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Evaluating Offsite Technologies for Affordable Housing

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Abstract

Availability of an attribute-based evaluation and selection system for offsite technologies is crucial for the adoption of these technologies in mass housing projects. Due to this gap, adoption of offsite technologies remains low in the Indian construction industry in spite of a huge requirement of 18.78 million housing units to be built by 2022. The traditional õsticks and bricksÑ approach is not likely to fulfil this demand. Adoption of offsite technologies has to be looked into as an option to deliver the extensive requirement in the area of affordable housing. Rejection of technology by evaluating the first cost alone is not the desired strategy to evaluate these offsite technologies. To evaluate and adopt these offsite technologies in affordable housing segment, a holistic selection framework encompassing a set of attributes is needed. This paper identifies a holistic selection framework with a set of offsite specific attributes alongside a set of standard attributes that are mandatory and desired for the adoption of offsite technologies in the affordable housing. Simple scoring of attributes is utilized in devising the framework. This framework is tested and validated on a case study where offsite technologies are used.

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Keywords: Offsite Technologies; Affordable Housing; attributes; selection framework

1. Introduction

Looking at the shortage of the housing in India, the Government has outlined a vision of ÈHousing for AllŠ (HFA), 2022 which has now been formalized as the ÈPradhan Mantri Awas YojanaŠ. This scheme is launched with an aim to provide housing for all the citizens under economically weaker section (EWS) and low-income group (LIG) categories. In this scheme, construction of 18.78 million houses across the country within next seven years [1] is planned.

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Offsite technology adoption in the housing sector would achieve this grand vision of India. Offsite technologies that are superior to the traditional approach have to be mainstreamed in the industry to construct such large volume of housing stock. Offsite can be a game changer for the housing industry in India. In the case of traditional approach of project execution, numerous sub-contractors have to be engaged and are to be managed to deliver the common deadline. There are many unforeseen factors such as weather, government approvals, labour shortage, etc. that can affect the delivery of the project in the traditional system. In a factory built approach, we have all the work trades right from carpenters to plumbers working simultaneously in a controlled environment eliminating the risks associated with wastage, etc. This study will provide an awareness of different parameters and a holistic framework for evaluating offsite technologies in construction, and increasing knowledge related to the offsite construction. It is very important to document and evaluate these offsite technologies, to be implemented in other regions as well, thereby ensuring that the mission set HFA by 2022 is accomplished.

2. Literature Review

Offsite Construction (OSC) helps us transfer the construction activities into a controlled environment enabling us to organize the workforce in a process similar to manufacturing, enabling us to achieve a higher standard of quality, increased productivity, and waste reduction thereby increasing the overall efficiency of the process. The process also helps implement lean, six sigma, etc. in the design and construction processes. Various reports and research as shown in Table 1 claim that offsite construction can result in 90% reduction in site wastage when compared to conventional construction practice. Offsite is being widely used for the construction of temporary structures such as site offices, and permanent structures such as hotels, hostels, office buildings and residential houses. The materials used in the manufacturing of different offsite components or panels can be handled with better efficiency by practicing proper supply chain management resulting in better control over the design and production process. The wastages will also decline significantly by practicing integrated design, procurement and management.

2.1. Benefits of Offsite Construction

Offsite reduces the time spent on site drastically since most of the activities are performed inside closed environment within a factory. Most of the activities that are done on a production line can be completed in a fixed time frame [2]. Other benefits include:

- The components or panels produced in the controlled condition of the factory can be scrutinized for stringent quality check measures, proper supervision of materials and workmanship, improved quality and a better product. [3]
- Construction process can be outsourced to external facilities reducing the requirement of labour, which is the major problem in most of the housing projects
- Better testing facilities can be made e.g. prototype testing, which will improve the design efficiency and other design parameters.

2.2. Barriers to Offsite

In spite of numerous benefits over traditional construction, offsite faces many implementation barriers [4], [5]. Some barriers include:

- Resistance to Change: In these technologies, the traditional culture which we follow needs to be changed, also the skill requirements need to be redefined, and also the team needs to have an improved understanding of project management, scheduling and planning. In addition to this, there are constraints in terms of process, product, quality, technology and market [6]
- Capital Investment: There is a requirement of huge capital to set up manufacturing units for offsite. The project needs to be in the economies of scale in order to invest such capital.
- Guidance and Information: There is more guidance required in this case. The flow of information between different teams of design, production and assembly are unlike conventional construction. More Integrated approach and knowledge are required in this case.

- Traditional Construction Business Models: The business model is altogether different from the traditional approach in the case of cash flow. Also in the case of India, the tax structure in this type of product based construction is different from traditional construction.

Table 1 Research on offsite construction by different Authors

S.No	Authors	Title	Main Findings
1	(O Baba, Joseph, & Shamil, 2012)	*Off-Site Production (OSP) and Benefits in the UK Construction Industry: Theoretical Approach*	OSP is used to a limited extent. Potential possibility of transforming construction into manufacturing industry. OSP provides greater client choice. OSP can be regarded as a sustainable choice reducing the harmful emissions by increasing recycling practices.
2	(H. , Gidado, & Ashton, 2014)	*Factors and Drivers Effecting the Decision of Using Off-Site Manufacturing (OSM) Systems in House Building Industry*	Identification of key decision-making parameters at the evaluation stage
3	(Bendi, Arif, Sawhney, & Iyer)	*Offsite Construction in India - An Exploratory Study*	Drivers such as high demand, quality speed and Constraints such as long delivery times, etc., pertaining to offsite construction in India are highlighted
4	(Azhar, M.S, & Ahmad, 2013)	*An Investigation of Critical Factors and Constraints for Selecting Modular Construction over Conventional Stick-Built Technique*	Identified 12 decision-making factors and six constraints for selection of modular construction
5	(Blismas, Wakefield, & Hauser, 2010)	*Concrete prefabricated housing via Advances in systems technologies – Development of a technology roadmap*	Technology and innovation roadmap of concrete prefabricated housing system is discussed. Grid based design to an advanced kit of parts is discussed with Return on investments.
6	(Hashemi, 2015)	*Offsite Manufacturing: A Survey on the Current Status and Risks of Offsite Construction in Iran*	Key issues to apply off-site manufacturing (OSM) is discussed, and education of architect about OSM is identified as crucial for its successful application.
7	(Arif, Bendi, Sawhney, & Iyer, 2012)	*State of offsite construction in India-Drivers and barriers*	Indian perceptions about offsite construction methods are discussed. Time & cost are the drivers for offsite and need for a transformation is the barriers to offsite adoption in India.
8	(Mostafa, Dumrak, Chileshe, & Zuo, 2014)	*Offsite Manufacturing in Developing Countries: Current Situation and Opportunities*	Strategies integrating offsite manufacturing and lean concepts are presented
9	(Pan, Dainty, & Gibb, 2012)	*Establishing and Weighting Decision Criteria for Building System Selection in Housing Construction*	Decision matrix of three level with 50 criteria for evaluating building systems is presented for the UK.
10	(Kolo, Rahimian, & Goulding, 2014)	*Offsite Manufacturing Construction: A Big Opportunity for Housing Delivery in Nigeria*	Barriers and potential benefits for the adoption of Offsite Manufacturing in Nigeria are presented.
11	(Elnaas, Ashton, & Gidado, 2009)	*Decision-making process for using off-site manufacturing systems for housing projects*	Factors affecting the use of Offsite manufacturing in the UK and conceptual model for decision marking are discussed
12	(Arif, Goulding, Sawhney, Iyer, & Pour-Rahimian, 2013)	*Offsite Construction Priorities In India: An Exploratory Research*	Implementation roadmap and priorities for adoption of off-site construction in India are presented
13	(Nanyam, Sawhney, Basu, & Prasad, 2015)	*Selection framework for evaluating housing technologies*	Multi- attribute evaluation framework of mandatory and desired & preferred attributes are presented along with a case study application

2.3. Adoption of Offsite construction in Europe, Australia, Japan and UK

Several differences between offsite commitment and delivery owing to lack of sufficient infrastructure is highlighted by a researcher in the context of Australian housing. Firms such as prefab AUS, Australian research training for prefabricated housing are bridging the gap [7]. Australia has an adoption percentage of 3% in prefab housing when compared to Japan which has 13% adoption of modular offsite construction. [8]. In addition to Australia, UK has incorporated offsite methods into their Vision 2020 plan for construction sector. When it comes to construction industry at European Union, a research project titled ÈManu BuildŠ is formulated to improve the uptake of offsite practices [6]. European Union is always ahead in terms of adopting offsite production in construction sector and as a step towards training, Virtual reality environment has been researched to resolve all the problems associated with offsite construction training to job workers. [9]

2.4. Research Gap and Indian scenario

Several researchers over the last ten years have tried to focus on the project coordination, integrated design, risks, barriers and advantages associated with offsite construction. There were very few researchers [10], [11], [12] who evaluated the adaptability of emerging technologies in the construction sector and not specific to offsite construction. This paper tries to fill the gap by presenting a holistic framework for evaluating offsite technologies. Recent examples of offsite construction in India is discussed hereafter to show the prominence of utilising the offsite construction in Indian projects. IndiaÑs first offsite manufactured building was constructed at a university campus at in Mangalore which is a residential project comprising three eight-storey buildings summing up to 100,000 square feet. Time of construction was reduced drastically from 24 months to 9 months. Entire elements of the building such as wall panels, hollow core slabs, facades, windows, doors and toilets were prefabricated with all the services embedded in. Innovative graphic concrete technology is adopted for the first time [13]. Construction of a USD 50 million commercial building in Bengaluru utilising offsite construction with 1.5 million square feet is scheduled to be completed in 13.5 months resulting in 50% time and cost savings to the stakeholders involved. Double walling technology is utilized for the project to ensure timely delivery with utmost quality [14].

3. Objectives & Methodology

The research aim is to evaluate different emerging technologies in Offsite Construction so as to utilize them in housing construction and rank these technologies based on different attributes so as to adopt the best and suitable technology. The research aim is further bifurcated into the following objectives:

- **Identification of attributes that affect the adoption of off-site construction technologies**: Detailed literature review is carried out to identify the attributes that affect the adoption of off-site construction technologies. A literature review is summarized bellow in Table 2 listing out attributes identified by various researchers to evaluate technologies in construction.

Table 2 Attributes identified in the literature for evaluating new technologies

Author	Parameters for Selection of Appropriate Technology
(Sultan, 2004)	Ease of construction, Production rate, Maintenance, Material Cost, Capital Investment, Adaptable, comfort, Acceptance, Professional Cost and Sweat Equity
(H. , Gidado, & Ashton, 2014)	Time, Quality, cost, predictability, productivity, Interface Issues, Environment issues, performance, labour, lack of space, safety, project complexity, logistics, resource availability, planning issues and market condition
(Azhar, M.S, & Ahmad, 2013)	Design related Module related, site attributes, Labour considerations, Manufacturing unit, Transportation and equipment, organisation readiness, codes, permits, technology related, Owners perspective, project risk factors, Sustainability, finance-related factors
(Hashemi, 2015)	Size of project, design quality, total costs, speed of construction, quality of products

(Arif, Bendi, Sawhney, & Iyer, 2012)	Client influences, building regulations, skill shortages, environmental impact, Health & Safety, Quality, Onsite duration, time and cost
(Pan, Dainty, & Gibb, 2012)	Time, cost, quality, Process, safety and sustainability, procurement, regulatory issues, legal issues
(Ganiron Jr & Almarwae, 2014)	Structural properties, sound insulation, Durability, finishes, design, construction, economic factors
(Elnaas, Ashton, & Gidado, 2009)	Speed of construction, quality, interface problems, environmental impacts, overall cost, return on investment, people culture, availability of plant & equipment, clients experience, information availability, skills of the team,
(Nanyam et al. 2015)	Functional requirements, sustainability, finish quality, economic viability, maintenance, constructability

- **Development of Framework of attributes for evaluation of offsite construction technologies**: Attributes are identified through expert review of offsite technologists working in the field and are categorized into standard and offsite attributes. The methodology is captured in Figure 1.

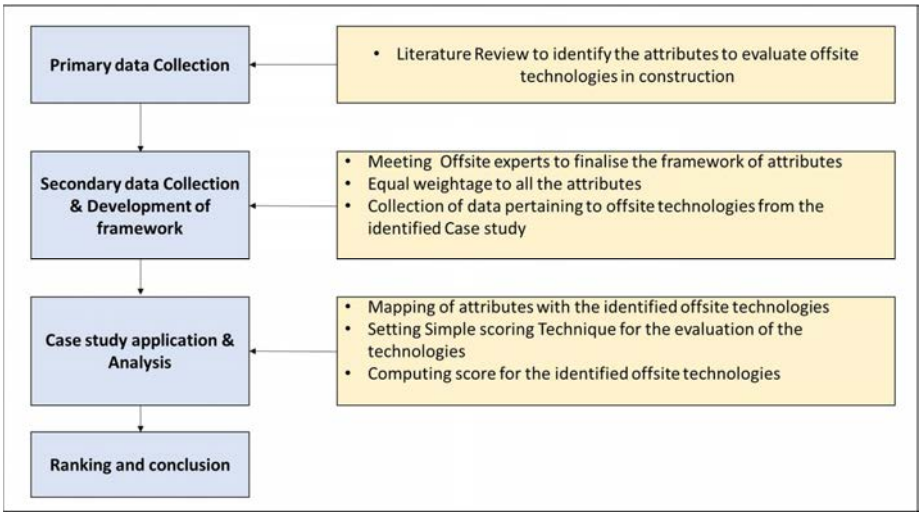

Figure 1: Research Methodology

- **To present a subjective and quantitative assessment of the technologies mapping the considered attributes**: A case study is taken for the application of the developed framework to assess the offsite technologies mapping the considered attributes. Comparing various technologies based on the set of attributes using simple scoring technique is carried out to rank these technologies based on the evaluation framework of multi attributes. Rating is taken as 10 for high compliance, the medium is given as 6, and Low is given as 3 and 0 if it is not applicable on a scale of 10. The Same scoring is used for five scale scoring also.

4. Offsite Technology Evaluation Framework

Based on the extensive literature review, certain attributes were identified and classified into standard and offsite specific attributes. Brainstorming was done with the help of offsite experts, and a framework of attributes along with assessment criteria was arrived as shown in Table 3.

Table 2 Framework of Attributes for selection of Offsite technologies with scores

Standard Attributes	Assessment criteria	Score

Stability requirements	Load considerations & performance of Joints	10
Design Efficiency	Carpet Area/Super area	10
Thermal Comfort	Compliance with IS 3792:1978	5
Water Resistance	Requirement of waterproofing	5
Finish Quality	Requirement of additional repairing	5
Offsite Specific Attributes	**Assessment criteria**	**Score**
Economies of scale	Minimum Dwelling units required	10
Cost Savings	% Cost savings	10
Skilled Labour requirement	Level of skilled labour required	5
P&M Requirement	Huge P&M requirement	5
Time savings	% Time Savings	10
Environmental Aspects	Use of local Materials	5
Generation of waste	% wastage w.r.t conventional	5
Transportation	Location of plant from site	5
Interface issues	Presence of issues	5
Technology transfer	Possibility of transfer	5

5. Case Study

A project executed at Vijayawada, Andhra Pradesh, India is considered for analysis. Plan of the unit is kept standard for the implementation of various technologies on the Model Project. The project sponsor decided to keep the architectural plan similar for all the units with standard area i.e. 300 square feet. Four technologies are considered for evaluation, and their basic characteristics along with implementation difficulties are notified in Table 4.

Table 4: Description of four technologies used for the project

	EPS panel walls and roof technology	**Precast Technology**	**VME Precast Pvt. Ltd.**	**Composite Steel Structure**
Description	This technology involves the construction of conventional foundation with EPS panel walls and roof further Shotcreting is done on the EPS Panel and final finishing.	This technology involves construction of Conventional Foundation with Precast wall elements and HCS (Hollow Core Slab)	This technology involves installation of Precast Foundation with modular walls and Hollow Core Slab followed by finishing	This technology involves the in-situ construction of the foundation, erection of structural steel columns and beams upon which the installation of precast panels (EPS sandwiched between Cement plaster boards) is done. System has provision for Aluminum Window and Door fittings
Materials Used	Conventional construction material for casting foundation like Concrete, Rebar, etc., EPS panels, Wireframes for joining of panels in different shapes, Binding Wire and Formwork	Conventional construction material for casting foundation like Concrete, Rebar, etc. Hollow Core Slab panels, Tilting table for casting the panels, Stacks for precast panels, GP-2 for grouting, Formwork	Conventional construction material for stairs etc. like Concrete, Rebar, etc., Precast Foundations, Precast Plinth Beam, Precast Slab, 3 Dwell units, GP-2 Grout and Foam Spray for joints	Conventional construction material for casting foundation like Concrete, Rebar, etc., Wall Panels, Hollow Square steel conduits, Steel I-section, Rectangular Conduits, Steel Channel section, Bolts, Fiber Cement Mortar for joints

Equipment	Welding Machine, Portable Concrete Mixer, in this case, Shotcrete Machine, Crane F15	Concrete Pump, RMC can also be used in case of mass production, Crane/Hydra	Crane F 15	Welding Machine, Portable Concrete Mixer, in this case, Crane/Hydra
Implementation Difficulties	ˇ High workmanship and labour intensive job ˇ Requirement of special equipment for Shotcreting ˇ Lack of skilled manpower for handling special equipment ˇ Difficulty in gaining the set thickness of the wall mostly it exceeds the normal thickness which can reduce the carpet area. ˇ Difficulty for modification (might be expensive) ˇ For future expansion, provisions need to be taken care of during the design otherwise not possible.	ˇ Careful Handling and stacking of Precast elements ˇ Team faced problem in casting elements on flat plate ˇ Work was stalled as the team was setting up Tilting table for Precast	ˇ Involves minimum In-Situ construction work ˇ Careful handling of Elements ˇ Joints need to be tested for water tightness ˇ Assembly of elements needs proper supervision ˇ Skilled Labour required ˇ Transportation and Handling can prove to be an issue.	ˇ Requirement of highly sophisticated tools and equipment ˇ Requirement of Good precision in working ˇ Design compatibility for expansion in future up to three more floors. ˇ Conduits will not be concealed as it might result in cracking of the panels ˇ Translator required to communicate with the site team. ˇ Site logistic needs to be planned properly so as to avoid any clashes and material wastages due to mishandling of panels etc. ˇ The requirement of a skilled workforce for installation of various panels. ˇ Transit delay in imported material could result in project delay ˇ High import duties and transportation cost.

6. Results and Discussion

Developed framework of attributes is applied to the identified four offsite construction technologies by assigning scores to each of the attributes. All the technologies are rated individually based on the assessment criteria provided and their compliance to each attribute by the group of experts. Further to that, all the technologies are compared based on their ratings for the standard and offsite specific attributes as shown in Figure 2. The comparison is made based on the total score which technology was given based on the performance of each head. Also, the total score of each attribute under the standard and offsite specific has been calculated with a total score of the sub-attribute under the head attribute. The overall score for the standard attribute is 35, and the offsite specific attribute is equal to 65. All the technologies were rated based on the same criteria, and their performance has been ranked based on the score obtained.

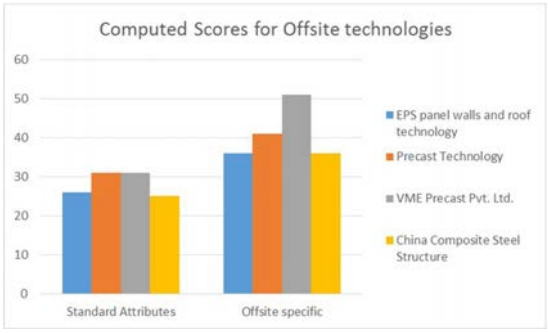

Figure 1 Computed Scores for Offsite Technologies

The major inference that we can derive from the above analysis is that the VME Precast has the maximum score when compared to other technologies i.e. 82 out of 100. It is one of the best technologies that are being demonstrated on the

site followed by Precast, then by EPS panel system and Composite Steel Structure in the respective order. So we can adopt VME Precast as one of the most suitable options for execution of the project. VME Precast qualifies under the volumetric construction. Refer Figure 3 for the relative scores w.r.t other technologies. Secondly, precast technology is also equally good option except for certain attributes, and this qualifies under the head of the panelized method of OSC. The performance of EPS & Composite is better when it comes to fire resistance, thermal comfort and acoustic performance. Whereas VME Precast supersedes other technologies when it comes to attributes such as cost, interface, time and finish quality. Constructability is also a bit more tedious in other technologies. When considering Composite technology, it involves a lot of in-situ work apart from having prefabricated and precast components.

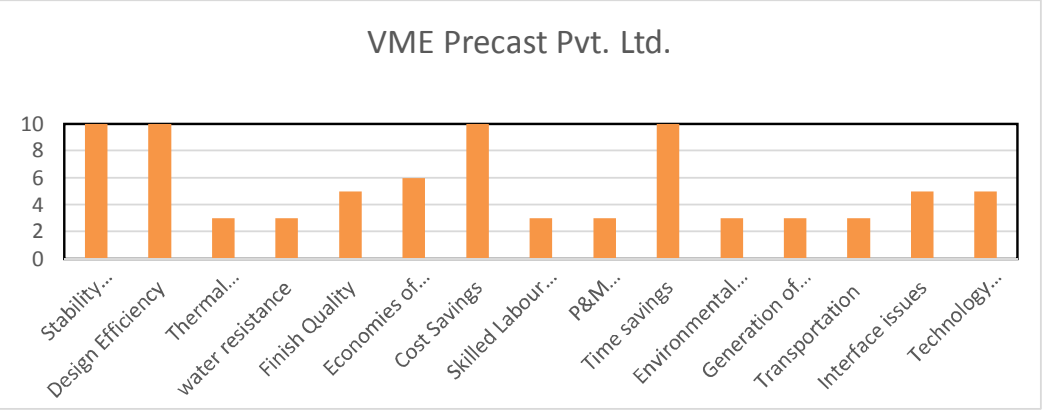

Figure 2 Analysis of VME Precast relative with respect to other technologies

7. Conclusions

To overcome the shortage of housing units in India, usage of offsite construction is mandatory considering different parameters. The results of this study have evaluated the scores for four different offsite technologies based on the finalized attributes. Based on the relative scoring with respect to conventional systems, it has been observed that some technologies are good when it is evaluated against thermal comfort, while some scored better in the aspects of cost and time. Based on the rating and the total score evaluation, the technology which obtained the highest score is VME Precast. It has got maximum score in finish quality, fewer interface issues, time and cost savings when compared to other offsite technologies. There are certain aspects lagging for this volumetric construction technique such as economies of scale, erection requirement, and proximity of the plant to the site which needs to be worked out to make it a perfect choice for adoption. Other technologies can also be adopted by working on some of the aspects such as the water resistance, finish quality, and design efficiency. These scores are valid for EWS and LIG housing adoption itself, and it might change when it comes to adoption in MIG (Middle Income Group) and HIG (Higher Income Group) housing where there is a requirement for good architectural flexibility, furniture, and fixtures. VME Precast technology being into the category of volumetric construction provides a great opportunity for offsite construction. Most of the work is carried in a controlled environment which improves the efficiency of construction by reducing the workmanship at the site and in-turn reducing the wastages and involvement of more and more work-force at the site. Also, it will contribute to sustainability aspects by use of more sustainable materials thereby releasing less pollution in the open environment. To make the process more efficient, many techniques of manufacturing can be adopted such as Lean, 5S, Six Sigma or the Last Planner system. Integration of Lean principles and green concepts can improve the efficiency of Offsite construction particularly volumetric construction. One of the shortcomings of VME Precast is their presence only in the southern part of India. More agencies are be encouraged to adopt such technology in various parts of India to overcome the shortage in housing stock. In addition, research and development needs to be encouraged for catalysing the adoption of offsite technologies.

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