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A Dual-Factor Structural Model for Assessing the Determinants of Prefabrication and Modular Construction Uptake in India

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Abstract - Rapid urbanization demands improved project delivery in terms of fast, affordable, and sustainable building solutions. Despite the prefabrication and modular solutions offering a wide range of benefits, the Indian construction industry is well behind in adapting to a changeover. Even though several research works have been carried out in the domain of technology adoption challenges, the results are broad and encompass global trends. This study was conducted under industry-specific conditions to measure and analyse the influence of various latent variables on adopting prefabrication methods in the Indian scenario. This study aims to explore and analyse those retarding factors along with enablers that affect the adoption of various prefabrication methods with a dual-factor perspective. The primary cause factors were extracted from an in-depth literature review and converted into measurable indicators within a structured questionnaire. The survey was conducted among industry professionals actively involved in prefabricated construction projects. Collected data was analysed using the Partial Least Squares Path Modeling (PLS-PM) method, keeping the technology implementer and receiver as the primary decision-makers. The results reveal how the indicators associated with the negative customer perceptions (technology receiver group) have a greater impact on adopting prefabrication and modular methods. Also, internal organization barriers like huge initial investment requirement and skill shortage retard the transformation process. The study projects the need for skill upliftment in the prefab sector, an increased customer awareness, and improved building performance (post construction), which play a significant role in the shift. Furthermore, the study provides practical insights to industry professionals seeking to modernize their construction practices.

***Keywords*:** Barriers and enablers, Technology adoption model, Prefabricated construction, Modular Construction, Partial Least Squares Path Modeling (PLS-PM).

1. Introduction

As a growing economy and a developing nation, India is also facing challenges in meeting the demands of rapid urbanization. The current city infrastructure lacks many ways to accommodate the growing population. One of those challenges is a scarcity of land. Sticking to conventional construction practices not only consumes time, but retard the economic growth also. Even though the infrastructure sector has adapted to modern construction methods, housing and other building sectors lag in adopting off-site or prefab construction methods [1]. The Indian construction sector is also facing periodic quality decline, cost, and time overrun issues. As part of quality improvement and production upliftment, the Indian construction industry needs a change from onsite to offsite methods [2]. Underdeveloped technology adoption rate, fewer customization, and lack of a systematic design methodology are a few inhibitors for this change [2], [3], although, prefab and modular construction techniques have many advantages based on sustainable aspects and customized project delivery.

To accelerate the adoption of new construction technologies to improve the pace and quality of work, Ministry of Housing and Urban Affairs (MoHUA) has conceptualized the Global Housing Technology Challenge – India (GHTC-India). Through this platform, government aimed to facilitate a holistic eco-system to identify appropriate trending technologies around the world. Also, through this platform, authorities tried to identify relevant stakeholders towards the technology transition in the housing and construction sectors of India. The main aim is this mission is to address the challenges of rapid urban growth and its attendant requirements. The agenda of this scheme is to finish the construction of nearly 11.2 million houses by 2022, and over 10.8 million houses have already been sanctioned so far. About one third of these projects use new technologies. Construction of houses at this scale offers an opportunity for new and alternative technologies from across the globe which may trigger a major transition through introduction of cutting-edge building materials, technologies, and processes.

The Government of India has further emphasized the need to accelerate the adoption of new construction technologies to fast track and improve quality of construction under the Pradhan Mantri Awas Yojana (Urban) (PMAY (U)) – Housing for All Mission in order to address the challenges of rapid urban growth and its attendant requirements. Through Global Housing Technology Challenge -India, 54 new proven technologies have been identified. These are of innovative housing technologies from across the globe which are cost effective, speedier, sustainable and disaster-resilient and ensure a higher quality of construction of houses, meeting diverse geo-climatic conditions and desired functional needs. These technologies are now being showcased through execution of Light House Projects (LHPs) across six States (details illustrated below in Table 1).

Table 1: Shortlisted Entries in GHTC-INDIA (2019)

S. No.	Innovative Technologies	LHPs under GHTC (India)	Description
1	Precast concrete construction systems- 3D-Volumetric Precast	Ranchi, Jharkhand	Mass production of entire units as modules in factories
2	Precast concrete construction systems	Chennai, Tamil Nadu	Precast components assembled at site (Mass production of structural components in factories)
3	Light gauge steel structural system and pre-engineered steel structural systems	Agartala, Tripura	Cold rolled steel and pre-engineered sections that is not energy intensive to produce
4	Prefabricated sandwich panel system	Indore, Madhya Pradesh	Alternative for brick walls as filler walls in case of framed structures (precast RCC beams and columns, hollow core slabs, EPS Sandwich panel walls)
5	Monolithic Concrete Construction systems	Rajkot, Gujarat	All walls/openings/floors are casted monolithically on site using modular formwork (tunnel form)
6	Stay in place formwork systems	Lucknow, Uttar Pradesh	Formwork that acts as structural support/ insulation that remains with the building (steel structural system, composite decking floor)

Even though the Indian and state governments are taking initiatives to showcase and promote various modern methods of construction, the majority of the private construction sector still prefers the conventional methods of construction over prefab construction methods, unless a critical demand is generated from the receiver side. Several researchers have published their insights regarding potential challenges and enablers of prefab construction adoption [1-4]. However, the current study mainly focuses on the regional aspects rather than replicating the global studies, keeping the upcoming industry practitioners as a beneficial group. Authors considered the current industry-specific conditions to explore and analyse the retarding factors along with enablers that affect the adoption of various prefabrication methods with a dual-factor perspective. The scope of the study is limited to the interaction of technology providers and technology receiver groups as decision makers under the effect of positive mediating factors. The results are demonstrated using the concept of Partial Least Square Path Modeling (PLS-PM) methodology [5], [6]. The final model shows the major driving factors of industry transformation. Furthermore, the study showcases practical insights to industry professionals seeking to modernize their construction practices. This paper is divided mainly into four sections. The upcoming sections include a detailed methodology, results, discussions, and a conclusion. The primary reference research works are listed at the end of the paper.

2. Methodology

The study followed a three-stage methodology (demonstrated in Fig. 1). The first stage constitutes an in-depth literature review. The main aim of the literature study is to understand and extract the possible challenges and enablers of adopting prefab methods in the construction industry. The initial research started with global studies and was later narrowed down to regional papers for better understanding. Since the scope of this study is limited to the technology provider and receiver categories, the corresponding influencing factors are extracted and utilized for further analysis and interpretation of results. Three independent constructs and eighteen indicator sets are finalized through literature review for developing the conceptual structural model (the details are demonstrated in Table 2 and explained in the upcoming sections).

The critical part of this study constitutes the second stage of the methodology, where an industry study and data collection are carried out extensively to validate the impact of identified independent constructs on the adoption of prefab and modular methods. The identified indicators were measured using a structured questionnaire survey. Since India has just begun to adopt prefab techniques, only a few companies are engaged in this sector (fewer than 100). Hence, the survey targeted experts with at least five years of experience in prefab techniques. Twenty-eight industry professionals participated in the study and recorded their perceptions about the indicators on a five-point Likert scale (0-Strongly disagree, 1- Disagree, 2- Neutral, 3- Agree, 4- Strongly Agree) [7].

The third stage of the study constitutes the analysis and interpretation of results. SmartPLS 4 software is used to carry out the PLS-PM analysis. The main output of this study is a PLS structural model connecting the independent and dependent constructs, illustrated in detail in the upcoming section.

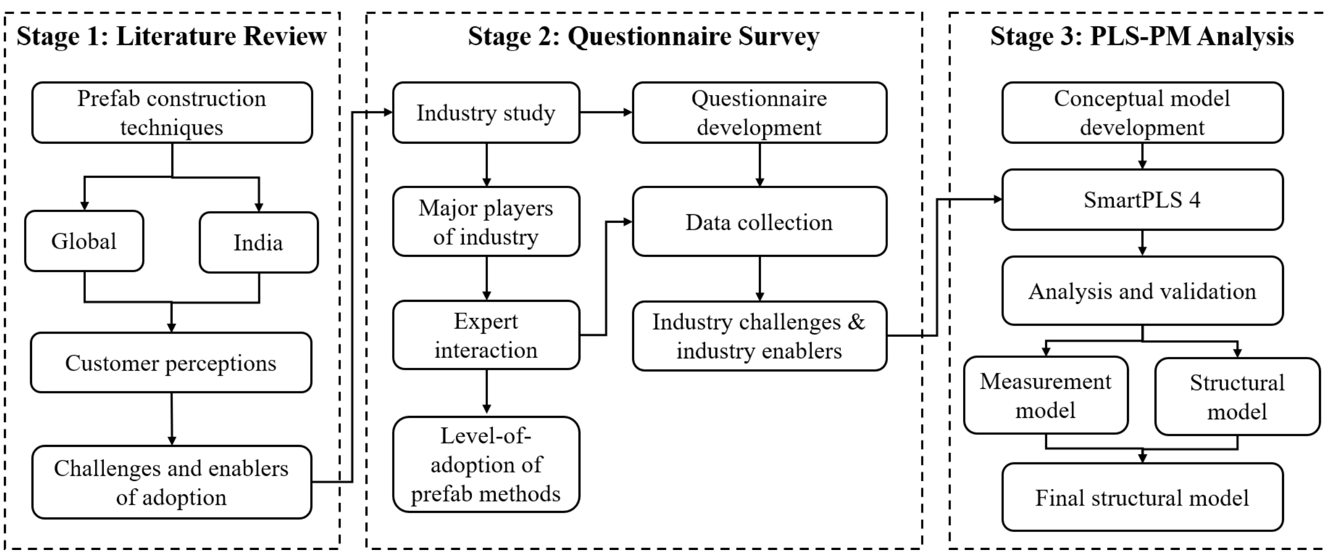

Fig. 1: Schematic flow of study

3. Results and Discussion

The results and discussion section is subdivided into three subsections; the first section explains the results of the literature review on industry enablers and challenges. The second section is focused on the questionnaire development and data collection among industry professionals. The third section presents the PLS-PM-based data analysis results and further interpretation using SmartPLS 4.

3.1 Industry Challenges and Enablers

The study kept the technology provider and receiver groups as key decision makers in the adoption of prefab and modular methods of construction. The end-users or customers are primarily responsible for adopting prefabrication techniques. Customers' preferences for faster, affordable, and high-quality construction are more likely to drive the developer toward adopting prefab methods to meet those expectations. In reverse, the customers' lack of awareness and trust about modern methods inhibits the developer from embracing the change [8].

The literature study also proves that a post-occupancy evaluation and feedback loop are essential to validate the benefits of off-site methods. Users' feedback on the post-construction performance of the building influences future adoption through trust and reputation [9]. One significant barrier in precast buildings is the difficulty of modifying or replacing components at later stages of their occupancy span. Also, joint leakage and faulty joints create strong negative perceptions towards adopting precast buildings. Here, meeting quality standards and ensuring the leakproof design of joints are essential when considering precast methods. Further, creating awareness among the user group is vital for faster adoption of modern construction methods.

Compared to customers' perceptions of prefab methods, the internal barriers within the organization (technology provider) are more critical from a developer's perspective [7]. One of the main barriers is the skill shortage of industry professionals experienced in these modern methods. Lack of past prefab project experience is the primary reason for this. Since India is in a transforming stage, the only solution for skill shortage is to provide employee training for skill upliftment [10].

Here, digitalization plays a vital role in attaining the perceived benefits of prefab techniques [11]. Digitalization demands collaborative teamwork within a shared digital platform. However, multi-disciplinary collaboration and knowledge sharing are significant barriers to the execution of the design process [12]. Hence, digitalizing the construction design process may trigger change resistance towards innovation. Moreover, bringing digitalization and providing training demands extra investments prior to the off-site shift. However, the decision to adopt prefab or modular construction has multiple execution level barriers. A substantial initial investment is required for plant setup, transportation, and handling machinery [8]. Also, developers prefer prefab methods where mass production of similar components is needed. Also, prefab methods demand location proximity of the factory relative to the project site to reduce dependency on transporting machinery and related costs.

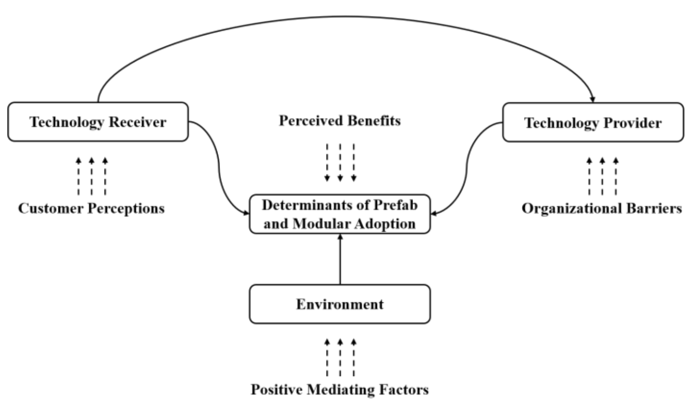

Fig. 2: Conceptual model

To mitigate the barriers, the mediating factors can play a significant role. For example, favourable government policies and subsidies for adopting prefab methods can positively impact both the customer and the developer [13]. Table 2 demonstrates the detailed list of constructs under consideration and their measurable indicator variables. The conceptual model proposed (Fig. 2) connects the technology receiver and provider to the determinants of adopting prefab methods. The perceived benefits of prefab methods and other mediating factors also impact the adoption model (a detailed list is in Table 2).

3.2 Questionnaire Survey and Data Collection

The questionnaire survey was conducted among the prefab industry professionals in India. Since India is in the beginning stage of prefab adoption, there are lesser than a hundred companies engaged in various modern methods of construction. Hence, the survey was conducted among the targeted expert population with at least five years of work experience in the prefab sector. Overall, twenty-eight professionals shared their perceptions through the survey. Even though PLS-PM advises to use a minimum sample size of "10-times number of indicators" for ease of application [14], researchers like Kock, and Hadaya, proposed alternate theories like "the inverse square root method", and "the gamma-exponential method" that proved and validated PLS-PM to be applicable with fewer sample size also [15].

The questionnaire recorded the perceptions on a five-point Likert scale (0-Strongly disagree, 1- Disagree, 2- Neutral, 3- Agree, 4- Strongly Agree). More than ninety percent of the respondents belonged to the design phase of prefab projects (Project management and coordination, structural or architectural design). More than ninety-six percent of the companies use conventional or prefab methods based on project scope and requirements. For more than eighty-five percent of companies, the level of adoption of prefab techniques is precast concrete construction at the component level.

3.3 Partial Least Square Path Modeling (PLS-PM) using SmartPLS 4

The primary aim of this study is to establish a relation between the technology provider and receiver, and structurally validate and illustrate the impact over the adoption of prefab and modular methods (the final output structural model is illustrated in Fig. 3). Using the PLS-PM statistical approach, the authors validate the structural equation representing the interconnectedness between latent variables. PLS-PM provides more flexibility than covariance-based structural equation modeling (CB-SEM) regarding sample size and predictive and exploratory analysis [6]. Accuracy is achieved through the bootstrapping method for calculating both path coefficients and p-values.

In PLS-PM, indicator loadings of 0.70 are preferable over the latent variable, but as an exploratory model, greater than 0.4 can also be acceptable. Most indicator loadings in the current model under consideration fall above 0.4. The perceived benefits of prefab and modular adoption show a reflective type, where the latent variable defines the indicators. Also, the internal consistency of the construct is 0.753, falling between 0.70 and 0.95, and it is proven reliable. The Average Variance Extracted (AVE) obtained is 0.505 (above 0.50), which gives convergent validity between constructs and indicators [6], [12]. Bootstrapping results show a significant (p value 0.013, less than .05) connection between the customer perception towards the organizational factors. The explanatory side of this model is expressed through the R2 value, the degree to which the independent variables explain the variance in the dependent variable. The R2 value obtained for the determinants of prefab and modular adoption is 0.527, which means other latent variables explain 52.7% of the variance. Similarly, customers' perceptions can explain 41.7% of the variance in the organizational factors.

Table 2: List of constructs and indicators

Constructs under consideration	Variable type	Indicator set	Code	References from literature
Customer perceptions (Technology receiver)	Independent variable	Minimal customer awareness and acceptance	MCA	[1], [3], [6], [8], [9], [13], [16]
		Stigma of past technical errors (like faulty/leaking joints)	PTE	
		Difficulty of component replacement for post construction modification or repairing	PMR	
Organizational barriers (Technology provider)	Independent variable	Change resistance towards innovative methods	CR	[1-4], [6], [7], [9], [13], [14]
		Multi-disciplinary participant collaboration and knowledge sharing difficulties in the design phase	CKS	
		Shortage of skilled industry professionals and lack of prefab project experience	SS	
		Initial capital investment is huge for plant setup, transportation and handling machineries	HI	
		Prefab methods are only suitable for mass housing or for mass production of similar components	MP	
		Required location proximity of the factory relative to the project site	PP	
Mediating factors (Positive)	Independent variable	The integration of automation in to prefab construction can bring transformative benefits	A	[1], [3], [6], [8], [11]
		Government policies and subsidies promoting adoption	GPS	
		Availability of design codes and quality checks	DCQC	
Determinants of prefab and modular adoption (Perceived benefits)	Dependent variable	Prefab construction can provide smoother contracting and procurement process	SCP	[1], [3], [6], [8], [10]
		Financial payback exceeds initial investment over the time	PB	
		Prefab production assures workers health and safety	H&S	
		High performance in terms of quality and speed of construction	PQS	
		The controlled factory environment in prefab construction allows for a more predictable timeline and budget	PTB	

The indicator loadings of the measurement model represent the indicator strength over the latent variable. In the current study, all three independent variables are formative type, where the indicators define the latent variable. The factor loading of past technical error (PTE) has a strong inverse relation with customer perception. Similarly, skill shortage (SS), collaboration, and knowledge sharing difficulties (CKS) are inversely connected to organizational factors. Among mediating factors, the adoption of automation (A) shows the highest factor loading. Considering the customer perception, all the indicator factors like minimal customer awareness (MCA) and Possibility of post construction modification and repairing (PMR) show higher factor loadings. Meanwhile, technical errors and leaky joints show inverse factor loading. Customer perceptions substantially impact organizational factors, which can be assessed through the path coefficient value.

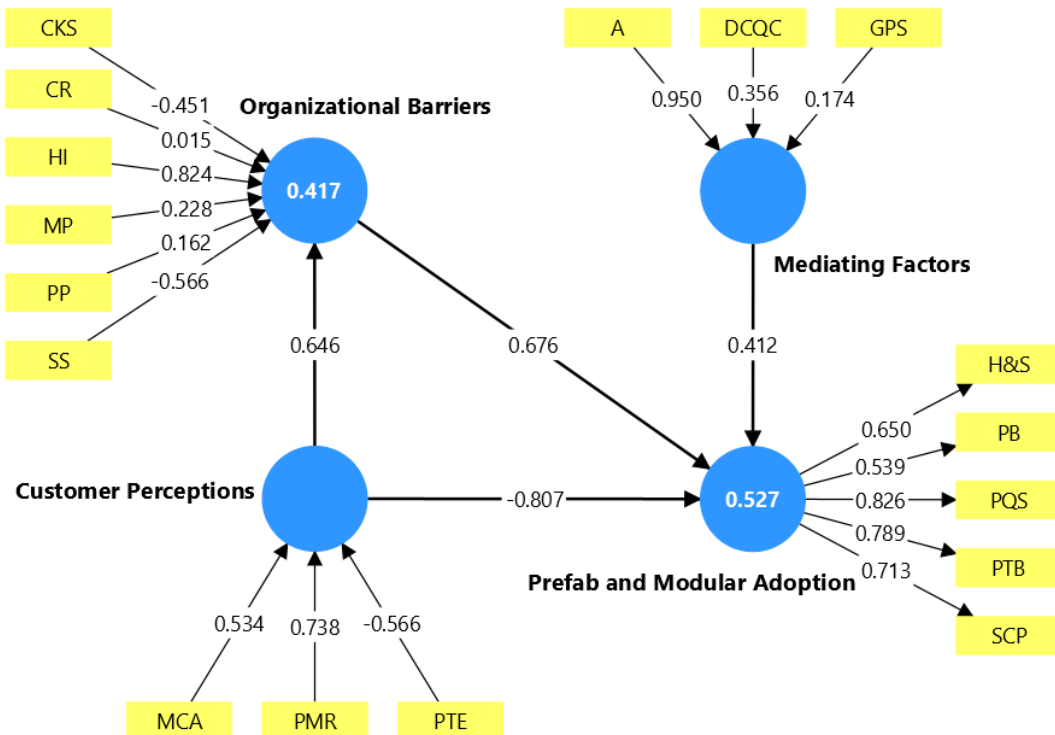

Fig. 3: Final output structural model

4. Conclusion

The study projected the impact of customer perceptions and internal organizational barriers on the adoption of prefab and modular techniques by the Indian construction sector. The results also showed that adopting automation to prefab methods can catalyse the transformation and maximize the perceived benefits of prefab construction. The criticality of customer perception over technology adoption is strongly proven through the study. The PLS-PM model represented both the retarders in adopting prefab techniques and the perceived benefits of adoption.

The results reveal how the indicators associated with the negative customer perceptions (technology receiver group) have a greater impact on adopting prefabrication and modular methods. Here, customer awareness is a major driving force towards a transformation. Also, internal organization barriers like huge initial investment requirement and skill shortage are retarding the transformation process.

The study projects the need for skill upliftment in the prefab sector, an increased customer awareness, and improved building performance (post construction), which play a significant role in the shift. The study's conclusion applies to all developing nations facing obstructions in adopting prefab methods. The practical applicability of the framework to other such systems depends on end-user characteristics, existing government policies, and technological updates. If a country has policy support, customer acceptance, and high-skilled resources, the prefab adoption will be easier. Even though the study provides practical insights to industry professionals, more dimensions or decision-making factors can be added to the existing structure to showcase more possible determinants.

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