated as one man-day. In comparison, 5m$^2$ of an precast panel system selected can be potentially finished with the same one man-day [18].

Table 1 shows the approximate man-days required to finish the walls on the respective floors of the building using the conventional masonry work method and employing precast wall panels. It states that using wall panels in the place of the traditional masonry system will potentially save around 807 man-days. In other words, the second method will save approximately 80% of labour time, thus spiking productivity. With the increasing time constraints of building projects in Sri Lanka, shifting into precast construction has the potential to support in temporal regard.

**Table 1 - Comparison of Approximated Construction Times for the Completion of Walls by Conventional Method and Precast Method (Source: [18, 31])**

| | Conventional masonry work/(man-days) | Precast wall panel system/(man-days) |
|---|---|---|
| Ground floor | 225 | 45 |
| First floor | 255 | 51 |
| Second floor | 274 | 55 |
| Third floor | 255 | 51 |
| Total | 1,009 | 202 |

Considering the same scenario of using a precast wall panel system in the place of conventional masonry workings, the rough estimation of cost savings is derived from the perspective of plaster application. Wall panel system has eliminated the plaster on both sides of the walls. It requires only a 3-5 mm skim coat for the finishing process [31]. Table 2 tabulated a cost breakdown for wall finishing on the four floors of the building for the two construction techniques. It shows that using the precast wall system has saved around 65% of the wall finishing costs due to plaster elimination.

**Table 2 - Cost savings from Precast Wall System due to Plaster Absence (Source: [18, 31])**

| | Conventional wall finishing/ (LKR) | Precast panel-based wall finishing/ (LKR) | Savings/ (LKR) |
|---|---|---|---|
| Ground floor | 166,400.00 | 58,500.00 | 107,900.00 |
| First floor | 220,179.20 | 77,406.75 | 142,772.45 |
| Second floor | 236,800.00 | 83,250.00 | 153,550.00 |
| Third floor | 235,987.20 | 82,964.25 | 153,022.95 |
| Total | 859,366.40 | 302,121.00 | 557,245.40 |

### 4.2 Case 02: Transportation and Total GHG Emission Factor

This case is targeted at assessing the performance in terms of GHG emissions. A not in-depth consideration may give the idea that upgraded technologies in prefabrication plants and additional transportation of prefabricated components will increase the impact on the environment. Thus, it is vital to explore the relevance of these statements. Consequently, this could affect the decision-making in choosing construction methods in the future in Sri Lanka.

The CB has four storeys. The prefabrication rates from a Chinese study [32] were used to extrapolate a hypothetical prefabricated building (HPB) for comparison. The prefabrication rate of CB is set as 0%, whereas the prefabrication rate of HPB has taken as 10.5% by the concrete volume. Based on the reference study, the slabs, staircases, and facades were the prefabricated components for HPB.

The goal of case 01 is to evaluate the GHG emissions of the transportation and total GHG emissions of CB and HPB using the LCA methodology. Transport emissions were separately presented to assess the effect of distance between the off-site facility and the final construction site. The system boundary was set as cradle-to-gate of CB and HPB. Moreover, transportation phases of CB (raw material transportation) and PHB (raw material transportation and prefabricated component transportation) were selected to assess the transportation effect. The unit of analysis is considered at the material level.

Furthermore, the functional unit was defined as a construction floor area (1749.36 m$^2$). Bill of quantities (BOQ), the drawings of the selected case study, relevant literature, relevant reports from Sri Lanka and internationally authorised organizations, and EcoInvent v.3.3 were the sources used for developing the life cycle inventory. SimaPro 8.3 (Ph.D. version) was employed as the modelling software of the LCA. Moreover, IPCC 2013 GWP 100a, an impact assessment method that quantifies the GHG emissions affecting climate change, was utilized in SimaPro software.

Figure 7 shows that the GHG emissions of the transportation activities of CB are 13.20 tCO$_2$(eq), whereas HPB is 12.42 tCO$_2$ (eq). It indicates that, even with the additional transportation activity of prefabricated components, the HPB performs better in terms of overall transportation. On top of that, a sensitivity analysis was conducted to investigate the effect of distance between the construction site and the prefabrication factory. The distance was changed from 10 km to 50 km at 10-unit intervals. Figure 8 depicts that the effect of GHG emissions by the extra distance to cover has less impact on the total GHG emissions.

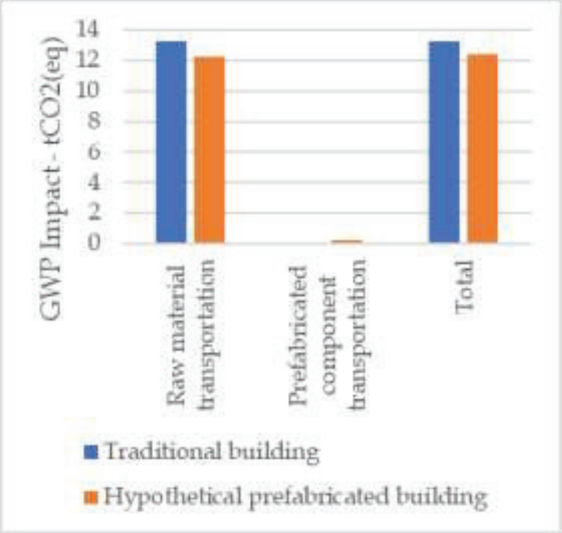

**Figure 7 - Transportation GHG Emissions of CB and HPB**

The total GHG emissions (Cradle-to-gate) of the TB is 466.01 $tCO_2$ (eq), whereas HPB is 461.91 $tCO_2$ (eq). HPB slightly performs better than the CB in terms of total cradle-to-gate GHG emissions. The reduction of 1% of GHG emissions is specific to the demonstrated HPB-CB case study.

PFC has further elevated potential with increasing prefabrication rates. Moreover, increasing machine and worker efficiency in prefabrication plants will favour the reduction of emissions. As analysed in Case 01, time and cost savings has an extensive positive blend towards sustainability.

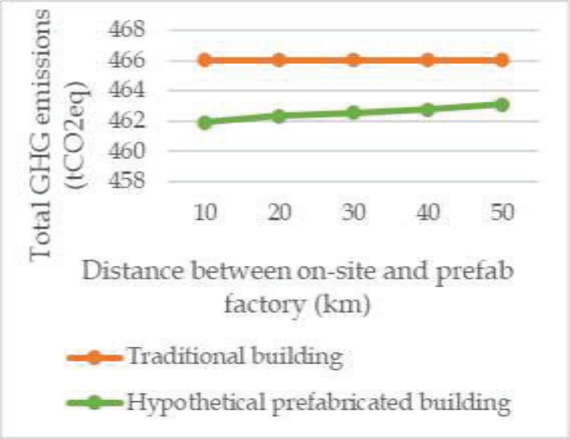

**Figure 8 - Effect of distance between the Construction Site and the Prefabrication Factory**

## 5. Conclusions

The construction industry is constantly pressurized with the never-ending demand and the requirement to comply with sustainability and quality standards. PFC, as an MMC, has the capabilities to answer these requirements. Sri Lanka, as a developing nation, is still lagging in adopting PFC techniques in its construction projects. This study has focused on presenting the current progress of some leading construction organizations adopting PFC. Secondly, an adoption strategy was proposed to overcome the critical barriers hindering the growth of the PFC methods. Finally, the pilot case study demonstrates the positive potential of PFC in terms of time and cost savings and reduced GHG emissions. Further interpretation understood the support of lowered construction times on sustainability by cost savings and environmental benefits from less on-site waste and emissions from fuel and electricity usage of construction machines.

Sri Lanka needs active government, industry, and academia collaboration to gain a proficient uptake in PFC. Government should support construction firms and R&D firms with more monetary funds and regulations and policies favouring the PFC promotion and adoption. At the same time, construction organizations should show enhanced flexibility to shift into these new technologies with long-term strategies. As a society, common people have a responsibility to become aware and understand the neediness of these MMCs for the betterment of future generations.

More research is required to identify the specific limitations, issues, and opportunities in Sri Lankan PFC adoption. Structured and systematic surveys for in-depth analysis of these aspects in PFC in Sri Lanka could be carried out. In the environmental sustainability domain, extended work requires assessing other environmental impacts. On top of that, evaluating scenarios such as prefabrication rate and use of alternative materials is crucial in the Sri Lankan context [33]. Moreover, further research is required in the life cycle sustainability assessment (LCSA) of PFC, combining LCA, LCC, and S-LCA. On top of that, prefab factory, and supply chain simulations to evaluate and identify factory and supply chain dynamics are current research requirements with considerable benefits in the long term. Consequently, plant and supply chain simulation can aid in sustainability evaluation from a manufacturing perspective.

Research on identifying plant and supply chain dynamics to enhance sustainability is seldom; thus, this research area has a greater potential even in Sri Lanka.

Furthermore, circular economy (CE) strategies integrated into construction practices should be a must in the coming decades. However, CE adoption is a relatively new research area for most of the world, including Sri Lanka. Hence, this also has a vast potential for future research. More importantly, future research can focus on conducting comparative analyses with actual prefabricated buildings in Sri Lanka.

## Acknowledgement

The authors would like to express their sincere gratitude to Dr. C.S. Bandara for the support given for acquiring valuable information needed for this research study.

## References

1. Xia, B., Ding, T. and Xiao, J., Life Cycle Assessment of Concrete Structures with Reuse and Recycling Strategies: A Novel Framework and Case Study. *Waste Management*, 2020. 105: p. 268-278.
2. Balasbaneh, A.T. and Marsono, A.K.B., Strategies for Reducing Greenhouse Gas Emissions from Residential Sector by Proposing New Building Structures in Hot and Humid Climatic Conditions. *Building and Environment*, 2017. 124: p. 357-368.
3. Satola, D., et al., Comparative Life Cycle Assessment of Various Energy Efficiency Designs of a Container-Based Housing Unit in China: A Case Study. *Building and Environment*, 2020. 186: p. 107358.
4. Jin, R., Hong, J., and Zuo, J., Environmental Performance of Off-Site Constructed Facilities: A Critical Review. *Energy and Buildings*, 2020. 207: p. 109567.
5. Hao, J.L., et al., Carbon Emission Reduction in Prefabrication Construction during Materialization Stage: A BIM-based Life-Cycle Assessment Approach. *Science of The Total Environment*, 2020: p. 137870.
6. Du, Q., et al., Impact of Prefabrication Technology on the Cradle-to-Site $CO_2$ Emissions of Residential Buildings. *Clean Technologies and Environmental Policy*, 2019. 21(7): p. 1499-1514.
7. Yin, X., et al., Building Information Modelling for Off-Site Construction: Review and Future Directions. *Automation in Construction*, 2019. 101: p. 72-91.
8. Hu, X. and Chong, H.Y., Environmental Sustainability of Off-Site Manufacturing: A Literature Review. *Engineering, Construction and Architectural Management*, 2019.
9. Kamali, M. and Hewage, K., Life Cycle Performance of Modular Buildings: A Critical Review. *Renewable and Sustainable Energy Reviews*, 2016. 62: p. 1171-1183.
10. Father of Sri Lankan Engineering:on 01 May 2022)]; Available from: https://www.kulasinghe.com/patents.htm.
11. Koones, S., Prefabulous Small Houses. 2016: The Taunton Press.
12. Chang, Y., et al., Unlocking the Green Opportunity for Prefabricated Buildings and Construction in China. *Resources, Conservation and Recycling*, 2018. 139: p. 259-261.
13. Balasbaneh, A.T. and Ramli, M.Z., A Comparative Life Cycle Assessment (LCA) of Concrete and Steel-Prefabricated Prefinished Volumetric Construction Structures in Malaysia. *Environmental Science and Pollution Research*, 2020. 27(34): p. 43186-43201.
14. Singh, M.R. and Naskar, S., Smart Construction: Case of '3-S'Prefab Technology for Sustainable Mass Housing, in Smart Cities—Opportunities and Challenges. 2020, Springer. p. 301-316.
15. Uthpala, H. and Ramachandra, T., Study on Modern Methods of Constructions used in Sri Lanka. *Construction Materials and Systems*, 2015: p. 155.
16. Sanjeepan, R., Application of off-site Construction in Sri Lanka. 2017.
17. De Silva, C.S.R., Prefabricated Building Method in Sri Lanka and user Attitude. 2017.
18. ICC, ICC-ACOTEC Precast Wall Panels-Saves Material, Labour & Time. p. 8.
19. DailyFT. Mount Clifford Residencies Homagama by ICC Set to Redefine Urban Living in the New Normal. 2020:on 05 May 2022)]; Available from: https://www.ft.lk/PropertyConstruction/Mount-Clifford-Residencies-Homagama-by-ICC-set-to-redefine-urban-living-in-the-new-normal/10516-703893.

20. Peradeniya, U.o. WELCOME TO EDIRIWEERA SARACHCHANDRA HALL. 2020: on 23 May 2022)]; Available from: https://www.pdn.ac.lk/halls/EdiriweeraSarachchandraHall/.

21. Corporation, S.D.C. Pioneers in Infrastructure Construction. :on 01 May 2022)]; Available from: http://www.sdcc.lk/about-us.html.

22. Corporation, S.D.C. Our Products. :on 01 May 2022)]; Available from: http://www.sdcc.lk/our-products.html.

23. Advantis. Convertainers®(Container Conversions). 2022:on 01 May 2022)]; Available from: https://advantis.world/engineering/services/construction-solutions/convertainers.

24. Advantis. Pre-fabricated Steel Buildings. 2022:on 01 May 2022)]; Available from: https://advantis.world/engineering/services/construction-solutions/pre-fabricated-steel-buildings.

25. Hong, J., et al., Barriers to Promoting Prefabricated Construction in China: A Cost–Benefit Analysis. *Journal of cleaner production*, 2018. 172: p. 649-660.

26. Salama, T., Salah, A., and O. Moselhi, Configuration of Hybrid Modular Construction for Residential Buildings. *International Journal of Innovation, Management and Technology*, 2017. 8(2): p. 106.

27. Chiang, Y. H., Chan, E.H.W., and Lok, L.K.L., Prefabrication and Barriers to Entry—A Case Study of Public Housing and Institutional Buildings in Hong Kong. *Habitat International*, 2006. 30(3): p. 482-499.

28. Mao, C., et al., Major Barriers to Off-Site Construction: the Developer's Perspective in China. *Journal of Management in Engineering*, 2015. 31(3): p. 04014043.

29. Xu, Z., Zayed, T., and Niu, Y., Comparative Analysis of Modular Construction Practices in Mainland China, Hong Kong and Singapore. *Journal of Cleaner Production*, 2020. 245: p. 118861.

30. Wang, H., et al., Life Cycle Environmental and Cost Performance of Prefabricated Buildings. *Sustainability*, 2020. 12(7): p. 2609.

31. ICC, ICC-ACOTEC Precast Wall Panels. p. 2.

32. Mao, C., et al., Comparative Study of Greenhouse Gas Emissions between Off-Site Prefabrication and Conventional Construction Methods: Two Case Studies of Residential Projects. *Energy and Buildings*, 2013. 66: p. 165-176.

33. Jayawardana, J., et al. Life Cycle Assessment for Modular-Constructed Buildings: A Proposed Methodological Framework. in *12th International Conference on Structural Engineering and Construction Management*. 2023. Springer.