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EXPLORATION OF AVAILABLE OFFSITE CONSTRUCTION METHODS IN INDIAN CITIES FOR COST AND TIME SAVINGS IN HOUSING CONSTRUCTION

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ABSTRACT

Observing the current rate of growth of Indian cities and their future predictions, there is a huge demand for urban housing. India aims to achieve adequate safe and affordable housing for all by 2030 and the current shortage of dwelling units is at 20 million and rising. Achieving such huge demands in a short time using traditional construction methods have a lot of drawbacks like rise in pollution, construction waste, worker safety etc., which in turn cause hikes in cost and time of completion of a project. Offsite techniques can help mitigate or avoid a lot of these ill effects by transferring all impeding activities to a controlled environment. Here we identify the suitable and most convenient approach of construction that can be followed by comparing offsite construction with traditional construction and composite construction. Then evaluate the identified offsite building techniques available to us and, based on Cost and Time parameters to identify a most feasible solution, by tabulating the time and costs incurred. This is done by AHP analysis on basis of technical, manufacturer specifications, on- site performance and literature. Finally we can deduce the most suitable offsite technique for mass housing construction for low to medium rise construction and come to a conclusion that choosing GFRG we would reduce overall cost and time of construction on site for housing and it could help to achieve speedy and cost effective construction solution to best suit the growing needs of the urban settlements.

Keywords: Affordable Housing, Offsite Construction, Prefabrication Construction, Industrialised Construction

1. INTRODUCTION

India is a country with a number of fast growing cities and the future predictions show a huge need for developing housing and shelter for the same under a short time period. To keep up with the growing demands, there is a dire need to explore various fast and optimal construction techniques to and close the gap and reduce the shortage of housing and supporting infrastructure. Offsite construction would be a suitable solution to this issue.

Offsite construction is a construction technique where Designing manufacturing and fabricating of building elements are done in a factory or

manufacturing unit and then assembled or installed on site. These could involve a part of a building or unit or a preassembled module. Such methods greatly reduce the time, cost of construction compared to the traditional methods. This is possible due to reduced labour charges, better control, reduced wastes and proper management under a controlled setting. However these techniques are less commonly used, as opposed to traditional techniques in the country. This is due to lack of knowledge on available options and direct benefits of using these methods.

1.1. LITERATURE REVIEW

Prefabrication was extensively used in housing post-World War II, all across Europe and other areas, even in notable projects of renowned architects. However, the early use of prefabricated projects often presented problems and performed poorly. With the current advancements in technology a surge in osm techniques was noticed and Hosseini (2018) performed an analysis on 501 journal articles to examine the state of off-site construction research and identify the current dominant research themes. It was pointed out that there is a need for research on operational, management and strategic considerations in the process of expending the offsite construction practices.

Zakaria (2018) reviewed the literature to identify factors that influence decision making process when using offsite strategies in the housing sector. They categorized influencing factors as contextual factors, structural factors and behavioral factors.

Razkenari, M., Fenner, A., Shojaei, A., Hakim, H., & Kibert, C. (2020) In a US based study on the comparative processes involved in offsite construction, critically analysed all the steps involved. Important factors were identified by a questionnaire survey based analysis, which identified core elements to form a conclusive report. Drivers and Barriers, Swot analysis was done. They established that contractor knowledge, inflexibility and knowledge gap were main barriers and design innovations.

Attouri, E., Lafhaj, Z., Ducoulombier, L., Lin'eatte, B. (2022) conducted a france based study on OCM owing to the low levels of Ocm practices in France. A literature review was done on benefits and questionnaire survey was conducted to get realistic feedback. Then a frame of benefits, willingness and hindrances were identified. And the measures to be taken for the implementation were consolidated. They identified long coordination work between the design office and the prefabricator, Design changes and obligations to select low cost vs better value output and High initial costs as barriers to implementation.

Pan, W. P. R., & Sidwell, R. (2011) resolved the doubts and un-surety in the UK's industry in the practical application of OCm by means of 20 case studies over a 5 year period, for buildings using various techniques and the actual cost benefits were summarised, and the easiest and cheapest option was identified. They concluded that OCms were beneficial and the scope for future use was highlighted.

Gan, X., Chang, R., Zuo, J., Wen, T. (2018) despite theoretical acceptance a lag in practical implementation was studied and analysed. Questionnaires n surveys were taken and the complexities and inter dependencies for implementation were analysed using MICMAC technique and barriers were identified and classified. This research could give policy makers a framework for forming new suitable norms for wider adoption of OCm in construction sector in china.

Nihar (2017) Benefits and barriers to offsite method is discussed and a framework is made for selection of OCm and compares attributes of standard n

offsite methods. And this is then validated by testing the framework on an Indian site using Offsite methods as a case study.

MacAskill, S., Mostafa, S., Stewart, R. A., Sahin, O., & Suprun, E. (2021) to solve the Australian housing shortage due to supply and affordability reasons Ocm was explored on comparison with traditional methods. The extent to which the shortage can be solved using these methods mainly in housing sector of 2-3bhk units was derived. These results could directly benefit govt supported housing strategies.

1.2. RESEARCH GAP AND CONTRIBUTION

Prior studies have been done on the benefits of offsite construction and it has been shown that it is beneficial in achieving cheaper construction, reduced construction time, reduction in site related safety incidents, reduction in pollution levels. But there was no conclusive comparative study based on the current Indian market scenario and in turn it was not available to the stake holders the other methods and technology available to them. Hence the current study focuses on identification and comparison of the locally available methods to the traditional methods that identifies and frames the aspects involved. Then analyse the findings mainly based on cost and time parameters. This would in turn that would help us identify a suitable technique as per the main priorities to achieve our goals.

2. METHODOLOGY

The aim of this study is to evaluate the currently available technologies in Offsite Construction that can made use of in construction of mass housing and rank these techniques based on various aspects that are important in this context in order to adapt the best and suitable technology.

Analytical Hierarchy Process developed by Thomas L. Saaty (1980) is a method to solve the problems of multi criteria decision making in which both qualitative and quantitative criteria can be considered. It works on paired comparison and helps with judgement and calculations. Here we can chose to analysis the aspects if this study using AHP owing to its simple structure. In accordance with the Miller's Law, basing on an individual's ability to normally compare only 7±2 items at the same time, this study looks into the aspects of attractiveness, convenience, easy access, features of storage, similar competitors, installation time and cost as main factors of evaluation.

A similar approach to analyse the factors in the current context can be done, as observed from the structure of AHP model in the ranking of effective factors on the cost, time and quality of MHBPs (Mass House Building Projects) in Iran. This can be applied here to analyse the various factors under the 3 categories of cost time and quality.

The basic methodology for this study will be a 3 stepped process as given by the chart below.

Figure 1

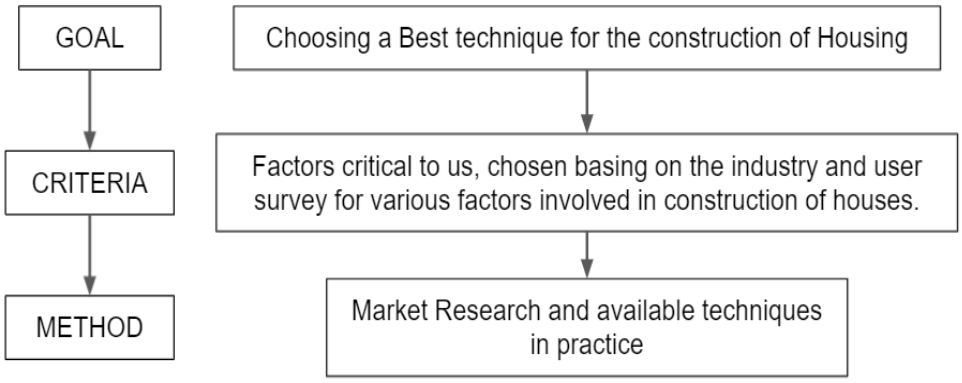

Figure 1 Methodology of the Study

From literature studies we can derive upon the important factors for this typology of construction. They are in order of Priority Time, Cost, Ease of construction and Quality or the aesthetic finish of the final product.

These identified factors are then used to evaluate the suitable technique or the construction approach that would be most suitable to implement and meet the priorities. Applying the AHP process to evaluate the final result between the selected materials Pair wise comparisons per each category can be worked out and with the help of their respective weightages Results can be calculated, and the importance of each factor of comparison can be identified by the respective weightages and values obtained.

Figure 2

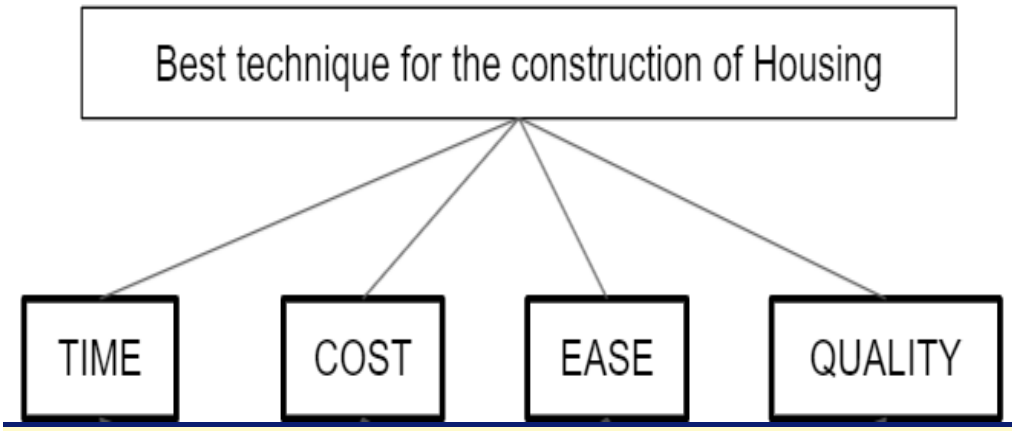

Figure 2 Important Parameters Considered

2.1. MATERIALS CONSIDERED

From market study and analysis a versatile material is used for comparison as composite construction was found to be ideal case of for offsite construction implementation and using the OCM for the shell or the super structure of the buildings.

Three such materials have been identified for their versatile usage as walls, Vertical Transportation application and their use as flooring and roofing. This similar category evaluation gives us a base parameter for comparison,

applicability and similar versatility in usage which in turn adds to ease of implementation without involving multiple new materials in the construction project.

Then the 3 case scenarios are considered and all their cost components and related values are summarised from the example project, and a model is synthesised. When the final matrices are evaluated and the one with the highest weightage would be the most suitable technique for implementation.

2.2. CASE STUDY

A residential construction project that was executed at Chennai, Tamil Nadu, India has been considered for analysis. This residence is Plan of the unit of a small standard EWS housing unit is considered for the analysis and the same plan is kept constant as a model project in order to apply the other technologies considered for the implementation for evaluation.

Figure 3

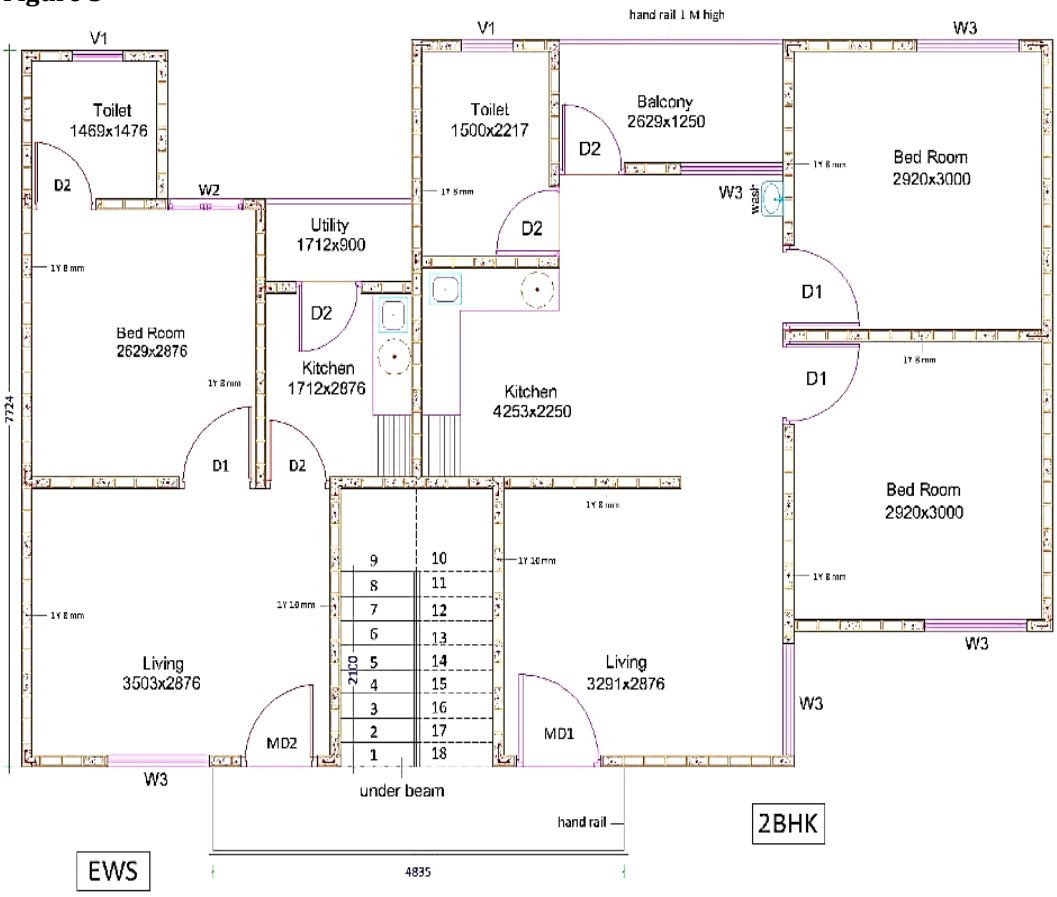

Figure 3 Typical Floor Plan Considered for Analysis

Three technologies are considered for evaluation, and the basic characters and description of each, the implementation difficulties of each method are noted below. The systems considered are mainly precast or hollow sandwich panel roof wall and slab systems as it is easier to evaluate similar systems more precisely as opposed to varied systems or steel frame structures.

The systems chosen are considered on the factors of similar life, similar appearance and performance for the considered end use.

1) EPS panel walls and roof technology

Description: Construction using these panels requires a conventional foundation on which EPS panel shall be installed as the base walls and also as roof. After that, the EPS Panel is shotcreted, and final finishing is carried out.

Materials used: Conventional material is used for construction of the foundation and it is casted using Concrete, Reinforcements etc.; EPS panels; Wireframes which are used to link these panels into various shapes; basic Formwork and Binding Wire.

Equipment: Portable Concrete Mixer (in the current scenario), Shotcrete Machine, Welding Machine, Crane F15

Difficulty in Implementation:

- It requires a high workmanship and is labour intensive
- Special equipment is Requirement for Shotcreting
- Shortage of skilled personnel to operate special equipment.
- Difficulty in maintaining the pre requisite wall thickness and in most cases it exceeds the set thickness, reducing the carpet area.
- Difficult to modify once casted and modification would be expensive.
- Advance provisions need to be made for future expansion during the design phase, failing which easy expansion is not possible or practical.

2) VME Precast units

Description: Construction using this precast units provides us an option to even assemble the foundation system using the precast units on site and with modular walls and a Hollow Core Slab for roof which is done for final finishing.

Materials used: Conventional construction material like Concrete and reinforcement etc. can be used for stairs; Rebar, Precast Foundations or footings, Precast Beams for plinth, Precast Slab for roof; grouped unit housing plan; GP2 Grouting compound and a Foam Spray (ccSPF) is used for joints.

Equipment: Crane (4x4 – 14 tonne)

Difficulty in Implementation:

- Minimum work is done In-Situ and needs maximum pre
- Careful handling is required for all the Elements
- All Joints and seals need to be tested for water tightness
- Proper supervision is a must during the assembly of elements
- Skilled Labour is required for careful handling, assembly.

Transportation of these precast elements and Handling can cause issues, due to the level of care and attention required to not damage them in transit or loading and installing etc.

3) GFRG Rapid wall construction technology

Description: These are large building panels that are significantly load bearing. They are manufactured using calcined gypsum, glass roving fibres for additional reinforcement and other special additives. This product can be utilised in the entire building as various uses in floors, roofs, parapets, sunshades, staircases and lift wells. This can significantly reduce the need for any in-situ casting of RCC.

Materials Used: Conventional construction material for foundations and plinth, forming the base of the building like Concrete, Rebar, etc. precast walls and

slab panels with on-site assembly and installation, additional rebar and reinforcement

Equipment: Crane fitted truck, Lifting jaws and spreader bars, under panel spreader bar, wooden blocks, Adjustable lateral props, Clamping system

Difficulty in Implementation:

- Floor plan and wall locations have to be kept constant for all the storeys, in multi-storeyed buildings.
- Strict following of the provided guidelines is necessary while cutting the panels, transportation, and erection.
- Strict adherence to guidelines has to be taken at joints, during application of primer and waterproofing.
- Spans larger than 5m are not preferable.
- Building height is restricted to 6 to 10 floors
- Curved walls and roof slabs are not implementable.

3. ANALYSIS AND FINDINGS

Analysis is done on the 3 methods by allotting a weightage based on priorities chosen. In current scenario since Time is considered the highest factor and a rating for time vs cost is taken as 7 for very strong and demonstrated importance is considered as delays are commonly observed in the majority of the ongoing mass housing projects. Closely followed is the tie to cost relation for the east of construction and implementablity at a weightage of 5 with Strong Importance and Quality of the finished product aesthetics are weighed at 3 for its moderate importance in our considered area of study.

Table 1

Table 1 Importance Criteria for AHP Matrix

Rating Scale	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
2	Weak	Between equal and moderate
3	Moderate importance	Experience and judgment slightly favor one element over another
4	Moderate plus	Between moderate and strong
5	Strong importance	Experience and judgment strongly favor one element over another
6	Strong plus	Between strong and very strong
7	Very strong or demonstrated importance	An element is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	Between very strong and extreme
9	Extreme importance	The evidence favoring one element over another is one of the highest possible order or affirmation

Evaluating the matrix from the above considered values for each combination of the factors chosen we can calculate the hierarchy by the following table, with chosen parameters taken along both the rows and columns.

Table 2

Table 2 AHP Matrix Evaluation

	Time	Cost	Ease	Quality
Time	1	1/7	1/5	1/3
Cost	7	1	2	3
Ease	5	1/2	1	3
Quality	3	1/3	1/3	1

Then calculation for the Nth root of the above values is done for each parameter. I.e. Time, Cost, Ease and Quality to obtain 4 values that form the A1 Matrix for further evaluation is formed from the obtained values.

Nth root to product of the values:

TIME = (1x1/7x1/5x1/3) ^ ¼ =0.31239

COST = (7x1x2x3) ^ ¼ =2.5457

EASE = (5x1/2x1x3) ^ ¼ =1.654

QUALITY = (3x1/3x1/3x3) ^ ¼ =0.759

A1 MATRIX is given as $\begin{pmatrix} 0.3123 \\ 2.5457 \\ 1.654 \\ 0.759 \end{pmatrix}$

SUM = 0.3123+2.5457+1.654+0.759 =5.2728

Weighted priorities of each criteria are derived and a second matrix is formed for the suitable proportional split up of the factors considered and their grading.

0.31239/5.2728 = 0.059246

2.5457/5.2728 =0.4828

1.654/5.2728 =0.31385

0.759/5.2728 =0.1441

A2 matrix is given as: A2= $\begin{pmatrix} 0.059246 \\ 0.4828 \\ 0.31385 \\ 0.1441 \end{pmatrix}$

The 2 matrices thus obtained are again checked for consistency and crosschecked for the assessment of the assigned weights. Checking the obtained matrix weightages for consistency by adding proportions into a whole number 1.

Check A2 = 0.059246+0.4828+0.31385+0.1441 =1

Figure 4

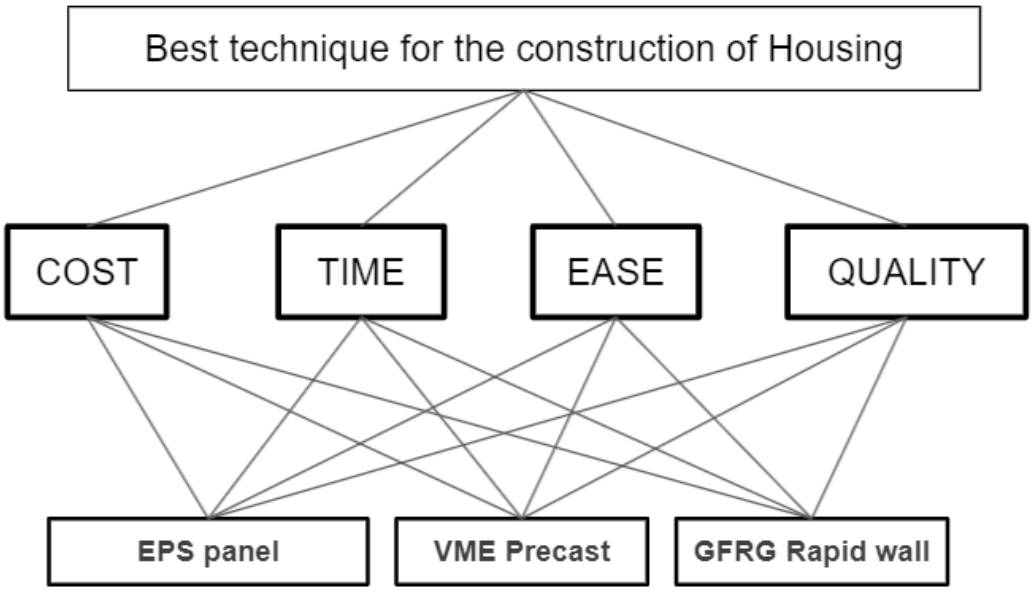

Figure 4 AHP Analysis Chart

Then the 3 case scenarios are considered and all their cost components and related values are summarised from the example project, and a model is synthesised.

The tabular matrix is formed for the chosen products and their respective values for cost panel per unit area, Time taken to erect the structure on average from the market and literature, Ease of construction on relative comparative grading, and the quality of finish obtained from the finished product on a comparative scale. It is given by the matrix B1 as below.

Table 3

Table 3 AHP Matrix B1

	Cost	Time	Ease	Quality
EPS panel	95	35	4	3
VME Precast	354	25	3	5
GFRG Rapid wall	238	30	5	4

This matrix is evaluated by AHP method, considering the highest ranking of each criteria based on the 4 parameters to derive Matrix B2.

Table 4

Table 4 AHP Matrix B1 Evaluation

	Cost	Time	Ease	Quality
EPS panel	95/95	25/35	4/5	3/5
VME Precast	95/354	25/25	3/5	5/5
GFRG Rapid wall	95/238	25/30	5/5	4/5

Table 5

Table 5 AHP Matrix B2				
	Cost	**Time**	**Ease**	**Quality**
EPS panel	1	0.7143	0.8	0.6
VME Precast	0.26863	1	0.6	1
GFRG Rapid wall	0.39916	0.8333	1	0.8

The product of both matrices A2 and B2 for the ranked variables and the relative weightage gives us the final result

$$\begin{bmatrix} 1 & 0.7143 & 0.8 & 0.6 \\ 0.26863 & 1 & 0.6 & 1 \\ 0.39916 & 0.8333 & 1 & 0.8 \end{bmatrix} \text{X} \begin{bmatrix} 0.059246 \\ 0.4828 \\ 0.31385 \\ 0.1441 \end{bmatrix} = \begin{bmatrix} 0.71464 \\ 0.83111 \\ 0.85111 \end{bmatrix}$$

Table 6

Table 6 AHP Final Matrix	
EPS panel	0.74164
VME Precast	0.83111
GFRG Rapid wall	0.85111

The final product matrix obtained gives the respective weightage and score for the 3 categories and the same values can be tabulated as given above. The highest weightage obtained here can be observed for GFRG method and it would be the material to give us an optimum solution.

4. DISCUSSIONS

Among the three evaluated categories of construction methods, it is observed that the GFRG panels were considered to be overall suitable for the use in housing construction with a weighted score of 0.8511. Only closely followed by VME pre cast panels with a 0.83111, followed by Eps panels with 0.74164.

These evaluated scores can be valid for LIG housing and EWS units adoption and these scores can change when it comes to implementation and modification of these techniques for use in larger luxurious scales such as MIG Housing (Middle Income Group) and HIG Housing (Higher Income Group), where a decent architectural freedom is required in design and planning, and there is a higher need for providing custom furniture, and fixtures.

One of the drawbacks of GFRG Panels is that it exists only in southern India and it could lead to cost overshot due to transportation to other localities. Certain aspects are currently lagging for implementing this construction technique like the need for a skilled crew of workers, Waterproofing professionals, Erection crew and specially trained engineers for construction with an experience in GFRG construction. On site concreting works (4 pours required), requirement of equipment and skill needed for elements erection. Also to ensure that GFRG is the ideal material to use in construction, it is necessary to ensure the easy access of the production plant from the construction site.

The other technologies we studied and analysed can also be adopted in certain cases of housing by working out some of the tricky aspects involved such as the

water resistance, final quality of surface that's obtained, and the versatility in design. Since a lot of the work required in this process is undertaken in a controlled setting, workmanship at the site is kept to a minimum and this in turn improves the of construction efficiency by keeping the construction wastes generated to a minimum and reduces the need to enrol a larger work-force at the site. To overcome housing shortages, more authorities are encouraged to introduce and study such techniques in different parts of the country.

5. CONCLUSIONS

To overcome the current housing shortage in India, it's apparent that using offsite construction is the option that's best suitable considering the various parameters of cost, speed and efficiency. Various studies concluded that the barriers and drivers to implementation can be overcome easily and in case of satisfying mass needs of housing this type of construction will be the most suitable. The current study evaluated the current available techniques of offsite construction based on the finalized important attributes of cost, time, ease and quality.

Based on the relative scoring and importance of the attributes, GFRG panel system has got maximum score in ease of finishing of work, fewer issues with the interface, and higher savings of cost and time when compared to other offsite technologies for LIG housing. Overall sustainable construction can be achieved due less wastage and pollution due to a contained manufacturing and assembly process. But drawbacks is that this method needs a further development, improved proximity and availability to be suitable for use in other parts of the country. Additional research and development is necessary for wider applicability. Furthermore, by the integration of lean principles with the green construction concepts along with these techniques, we can improve the efficiency of off-site construction, especially volume construction.

CONFLICT OF INTERESTS

None.

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None.

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