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Determinants of Prefabricated Volumetric Modular Construction Implementation and Upscaling in India

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Abstract

One cutting-edge technique aimed at reducing the negative impacts of construction—including material waste, energy use, and environmental issues—is prefabricated volumetric modular building. It also seeks to shorten building durations and improve overall quality. The Indian building sector still uses relatively little volumetric modular construction, despite the fact that it is widely used in many developing nations because of its various advantages. However, preliminary findings also showed that there are several barriers preventing volumetric modular building from being widely used. Consequently, these constraints will be employed to explore the critical factors that contribute to Prefabricated Volumetric Modular Construction's (PVMC's) successful implementation in India. The determinants shall further be validated through case study and expert survey. The outcome of this analysis will have a matrix showing the key determinants and their limitations ranked in order of their importance and the correlation between each of the determinants. The proposed matrix shall provide decision makers with valuable insights into understanding which determinants to give more importance to and which sector or area in the industry should be targeted for the implementation of PVMC and it is believed that this matrix shall play an important role in the overall upscaling of PVMC in India.

Keywords: Volumetric modular construction, implementation, limitations, upscaling areas, sustainable

INTRODUCTION

Prefabricated Volumetric Modular Construction (PVMC) is the process of assembling fully enclosed, six-sided building modules in an offsite factory setting and transported to the site and are then erected onsite to make up a larger structure. Modules are 70%–90% completed off-site in a controlled factory environment and transported and assembled at the final building site [1].

As people become more conscious of the environmental, social, and economic implications of today's construction processes, they are able to adopt practices that are thought to be more long-term sustainable [2]. Conventional construction methods have long been criticised in the construction industry for their high waste production, low productivity, low degree of safety, and durability [3, 4]. PVMC can offer substantial advantages in place of these issues, including decreased time, less waste, enhanced quality, decreased emissions into the environment, enhanced workspace, and decreased energy and water usage [2, 5, 6].

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In terms of how it affects environmental preservation, PVMC is recognised as a sustainable building technique. The impact of prefabrication on the decrease of construction waste and the ensuing waste management operations, such as waste classification, recycling, and disposal, is a significant component of this viewpoint [7]. According to recent studies, PVMC is currently required in order to address the issues of speed and quality in the construction sector and counteract the lack of housing for a nation's expanding population [8].

Although modular building has gained popularity throughout the world, it is still in its infancy and little is known about its drawbacks and effective ways to address them [9]. Thus, this research study will map the area for strengthening to upscale PVMC in India and deal with an in-depth analysis of the barriers to PVMC application globally.

In the initial part of the dissertation, titled ''Analysis of Volumetric Modular Construction and its Future Prospects in India,'' the research focused on the manufacturing processes involved in Volumetric Modular Construction (VMC). This examination was conducted through case studies and comprehensive desktop research. Additionally, an expert survey was carried out to identify and highlight the key constraints and challenges specific to the Indian context. These research findings are intended to provide valuable support for the subsequent dissertation (Dissertation II) by enriching and augmenting the overall research and analysis.

LITERATURE REVIEW

VMC

The most cutting-edge off-site construction technique now in use is modular construction. Using this technique, fully fitted volumetric units, or modules, are produced that come with trim work and installed plumbing, electrical, and mechanical systems. As part of the building's framework, up to 80% of the work can be finished at off-site facilities before being transported and installed on-site [10].

Some scholars define modular construction as the assembly of any kind of pre-assembled components to form a building or a portion of it, in addition to volumetric units. From now on, the term ''module'' refers to the greatest volumetric unit (including finishes, fixtures, and fittings) that can be transported from a facility and subsequently installed on-site in order to prevent any misunderstandings regarding the interpretation of this study [11]; while the term modular construction is used to describe the construction method of designing, manufacturing, transporting, and installing the modules on-site to form the building [12].

The literature that is now available provides a detailed description of how modular construction can help alleviate some of the bottlenecks in the construction sector [13–22]. Table 1 For instance, excessive geometric variability risks in modular components raise concerns from potential adopters since they offer serious hazards to operational effectiveness and necessitate improving the capabilities of construction labour.

Area for Upscaling of PVMC in India

The upscaling of VMC in India has the potential to bring significant benefits to various sectors and areas. Following are some key areas and sectors where VMC can be effectively applied and scaled up in India:

1. *Affordable Housing:* Affordable housing is a pressing issue in India, particularly in urban areas. VMC offers an efficient way to construct affordable housing units quickly and cost-effectively [23, 24]. The National Building Construction Corporation (NBCC) has explored modular construction as a viable solution to address India's housing challenges, especially for economically disadvantaged communities [23]. In India, increased demand for low-cost or affordable housing is leading to growing popularity of modular buildings among housing and

real estate developers. Additionally, a sustained government push for digitalisation and adoption of latest construction technologies like BIM is an important driver for the adoption of modular construction. In fact, government initiatives like “Digital India”, “Housing for All”, and “Bharatmala Pariyojana” among others have given a significant boost to the adoption of modular construction in India [24].

2. *Education Sector:* The education sector in India faces a growing demand for quality educational institutions. Modular construction can effectively address this need by enabling the swift construction of schools, colleges, and vocational training centres. The National Education Policy (NEP), 2020 highlights the requirement for improved educational infrastructure, making modular construction a valuable approach to meet the evolving demands of the education sector [25].
3. *Healthcare Facilities:* Rapidly expanding healthcare infrastructure is crucial for improving healthcare access in India. Modular construction techniques enable the rapid construction of healthcare facilities like hospitals and clinics [26, 27]. The Ministry of Health and Family Welfare emphasises the importance of infrastructure development in the healthcare sector to ensure timely access to medical services, particularly in underserved areas or during health crises [22].
4. *Disaster Relief and Housing:* India is prone to natural disasters such as floods, earthquakes, and cyclones. Modular construction is well-suited for disaster relief efforts, providing quick and resilient housing solutions for affected populations. The National Disaster Management Authority (NDMA) recognises the importance of disaster-resilient housing, and modular construction methods align with these goals, ensuring that disaster victims have access to safe and sustainable shelter [28].
5. *Hospitality Industry:* The hospitality industry in India, which includes hotels and resorts, often faces the need for rapid construction to meet seasonal demands. Modular construction can significantly reduce construction timelines, allowing the industry to accommodate guests more quickly. Industry reports and discussions on hospitality development in India frequently mention various construction methods, including modular techniques, to meet the dynamic needs of the sector [17, 3].
6. *Industrial and Warehousing:* India’s industrial and warehousing sectors are growing rapidly due to economic expansion and increased trade. Modular construction offers a practical solution for building industrial facilities, warehouses, and logistics centres [29, 30]. The Ministry of Commerce and Industry plays a significant role in promoting industrial growth, and modular construction can support these efforts by providing efficient and adaptable construction methods for businesses [20].

Table 1. Limitations of PVMC.

S.N.	Limitations	References
L1	High initial cost	[13], [14], [2], [9], [15], [16], [17]
L2	Lack of potential investors	[15]
L3	Less flexibility in design	[13], [14], [2], [9], [15], [16]
L4	Higher transportation cost	[14], [15], [16], [18]
L5	Lack of technology	[14], [19], [16]
L6	Lack of tools and equipment	[19], [16]
L7	Require more skilled labour	[13], [2], [2], [16], [17]
L8	Lack of awareness and expertise	[14], [15], [16]
L9	Lack of regulatory frameworks	[14], [2], [15], [16]
L10	Site constraints ang logistics	[2], [19], [16], [17]
L11	Cultural and aesthetic preferences	[14], [16]
L12	Leakage in joints	[2]
L13	Complexity of connection	[13]

L14	Lack of demand	[2], [16]
L15	Lack of coordination and communication among stakeholders	[13], [9], [15], [17]
L16	Lack of government support	[13], [14], [15], [20]
L17	Lack of experience and expertise	[13], [2]
L18	Lack of building codes and standards	[13], [16]
L19	Poor supply chain integration	[15], [16]
L20	Poor market and society acceptance	[13], [15]
L21	Higher construction cost	[13], [9], [15], [16], [17]
L22	Additional crane cost	[13], [15], [16]
L23	Complexity of design on seismic performance	[13], [18]
L24	Complexity of design on fire resistant performance	[13]
L25	Limitation of weight and dimensions	[13]
L26	Damage to modules during transportation	[13], [14], [9], [15]
L27	Limitation of transport routes	[13]
L28	Demand for on-site modules storage	[13]
L29	Lack of quality inspection standard	[13]
L30	Risk of increasing unemployment	[15]
L31	Lack of market competition	[15], [16], [17]
L32	Lack of government incentives	[14], [15], [16], [18]
L33	Lack of suppliers or factory or manufacturers	[15], [16]
L34	Complex logistical management	[14]
L35	Difficulty in carrying out onsite modifications	[15], [18]
L36	Industry resistance to change and innovation	[14], [15], [16], [17]
L37	Transportation restriction and regulations	[9]
L38	Early design freeze	[16], [15], [21], [17]
L39	Low level of R&D in the industry	[14], [9], [22]

Data Collection

Case Study

Project Details

Storey: 10 floors
Size of the project: 2,553.60 sq. m.
Developer: Synergy Thrislington.
Structural Consultant: Syal & Associates

The case study's core objective is to glean valuable insights from industry experts regarding the implementation of PVMC in their projects. By engaging with professionals directly involved in PVMC methodologies, the study aims to uncover detailed information about PVMC. This firsthand knowledge will provide a nuanced understanding of the challenges, successes, and practical considerations associated with PVMC (Figure 1).

In tandem, the case study seeks to validate a predefined set of determinants linked to PVMC. These determinants encompass critical factors. Through expert opinions and real-world examples, the study aims to confirm the significance and relevance of these determinants, providing a robust foundation for understanding the key drivers of success in PVMC projects.

Expert Survey

Expert survey is undertaken to rank determinants and identify potential areas for scaling up PVMC in India. The responses obtained from the expert survey will also be utilised to assess the correlation between various determinants.

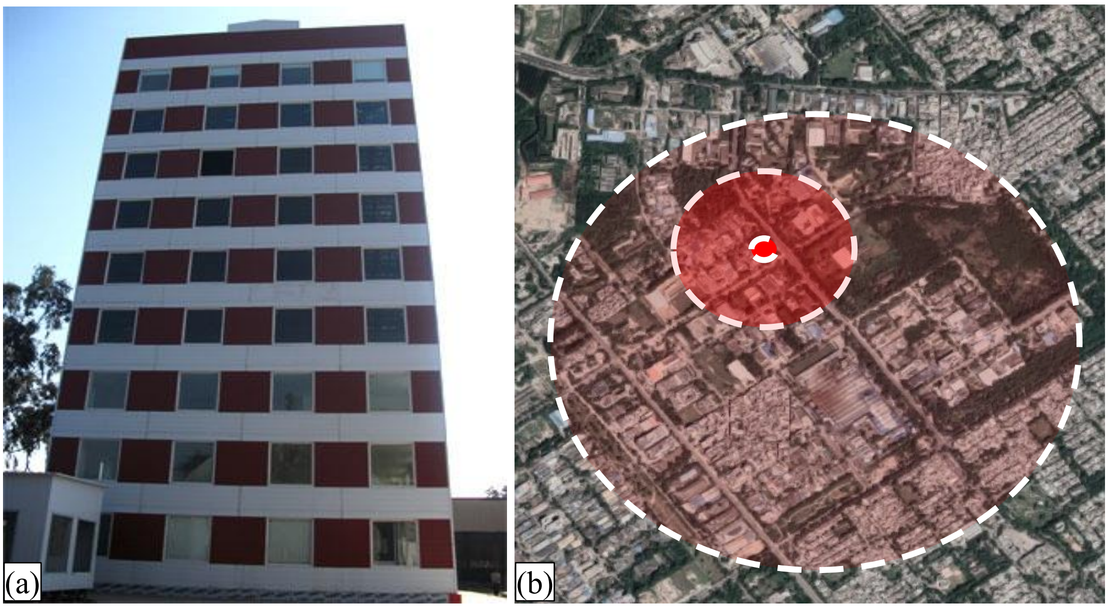

Figure 1. (a-b) Instacon building, Mohali.

Information on profiles, experience, and perception to the determinants has been discussed and evaluated according to the survey. The sample size shall be calculated as per Cochran's formula and the survey is circulated in online mode.

Using those ratings given by the respondents and Relative Importance Index (RII), the determinants and its limitations shall be ranked according to their importance.

DATA ANALYSIS

Cronbach's Alpha

Reliability and validity of the questionnaire responses has been analysed using Cronbach's Alpha through SPSS. The questionnaire was divided into two sections – Section 1 dealing with determinants and its limitations and Section 2 dealing with Area for upscaling of PVMC in India.

Reliability coefficients of the scales are found to be highly reliable (alpha = 0.85) for Section 1 (determinants and their limitations) and moderately reliable (alpha = 0.56) for Section 2 (area for upscaling of PVMC in India).

RII

Section 1: Determinants and their Limitations

The determinants (D1, D2, D3, D4, D5, D6, D7), as revealed through Thematic Analysis, have been prioritised according to their significance as indicated by responses from the Expert survey (Table 2). Leading the rankings is a skilled workforce with a score of 0.83, closely trailed by supply chain and logistics at 0.82. Regulation and standards, along with advanced technological infrastructure, share the next position with an identical score of 0.81 (Tables 3–7). Following closely are government initiative and public perception and consideration, both sharing a score of 0.77. Lastly, market demand holds the sixth position with a score of 0.76 (Tables 8 and 9).

The limitations categorised under each determinants (D1, D2, D3, D4, D5, D6, D7) are also ranked in order to understand their importance level based on the responses received from expert survey.

The ranking of limitations for each determinants are as follows:

Section 2: Area for upscaling of PVMC in India

The area or sector which needs to be targeted for upscaling of PVMC in India has been identified through literature study (Table 10). These set of areas are then validated through expert survey to understand their importance, as to know which area has more potential for growth with respect to PVMC.

Table 2. RII for determinants.

Code	Determinants	Rating					Total	∑W	∑AN	RII
		1	*2*	*3*	*4*	*5*				
D3	Skilled workforce	0	2	1	18	9	30	124	150	0.83
D4	Supply chain and logistics	0	1	5	14	10	30	123	150	0.82
D1	Regulation and standards	1	1	4	13	11	30	122	150	0.81
D2	Advanced technological infrastructure	1	1	4	14	10	30	121	150	0.81
D6	Government initiative	1	0	8	14	7	30	116	150	0.77
D7	Public perception and consideration	0	3	3	20	4	30	115	150	0.77
D5	Market demand	0	0	10	16	4	30	114	150	0.76

Table 3. RII for D1. Regulations and standards.

Code	D1. Regulation and Standards	Rating					Total	∑W	∑AN	RII
		1	*2*	*3*	*4*	*5*				
L18	Lack of building codes and standards	0	1	4	16	9	30	123	150	0.82
L9	Lack of regulatory frameworks	0	0	5	20	3	28	110	140	0.79
L37	Transportation restriction and regulations	0	2	8	14	5	29	109	145	0.75
L29	Lack of quality inspection standards	0	3	9	9	8	29	109	145	0.75

Table 4. RII for D2. Advanced technological infrastructure.

Code	D2. Advanced Technological Infrastructure	Rating					Total	∑W	∑AN	RII
		1	*2*	*3*	*4*	*5*				
L35	Difficulty in carrying out onsite modifications	0	0	5	16	7	28	114	140	0.81
L3	Less flexibility in design	0	1	4	19	2	26	100	130	0.77
L5	Lack of technology	0	1	7	16	5	29	112	145	0.77
L6	Lack of tools and equipment	0	2	6	14	6	28	108	140	0.77
L12	Leakage in joints	0	2	9	14	3	28	102	140	0.73
L25	Limitation of weight and dimension	0	2	8	15	2	27	98	135	0.73
L13	Complexity of connection	1	1	8	16	2	28	101	140	0.72
L23	Complexity of design on seismic performance	0	3	12	11	2	28	96	140	0.69
L24	Complexity of design on fire resistant performance	0	2	15	9	1	27	90	135	0.67

Table 5. RII for D3. Skilled workforce.

Code	D3. Skilled Workforce	Rating					Total	∑W	∑AN	RII
		1	*2*	*3*	*4*	*5*				
L17	Lack of experience and expertise	0	0	4	15	11	30	127	150	0.86
L7	Require more skilled labour	0	0	2	18	9	29	123	145	0.85
L38	Lack of training programmes	0	1	3	14	11	29	122	145	0.84

Spearman Correlation

After RII had been performed to understand the importance (Table 11) level of the identified determinants, correlation analysis between determinants (D1, D2, D3, D4, D5, D6, D7) is conducted through Spearman's Correlation using SPSS to investigate the relationships between the determinants, where:

D1=Regulation and standards;
D2=Advanced technological infrastructure;
D3=Skilled workforce;
D4= Supply chain and logistics;
D5=Market demand;
D6=Government initiative; and
D7=Public perception and consideration.

Table 6. RII for D4. Supply chain and logistics.

Code	D4. Supply Chain and Logistics	Rating					Total	∑W	∑AN	RII
		1	*2*	*3*	*4*	*5*				
L28	Demand for on-site module storage	0	1	3	21	2	27	105	135	0.78
L10	Site constraints and logistics	0	1	6	17	4	28	108	140	0.77
L19	Poor supply chain integration	0	2	3	18	5	28	110	140	0.77
L4	Higher transportation cost	0	1	8	13	5	27	103	135	0.76
L34	Complex logistical management	0	0	10	14	3	27	101	135	0.75
L27	Limitation of transport routes	0	5	6	12	5	28	101	140	0.72
L26	Damage to modules during transportation	0	3	7	15	2	27	97	135	0.72
L25	Limitation of weight and dimensions	0	3	11	9	4	27	95	135	0.70

Table 7. RII for D5. Market demand.

Code	D5. Market Demand	Rating					Total	∑W	∑AN	RII
		1	*2*	*3*	*4*	*5*				
L1	High initial cost	0	0	4	15	8	27	112	135	0.83
L33	Lack of suppliers or factory or manufacturers	0	2	6	14	5	27	103	135	0.76
L31	Lack of market competition	0	2	6	15	3	26	97	130	0.75
L22	Additional crane cost	0	2	11	7	7	27	100	135	0.74
L21	Higher construction cost	0	5	12	5	6	28	96	140	0.69

Table 8. RII for D6. Government initiative.

Code	D6. Government Initiative	Rating					Total	∑W	∑AN	RII
		1	*2*	*3*	*4*	*5*				
L8	Lack of awareness and expertise	0	0	0	17	11	28	123	140	0.88
L38	Lack of training programme	0	0	3	16	9	28	118	140	0.84
L32	Lack of government incentives	0	0	5	20	3	28	110	140	0.79
L16	Lack of government support	0	0	8	17	4	29	112	145	0.77
L32	Lack of suppliers or factory or manufacturers	0	2	10	12	4	28	102	140	0.73

Table 9. RII for D7. Public perception and consideration.

Code	D7. Public Perception and Consideration	Rating					Total	∑W	∑AN	RII
		1	*2*	*3*	*4*	*5*				
L2	Lack of potential investors	0	0	7	17	5	29	114	145	0.79
L11	Cultural and aesthetic preferences	0	0	4	23	3	30	119	150	0.79
L39	Low level of R&D in the industry	0	0	5	20	2	27	105	135	0.78
L20	Poor market and society acceptance	1	0	7	19	2	29	108	145	0.74
L15	Lack of coordination and communication among stakeholders	0	2	9	16	1	28	100	140	0.71
L30	Risk of increasing unemployment	0	6	12	8	3	29	95	145	0.66
L36	Industry resistance to change and innovation	1	4	10	11	2	28	93	140	0.66

Inferences

RII: In the analysis based on the RII, it is evident that the top determinant is a skilled workforce, securing a score of 0.83, closely followed by supply chain and logistics at 0.82. Regulation and standards, along with advanced technological infrastructure, share the subsequent position with an identical score of 0.81.

Under the determinant D1. Regulation and standard, the primary limitations are identified as lack of building codes and standards (L18). Similarly, for D2. Advanced technological infrastructure, the principal limitation is noted as difficulty in carrying out onsite modifications (L35). Moving on to D3. Skilled workforce, the major limitation is highlighted as lack of experience and expertise (L17). In the case of D4. Supply chain and logistics, the significant limitation is recognised as demand for on-site module storage (L28). Addressing D5. Market demand, the major limitation is outlined as high initial cost (L1). Under D6. Government initiative, the principal limitation is lack of awareness and expertise (L8). Lastly, for D7. Public perception and consideration, the major limitation is identified as lack of potential investors (L2).

Table 10. RII for area for upscaling of PVMC.

S.N.	Area for upscaling of PVMC	Rating					Total	∑W	∑AN	RII
		1	*2*	*3*	*4*	*5*				
2	Education sector	0	0	5	17	8	30	123	150	0.82
4	Disaster relief housing	1	1	4	14	10	30	121	150	0.81
1	Affordable housing	0	1	6	18	5	30	117	150	0.78
6	Industrial and warehousing	0	0	7	19	4	30	117	150	0.78
3	Healthcare facilities	1	2	7	15	5	30	111	150	0.74
5	Hospitality industry	1	3	14	8	4	30	101	150	0.67
7	Residences	0	5	11	12	2	30	101	150	0.67

Table 11. Correlation coefficients of the determinants.

	D1	D2	D3	D4	D5	D6	D7
D1	1	0.333	0.520**	0.393*	0.026	0.128	0.375*
D2	-	1	0.577**	0.878**	0.266	0.424*	0.312
D3	-	-	1	0.587**	0.410*	0.409*	0.084
D4	-	-	-	1	0.125	0.271	0.242
D5	-	-	-	-	1	0.738**	0.484**
D6	-	-	-	-	-	1	0.506**
D7	-	-	-	-	-	-	1

***. Correlation is significant at the 0.01 level (2-tailed)*
**. Correlation is significant at the 0.05 level (2-tailed)*

In terms of priority for upscaling PVMC, the education sector emerges as the top choice, with disaster relief housing ranking second, followed by affordable housing, industrial, and warehousing, healthcare facilities, hospitality industry, and residences, in descending order of preference.

Correlation Analysis

Of all the determinants, D3 i.e., skilled workforce has the maximum relationship with other determinants followed by D6 i.e., government initiative.

CONCLUSION

The outcome of the whole research consists of three Matrix namely Matrix A, Matrix B, and Matrix C. Matrix A showing the ranking of determinants and their limitations in order of their importance. This shall be used by future endeavours or government body to understand which determinant is the most important to consider when implementing PVMC in India and what are the major limitations for each determinant that needs to be tackled for successful adaptation of PVMC in India.

Second matrix, Matrix B consist of ranking of area or sector in the industry that should be targeted for the implementation of PVMC.

The third matrix, Matrix C is designed to capture the strength of relationships or correlations among the determinants. This matrix serves as a tool to identify the extent to which specific determinants are interrelated, shedding light on which determinants exhibit the highest degrees of correlation. Consequently, it enables us to discern the influence of one determinant on another, providing insights into how improvements in one determinant can impact others.

Matrix A. Ranking of determinants and their limitations.

Ranking	**Determinants**	**Limitations**	**Ranking**
1	Skilled workforce	Lack of experience and expertise	1
		Require more skilled labour	2
		Lack of training programmes	3
2	Supply chain and logistics	Demand for on-site module storage	1
		Site constraints and logistics	2
		Poor supply chain integration	3
		Higher transportation cost	4
		Complex logistical management	5
		Limitation of transport routes	6
		Damage to modules during transportation	7
		Limitation of weight and dimensions	8
3	Regulation and standards	Lack of building codes and standards	1
		Lack of regulatory frameworks	2
		Transportation restriction and regulations	3
		Lack of quality inspection standards	4
4	Advanced technological infrastructure	Difficulty in carrying out onsite modifications	1
		Less flexibility in design	2
		Lack of technology	3
		Lack of tools and equipment	4
		Leakage in joints	5
		Limitation of weight and dimension	6
		Complexity of connection	7
		Complexity of design on seismic performance	8
5	Government initiative	Lack of awareness and expertise	1
		Lack of training programme	2
		Lack of government incentives	3
		Lack of government support	4
		Lack of suppliers or factory or manufacturers	5
6	Public perception and consideration	Lack of potential investors	1
		Cultural and aesthetic preferences	2
		Low level of R&D in the industry	3
		Poor market and society acceptance	4
		Lack of coordination and communication among stakeholders	5
		Risk of increasing unemployment	6
		Industry resistance to change and innovation	7
7	Market demand	High initial cost	1
		Lack of suppliers or factory or manufacturers	2
		Lack of market competition	3
		Additional crane cost	4
		Higher construction cost	5

Matrix B. Ranking of area for implementation of PVMC.

Ranking	Area
1	Education sector
2	Disaster relief housing
3	Affordable housing
4	Industrial and warehousing
5	Healthcare facilities
6	Hospitality industry
7	Residences

Matrix C. Determinants with their correlation.

S.N.	Determinants	Correlation
1	D1. Regulation and standards	D3, D4, D7
2	D2. Advanced technological infrastructure	D3, D4, D6
3	D3. Skilled workforce	D1, D2, D4, D5, D6, D7
4	D4. Supply chain and logistics	D1, D2, D3
5	D5. Market demand	D3, D6, D7
6	D6. Government initiative	D2, D3, D5, D7
7	D7. Public perception and consideration	D1, D5, D6

Recommendation

According to the research findings, some criteria that have the highest rankings and largest correlations should receive special attention in order to successfully deploy PVMC in India. The analysis reveals that several characteristics are very important, including having a qualified personnel, having an efficient supply chain and logistics, and adhering to norms and standards. It is therefore advised to give priority to these elements since they are essential to the efficacy and accomplishment of PVMC projects in the Indian setting.

The study's conclusions emphasise that the adoption of PVMC should strategically centre on the education sector. As such, it is highly recommended that the implementation process in this specific industry be initiated and that a thorough investigation of its broad extent and possible opportunities be conducted. This strategy will make it easier to comprehend the special needs and opportunities found in the education sector, opening the door to more efficient and customised PVMC applications.

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