Sustainable Performance Criteria for Prefabrication Construction System

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Abstract- Prefabrication has been considered an effective alternative to conventional building. It has gained an increasing amount of attention over the last few decades towards achieving sustainable goal. To develop prefabricated housing and address challenges in construction industry, the Indian government is encouraging prefabricated construction system. A critical review was conducted to identify the potential usage of prefabrication construction system compared to conventional construction methods. Through a comprehensive review of relevant literatures it was observed that, prefabricated construction system has become increasingly popular and widely promoted due to its potential to improve the construction environment, quality and productivity.

Index Terms- Prefabrication, Sustainable, Economic, Social, Environmental

I. INTRODUCTION

According to a report titled Brick by Brick: Moving towards 'Housing for All', by RICS (Royal Institution of Chartered Surveyors), in association with international property consultant Knight Frank, by the year 2030, more than 40% of the Indian population will live in urban India, as against the current figure of 34%, which is likely to create a demand for 25 million additional affordable housing units. The report estimates that the current housing shortage in urban areas is around 10 million units. Most of the housing shortage lies in the Economically Weaker Section (EWS) and Lower Income Group (LIG) segment. This problem has been growing exponentially with increasing in urbanization. In urban areas, India has a great challenge to achieve the target of 10 million houses by 2022 [1]. The massive housing deficit, highlighted by the problem of affordability cannot be tackled through conventional technology utilized in the construction industry. Emerging technologies will play a vital role in effective implementation of policies like Housing for All [2]. A growing awareness of environmental, social and economic problems associated with contemporary architecture and industry have led business leaders, corporations and nations across the world to adopt practices that are deemed to be more sustainable over the long term. While at present most of these practices have been aimed at reducing resource consumption, energy use and emissions, there really hasn't been a drastic or fundamental redesign of the entire approach to the process of visualisation and creation of the built environment. Revolutionary housing concepts like the 'India Concept House'- a prefabricated building solution-can help achieve cost savings both in the short term and over the life of the structure [3]. This study is focused on critical review on adoption of prefabricated construction and identifying such challenges faced by the prefabricated technology and providing amicable solutions to the challenges identified at the industry level.

II. DEFINITIONS

Prefabrication is the act of collecting segments of a structure in a manufacturing process or other assembling site, and transporting complete congregations or sub-gatherings to the development site where the structure is to be constructed [4].

Industrialized Building System (IBS) has become a term to represent those terminologies base on research in the context Malaysian construction industry. The term IBS is widely used by the government, practitioners and researchers in this country to represent industrialization in construction. The term IBS is defined as an innovative process of building construction using the concept of mass-production of industrialized systems, produced at the factory or onsite within controlled environments, it includes the logistic and installation aspect of it, done in proper coordination with systematic planning and integration [5].

Capsule unit is a term refers to a prefabricated living space that accommodates the everyday essentials of a person. The replaceable capsule units are prefabricated and assembled in factories and then installed into a concrete core which contains the public utilities as stairs, elevators, plumping and electrical systems [6].

According to Modular Building Institute, Modular construction is a process in which a building is constructed off-site, under controlled plant conditions, using the same materials and designing to the same codes and standards as conventionally built facilities – but in about half the time. Buildings are produced in "modules" that when put together on site, reflect the identical design intent and specifications of the most sophisticated site-built facility – without compromise.

According to International Building Code 2015 (G223-15), Relocatable building is defined as a partially or completely assembled building constructed and designed to be reused multiple times and transported to different building sites.

III. Sustainable aspects

Prefabricated construction is considered as a sustainable construction approach due to its different advantages related to cost reduction, energy efficiency, and environmental conservation. The following section deals with the comparisons categorized by economic criteria, social criteria, and environmental criteria between prefabrication and on-site construction method have been identified. This creates a valuable base for the development of sustainable performance criteria

A. Economic Criteria

Almost every paper on success criteria in prefabrication construction never forgets to mention about two criteria namely cost and time which are often grouped under project efficiency dimension. Reducing cost and time are major concerns for both consumers and manufactures in the building industry. When compared to conventional construction methods, the prefabricated construction system provides significant reductions in time [7, 8, 9, 10, 11]. Construction time for prefabrication is less than half of on-site construction [12]. Up to 70% time saving can be achieved when compared in-situ construction and average reduction in construction time can achieve 20% when compared with onsite construction [13]. In case of prefabrication system, site preparation and prefabrication of components can occur simultaneously, and the erection process is fast [13, 14]. Further, prefabrication is independent of adverse weather which has almost no impact on the schedule of the prefabrication manufacturing [13]. This also reduces the construction time of projects using the prefabricated construction when compared to conventional construction.

When compared to conventional design, the prefabrication design has different complexities and pre-project planning is quite important for prefabrication construction system. Prefabrication require more engineers, quality controllers and skilled labourers, these requirements will increase the cost of the design phase [11]. The higher initial and transportation costs are the main economic hurdles of prefabricated versus conventional construction methods [15]. From a multiple case studies carried out by many researchers the total cost of prefabricated construction is significantly higher than that of conventional construction methods [16,17,18,19,20]. Further, from various research papers it was observed that cost of pre-cast may vary with the type and the size of construction. For a small project the cost of pre-cast increases due to no production of elements in bulk. However, for bigger projects the cost may decrease significantly [21,22,23,24]

B. Social Criteria

Social criteria of construction projects reflects the extent to which the lifecycle of construction projects meets the demands of anticipated or existing social demands. Compared to economic and environmental criteria, social criteria associated with construction projects are the least explicit in the “triple bottom line” principle of sustainable development [25]. The social criteria namely, workers’ health and safety, health of occupants, labour availability, traffic congestion and community disturbance were taken into account by many researchers in the comparative study of prefabrication construction system with conventional construction practices. When compared to the conventional construction practices prefabrication construction system improve workers health and safety due to cleaner and good working environments. Prefabricated elements are manufactured in a factory in controlled setting to reduce on site construction activities and construction duration. This reduce construction noise, dust and other pollutants faced by nearby community. The prefabrication construction method is beneficial in urban areas were traffic conjunctions may be avoided [13, 26, 27].

Further, in the construction industry, safety plays a vital role as well as a challenge for contractors and owners. Improving safety performance for construction projects should be among the one of the important priorities of construction practitioners. In recent decades many construction studies have been conducted to identify safety risks and improve safety performance in this industry. From various studies it was concluded that construction jobs at manufacturing plants are potentially safer than on-site operations, and the majority of the accidents occurred on site. Off-site construction can improve safety performance in various ways [28, 29, 30, 31].

C. Environmental Criteria

According to the International Energy Agency report 2019, the buildings and construction sector accounted for 36% of final energy use and 39% of energy and process-related carbon dioxide (CO2) emissions in 2018, 11% of which resulted from manufacturing building materials and products such as steel, cement and glass [32]. India is currently at a crucial juncture where it is aiming for economic growth to meet the basic needs of its 1.3 billion people. The construction sector is highly resource and energy intensive, it is therefore imperative that it moves towards a path of environmental sustainability. The transformation in construction industry will play a vital role in reducing energy consumption in India. Prefabrication construction system improves sustainability in construction and provides environmental benefits [33,34]. The sustainable benefits of prefabricated buildings have been addressed in many studies. Prefabricated buildings result in fewer emissions than conventional buildings in the construction phase [35]. Environmental criteria namely, construction waste, pollution generation, energy consumption and water consumption were accounted by many researchers in their studies to compare benefits of prefabrication construction system with that of conventional methods. [36, 37]

Construction industry produces a large amount of construction waste during various phase and is generally regarded as a major contributor for the degradation of environment. The application of prefabrication construction system shows significant reduction in wastage, which can be achieved compared with the conventional methods of construction.[31, 38, 39, 40]. A study shows that the reuse of materials in prefabricated steel buildings saves about 81% of embodied energy and 51% of materials by mass. Prefabricated houses also reduce CO2 operating emissions by approximately 50% in annual households [41,42]

IV. CONCLUSION

A critical review was conducted to evaluate the sustainable performances of prefabrication construction compared with conventional construction. The review mainly focused on the sustainable performances in the construction phase based on the sustainable triple bottom line: economic, social and environmental aspects. Prefabrication is economical when compared to other conventional methods, prefabrication is a cost and time saving construction method which assures quality of concrete to its maximum extent. From various studies it was concluded that construction jobs at manufacturing plants are potentially safer than on-site operations. Further, prefabrication construction system improve workers health and safety due to cleaner and good working environments. This review confirms that prefabrication has many environmental benefits over conventional approaches in the construction phase and has greater performances regarding sustainable construction in terms of construction waste, energy consumption, site disruption, water consumption, and pollution generation.

REFERENCES

[1] https://housing.com/news/india-will-need-25-million-more-affordable-housing-units-rics-and-knight-frank-report
[2] V. N. Nanyam, A. Sawhney, R. Basu and J. K. Prasad, "Selection framework for evaluating housing technologies," Elsevier, Procedia Engineering, pp. 333-341, 2015.
[3] http://www.sustainabilityoutlook.in/content/prefabrication-%E2%80%93-stepping-stone-sustainable-development-india
[4] Alireza Baghchesaraei, Meltem Vatan Kaptan and Omid Reza Baghchesaraei, "Using Prefabrication Systems in Building Construction", International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 24 (2015) pp 44258-44262
[5] Kamar. KAM, Alshawi. M, and Hamid. ZA. "Barriers to Industrialized Building System (IBS): the case of Malaysia". BuHu 9th International Postgraduate Research Conference (IPGRC): Salford, United Kingdom, 471-484, 2009.
[6] Lin Z, 2011. "Nakagin Capsule Tower: Revisiting the Future of the Recent Past". Journal of architectural education, 65(1), pp.13-32
[7] Lawson, R.M.; Ogden, R.G.; Bergin, R. "Application of modular construction in high-rise buildings". J. Archit. Eng. 2012, 18, 148–154
[8] Paya-Marin, M.A.; Lim, J.; Sengupta, B. "Life cycle energy analysis of a modular/ off-site building school". Am. J. Civ. Eng. Archit. 2013, 1, 59–63.
[9] Kozlovská, M.; Kaleja, P.; Struková, Z. "Sustainable construction technology based on building modules". Adv. Mater. Res. 2014, 1041, 231–234.
[10] Aye, L.; Ngo, T.; Crawford, R.H.; Gammampila, R.; Mendis, P. "Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules". Energy Build. 2012, 47, 159–168.
[11] Satheeskumar Navaratnam , Tuan Ngo ,Tharaka Gunawardena and David Henderson, "Performance Review of Prefabricated Building Systems and Future Research in Australia", Buildings 2019, 9, 38; doi:10.3390/buildings9020038
[12] R. Wong, J.L. Hao, C.M.F. Ho, "Prefabricated building construction systems adopted in Hong Kong", Proc. of the International Association for Housing Science on Word Congress of Housing: Process and Product, Montreal, Canada, 2003.
[13] Ying Chen, Gül E. Okudan, David R. Riley, "Sustainable performance criteria for construction method selection in concrete buildings", Automation in Construction 19 (2010) 235–244
[14] Kawecki, L.R. "Environmental Performance of Modular Fabrication: Calculating the Carbon Footprint of Energy Used in the Construction of a Modular Home". Ph.D. Thesis, Arizona State University, Tempe, AZ, USA, 2010.
[15] Jaillon, L.; Poon, C.S. "Sustainable construction aspects of using prefabrication in dense urban environment: A Hong Kong case study". Constr. Manag. Econ. 2008, 26, 953–966.
[16] Mao, C.; Xie, F.; Hou, L.; Wu, P.; Wang, J.; Wang, X. "Cost analysis for sustainable off-site construction based on a multiple-case study in China". Habitat Int. 2016, 57, 215–222.
[17] Hong, J.; Shen, G.Q.; Li, Z.; Zhang, B.; Zhang, W. "Barriers to promoting prefabricated construction in China: A cost e benefit analysis". J. Clean. Prod. 2018, 172, 649–660.
[18] Lei Jiang , Zhongfu Li , Long Li ,and Yunli Gao, "Constraints on the Promotion of Prefabricated Construction in China", Sustainability 2018, 10, 2516; doi:10.3390/su10072516
[19] Nihar Nanyama, Riddha Basua, Anil Sawhneyb, Harsh Vikrama and Gourav Lodhaa, "Implementation of Precast Technology in IndiaÙ Opportunities and Challenges", Procedia Engineering 196 (2017) 144 – 151
[20] Karthikeyan, Vinodhini, Aparna, Monika, and Sathish Kumar, "Study on Comparison between Prefabricated and Conventional Structures", International Journal of Civil Engineering and Technology, Volume 9, Issue 5, May 2018, pp. 1–8
[21] U. D. Dabhade, N.A. Hedaoo, Dr. L.M. Gupta and Dr. G.N. Ronghe, "Time and Cost Evaluation of Construction of Steel Framed Composite Floor with Precast Concrete Floor Structure", 26th International Symposium on Automation and Robotics in Construction, Austin TX, U.S.A, 2009, Pg 139-148.
[22] Raghavendra K. Holla , Siddhant Anant, Muzzammil Ali Mohammad, Aakash Periwal and Aakash Kapoor, "Time, Cost, Productivity and Quality analysis of Precast Concrete System", International Journal of Innovative Science, Engineering & Technology, Vol. 3 Issue 5, May 2016.
[23] K.V.Vinoth Kumar and R.Nagavinothini, "Investigation on the Effective Usage of Prefabricated Elements in Construction Projects and developing a Module to reduce time and cost", International Journal of Science, Engineering and Technology Research, Volume 5, Issue 4, pp.856-859, April 2016
[24] Anant Bhosale and , Sushma Kulkarni, "Comparative Study of Prefabrication Constructions with Cast-in-Situ Constructions", International Journal of Advance Engineering and Research Development, Volume 4, Issue 3, pp 779-785, March -2017
[25] Wang, Y.; Han, Q.; de Vries, B.; Zuo, J. "How the public reacts to social impacts in construction projects? A structural equation modeling study". Int. J. Proj. Manag. 2016, 34, 1433–1448.
[26] Anthony Craig, Richard Laing, and Martin Edge, "The social acceptability of prefabrication and standardisation in relation to new housing", 16th IAPS Conference "21st century:

Cities, social life and sustainable development, Paris, 4th-7th July 2000
[27] C. Pasquire, A. Gibb, N. Blismas, "What should you really measure if you want to compare prefabrication with traditional construction", Proc. IGLC-13, IGCL, the International Group for Lean Construction, Sydney, Australia, 2005, pp. 481–491.
[28] Grant, A., & Hinze, J. , "Construction worker fatalities related to trusses: An analysis of the OSHA fatality and catastrophic incident database", 2014 Safety Science, 65, 54-62.
[29] Maryam Mirhadi Fard, Seyyed Amin Terouhid, Charles J. Kibert and Hamed Hakim, "Safety concerns related to modular/prefabricated building construction", International Journal of Injury Control and Safety Promotion, 2015, http://dx.doi.org/10.1080/17457300.2015.1047865.
[30] Vanclay, F. "Principles for social impact assessment: A critical comparison between the international and US documents".. Environ. Impact Assess. Rev. 2006, 26, 3–14.
[31] Shubham D. Auti and Jalindar R. Patil, "Prefabrication Technology - A Promising Alternative in Construction Industry", International Journal of Science and Research, Volume 8 Issue 8, August 2019 pp 240-244.
[32] www.iea.org/topics/buildings
[33] Yunus, R.; Yang, J. "Legislative challenge to sustainable application of industrialized building system (IBS)". J. Teknol. 2015, 63, 1171–1183.
[34] Cuadrado, J.; Zubizarreta, M.; Rojí, E.; Larrauri, M.; Álvarez, I. "Sustainability assessment methodology for industrial buildings: Three case studies". Civ. Eng. Environ. Syst. 2016, 33, 106–124.
[35] Mao, C.; Shen, Q.; Shen, L.; Tang, L. "Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects". Energy Build. 2013, 66, 165–176.
[36] Kaicheng Shen , Chen Cheng , Xiaodong Li and Zhihui Zhang, "Environmental Cost- benefit Analysis of Prefabricated Public Housing in Beijing", Sustainability 2019, 11, 207; doi:10.3390/su11010207
[37] Yongsheng Jiang, Dong Zhao, Dedong Wang and Yudong Xing, "Sustainable Performance of Buildings through Modular Prefabrication in the Construction Phase: A Comparative Study", Sustainability 2019, 11, 5658; doi:10.3390/su11205658
[38] Zhengdao Li , Geoffrey Qiping Shen and Mustafa Alshawi, "Measuring the impact of prefabrication on construction waste reduction: an empirical study in Shenzhen, China", https://doi.org/10.1016/j.resconrec.2014.07.013
[39] Baldwin A, Poon C-S, Shen L-Y, Austin S, Wong I. "Designing out waste in high-rise residential buildings: Analysis of precasting methods and traditional construction. Renewable energy". 2009;34:2067-73.
[40] Jaillon L, Poon C, Chiang Y. "Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong". Waste management. 2009;29:309-20.
[41] Aye, L.; Ngo, T.; "Crawford, R.H.; Gammampila, R.; Mendis, P. Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules". Energy Build. 2012, 47, 159–168.
[42] Paya-Marin, M.A.; Lim, J.; Sengupta, B. "Life cycle energy analysis of a modular/ off-site building school". Am. J. Civ. Eng. Archit. 2013, 1, 59–63.

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