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ROLE OF PREFABRICATED PREFINISHED VOLUMETRIC CONSTRUCTION IN ENHANCING CONSTRUCTION PRODUCTIVITY: SRI LANKAN PERSPECTIVE

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ABSTRACT

Low productivity is an inherent characteristic of the construction industry. Prefabricated Prefinished Volumetric Construction (PPVC) is widely acknowledged for its high level of productivity. Thus, this study focuses on increasing the Construction Productivity (CP) in Sri Lanka through the implementation of PPVC. Herein, the research objectives are to explore the role of PPVC in increasing the CP and investigate the barriers to implementing PPVC in Sri Lanka. The research aim was accomplished by collecting data through expert interviews and analysing it through manual content analysis. Findings revealed that in Sri Lanka, the average CP rate can be doubled by implementing PPVC. Overall, PPVC increases the CP by reducing labour, accelerating project duration, making project management much more effective and minimising wastage. Nonetheless, the use of PPVC is relatively limited in Sri Lanka. The high initial cost is the main barrier to the adoption. Findings identified the necessity of specialised machinery, production plants, and skilled labour as the main cost drivers. Complications and high costs in transporting PPVC modules are critical barriers to the implementation of PPVC in Sri Lanka. Additionally, less demand, lack of technical expertise and less enthusiasm for research and development act as barriers. Most of the contractors do not have the technical capability needed for PPVC. Moreover, less governmental support and material shortages hinder the adoption of PPVC. Having an in-depth understanding of the barriers forms the foundation to tailor strategies and overcome the challenges. Accordingly, this research sheds light on the realm of concurring PPVC in Sri Lanka.

Keywords: *Barriers; PPVC; Prefabrication; Productivity; Sri Lanka.*

1. INTRODUCTION

The Construction Industry (CI) plays a predominant role in a country's economic development (Adebowale & Agumba, 2023; Manoharan et al., 2023). CI consumes about 50% of the global raw material, accounting for over 35% of the energy-related greenhouse gas emissions and generates about 35% of the world's solid waste (Nawaz et al., 2023).

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In Sri Lanka, the CI contributed 6.1 % of the GDP (Central Bank of Sri Lanka [CBSL], 2021). Moreover, the sector inherits unique characteristics including lengthy timelines, complex procedures, high resource consumption, low productivity, high risks, and extensive stakeholder involvement (Dixit, 2018; Ma et al., 2016; Vogl, 2015; Zou et al., 2007).

Productivity dictates how efficiently the resources are utilised to deliver the outcomes. Literature acknowledged it as a major parameter of assessing the economic performance and competitive advantages of an industry (Adebowale & Agumba, 2023; Manoharan et al., 2023). Productivity could be measured in different aspects including labour productivity, capital productivity, energy productivity etc (Navaratna & Jayawardane, 2007). However, measuring productivity only through a single aspect will misinterpret the efficiency of utilising other resources (Zhan & Pan, 2020). Consequently, the phenomenon of 'total factor productivity' which considers all inputs concerning the production process was introduced (Navaratna & Jayawardane, 2007). The construction total factor productivity is defined as "a measure of the efficiency of the industry in exerting resources (i.e., labour, capital, and materials) to produce output, as measured by the value-added of physical construction quantities produced" (Zhan & Pan, 2020). To avoid the use of convoluted language, hereafter 'construction total factor productivity' will be referred to as 'Construction Productivity' (CP). Further to the authors, fluctuating economic environment, low technological innovation in construction, labour issues, and complex management systems cause the low CP. Additionally, due to the prevailing economic crisis in the country, Sri Lankan CI has been experiencing stringent challenges such as cost overruns, material shortages, difficulties in obtaining funds and less governmental support thus resulting in low CP (Soyza, 2022).

Notwithstanding the efforts to enhance the CP, it remains low compared to other industries (Borg & Song, 2015; Jarkas & Radosavljevic, 2013). However, enhancing the CP is crucial for a country's sustainable economic development (Abdel-Wahab & Vogl, 2011). The CP enhancement framework introduced by Zhan and Pan (2020) identified encouraging technological innovation in construction as a key productivity enhancement strategy. Further to the authors, the prime objective of encouraging technological innovation is to promote advanced construction management and labour-saving technologies which ultimately enhance the CP.

Literature acknowledged prefabrication as an innovative technological approach which greatly enhances the CP (Jayawardana et al., 2023; Li et al., 2016; Mao et al., 2016). It is a good solution for limited land availability and site access as it provides a unique opportunity to commence construction even before the site is available (Gunawardena et al., 2016). In the 2nd Construction Productivity Roadmap, the Building and Construction Authority of Singapore contended the widespread adoption of prefabrication to achieve a quantum leap in productivity improvement (Shang et al., 2021). Importantly, Prefabricated Prefinished Volumetric Construction (PPVC) is a technically advanced branch of prefabrication which recorded a high level of productivity compared to other prefabrication methods (Shang et al., 2021; Xu et al., 2020). It involves manufacturing completed modules with finishes for walls, floors, and ceilings in off-site factories, transporting them to the construction sites and installing them (Arif & Egbu, 2010; Kamali & Hewage, 2017; Mao et al., 2016). The execution of PPVC is significantly higher in developed countries compared to developing economies such as Sri Lanka (Jayawardana et al., 2023; Kamali & Hewage, 2016). For example, by 2019, about 35%

of the newly constructed public housing projects in Singapore were PPVC (Hwang et al., 2018b). When considering the Asian region, developing economies such as China and Malaysia have demonstrated greater progress over the last two decades in promoting, adopting, and supporting PPVC compared to Sri Lanka (Balasbaneh & Ramli, 2020; Chang et al., 2018). Herein, Hwang et al. (2018b) developed a computerised knowledge-based decision support system for PPVC to facilitate construction professionals in the implementation. In the Sri Lankan Context, Gunawardena et al. (2016) studied the feasibility of adopting prefabricated technologies as a whole. Further, Jayawardana et al. (2023) proposed an adoption strategy to overcome the barriers to implementing prefabrication as a whole in the Sri Lankan context. Even though there are studies conducted about the performance evaluation, technology system, identifying barriers, and developing strategies of PPVC globally (Xu et al., 2020), seldom literature focuses on the productivity aspect of PPVC in the Sri Lankan context. Importantly, PPVC has not reached the limelight in Sri Lanka yet and thus it is necessary to overcome the inherent barriers to take PPVC into the mainstream and stabilise its applications (Jayawardana et al., 2023). As the initial step of achieving that goal, this study aims to enhance the CP in Sri Lanka through the implementation of PPVC. Accordingly, the study has two objectives i.e., (i) Explore the role of PPVC in increasing the CP, and (ii) Investigate the barriers to implementing PPVC in SL.

2. LITERATURE REVIEW

2.1 PREFABRICATED CONSTRUCTION

Prefabrication replaces most of the on-site construction with off-site manufacturing and has played a significant role in the CI for a long time. Consequently, it is rapidly evolving into an essential component in the CI (Gunawardena et al., 2016). Sri Lanka has used prefabrication from time to time, especially in bridges and road works (Gunawardena et al., 2016). There are various categories of prefabricated construction. However, most of the classifications are based on industry practices and theoretical assumptions rather than a rigorous systematic evaluation (Ginigaddara et al., 2022). The numerous taxonomies and terminologies cause blurred boundaries between different systems (Gosling et al., 2016). For instance, the difference between volumetric pods, modules, and complete buildings is not defined in most of the classifications (Ginigaddara et al., 2022). Consequently, the researchers deployed a systematic scientific process and developed an off-site construction typology (refer to Figure 1) that depicts the holistic nature of different types.

However, partially agreeing with the findings of Ginigaddara et al. (2022), focusing on the Sri Lankan CI, Uthpala and Ramachandra (2015) identified two volumetric construction types i.e., (i) modular constructions, and (ii) pod constructions. Herein, referring to Wu and An (2014), Uthpala and Ramachandra (2015) defined modular constructions as prefabricated room-sized volumetric units that are normally fully fit out while manufacturing and are installed on-site as load-bearing building blocks. Further analysis of the two classifications revealed that upon a critical review of different terms Ginigaddara et al. (2022) selected the term 'module' to refer to what was referred to as 'modular construction' in various studies. Outstanding the other forms of prefabrication, prefabricated modules are acknowledged as the future of the CI (Liew, 2018; Xu et al., 2020).

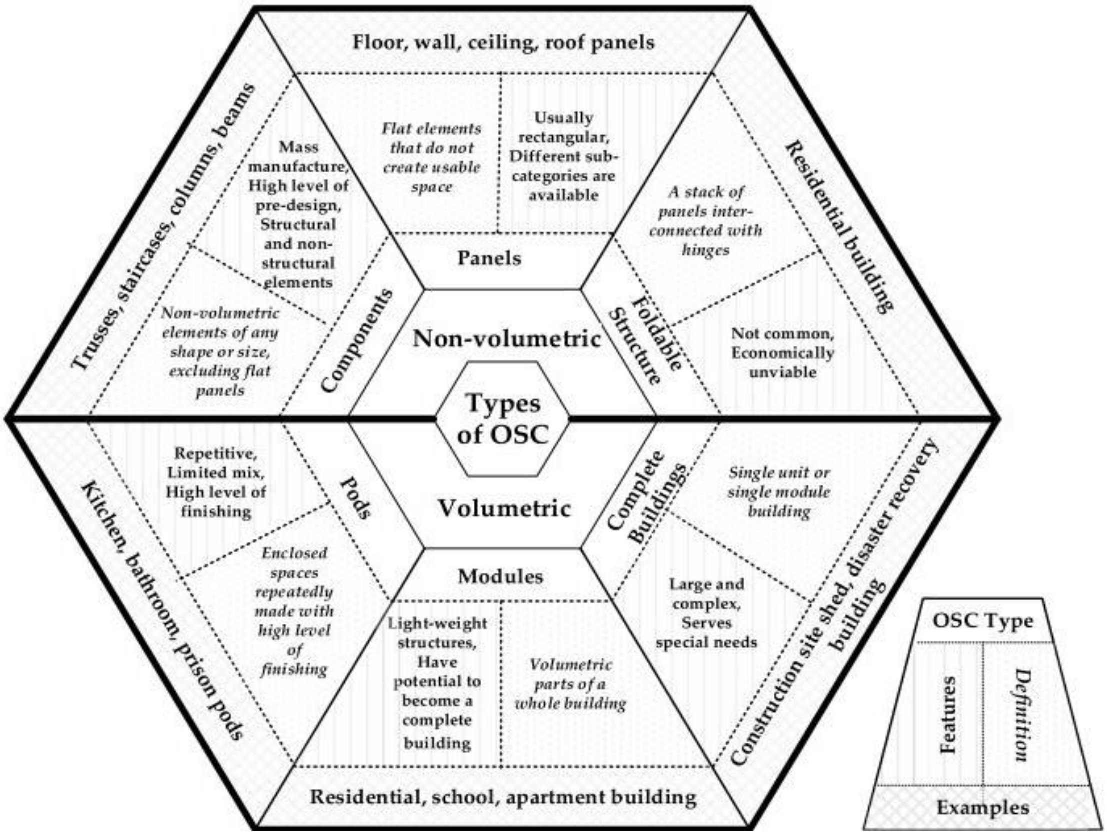

Figure 1: Definitions, examples, and features of the validated OSC typology

Source : (Ginigaddara et al., 2022)

PPVC is the synonym terminology of prefabricated modules (Xu et al., 2020). Based on the load path PPVC modules can be categorised into two types i.e., (i) load-bearing wall modules, and (ii) corner-supported modules as shown in Figures 2 and 3, respectively (Liew, 2018).

In China, PPVC has been actively practising since 2017 (Xu et al., 2020). Further to the authors, North Hill Residence Hall of Nanyang Technological University (NTU) is the first PPVC project in Singapore (Xu et al., 2020). Importantly, PPVC plays a vital role in post-disaster reconstruction (Gunawardena et al., 2016). Herein, the authors highlighted key examples such as Post Katrina Housing in Mississippi, USA and reconstruction after Haiti Earthquake in 2010, Haiti. Compared to other prefabrication methods PPVC has several advantages such as reduced labour and time consumption (Gunawardena et al., 2016), minimum disruption to the adjacent services, improved quality, increased productivity, and sustainability (Xu et al., 2020). Despite the advantages and the fact that Sri Lankan CI is suffering from limited availability of domestic labour (Nawarathna et al., 2023), prefabrication does not own a satisfying share in the Sri Lankan construction market yet (Uthpala & Ramachandra, 2015). Thus, there is a critical need to investigate the potential of PPVC in addressing the issues in the CI and the reasons behind the limited implementation in the Sri Lankan context.

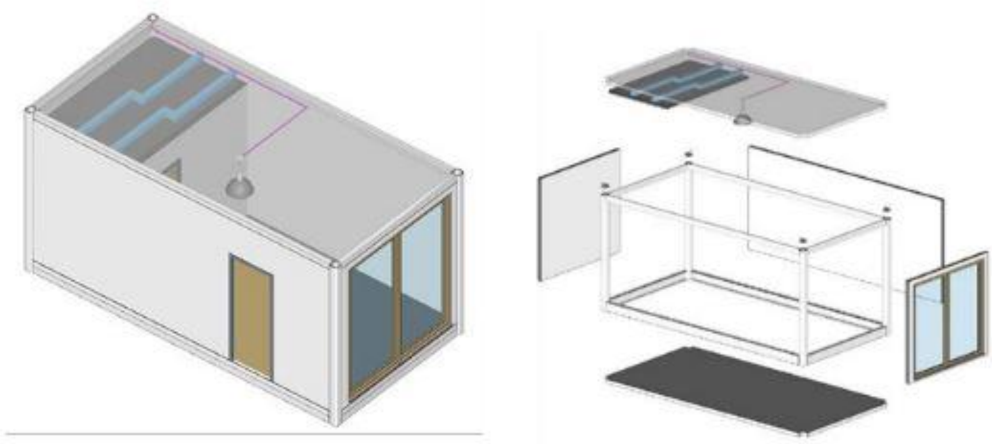

Figure 2: Load bearing wall modules

Source: Liew (2018)

Figure 3: Corner supported modules

Source: Liew (2018)

2.2 ROLE OF PREFABRICATED PREFINISHED VOLUMETRIC CONSTRUCTION IN INCREASING CONSTRUCTION PRODUCTIVITY

Literature encapsulates four salient factors that negatively affect CP i.e., (i) inefficient project management, (ii) unfavourable economic conditions, (iii) low technological innovations, and (iv) less governmental support (Soyza, 2022; Zhan & Pan, 2020). Construction project management involves four crucial steps of planning, executing, coordinating, and controlling the key resources: material, labour, and capital (i.e. funds and machinery) (Zhan & Pan, 2020; Zwikael, 2009). Managing construction projects is challenging due to the complexity of the CI, high stakeholder involvement, labour intensiveness, and dynamic organisational structures (Adebowale & Agumba, 2023; Dixit, 2018; Ma et al., 2016; Vogl, 2015; Zou et al., 2007). Inefficient project management causes cost enhancement, material wastage, subpar work, rework, and project delays and thus results in low CP (Albert et al., 2022; Khaled et al., 2017). On the other hand, unfavourable economic conditions and less governmental support are closely linked. Sri Lanka has experienced the significant impacts of this duo over the past few years. Consequently, the country has suffered from high inflation, high interest rates, high taxes and frequent changes in laws and regulations (Penttilä, 2006). The said conditions cause cost overruns, material shortages, difficulties in obtaining funds, and project delays and thus result in low CP (Soyza, 2022). The most notable repercussion of low technological innovations is the wastage of resources which paves the way for low CP. However, PPVC effectively addressed the above-discussed causes of lesser CP and thereby enhanced the CP.

PPVC is a lean production approach which consumes less labour compared to conventional construction (Hwang et al., 2018a; Jayawardana et al., 2023). Hence, PPVC has been highly acknowledged in Singapore as a sustainable mechanism to deal with the limited working-age population (Adebowale & Agumba, 2023). Furthermore, PPVC accelerates the construction process significantly and thus enhances CP (Jayawardana et al., 2023; Murali & Sambath, 2020). This was evidenced by the Crowne Plaza Changi Airport extension project which reported a 50% reduction in the construction programme as a result of adopting PPVC (Building Construction Authority [BCA], 2016). North Hill Residence Hall Project of NTU reported a six-month time saving as a result of adopting PPVC (Liew, 2018). Similarly, Chen et al. (2010); Jaillon and Poon (2008) and Wong et al. (2003) ascertained a nearly 50% time reduction in various projects compared to on-site construction. Because PPVC carries out the majority of the work in a controlled factory environment, it is less impacted by adverse environmental conditions (Murali & Sambath, 2020) and makes project management convenient (Shang et al., 2021). Further, the on-site installation is cleaner and safer compared to traditional on-site construction and thereby enhances the CP (BCA, 2017). Furthermore, Murali and Sambath (2020) contented reduced wastage as a widespread characteristic of prefabrication. Thus, PPVC greatly enhances the CP compared to traditional on-site construction.

2.3 BARRIERS TO IMPLEMENTING PREFABRICATED PREFINISHED VOLUMETRIC CONSTRUCTION

Notwithstanding the benefits, prefabrication is associated with inherent challenges (Murali & Sambath, 2020). By extensively investigating the adoption of PPVC in Singapore Shang et al. (2021) highlighted three critical barriers i.e., (i) ineffective on-site storage, (ii) high up-front payment, and (iii) transportation issues. Similarly, Murali and Sambath (2020) analysed the challenges in the Indian context and emphasised inadequate suppliers of prefabrication, lack of technical training, lack of adequate transport and logistics, and clients' less willingness as significant barriers. Cost intensity was discovered as the main cause of the slow application of prefabrication in the United Kingdom and China (Shang et al., 2021). Further, Hong et al. (2018) explored its significant impacts in developing countries. Correspondingly, Sri Lanka is facing several significant challenges as a developing economy with less industrialised construction and manufacturing sectors (Jayawardana et al., 2023). The authors identified six barriers i.e., (i) cost-related complications, (ii) unfavourable government policies and less support, (iii) low societal acceptance, (iv) shortage of experienced and skilled labour, (v) technical incapacity, and (vi) lack of country-specific life cycle databases.

Studies discovered the main cost drivers of PPVC as setting up manufacturing and holding yards, high-capacity tower cranes, staff training, storing and transporting. Moreover, researchers emphasised the complications and high costs associated with transportation in developing countries (Chiang et al., 2006; Murali & Sambath, 2020; Salama et al., 2017). Additionally, Sri Lanka is suffering from a lack of supportive policies, regulations, and incentives to encourage the implementation of PPVC (Jayawardana et al., 2023). Further, Uthpala and Ramachandra (2015) highlighted the resistance among construction companies and the public in adopting these technologies. The resistance is driven by beliefs such as low quality, loss of aesthetic appearance, inflexibility for design changes, high stress, and less long-term durability of prefabricated components (Jayawardana et al., 2023; Murali & Sambath, 2020). Further, contractors are reluctant to initiate the adoption of PPVC due to the risks associated with being the forerunner (Lee, 2017). Moreover, there is a concern that PPVC buildings are less stable against lateral loads, especially in circumstances such as earthquakes. However, the less vulnerable geographical position of the country favours the applicability of PPVC in Sri Lanka (Jayawardana et al., 2023). Accordingly, it is essential to make the community aware and thereby popularise PPVC (Murali & Sambath, 2020).

Effective implementation of PPVC requires expertise and knowledge of workers and management. However, Sri Lanka is lacking in originating and transferring knowledge and specialisation (Jayawardana et al., 2023). Notably, Sri Lanka is indolent in embracing innovative construction technologies and less enthusiastic in research and development initiatives (Jayawardana et al., 2023). Similarly, lack of technical training is a pressing issue in the adoption of PPVC in India (Murali & Sambath, 2020). The researchers discovered that though most of the construction stakeholders are rich in theoretical knowledge they are lacking in practical applications. Jayawardana et al. (2023) identified the absence of country-specific construction databases, essential for benchmarking PPVC against conventional construction, as a barrier to the widespread adoption of PPVC in Sri Lanka.

3. METHODOLOGY

The less application of PPVC in Sri Lanka constrained drawing a large sample of respondents for data collection. However, the qualitative approach collects data from comparatively a lesser number of participants and analyses in-depth (Creswell, 2012). Thus, this study used a qualitative approach to accomplish the research aim. Further, exploring the role of PPVC in increasing the CP and investigating the barriers to implementing PPVC in Sri Lanka require experts' inputs with in-depth knowledge of the context. Importantly, the accuracy of the data significantly influences in reaching of the aim. Thus, this study conducted expert interviews to collect data. In-depth interviews reflect interviewees' perspectives based on their experiences and understanding. Semi-structured interviews, while being guided by a defined framework allow the researcher for situational questioning based on the responses. Hence, semi-structured interviews were chosen for this research. Interviewees were selected through purposive sampling considering knowledge and experience in PPVC. Accordingly, twelve construction professionals were interviewed. Table 1 presents the profiles of the interviewees.

Table 1: Interviewee profile

Interviewee Code	Designation	Years of Experience
E1	General Manager	16+
E2	Project Manager	8+
E3	Quantity Surveyor	5+
E4	Project Manager	12+

Interviewee Code	Designation	Years of Experience
E5	Quantity Surveyor	4+
E6	Engineer - Modular building solutions	4+
E7	Planning & QA/QC Engineer	4+
E8	Quantity Surveyor	14+
E9	Site Manager	15+
E10	Site Engineer	18+
E11	Quantity Surveyor	4+
E12	Site Engineer	10+

Interviewees were questioned under three major sections. In the first section, the interviewee's background details were questioned. The second section focused on the role of PPVC in increasing CP whereas the third section focused on the implementation of PPVC in Sri Lanka. Accordingly, the current level of implementation and associated barriers to the implementation were discussed. Situational questions were raised to clarify and explore the details further. Collected data was analysed through manual content analysis and conclusions were drawn.

4. RESEARCH FINDINGS AND DISCUSSION

4.1 ROLE OF PREFABRICATED PREFINISHED VOLUMETRIC CONSTRUCTION IN INCREASING CONSTRUCTION PRODUCTIVITY IN SRI LANKA

All the experts acknowledged the ability of PPVC to enhance the CP. Especially, E4 strongly insisted that "PPVC is the most productive and efficient volumetric construction technology". Moreover, E1 stated that "*implementation of PPVC can double the CP compared to the conventional methods used in Sri Lanka.* According to the interviewee, the average CP rate is 40% whereas the achievable CP rate by implementing PPVC is 80%. Strengthening the argument further, E5, E6, E11, and E12 highlighted the requirement of taking necessary steps to enhance the implementation of PPVC in Sri Lanka and thereby mitigate the productivity loss. Importantly, E8 contented that PPVC can carry out the Sri Lankan construction industry to the next stage.

Empirical findings regarding the less human resource consumption of PPVC resonate with those of the literature findings. In line with the findings of Adebowale and Agumba (2023), E5 emphasised that PPVC is mostly used in developed countries such as Singapore and Australia and developing countries such as Malaysia due to the reduced human resources involvement. E3, E5, and E9 pinpointed that in PPVC each labour is specialised in a certain task to ensure that each activity is finished promptly and effectively. This ultimately lowers the overall labour requirement. Further, as emphasised by E1 the use of advanced machinery and equipment reduces the need for manual labour resulting in a more productive and streamlined manufacturing process. On the other hand, lack of on-site labour has been identified as a cause of enhanced costs and project delays. However, PPVC will mitigate the issue greatly due to the lower labour requirement. Similarly, E2 identified PPVC as an effective solution for the severe skill labour shortage in Sri Lanka. Accordingly, PPVC enhances the CP by reducing the labour input.

All the experts agreed that PPVC greatly accelerates the project duration compared to traditional on-site construction. While BCA (2016); Chen et al. (2010); Jaillon and Poon

(2008) and Wong et al. (2003) reported about 50% time reductions in PPVC projects, E1 pointed out that PPVC can achieve about 40% time-saving. Findings revealed several reasons for the reduced project duration. For example, E2, E7, E9, E10, and E11 commented that this is because the majority of the construction processes take place in controlled factory environments which are free from the disturbances by extreme weather conditions. Additionally, E2 identified simultaneous work both on and off-site as the primary reason for achieving reduced project duration in PPVC. Further, E3, E4 and E6 pinpointed that the repetitive nature of the units and completion of all elements including services insulation in one single plant provides fast-track construction. E9 added that "*early involvement of contractor shortens the construction period*". Thus, the findings of the expert interviews confirm the findings of the previous researchers regarding the significantly accelerated construction processes of PPVC. Importantly, E8 contended that "*the reductions in project durations followed by reduced preliminaries and opportunity costs and thereby enhance the CP*".

Being a less labour-intensive factory-oriented manufacturing process, PPVC allows more efficient project management compared to traditional construction. Accordingly, E3 and E9 mentioned that PPVC allows for better quality control, reduces rework, and improves the quality as the modules are manufactured in a factory. Additionally, as highlighted by E9, "*improved quality of the units reduces the onsite inspection*". Further, the application of finishes such as flooring, paint, and tiles in a factory under controlled circumstances lowers the possibility of mistakes. Moreover, E8 stated that "*innovative construction techniques used in PPVC guarantee that all parts are precisely measured and assembled and thus reduces the structural failures*". Adding to that, E1 pinpointed the use of steel formwork which achieves more accurate unit dimensions compared to the conventional formwork methods. Thus, the findings confirm that of Murali and Sambath (2020) and Shang et al. (2021) regarding the ability of PPVC to plan, execute, coordinate, and control the key resources efficiently thereby increasing the CP. Further to that, as highlighted by E3 and E5 PPVC enables cleaner and safer working conditions and reduces the risk of accidents as a result of carefully monitored production setting with strict adherence to safety protocols. In addition, E9 contented that "*early involvement of the contractor facilitates efficient project planning*". Further E1 claimed that the contractor's early involvement improves the buildability of PPVC and allows the project to be finished with fewer disputes.

According to E2 "*PPVC uses resources more productively and significantly minimizes the wastage compared to traditional construction*". E1, E3 and E11 explained the reason as PPVC modules are produced to precise specifications and thus result in little material waste.

4.2 Barriers to Implementing Prefabricated Prefinished Volumetric Construction in Sri Lanka

Findings revealed that the use of PPVC is relatively limited in the Sri Lankan CI. According to E1 and E3 certain construction companies in Sri Lanka have started to explore the use of PPVC, but not widely practicing. It is remaining as a relatively new and relatively less-used method of construction with inherent barriers to be overcome. The experts highlighted various reasons for the less acceptance of PPVC in Sri Lanka.

In line with the findings based on Singapore, the United Kingdom, and China, E1 discovered high initial costs as the main barrier to the adoption of PPVC in Sri Lanka.

Accordingly, experts identified the necessity of specialised machinery, production plants, and specialised labour as the main cost drivers. E9, E10, and E12 contented that the cost of the yard erection is significantly high to the extent that resists the contractors from adopting PPVC in Sri Lanka. Confirming the findings of Chiang et al. (2006); Murali and Sambath (2020); Salama et al. (2017) regarding the complications and high costs associated with transportation in developing countries. E10 claimed that "*requirements associated with module handling and transportation such as heavy vehicles and heavy capacity cranes make PPVC costly*". Additionally, E9 insisted that the project scope, complexity of the design, and the degree of customisation affect the initial cost of PPVC. Acknowledging the findings of Hong et al., (2018), regarding the significance of the higher upfront cost of PPVC in developing countries E11 and E12 stated that "*PPVC is cost-effective for larger projects rather than small-scale projects and thus it is challenging to justify the adoption of PPVC particularly for small-scale or low-budget projects*". However, E2 believed that PPVC is cost-effective for both small and large-scale projects.

Resonating with the literature findings regarding complications associated with module transportation, most of the expert's highlighted transportation as a critical barrier to the implementation of PPVC in Sri Lanka. Experts further mentioned that the "weight of the unit with the vehicle's weight will be considerably huge, where most of the bridges and culverts in Sri Lanka will not able to bear the weight". Additionally, tunnel clearance as well as abstractions by lower-level electrical and telecommunication cabling systems were identified as the challenges during the mobilisation of PPVC units. E1 and E9 pointed out that the long transportation routes and high traffic will increase the overall cost and cause delays which ultimately reduces the CP. Transporting the PPVC units on unsuitable or damaged roads could damage the modules causing additional rectification costs and reducing the quality. On the other hand, E6 pointed out the risks in handling and loading as another barrier to the implementation of PPVC in Sri Lanka. Since most of the accidents and damages happen during the lifting processes, additional precautions need to be taken. Additionally, E1 and E4 insisted on the storage problem as another barrier. Since the PPVC modules are huge and are being produced simultaneously in manufacturing yards, a large space is required for storage. Especially, E3 emphasised that "*preservation and curing of the modules also need large space*".

On the other hand, E7, E8, and E11 emphasized the lack of demand for PPVC as a barrier to the implementation in the Sri Lankan CI. Confirming the literature findings of Jayawardana et al. (2023) and Uthpala and Ramachandra (2015) regarding the low public acceptance, empirical findings revealed that reliance on conventional on-site construction methods and resilience to adopt innovative technologies lower the demand for PPVC. Herein, E3 stated that "*ordinary traditional citizens oppose residing in prefabricated buildings*". Further, E1, E4, and E5 highlighted that the low public acceptance resulted in a low demand for PPVC which is a significant barrier in the Indian context as well. Similarly, E6 contended that even though there is a good demand for prefabricated elements such as beams, wall panels, columns, and slabs the demand for PPVC is not at a satisfactory level. However, E2 believed that there is a rising demand for PPVC in Sri Lanka. In-depth analysis revealed that lack of knowledge and understanding is a critical barrier that prevents people from adopting PPVC. According to E1 "*most of the people have a myth about the durability of PPVC buildings and have an overconfidence on traditional construction*". Similarly, E1 and E9 mentioned that "the *general public as* *well as most of the construction stakeholders in Sri Lanka not aware of the long-term benefits of PPVC such as the high potential to enhance the CP*". Additionally, E1 stated that investors are reluctant to invest in PPVC due to the unawareness of its benefits. Accordingly, E12 stated that the lack of awareness leads to a lack of demand. However, E6 and E11 noticed an increasing trend in the level of acknowledgement of PPVC in the Sri Lankan CI.

The findings of the expert interviews strongly confirm the literature findings regarding the lack of technical expertise and specialisation which act as barriers to the implementation of PPVC. E5 stated that most of the construction professionals practising in Sri Lanka hesitate to implement PPVC due to the lack of necessary experience and expertise in PPVC. Thus, as pointed out by E2 "they only focus on the high initial cost of PPVC, instead of focusing on innovative approaches to reduce the cost". Similarly, E8 insisted that most of the construction companies do not have the technical capability needed for PPVC. For instance, precision engineering and logistical knowledge are needed for the assembly of building modules, which may not be a skill set possessed by conventional contractors. Further to the expert, the absence of experienced contractors may result in delays, higher costs, and poor quality of work, which discourage stakeholders from implementing PPVC. Similarly, E9 mentioned that implementing PPVC required considering several technological aspects such as design-related standards, load calculations, and wind patterns assessments which the construction professionals are not very familiar with. According to E5 "*service integration is more complex in PPVC compared to conventional construction*". Conversely, E1 and E2 mentioned that the repetitive design nature of the PPVC technology will make future project execution easier.

Findings revealed another significant barrier to the adoption of PPVC in Sri Lanka: less focus on research and development. E3, E6, and E7 emphasised that without adequate research it is challenging to drive the industry in the long term and to attract investors. Especially E6 mentioned that universities should play leading roles in disseminating knowledge regarding the globally trending innovative construction techniques such as PPVC. However, E2 noticed several noteworthy efforts taken by educational institutes, professional bodies, and the cooperate sector to overcome these barriers. According to E8, "*the level of awareness and expertise of PPVC in the Sri Lankan CI is slowly increasing, but there are still pressing requirements to fully realize its potential in the country*".

In addition to the literature findings, empirical findings identified a material shortage as a significant barrier to implementing PPVC in Sri Lanka. Further to experts, "*concrete, steel, and insulation are just a few key materials of PPVC which short supply may cause significant production delays and increased costs*". Especially E1 and E2 identified the impact of the COVID-19 pandemic, the economic crisis of the country, high inflation, and import restrictions as the root causes of the possible material shortages. On the other hand, most of the interviewees highlighted poor procurement methods as a major barrier to the implementation of PPVC in Sri Lanka. E1 stated that "*it can be challenging to ensure that these modules fulfil the quality and legal requirements without proper procurement procedures in place*".

Confirming the findings of Jayawardana et al. (2023) regarding the less governmental support, E1 claimed that "*PPVC is not sufficiently promoted by the Sri Lankan government*". However, Singapore experienced the complete opposite of this when implementing PPVC. Moreover, E2 mentioned that "*the government should promote the adoption through favourable policies, tax reductions, releasing import restrictions, and facilitating research and development*". Adding further to this argument E6 and E11 mentioned that experienced manufacturers and contractors should be the forerunners and thereby promote PPVC through knowledge and experience sharing. Figure 4 summarises the findings through a cause-and-effect diagram.

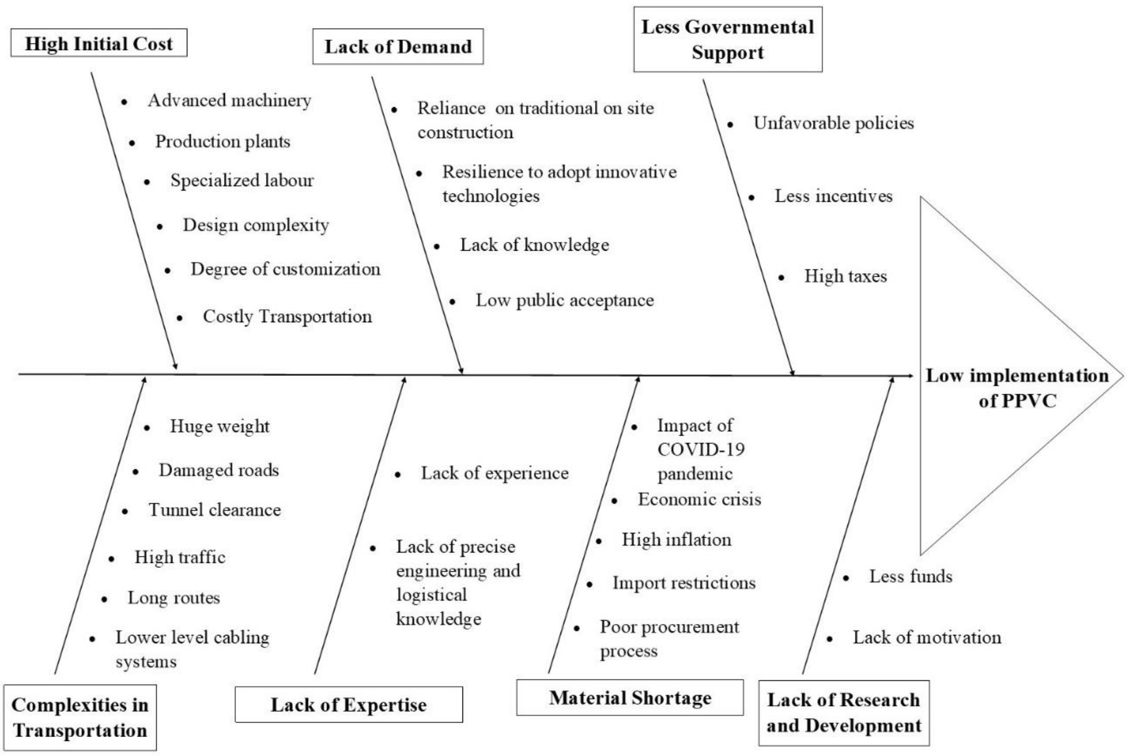

Figure 4: Cause and effect diagram of barriers to the implementation of PPVC in Sri Lanka

5. CONCLUSIONS

Low productivity is an inherent characteristic of the CI. Productivity could be measured in different aspects but measuring productivity only through a single aspect will misinterpret the efficiency of utilising other resources. Literature encapsulates four salient factors that negatively affect CP namely inefficient project management, unfavourable economic conditions, low technological innovations, and less governmental support. PPVC is an advanced branch of prefabrication which recorded a high level of productivity. The execution of PPVC is significantly higher in developed countries compared to developing economies. However, it has not reached the limelight in Sri Lanka. Even though studies have been conducted focusing on prefabrication or volumetric construction, seldom literature has specifically focused on PPVC. Addressing the niche, this study focuses on increasing the CP in Sri Lanka through the implementation of PPVC. The research aim was accomplished through a qualitative approach by collecting data through expert interviews and analysing it through manual content analysis.

Findings highly acknowledged the ability of PPVC to enhance the CP. In Sri Lanka, the average CP rate can be doubled by implementing PPVC. It lowers the overall labour requirement as a result of specialised labour, advanced machinery, and streamlined manufacturing processes. Similarly, PPVC greatly accelerates the project duration as a result of simultaneous work, controlled factory environments, the repetitive nature of the units and the early involvement of contractors. The reductions in project durations are followed by reduced preliminaries and opportunity costs. Additionally, PPVC can plan, execute, coordinate, and control the key resources efficiently thereby increasing the CP. Further, PPVC significantly minimises the wastage because of the production according to the precise specifications. Overall, PPVC enhances the CP by reducing labour, accelerating project duration, effective project management and minimising wastage.

Nonetheless, the use of PPVC is relatively limited in Sri Lanka. The high initial cost is the main barrier to the adoption of PPVC in Sri Lanka. Findings revealed the necessity of specialised machinery, production plants, and skilled labour as the main cost drivers. Moreover, the cost of the yard erection is significantly high to the extent that resists the contractors from adopting PPVC in Sri Lanka. The higher upfront costs make PPVC cost-effective only for mega-scale projects. Similar to the other developing countries Sri Lanka experiences complications and high costs in transporting PPVC modules which are critical barriers to the implementation of PPVC. Challenges during the mobilisation of PPVC units are identified as the inability of the bridges and culverts to bear the weight, tunnel clearance, abstractions by lower-level electrical and telecommunication cabling systems and accidents and damages during handling. Additionally, a lack of demand hinders the implementation of PPVC in Sri Lanka. Lack of knowledge is identified as the underlying reason for low public acceptance and low demand. Resilience to adopt innovative technologies also impacts the lower demand. However, certain experts noticed a rising demand for PPVC in Sri Lanka. Moreover, a lack of technical expertise and enthusiasm for research and development initiatives act as barriers to the implementation of PPVC. Most of the construction professionals practising in Sri Lanka hesitate to implement PPVC due to the lack of necessary experience and expertise. Similarly, most of the construction companies do not have the technical capability needed for PPVC. Additionally, the material shortage was identified as a barrier to implementing PPVC in Sri Lanka.

Implications of this research shed light on the realm of concurring PPVC in the Sri Lankan CI. An in-depth understanding of the barriers forms the foundation for tailoring strategies to overcome the challenges. Importantly, the government has a leading role to play in overcoming the barriers. Thus, it is recommended to pay attention to the findings when tailoring the government policies. Similarly, practitioners and researchers are encouraged to be inspired by the findings and work collaboratively to overcome the barriers. Despite the fulfilment of the objectives, this study has certain limitations. Herein, all the interviewees represented the contractor’s perspective and no statistical data was collected. Future researchers are encouraged to broaden the study while overcoming the limitations. Herein, investigating the pathways to overcome the identified barriers and comparatively quantifying the CP of PPVC are recommended.

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