# Critical Study of the Technological Interventions on the Evaluation of Affordable Housing to be Implemented Under PMAY

**Sai Charan Madala, SS.Asadi, D.Satish Chandra**

***Abstract: India's rapid urbanization associated with rapid growth has created the congestion, due to large scale migration into urban, on basic amenities like shelter, water and sanitation. The Government of India estimated a shortage on housing as 18.78 million units within LIG and MIG groups, which necessitated the need for the development of new technologies for low cost housing yet durable, sustainable and easy to build. The Indian government has launched a scheme, in June 2015, to meet this challenge under the name of 'Prime Minister Awas Yojana (PMAY)' with a slogan 'Housing for all by 2022', to address the housing problem in India and established a technology submission, Building Materials and Technology Promotion Council (BMTPC), to explore and identify new technologies that can be adapted for this scheme. Out of the (16) technologies recommended by the BMTPC for this scheme, selection of an optimal technology for given set of building conditions is a challenge for the engineers. This paper provides a solution for challenges in the selection of a technology like, affordability, sustainability, performance and ease of building in mass housing. Issues associated with all of these challenges have been considered to define the objectives of the project and for benchmarking the selection criteria. PUGH method has been used as a tool for bench marking. The Results from this PUGH method have highlighted that most of these technologies cater to the requirements of the building elements not for the total building system. These technologies have shown that they are highly inconsistent in respect of their performance. This method had given an opportunity to have deep insight into the performance of one technology over the other and hence has provided a benchmarking for the selection of appropriate technology.***

***Index Terms: LIG, MIG, PMAY, BMTPC, sustainability, benchmarking, PUGH method.***

## I. INTRODUCTION

In 2012, the housing shortage in India as estimated was 18.78million units (National Housing Bank, 2013), based on the census record and various other individual studies. Some other studies have projected the Indian urban population to reach 590 million by 2030 (McKinsey Global Institute, 2010) and shortage of housing to reach 110 million units by 2022 (KPMG, 2014). The housing sector in India suffers certain setbacks (National Housing Bank, 2013) like non-availability of land, encroachments, lack of funds, clumsy titles of land, unclear demand and supply, financial constraints dueto pressure on land and operational constraints on infrastructure. Also, the issues like shortage and expensive building materials, unscientific and poor management of construction, Lack of clarity on use of industrial waste and pressure on use of non-renewable resources in developing countries (Celly, 2007), adds fuel to the shortage of housing issue in India. But the use of alternate housing / construction technologies that can save time, reduce cost, create sustainable and quality housing system is a possible potential option to address all the housing related issues in India. Keeping in view the above, the Government of India, with the launch of prestigious mission 'Housing For All by 2002'has established a technology submission, called 'Building Material Technology Promotion Council (BMTPC)' to develop, certify and deploy technologies that can be adopted for implementation of 'HFA by 2022'.BMTPC endorsed, certified and recommended by Performance Appraisal Certification Scheme(PACS),an ample number of technology options that can be adopted for HFA'2022 with the choice left to the discretion of the implementing agencies for selecting the suitable technology to adopt for mass and low cost housing schemes. But no enough guidelines left for carrying out the comparison studies to choose the best fit technology in a given scenario of implementation of mass / low cost housing schemes to realize the true benefits of the technology. Hence there is need for the implementing agencies / developers to develop and adopt a method that is rational and determines the performance of their technologies. Instead, the development of every new technology has to be governed by the use of the best practices and standards of performance for betterment of their work in progressive manner. So the benchmarking of the technologies is the key for constructing quality and sustainable low cost mass housing projects / schemes like "Housing for All". Typically, a Pugh Method is one such method used to evaluate various alternatives against a baseline. It is also used when only one solution is possible or where there are many alternatives none of which are quite suitable and the optimal alternative is required. It can also be used to choose the best aspects of the various concepts to produce a hybrid, which hopefully will be better than the alternatives used initially. This study tried this tool for benchmarking of the technologies that are recommended by BMTPC for housing depending upon their suitability and performance based parameters.

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*A. SUITABILITY OF TECHNOLOGIES FOR HOUSING*

Our materials for construction, for the techniques and technologies of construction we adopt, are sourced from either natural or manufactured, impacts the cost of construction leading to escalation in building cost and affects the sustainable development. Hence the use of materials resulting from the renewable resources, Industrialization of construction, recycled building materials, Implementation of improved construction techniques and technologies, development of pre-caste building component systems are the need of the hour (Jha, 2014). Hence the construction profession has been added with a new dimension of expertise to adapt to explore, develop, select, adopt, deploy and employ new technologies and designs that are suitable to the scenario of consideration and context. So the knowledge on a technique of technology selection process with a due consideration of factors under the context of interest and benchmarking them has become a pre-qualification for a construction professional for technology implementation.

*B. FUNCTIONAL NEEDS*

Understanding the functional needs of housing is the essential part of this benchmarking of technology selection process. Anchoring these functional needs to the application of building codes and standards of performance, deriving the practices, procedures and product specifications that are compatible with the regional diversity and to be relevant to local context.

*C. SUSTAINABILITY NEEDS*

Selection of construction technology is also required to be relevant to support the resilient urban settlements that are responsive to climate change and other concerns (Globally recognized, UN-HABITAT-III-17, 2015). Hence, the selected construction technologies must be sensitive to comprehensive sustainability determinants for the benefit of good health, wellbeing, wealth, good social life and environmental sustainability. (As per the development, UNEP, 2013a). Criteria that measures the above in the building system are energy efficiency, materials, efficient water system, living comfort and sustainable site development. UNEP (2013a) too enlists these parameters for addressing the environmental aspects of sustainability. This process of technology selection, inclusive of sustainability, compliance to the needs of the ecosystem (as per UN Economic and Social Council, 2015).Green buildings are usually adopt technologies, based upon the aforesaid criteria, which are more of industrial technology centric and can undermine the social and economic determinants of sustainability framework. Easy to maintain and repair, waste management, efficient in creating, distributing and improving better social infrastructure and to provide services to all sections of societies, should be an integral part of building system (sustainable housing development, UNEP, 2013b). This includes the inclusion of universal design principles to cater for the needs of marginalized and vulnerable groups, reduces the gender discriminations and encourages all communities to be mixed socially with a due consideration to support, protect and enhance the landscapes, historical and cultural heritage (UNEP, 2013a). Therefore housing technology selection needs to be founded on a well- conceived sustainability framework.

*D. PERFORMANCE CODES AND STANDARDS*

Construction technology can be ranked based on its technical performance that measure the compliance to various national and international codes such as National Building Code of India-2005 (NBC) etc and standards. The Performance Appraisal Certification Scheme (PACS)is also seen as one such measure to assess the performance of technology of a building system. But by considering the need to be sensitive to the functional and sustainability parameters of building system to set the benchmarks in a holistic manner, in the selection of building technologies, as a current limitation, the parameters with NBC and Indian Standard (IS) codes as a reference were identified for the purpose of this paper.

## II. RESEARCH SIGNIFICANCE

The framework of selection to be developed is based on the criteria that is driven by an objective of beneficiaries' functional needs and standards for better performance. The typical is that the technologies being considered (by BMTPC) for the selection are developed not based on the common technical parameters but are aimed at meeting the stakeholder's functional needs and hence they are comparable. In the existing scenario of comparing the alternative technologies, it may be incomplete to compare them only on the basis of codes and standards, as that approach may tends to arrive at element-wise solutions rather the solution for the entire building system. Hence in this paper, the framework of selection, for benchmarking the technologies, is proposed to develop for the entire building system with wide application possibilities.

## III. METHODOLOGY FOR DEVELOPING FRAMEWORK

As was discussed, the development of this objective technology selection framework is aimed for the projects like PMAY (Housing For All by 2022) which are large-scale targeted and needs an assured performance of technology options. This framework shall be validated through the case of emerging technologies being promoted by the Government of India, under Technology sub- mission (BMTPC) of Housing for All Policy. Next, Areas of influencing performance are identified to derive the area-wise objective driven parameters, terms of demanded qualities and quality characteristics, for benchmarking. The process of PUGH is implemented for benchmarking of technologies based the influence of each of the parameters on the performance of different technologies. The results of the PUGH analysis is then analyzed to obtain comparative metrics of performance of the technologies under consideration. Comparative metrics derived from the PUGH process will give us useful holistic insights into the performance of the technologies with respect to each other and with respect to each standard of performance and hence will provide a sound base for decision making in selection of technology for housing.

*A. EMERGING TECHNOLOGIES UNDER INDIAN GOVERNMENT'S TECHNOLOGY SUB-MISSION:*

The Building Materials and Technology Promotion Council (BMTPC), Ministry of Housing and Urban Poverty Alleviation, Government of India, has been the responsible institution for studying, evaluating, certifying, promoting and recommending innovative construction technologies for adopting to be implemented for low cost mass housing schemes within the country. BMTPC has so far recommended the sixteen technologies, which include 1) **Monolithic Concrete Construction System (Plastic and Aluminum Formwork)**, 2) Modular Tunnel form, 3) Seismo-Building Technology (Precast Sandwich Panel Systems), 4) Advanced Building System – EMMEDUE, 5) Rapid Panels, 6) **Reinforced EPS Core Panel System,**7) Quick Build 3D panels, 8) Core wall Panel System, 9) **Glass Fibre Reinforced Gypsum (GFRG) Panel System, (Light Gauge Steel Structural Systems)**, 10) **Light Gauge Steel Framed Structure (LGSFS)**, 11) Light Gauge Steel Framed Structure with Infill Concrete Panels (LGSFS-ICP),12) **Steel Structural Systems, Factory Made Fast Track Building System,**13)**Speed Floor System (Precast Concrete Construction Systems),**14) Waffle-Crete Building System, 15) Precast Large Concrete Panel System, 16) **Industrialized 3-S system using cellular light weight concrete slabs & precast columns**. Out of the above mentioned sixteen technologies, seven (7) technologies are considered in this paper for analysis and validation of proposed selection methodology, that includes the technology numbers (1), (6),(9),(10),(12),(13) and (16), mentioned above Assessment and comparison of these technologies, on a generic framework, is done as a guide to their selection and presented in the Table-1below. (The data considered in this table did not cover the functional and sustainable needs in a holistic manner to describe them as alternatives). But his table will give us basic insight into each of the technology that they are limited to a specific building elements and their limitations from being representing to the integrated building system.

The following general observations, related to their performance, can be made.

1. These technologies are based on either concrete or steel that limits the use of dissimilar materials and give problems associated with the integrity of joints and are structural requirement driven to rely on composite construction techniques only.
2. Many of them are designed to address the element specific requirements of the building like walls, superstructures, or floors etc. and cannot be a solution for a whole building system.
3. The durability characteristics of these technologies are defined only for certain building components / elements.
4. The thermal properties of the whole building system can neither be defined nor maintained in any of these technologies and also each of the technologies have huge variations in their performances against the thermal performances.
5. The quality control system is defined only for building panel systems or constituent materials for most of the technologies and no specific quality control process has been defined for quality assurance of the whole building system, some technologies do not have any quality assurance plan at all.
6. The most challenging point of all with these technologies is that the variations for viability of adopting these technologies is quite high and confusing factor for real estate developers.

*B. NEED FOR BENCHMARKING AND OBJECTIVE SELECTION*

Benchmarking is a performance study by the parameters of technology / process by comparing them with the parameters of the standard / best process (Balachandran, 2010). Benchmarking enables the innovators to align their concentration and improve upon the weak areas to compare their work with the standards / best practices (Horne and Hayles, 2008). To develop a holistic approach to meet the functional and sustainability needs of housing in the country, the process of technology selection has to quantitatively assess the performance of technologies. Validating the performance of a technology through such a process is critical for the success of the technology. ISO 9000:2000 quality management system standards define validation as confirmation through the provision of objective evidence that the requirements for a specific intended use or application have been fulfilled.

**Table I : The data considered in this table did not cover the functional and sustainable needs in a holistic manner to describe them as alternatives**

| Technology | Structure | Wall | Floor | Durability | U- Value | Quality Assurance of Scale | Economy |
|---|---|---|---|---|---|---|---|
| Monolithic concrete construction system using Plastic-Aluminum formwork | Monolithic integrated solution | Monolithic integrated solution | Monolithic integrated solution | Based on durability of concrete | 3.58 W/m$^2$K for walls, 3.35 W/m$^2$K for roof | Dependent on material and process quality | Minimum 500 dwelling units to breakeven |


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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Monolithic concrete construction system using Aluminum formwork | Monolithic integrated solution | Monolithic integrated solution | Monolithic integrated solution | Panel durability defined, structural integration and system | 3.58 W/m$^2$K for walls, 3.35 W/m$^2$K for roof | Dependent on material and process quality | Minimum 500 dwelling units to breakeven |
| Expanded polystyrene core panel system | Structural integration not defined | Wall panels designed | Floor panels designed | Durability not established | 0.76 W/m$^2$ K for panel, avg. U-value for system not established | Established for off-site manufactured panels not established for integrated system | Plant minimum 1.5 Lakh sq.m production for 3 years |
| Industrialized 3-S system using precast RCC columns, beams and cellular light weight | Precast structural elements | Precast slabs | AAC precast blocks | Based on durability of concrete | 1.19 W/m$^2$K for walls, 3.35 W/m$^2$K for roof | Established for off-site manufactured elements, not for integrate system | Minimum 5000DUs for viability of plant |
| Concrete precast RCC slabs speed floor system | Structural integration not defined | Wall panels not designed | Floor panels designed | Based on durability of concrete | 3.35 W/m$^2$K for roof | Process not established | Maximum 100km distance from plant |
| Glass fiber reinforced gypsum (GFRG) panel building system | Structural integration not defined | Wall panels designed | Floor panels not designed | Durability for panels defined,dura bility after integration with structure not established | 2.85W/m$^2$ K for wall QA processnot | Process not established | Maximum 100km distance from plant |
| Factory made fast track modular building system | Structural integration defined | Wall panels designed | Floor panels designed | Based on material and process quality | 0.537 W/m$^2$ for wall with EPS insulation | Process not established | Stacking yard may be a limitation |
| Light guage steel framed structures | Structural component defined | Wall panels not designed | Floor panels not designed | Based on material and process quality | Dependent on wall and floor panels used | Process not established | N/A |

*C. Parameters For Benchmarking And Objective*

***Selection:*** In the context of Indian construction scenario, the housing sector suffered a setback due to low durability,slow construction process, and poor performance against functional and sustainability needs due to involvement of labour- driven and minimal or no mechanization activities. Chohanet al. (2015) has defined the determinants of housing quality as unit layout, workmanship in construction, garbage collection system, environmental conditions, appearance/design, internal conditions, and accessibility. And housing must be free from serious defects, energy efficient, healthy, safe, facilitative and secure. This can be achieved by working on parameters of housing quality, which include functionality, appearance, context, buildability, sustainable characteristics in town and landscape, quality of urban realm, accessibility and local permeability, legibility, adaptability, diversity, and choice (Chohan et al.,2015).Thus, selection of technologies for mass-scale housing construction with diverse geo-climatic, socio-cultural, economic, and hazard-vulnerable conditions requires an all inclusive approach to address functional needs like quality, durability, performance, and sustainability needs like environmental as well as socio-economic and cultural concerns. Based on the literature review on functional, sustainability, and performance needs of housing, input parameters have been narrowed down to eight, namely: strength and stability; compliance to code and standards; functional requirements; construction management aspects; maintenance; environmental; and, economic and social sustainability, as are presented in Table II

**Table II: Inputs for Benchmarking and Assessment Framework**

| Strength and stability | Functional requirements | Construction management aspects | Environmental sustainability | Economic sustainability | Social sustainability |
|---|---|---|---|---|---|
| • Structural performance<br>• Fire resistance | • Functional appropriateness<br>• Aesthetic aspects<br>• Affordability and adaptability<br>• Durability<br>• Protection against rain and moisture<br>• Thermal behaviour<br>• Acoustic behaviour<br>• Ease of fixing services<br>• User's satisfaction with space, light, acoustics, design, storage, etc.<br>• User's perception of thermal comfort<br>• User's perception of control of their environment<br>• Realization of the design intentions of the various stakeholders involved | • Industrialization of construction process<br>• Standardization and modular construction<br>• Cost-effectiveness of materials used<br>• Simplicity and versatility in construction<br>• Construction time and lead time<br>• Supply chain factors<br>• Health and safety<br>• Quality assurance | • Use of renewable resources for building materials<br>• Efficient use of existing conventional materials by producing factory made (pre-cast) building components<br>• Use of raw materials resources based on waste products<br>• Energy use<br>• $CO_2$emissions<br>• Use of sustainable and environment-friendly materials<br>• Water use<br>• Waste water management<br>• Indoor air quality<br>• Induction process for the user for his understanding of the operation of the building | • Economies of scale<br>• Construction cost<br>• Operation and maintenance cost<br>• Salvage value | • Employment generation potential<br>• Potential for involvement of local communities<br>• Potential of application of universal design principles<br>• Potential for protection and enhancement of landscapes, historical and cultural heritage<br>• Cultural appropriateness<br>• Potential for exchange of knowledge |
| Compliance to codes and standards | | | | Maintenance | |
| • Compliance to NBC<br>• Compliance to IS codes<br>• Compliance to Green Building Codes<br>• Compliance to other performance standards | | | | • Frequency of requirement of maintenance<br>• Ease of maintenance and replacement of mechanical components | |

*D. ASSESSMENT AND BENCHMARKING USING PUGH ANALYSIS*

Pugh method, invented by Stuart Pugh, is a concept selection process frequently used in engineering for making design decisions. Pugh analysis is a quantitative technique used to rank the multidimensional options of an option set. A basic decision matrix consists of establishing a set of criteria upon which the potential options can be decomposed, scored, and summed to gain a total score which can then be ranked. Importantly, the criteria are not weighted to allow a quick selection process. The advantage of this approach to decision making is that subjective opinions about one alternative versus another can be made more objective. Another advantage of this method is that sensitivity studies can be performed.Based on the Decision-Matrix (Pugh's method), this method is very effective for comparing concepts that are not refined enough / not possible for direct comparison with the engineering requirements.

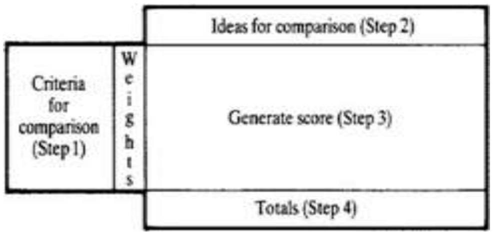


**Fig.1:PUGH Method (Decision-matrix) for making design decisions**

The method is an iterative evaluation that tests the completeness and understanding of requirements, quickly identifies the strongest concept. The method is most effective if each member of the design team performs it independently. The results of the comparison will usually lead to repetition of the method, with iteration continued until the team reaches a consensus.

*E. PUGH ANALYSIS FOR SELECTION OF ALTERNATE TECHNOLOGIES*

***Step-1: Development of criteria for comparison.***

All the parameters presented in the table-2 above, are considered for analysis except social sustainability


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parameters. Parameters considered are based on the literature review on functional, sustainability, and performance needs of housing, input parameters are narrowed down to eight ,namely: strength and stability, compliance to code and standards, functional requirements, construction management aspects, maintenance, environmental, economic and social sustainability.

***Step -2: Choosing technologies for selection***

Since this analysis for the selection of suitable technology for the implementation of 'Housing for all by 2022' and out of the above mentioned sixteen technologies, recommended by the Government of India's technology submission (BMTPC) seven (7) technologies are considered in this paper for analysis and validation of proposed selection methodology, that includes the technology numbers (1a), (1b), (6),(9),(10),(12),(13) and (16), mentioned above.

***Step -3: Generation of Scores.***

In this method the conventional building system is considered as datum with which all the other technologies are being compared to it as measured by each of the technology requirements. For each comparison the technology is evaluated as being better (+), the same (0), or worse (-). The matrix is developed with a excel spreadsheet and used +1, 0, and 1 for the ratings. Table-3 below shows the excel spread sheet for comparison of technologies.

**Table III: Pugh concept selection chart**

| Pugh Concept Selection Chart Template | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Conventional building system | Monolithic Concrete Construction System using Plastic-Aluminium Formwork | Expanded Polystyrene Core Panel System | Industrialized 3-S System using Precast RCC Columns, Beams and Cellular Light Weight | Concrete Precast RCC Slabs Speed Floor System | Glass Fibre Reinforced Gypsum (GFRG) Panel Building System | Factory Made Fast Track Modular Building System | Light Gauge Steel Framed structures (LGSF) |
| | | DATUM | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Compliance to codes and standards | • Compliance to NBC | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | • Compliance to IScodes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | • Compliance to Green Building Codes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | • Compliance to other performance standards | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 |
| Strength and stabi | • Structural performance | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | • Fire resistance | 0 | -1 | 0 | 0 | 1 | -1 | 0 | -1 |
| Functional requirements | • Functional appropriateness | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| | • Aesthetic aspects | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 |
| | • Affordability and adaptability | 0 | 1 | 0 | 0 | 1 | 1 | -1 | -1 |
| | • Durability | 0 | 0 | 0 | 0 | 1 | 1 | 0 | -1 |
| | • Protection against rain and moisture | 0 | 0 | 0 | 0 | 1 | -1 | 0 | -1 |
| | • Thermal behaviour | 0 | -1 | -1 | -1 | 0 | -1 | 0 | -1 |
| | • Acoustic behaviour | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | • Ease of fixing services | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | • User's satisfaction with space, light, acoustics, design, storage, etc. | 0 | 1 | 1 | 1 | 0 | 0 | 1 | -1 |
| | • User's perception of thermal comfort | 0 | -1 | 0 | 0 | 1 | -1 | 0 | 0 |
| | • User's perception of control of their environment | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | • Realisation of the design intentions of the various stakeholders involved | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 |
| Construction management aspects | • Industrialization of construction process | -1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | • Standardisation and modular construction | -1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | • Cost-effectiveness of materials used | 0 | 0 | -1 | 0 | 0 | 1 | 0 | 1 |
| | • Simplicity and versatility in construction | 0 | 1 | -1 | 1 | -1 | 1 | 1 | 1 |
| | • Construction time and lead time | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | • Supply chain factors | 0 | 1 | -1 | -1 | -1 | -1 | -1 | -1 |
| | • Health and safety | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | • Quality assurance | 0 | 1 | 0 | 0 | 0 | 1 | 1 | -1 |
| Environmental sustainability | • Use of renewable resources for building materials | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | • Efficient use of existing conventional materials by producing factory made (pre-cast) building components | -1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| | • Use of raw materials resources based on waste products | -1 | -1 | -1 | -1 | -1 | 0 | 0 | 0 |
| | • Energy use | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |


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|---|---|---|---|---|---|---|---|---|---|
| | • CO2 emissions | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | • Use of sustainable and environment-friendly materials | -1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 |
| | • Water use | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | • Waste water management | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | • Indoor air quality | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | • Induction process for the user for his understanding of the operation of the building | 0 | 0 | 1 | 0 | 0 | -1 | 0 | -1 |
| Mainten ance | • Frequency of requirement of maintenance | 0 | 1 | 1 | 0 | 0 | 0 | 0 | -1 |
| | • Ease of maintenance and replacement of mechanical components | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 |
| Econom sustaina | • Economies of scale | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| | • Construction cost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | • Operation and maintenance cost | 0 | 1 | 1 | 1 | 0 | 0 | 0 | -1 |
| | • Salvage value | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | Σ+ | +0 | +17 | +12 | +11 | +13 | +14 | +11 | +12 |
| | Σ- | -5 | -7 | -6 | -3 | -3 | -6 | -2 | -13 |
| | Σ | -5 | 10 | 6 | 8 | 10 | 8 | 9 | -1 |

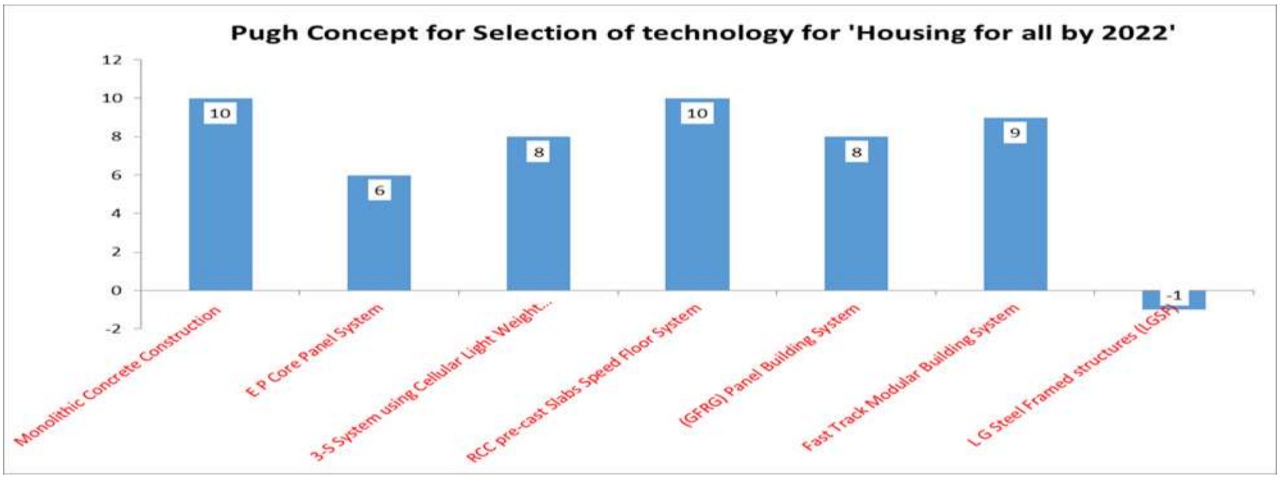


**Fig.2:**

***Findings from The PUGH method***

From the analysis of the seven (7) technologies with this technique, it is evident that all of the technologies underperform with respect to the performance standards, which in this case have been considered to be the National Building Code-2005, Indian Standard codes and the Energy Conservation Building Code-2007. The PUGH process also gives a comparative analysis of performance of these technologies with respect to each other. From the comparative analysis, it may be inferred that the Monolithic concrete construction and RCC pre- cast slab speed floor system have the highest performance among the seven technologies compared by the PUGH process. This inference has been drawn by totalling the competitive scores of the technologies obtained from the PUGH method. However, from the comparative analysis graph (Figure 3), it becomes evident that the technologies also show large variations in terms of performance against various demanded quality parameters. For instance, Light gauged frame steel structure has lowest performance as compared to others in terms of thermal insulation, durability, and fire resistance.Meanwhile, the Industrialised 3-S System and GFRG panel building system fares moderately well in all parameters. However, the performance of all of the technologies is inferior as compared to the performance standards.

Thus, the process of assessment and benchmarking of technologies gives useful insights into the comparative performance of each of these technologies and is hence, a useful tool for selection of appropriate technology for housing.

## IV. CONCLUSION

The Prime Minister Awas Yojana (PMAY), the mission of providing housing for all within a stringent timelines, to be achieved by 2022, has brought-in many challenges to engineers, policy makers and administrators across the country. These challenges gave way to many innovative technologies emerge in the domain of construction industry for implementation of mass housing schemes and programs like PMAY. The main driving factors for development of these new technologies are 1) Speed of construction 2) Cost of construction 3) Ease of construction 4) Quality of construction 5) Sustainability. Each of the available or developed technologies, though they are structural and functional requirement driven, is a special by its specifications to suit to different geographic, climatic and other exposure conditions. However, there are various


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factors that govern the selection of particular type of technology to be adopted for implementation of the low cost mass housing schemes like housing for all by 2022 mission.The guidelines under which the factors need to be considered for selection of suitable technology are demonstrated in this project. It is also been noted through this project that the technologies so far been evolved cater to building elements and not to the building system as a whole. More complicated process of technology, due to performance of technologies widely varies and inconsistent on various parameters tuned with the non-availability of adequate methods to assess technology, assessment has been demonstrated through the use of PUGH method. Hence, it is understood that the framework of objectives is useful that can drive the process of selection of appropriate technologies in terms of its suitability and performance which is useful for creating an adequate housing system. This objective framework depends upon the benchmarking standards for building system performance. So arriving at such benchmarking standards for building system is key for selection of new hosing technologies .It is concluded that the construction of best and quality low cost housing system within a specified time constraint starts with the selection of appropriate technology, selected by an objective driven methodology based upon the well-defined parameters with reference to the benchmarks.

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