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MODULAR BUILDING CONSTRUCTION IN PAKISTAN: AN EMPIRICAL INVESTIGATION OF THE DETERMINANTS OF ADOPTION IN THE HOUSING AND BUILDING SECTOR

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Abstract

Pakistan is facing a serious housing shortage of 10-12 million housing units, and the demand for new housing units is around 700,000 per year, which is far more than the supply. The traditional construction approach is insufficient to meet this increasing challenge due to its long project duration, labour-intensive process, cost overruns and low productivity. While modular construction has proven to be highly beneficial in other parts of the world, such as quicker project delivery, better quality, waste reduction, and sustainability, it has not been widely embraced in Pakistan. The present study aims to explore the factors that influence the adoption of modular construction in the housing and building sector in Pakistan by examining the impact of perceived performance benefits, organisational readiness, and technological readiness on the adoption intention, and the moderating effect of regulatory and policy support. The study used a quantitative, cross-sectional research design based on the Diffusion of Innovations Theory and the Technology Acceptance Model. A structured questionnaire was used to gather data from 312 construction professionals, including developers, contractors, architects, engineers, consultants, project managers, and regulatory officials from Karachi, Lahore, and Islamabad–Rawalpindi. The data were analysed with SPSS and AMOS by descriptive statistics, Confirmatory Factor Analysis (CFA) and Structural Equation Modelling (SEM). The results show that perceived performance benefits ($\beta = 0.41$, $p < .001$) and organisational and technological readiness ($\beta = 0.34$, $p < .001$) are significant positive factors for the intention to adopt modular construction. In addition, both relationships are greatly enhanced by the presence of regulatory and policy support, which underscores the need for an enabling institutional environment to support adoption. The most significant barriers cited were high initial capital investment, limited financing mechanisms and lack of regulatory recognition, while the most significant enablers cited were public-sector demand, reduced construction time and lower material waste. The study recommends that there is a need for coordinated efforts to strengthen the organisational capability and supportive regulatory reforms such as building code recognition, government procurement programs and financing schemes that are specific to factory construction to make modular construction a reality in Pakistan. The results add to the body of knowledge on industrialised construction and offer practical advice for policy makers and industry actors interested in increasing the delivery of housing using modular construction.

Keywords: Modular Construction, Offsite Construction, Prefabrication, Adoption Intention, Regulatory and Policy Support, Affordable Housing, Pakistan

INTRODUCTION

It is universally acknowledged that housing is a basic human need and in the Constitution of the Islamic Republic of Pakistan, the State has a mandate to promote the provision of housing as a necessity of life, under Article 38. With its strong links with poverty reduction, public health, urban stability and economic productivity, the provision of adequate, safe and affordable shelter has emerged as one of the most salient public policy challenges in the developing world (Farooqui, Ahmed, & Lodi, 2008). Adequate housing is acknowledged by the United Nations as a fundamental human right and a precondition for inclusive and sustainable development, in the New Urban Agenda and the Sustainable Development Goals. Even with these commitments, there is the growing gap in many countries of rapid urbanization between housing needs and the capability of the construction sector to provide sufficient housing. In South Asian countries, Pakistan is one of the countries with the highest housing shortage and there is a need of finding innovative and efficient solutions to the housing needs.

Pakistan is home to more than 240 million people with an annual growth rate of around two percent and it also has the highest rate of urbanisation in South Asia. This fast-growing population has placed a tremendous strain on the housing market. The national housing shortage is estimated at 10 to 12 million units and urban housing shortage is more than three million units (State Bank of Pakistan, 2020). The need for new housing units is estimated to be about 700,000 per year, while only about 500,000 are being built, leading to a continued shortfall. The shortage is especially pronounced in the low and lower middle-income groups, who are not able to access formal housing markets and consequently are forced to reside in the informal settlements of katchi abadis. World Bank estimates (2022) indicate that almost 50% of the urban population is living in these informal settlements where land insecurity, poor infrastructure, insufficient public services and poorly planned urban housing poses risks to people including floods, fires and earthquakes.

Resolving this housing crisis is critically dependent on the performance of Pakistan's construction industry, which has a key role in the national economy. The sector accounts for about 2-3% of the country's gross domestic product, and offers jobs to over 13% of the labour force, in addition to providing backward linkages to over 40 allied industries such as cement, steel, glass, ceramics and aggregates (Farooqui et al., 2008). The industry has the potential to be economically important, yet for the most part, it still uses traditional brick-and-mortar, cast in-situ construction methods, which have remained unchanged over the last 50 years. The traditional construction methods involve high dependency on skilled labor, cost and schedule overruns, quality control issues, wastage of material and resources at 10–15 percent, vulnerability to extreme weather conditions and long project time, with the project duration for low-rise housing developments ranging from 18 to 36 months. Closed loops in the productivity issues highlighted by Farooqui et al. (2008) remain a barrier to the ability of the industry to meet the increasing housing demand in Pakistan.

The underperformance of the construction industry compared to manufacturing industry is further accentuated by its low productivity. Mechanisation, automation and standardisation, coupled with quality management systems have been increasingly used in manufacturing, while construction has largely maintained a labour-intensive model that relies on on-site assembly of individual building components. As a result, the sector has not been able to realize the large gains in productivity that the manufacturing industries have enjoyed. Consequently, construction costs have been relatively high and project delivery has consistently been hindered by inefficiencies in time, quality and resource usage.

To overcome these longstanding problems, modular building construction has appeared in the international market as an innovative alternative to the traditional construction methods. Modular construction is based on manufacturing concepts and not on site-based construction. Modules produced in 3D dimensions or panels that have been panelised are made using structural systems, insulation, mechanical and electrical services and sometimes interior finishes, in controlled factory environments, before being transported to the construction site, where they are quickly fitted together (Gibb, 1999; Lawson, Ogden, & Bergin, 2012). The manufacturing-based method allows for repeatability of manufacturing processes,

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dimensional tolerancing, on-site factory quality control, and simultaneous on-site foundation construction and off-site module construction. In order to carry out all these activities at once, the duration of the project can be significantly shortened, and these are some of the key benefits of modular construction.

There is a wealth of international evidence to support modular construction. When scale of factory production is high enough, modular construction can cut project schedules by 20 to 50 percent and construction costs as much as 20 percent, according to the report, "Modular Construction: The Global Analysis" (2019) by Bertram, Fuchs, Mischke, Palter, Strube, and Woetzel from McKinsey. Their research further predicted that the EU and US modular construction market will be worth around US$130 billion by 2030. These skills have been witnessed in practical form around the world. The BROAD Sustainable Building Group in China was able to construct a 30-storey hotel in 15 days and a 57-storey building within 19 working days with the use of factory-made modules (Generalova, Generalov, & Kuznetsova, 2016). The public housing programme in Hong Kong also has adopted prefabrication for high-rise residential buildings, and the 461 Dean Street project in New York has shown that volumetric modular construction is viable for affordable high-rise housing in an urban built environment (Pan & Hon, 2020). In addition to speeding up and costing down the construction process, there are also significant benefits for construction waste reduction, reduction of dust and noise pollution on site, lower labour needs in construction sites, and energy efficiency of the built structures with higher manufacturing precision (Jaillon & Poon, 2008; Kamali & Hewage, 2016).

Such benefits are especially significant for Pakistan because of the need to deliver housing rapidly, not just for planned urban development but also for disaster recovery. Some 33 million people were affected by the devastating floods of 2022, and although the reconstruction of more than two million homes was affected, only a fraction of this number had been rebuilt in the first year (World Bank, 2022). Similarly, the frequent occurrence of major seismicity, such as the Kashmir earthquake in 2005, underscores the need for the construction systems that quickly provide engineered, code compliant houses after disaster in Pakistan. Moreover, the environment impacts of conventional brick kiln production combined with Pakistan's climate commitment through its updated NDCs further reinforce the need to consider other industrialised methods like modular construction which have reduced environmental impacts and less demand for resources.

Pakistan's housing needs and the benefits of modular construction coincide quite well, yet only a few housing projects in Pakistan are built using modular approaches. While the mainstream residential and commercial building still uses traditional construction methods, the use of prefabrication is mostly limited to industrial buildings, telecommunication shelters, security buildings, boundary walls and isolated donor-funded building projects. Current available information indicates that the technical challenges to more widespread use are smaller in

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magnitude than the organizational and institutional ones. A modified Technology Acceptance Model (TAM) was employed by Hamza, Azfar, Mazher, Sultan, Maqsoom, Khahro and Memon (2023) with 250 construction professionals from Pakistan, confirming that perceived usefulness and perceived ease of use have a significant impact on the acceptance of prefabricated construction technologies. Likewise, Khahro, Memon, Ali and Memon (2019) indicated that the greatest benefits of modular construction were the reduction in construction time and in material waste; the greatest barriers were increased initial costs and limited design flexibility. In addition, the most significant implementation risks identified by Pervez, Ali, Pamucar, Garai-Fodor and Csiszárik-Kocsir (2022) include the lack of technical expertise, limited manufacturing capacity and limited flexibility for modification to the design and during construction.

These research studies have yielded some useful information, but there are still some lacunae in the present literature. In particular, there is no theoretical framework that links the perceived performance benefits and organizational and technological readiness to the adoption of modular construction in the different regulatory and economic context within the Pakistan. Three major research gaps are thus apparent. First, to the best of our knowledge, no study in Pakistan had ever explored the demand-side drivers of adoption, which are practitioners' perceived benefits, and the supply-side enablers, organisational and technological readiness, simultaneously. Secondly, no study has examined whether the relationships between regulation and policy are moderated by the institutional environment in Pakistan. Third, existing research has not directly correlated the use of modular building with other national policies on affordable housing creation and after disaster reconstruction.

To fill these gaps, the present study examines the impact of the perceived performance benefits and the organisational and technological readiness on the intention to use the modular building construction for Pakistan. It also explores the moderating effect of regulatory and policy support on strengthening these relationships. Specifically the research aims are to: (1) empirically examine the relationship between perceived performance benefits and adoption intention; (2) empirically examine the relationship between organisational and technological readiness and adoption intention; (3) identify and rank the main barriers and enablers that influence industry stakeholders' intention to adopt modular construction; (4) determine whether perceived performance benefits and organisational and technological readiness moderate the relationship between regulatory and policy support and intention to adopt modular construction; and (5) determine whether perceived performance benefits and organisational and technological readiness moderate the relationship between regulatory and policy support and intention to adopt modular construction.

The research results of this study are hoped to be able to add value at the organisational, industrial and policy level. The validated research model offers a practical solution for the construction companies to measure their capabilities and determine where they should invest in the development of their workforce, technological capacity, and supply-chain integration. The study provides empirical evidence to the policymakers about the effectiveness of regulatory reforms and government support mechanisms for the promotion of modular construction. Academically, the research fills the gap by conceptualising and testing an integrated conceptual model, which integrates perceived performance benefits, organisational and technological readiness, regulatory and policy support, and intention to adopt. As far as the author's knowledge, this integration of constructs has not been looked upon together in the context of construction industry in Pakistan.

LITERATURE REVIEW

Modular and Offsite Construction: Concept and Evolution

Modular construction is one of the many offsite construction techniques that involve relocating a large amount of the construction work to the manufacturing facility, thereby minimizing the number of construction days onsite. While the practice has become more and more popular in the world in the last few decades, the terminology is still not standardised. The terms prefabrication, pre-assembly, modularisation, system building, industrialised building, modern methods of construction and offsite manufacture are often used interchangeably, even though there are subtle differences in the meaning of each term across countries and research traditions (Goodier & Gibb, 2007; Generalova et al., 2016). The absence of a consistent terminology has led to some conceptual confusion in the literature and has made cross-contextual comparisons of offsite construction difficult.

To give more conceptual clarity, Gibb (1999) designed one of the most accepted classifications of the offsite construction which he categorized into 4 progressive stages based on how much work is done in the factory before it is transported to the construction site. The first level is component manufacture and sub-assembly which includes the manufacturing of a range of standardised building components like windows, roof trusses and staircases. Non-volumetric pre-assembly is the second level and involves the creation of two dimensional structural components like wall panels, floor slabs and roof frames in the factory environment. The third level, volumetric pre-assembly, is the manufacture of three-dimensional elements which create habitable space which are then included in an independent structural framework on site. The most advanced stage is complete modular construction with fully volumetric building modules functioning as both the structural and functional parts of the building. The taxonomy shows that industrialisation is not a binary phenomenon in construction but a continuum along which construction industries can step by step develop as the technical capability, manufacturing capacity and demand for the construction industry grows.

On the extreme end of this spectrum comes the Modular Integrated Construction

(MiC) or Prefabricated Prefinished Volumetric Construction (PPVC). In this method, the modules are produced in the factory in 3D, structurally built and installed with mechanical, electrical, plumbing and interior finishing systems as close to finished rooms or apartments prior to delivery to site (Pan & Hon, 2020). No matter how much prefabrication is used, all modular construction methods have a shared philosophy of production, which is distinct from traditional construction on site. Modular construction is based on manufacturing principles, such as repeatable production processes, precise dimensional tolerances, factory quality inspection, parallel onsite and offsite operations, and so on, rather than relying on craft construction methods.Modular construction is based on manufacturing principles, which include repeatable production process, controlled dimensional tolerances, strict quality inspection in the factory, parallel onsite and offsite operations and others, rather than relying on craft construction methods. In particular, the concurrent progress of foundation works on site and the production of modules in factories significantly decreases project time and is one of the main benefits that is frequently linked to modular construction (Blismas, Pasquire, & Gibb, 2006).

Modular construction has been around since the nineteenth century, when prefabricated timber and cast-iron structures were shipped to aid in settlement and industrial growth. The technology did, however, see much development in the twentieth century when governments were looking for an efficient solution to the severe housing shortages that occurred after the two World War's. The Soviet Union industrialised volumetric construction during the 1970s, producing a large volume of reinforced concrete modules to satisfy the demand of the cities for housing building rapidly (Generalova et al., 2016). The manufacturing plants could produce standardized volumetric modules with dimensions of around 3.4 × 2.5 × 6.0 metres at a rate of more than fifty modules per day, and multi-storey residential buildings could be built in much less time than with traditional construction methods. This was a successful industrial development of the technical capability for volumetric construction but also uncovered significant constraints. Although the structural efficiency of the modular construction method was achieved, the little architectural diversity and the amount of finishing work following the installation of the modules prevented the public from accepting them, highlighting the fact that as well as being structurally efficient, a modular method of construction must be well-designed, flexible and effective in integrating factory-finished components to render a successful architectural finish.

Recent developments in structural engineering, digital technologies, manufacturing systems and logistics management have spurred the renewed global interest in modular construction. The rising use of modular construction that goes beyond temporary buildings and low-rise developments, is due to developments in the use of steel and composite structural systems, Building Information Modelling (BIM), Computer Aided Manufacturing (CAM) and integrated supply chains. Generalova et al. (2016) describe how the modern modular methods are widely used in multi-storey and high-rise structures around the world. The core structure is usually reinforced concrete or steel, and houses vertical circulation and building services, with the volumetric modules being made up of modules from the factory prefabricated to fit around these core elements. There are thus three basic structural solutions that have developed: load-bearing volumetric systems, modular systems using reinforced concrete, and hybrid systems of steel and concrete. The technological achievements illustrate the maturity and technical maturity of modular construction as a building technique. The engineering feasibility, of course, is no longer a significant obstacle to its broader implementation, but rather institutional readiness, industry investment, regulatory support and market acceptance.

Global Best Practices and International Case Studies

The experience gained worldwide is of the technical feasibility, economic viability and practical advantages of modular constructions, and lessons can be learned for countries which want to industrialise their construction sector. The overall idea of modular construction is fairly similar in different countries, but the speed of uptake and success has varied greatly with the extent to which the private sector and the Government have matched the level of institutional support and policies necessary, and the capability of the industry. Hence, studying the best practices from around the world offers some valuable lessons in determining the factors for a successful implementation of modular construction in developing countries like Pakistan.

A key example of large-scale modular construction can be found in China where industrialised construction systems have enabled the achievement of an unmatched speed without sacrificing the structural performance. In only 15 days, a 30-storey hotel and 57 days, a 57-storey tower were built with the BROAD Sustainable Building Group using its factory-produced steel modular system (Generalova et al., 2016). These building phases garnered a lot of media coverage, but a lot of work was done offsite to help the site assembly work go smoothly. The apparent speed of modular construction is a result of the extensive planning, optimized production processes, and well-coordinated logistics that took place before the modules were installed on site, with more than 2,500 volumetric modules produced in a period of some 4.5 months before the modules were installed on site. Of equal importance, however, these successes were achieved in a vertically integrated company that was involved in design, manufacturing, transportation and assembly, and had production levels sufficient to ensure the factories were used on a continuous basis. This organisational and industrial environment is relatively underdeveloped in the construction industry in Pakistan, and requires far more than technological ability to successfully implement modularity.

The example of Hong Kong is another one that is internationally known where the government has been consistent in its actions to enable long-term institutionalisation of modular construction. Housing Authority of Hong Kong (HAHK) gradually started using factory-made façade panels, semi-precast floor slabs, and volumetric units for bathroom and kitchen in residential towers over 40 storeys high to increase the level of prefabrication in its public housing programme (Jaillon & Poon, 2008; Generalova et al., 2016). Based on empirical evidence, such measures helped to improve the quality of construction work and to noticeably reduce onsite accidents, noise pollution, airborne dust (Jaillon & Poon, 2008) and construction waste. These developments have been further extended in more recent years in Hong Kong through the use of Modular Integrated Construction (MiC) in which government policy is clearly and strongly supportive of the use of industrialised construction for improving productivity, quality, safety and environmental sustainability (Pan & Hon, 2020). One of the major takeaways from the Hong Kong experience is the significance and importance of the public sector as a stable and long-term client. The government had also established a steady stream of housing projects, reducing the "chicken and egg" conundrum often linked with modular building because there was a market for the construction of modular manufacturing plants. If they do not have guaranteed demand, manufacturers will not invest in production capacity, and developers will not be sure of suppliers if they do not specify the modular systems.

The United States provides an example that shows that it is not only possible, but appropriate, to build complex affordable high-rise buildings using modular. Generalova et al. (2016) implemented over 900 factory manufactured modules with more than 200 different module types in the 32-storey 461 Dean Street residential tower in Brooklyn, New York. About half of the finished apartments were used for affordable housing applications, offering an important precedent for implementation of modular construction for affordable housing. The modules were built at a rate of about 4 per day in the factory, allowing the construction of one module floor per week, and a good quality control and interior finishing. But the project also brought to light the difficulties of new delivery system innovations in under-mature markets. Despite the start of the modular implementation, the contractual conflicts, chain constraints and coordination issues revealed that it is important to have equally developed management practices, contractual arrangements, and cooperation between stakeholders for successful modular implementation.

The success of the promotion of industrialised construction in Singapore and Malaysia provides further proof of government's leadership role. The Building and Construction Authority (BCA) integrated the Prefabricated Prefinished Volumetric Construction (PPVC) into specific government land sale projects, thus gaining momentum for the use of modular construction in the public and private sectors in Singapore. Likewise, Malaysia implemented its Industrialised Building System (IBS) policy in 2006 that prescribes minimum level of prefabrication for public buildings projects (Pan & Hon, 2020; Steinhardt & Manley, 2016). Both countries

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had a construction industry that was largely labour intensive, and relied on traditional wet trades. Governments, however, succeeded in promoting the move towards industrialisation through the use of rules and regulations, demonstration projects, accreditation systems, and training schemes for the industry. The Malaysian case, however, is a case in point that it is not enough to have regulations. The uptake by public sector grew significantly, but for private sector uptake, the industries' capacity to manufacture, ability to finance, skilled labour availability, and confidence in the industry has taken longer than the regulatory expectations. From this experience, it is clear that the whole construction industry needs to be developed in coordination for successful industrialisation, not just by policy intervention alone.

The following are some key lessons learnt from these international case studies, which are directly applicable in Pakistan. First, they show that modular construction is a technically proven means of construction and is scalable, offering substantial benefits in terms of project speed, quality, workers' safety, environmental performance and waste reduction. Second, they point to the fact that the adoption of these technologies has always been facilitated by enabling institutional settings featuring government commitment, a stable market demand, regulatory recognition of modular technologies, and financial mechanisms to mitigate the risks of investing in a factory. Lastly, evidence suggest that the reasons why modular construction is not widely taken up are seldom technological. However, they are mostly organization, institutional, and market, and future research should focus on shifting from just technical aspects to consider the overall impact of the perceptions of stakeholders, the organizational readiness and the regulatory support on the adoption of modular construction technologies.

Perceived Performance Benefits of Modular Construction.

The extent to which people believe that the building of modules offers performance benefits has been found to be one of the most important factors determining the adoption of modular construction. Theoretically, organisations are more likely to adopt new technologies when they see clear benefits to the existing technology (innovation adoption theory). These benefits fall into four general categories in the modular construction literature: project time savings, cost performance, quality enhancement and environmental considerations. While these benefits may differ from project to project and country to country, the evidence from around the world is clear when modular construction is supported by the right organisation and market conditions, it performs better than traditional construction.

Within these advantages, the short project duration, which is widely documented and well-recognized, is the most commonly accepted benefit of modular construction. In contrast to traditional construction, which is mostly linear and is very sensitive to site conditions, modular construction also allows offsite manufacturing to occur simultaneously with onsite foundation construction. In contrast with the conventional projects, the factory production is much less disrupted by the weather and other uncertainties it is exposed to. This allows for considerable reductions in overall construction programmes as a result. Industrialised construction offers huge productivity gains with a reduction in project schedules of between 20 and 50 percent, as found by Bertram et al. (2019). The same study was conducted in Pakistan and found to be similar. While other benefits of modular construction are well-known, Khahro et al. (2019) identified reduced construction time as the greatest perceived benefit, even over the benefits recognised by most construction practitioners such as waste reduction. In addition, Blismas et al. (2006) state that the economic values of time saving are often underestimated by methods used routinely to evaluate projects, which typically only account for the direct cost of construction and do not consider the indirect economic values of time saving, such as the early occupancy of the project, the reduction in preliminary costs and the reduction in financing costs due to shorter construction programmes. This is especially significant in Pakistan where financial cost of construction is relatively high and interest rates are in double digits which can significantly enhance the overall viability of a project and its investment rate of return with shorter construction duration.

The connection between modular construction and the cost of a project is far more complicated than the connection between modular construction and construction time, although cost reduction is often touted as another benefit of modular construction. Modular construction doesn't always lower the initial cost of construction, it shifts the entire project cost curve by adding costs for factories and transportation but subtracting costs related to onsite labour, material waste and project cost uncertainty. This makes the economic advantage of modular construction highly dependent upon the scale of production, utilisation of the factory, and the maturity of the supply chain (Mao et al., 2015; Bertram et al., 2019). Previous research suggests that projects that do not run at a near maximum production will have higher costs as manufacturing facilities may not realize economies of scale. On the other hand, in a scenario of relatively stable demand and high production volumes, modular construction can provide substantial cost savings (Hong, Shen, Li, Zhang, & Zhang, 2018; Jaillon & Poon, 2008). The results of these findings have significant implications for Pakistan. Financial competitiveness of modular construction is likely to be more dependent on whether or not there is a sustained demand in the market, backed by consistent public housing schemes and industrial investment, rather than on modular technology itself. Moreover, certain cost is another benefit that is not always explored. Even if the cost of the initial mod panels is not significantly lower than traditional panels, the cost predictability of modular construction projects can be valuable in a construction environment where projects have a high tendency for cost escalation and budget overruns.

In addition to being faster and cheaper to build, modular construction has a number of benefits when it comes to quality and environmental issues. The advantages of factory based production are that the production is carried out within an environment that is controlled as opposed to a traditional site, the production is based on standardised practices, and there is a continuous inspection regime. These factors help to improve the dimensional accuracy, reduce construction defect, achieve higher degree of air tightness and provide higher level of thermal performance (Kamali & Hewage, 2016; Tam, Tam, Zeng, & Ng, 2007). Modular construction has always been linked with significant environmental benefits, apart from the quality improvements. According to Jaillon and Poon (2008) and Tam et al. (2007), factory production can cut down on construction wastes by up to half and at the same time cut down on dust emission, noise pollution and water contamination on the site. These enhancements have a direct impact on overall sustainability goals and drive progress towards more sustainable construction methods.

Quality and environment related benefits are very relevant in the context of Pakistan. A large proportion of its housing stock is in the region where earthquakes and other natural hazards are a threat, where the structural reliability of buildings is directly relevant to public safety. Compared to conventional construction methods, factory-manufactured modules offer greater dimensional accuracy, pre-engineered structural connections, and more uniform construction quality, which can help increase building resiliency in hazard prone areas. Simultaneously, the use of fewer materials and less construction waste help Pakistan fulfill its environmental goals by alleviating stress on natural resources and emissions from traditional construction practices. However, Kamali and Hewage (2016) note that there are a few contextual factors that affect the environmental performance of modular construction, such as transportation distances, logistics planning and project design. Although there are some environmental advantages and disadvantages that can be mitigated by additional transportation needs, based on the life cycle analysis, it is found that the life cycle environmental performance of modular construction generally outperforms conventional construction.

Overall, the current literature suggests robust empirical confirmation of the performance gains of modular construction in many aspects such as construction speed, cost certainty, quality, sustainability and resilience. However, whether these benefits actually contribute to technology uptake will vary greatly depending on the perceptions of industry stakeholders about the benefits they could see within their own organisational and institutional settings. Hence, perceived performance benefits are the most important demand side factors that influence the adoption of modular construction in Pakistan and therefore the theoretical basis of the study of practitioners' intentions to adopt MC in Pakistan.

The Organisational and Technological Readiness

The performance benefits of modular construction have been proven, but the

knowledge of the benefits is not enough to guarantee successful adoption. Organisations will need to have developed the technological means, managerial expertise, financial capacity and networks to enable the implementation of the modular construct, which is also a different way of delivering a project. Organisational and technological preparedness thus has become one of the major factors influencing the uptake of modular construction. Previous studies have been consistent in indicating that organisations are more likely to adopt industrialised construction methods when they have the in-house resources needed to successfully design, manufacture, logisticate, and assemble the products on site.
Research in other parts of the world has identified organisational readiness as a multi-faceted construct that includes technical knowledge, employee skills, supply chain integration, financial resources and stakeholder collaboration. Based on a thorough international literature review, Wuni and Shen (2020) identify the main barriers to the adoption of modular construction in four interconnected categories: knowledge and experience gap, immature supply chain, financial restrictions, and fractured stakeholders. These barriers work together, so they are reinforcing each other and are systemic, making it harder to invest in modular technologies. They found that, in addition to the capacity of any particular organisation, the entire construction ecosystem in which the firms are operating influences successful adoption.
Likewise, Mao et al. (2015) reported that the key barriers to modular construction in China were perceived as the lack of expertise in designing modules, limited access to modular component suppliers and high initial capital costs. The results show that organisations might have an appreciation of the technical benefits of modular construction but not be willing to take up the practice due to investment, supplier and expert issues. As such, having a well-developed industry supply chain is a key enabler that helps companies translate a positive perception into action.
The lessons that can be learned from the experience of developed markets in construction confirm the need for organisational readiness. Although many housebuilders in the United Kingdom were aware of the potential benefits, they were not prepared to use offsite construction (Pan, Gibb & Dainty, 2007). They were not as much deterred by the technology as the business models, organisational habits and skills of their existing workforce that had developed around traditional construction practices. Likewise, Rahman (2014) found that lack of in-house technical skills and unwillingness to alter the long-standing organisational practices were found to be major factors affecting the industrialization of construction. These research works show how much organisational change is sometimes needed for technological innovation, such as the adoption of new management models, the modification of procurement processes, the training of the work force, and increased cooperation and communication within the project supply chain.
Many of these are challenges that have been identified on a global scale, and are evident in the Pakistani context. Pervez et al. (2022) used the fuzzy Delphi

screening and full-consistency prioritisation techniques to identify that three risks of modular implementation were most affecting in Pakistan, namely, lack of technical skills and experience in modular construction, lack of manufacturing capacity, and lack of flexibility to accommodate changes during the construction process. It seems that while industry stakeholders might recognise the opportunities of modular construction, there are a number of missing organizational and technological enablers that would need to be in place for this approach to become prevalent. Especially the lack of specialized manufacturers, seasoned designers and technically trained workforce is a challenge to the industry readiness.

The second dimension of organisational readiness has to do with the structure of the construction supply chain. In the conventional construction system in Pakistan, the architects, engineers, contractors, subcontractors, and suppliers are involved in a sequence of sequential processes, in which each one is responsible for one stage of a construction project, and in which competitive tendering is based on the lowest price possible. This approach of a fragmented approach is suitable to the traditional construction approach, but is not suitable to the modular approach of an integrated project delivery model. Modular projects require designers, manufacturers, contractors, suppliers and clients to work together in the early stages of project design to ensure that manufacturing requirements are integrated in the project design. In conclusion, the key to a successful modular implementation lies in sustainable partnerships, holistic planning and collaboration in decision-making across the project's entire lifecycle. However, as Pan et al. (2007) pointed out, much of the opposition to offsite construction is no technical issue but rather, incompatibility with traditional contractual practices, procurement and business models.

Together, the literature that is available suggests that readiness of the organizations and the technologies are key supply-side factors for the uptake of modular construction. While there may be perceived benefits to performance in relation to modular construction, these benefits are not likely to be realised if they are not supported by managerial commitment, collaborative supply chains, financial capability and technical expertise within the firm. To this end, organisational and technological readiness is a crucial competency that can help businesses transform positive perception into real decision for adoption. In the context of Pakistan, where industrialised construction is still at the initial level of development, building organisational readiness is likely to prove crucial in helping to speed the larger scale spread of the modular construction technologies.

Regulatory and Policy Support

The experience of international companies indicates that in addition to the firm's ability, the regulatory and policy climate is an influential factor on the uptake of modular construction. Building codes, public procurement schemes, financial incentives and housing policies minimise uncertainty, and promote investment in the manufacturing capacity. Comparative analysis shows that countries that have the modular system well regulated and have a stable demand in the public sector have adopted the use of prefabrication in construction to a much greater extent (Steinhardt & Manley, 2016).

There are a number of policy mechanisms, which are of specific relevance. Significant risks that block approvals are avoided by the building regulations that explicitly accept volumetric and prefabricated systems and public housing programmes guarantee the predictable demand, thus enabling manufacturers to benefit from economies of scale. Financial incentives and construction-finance facilities that allow factory production stage makes the investment barriers even lower (Hong et al., 2018; Arif & Egbu, 2010). If that's not the case, companies might be reluctant to implement a modular approach even if they are aware of the advantages it can offer.

Institutional support via regulations and policies is therefore not only a factor but an amplifier to the impact of other factors, from an institutional perspective. Risk in the policy environment is lower and recovery of investment more likely, thus more likely to take action when perceived performance benefits and organizational capabilities. This seems to justify the moderating role of regulatory and policy support in the present study.

Theoretical Framework

Rogers' Diffusion of Innovations theory and the Technology Acceptance Model (TAM) are the theories which underpin the study. According to Rogers (2003) the perceived attributes of relative advantage and compatibility are key factors that influence adoption while TAM postulates that perceived usefulness and ease of use are factors that influence behavioural intention (Davis, 1989; Venkatesh & Davis, 2000). In this study, perceived performance benefits are the relative advantage of modular construction, organisational and technological readiness is the ability to put the modular construction into practice and regulatory and policy support is the institutional environment that supports the adoption of modular construction. These concepts of technology acceptance were found to be relevant in the context of prefabrication industry in Pakistan by Hamza et al. (2023). An integration of both theories offers a model with the ability to explain supply-side capabilities and demand-side perceptions in the same model, and with the incorporation of institutional influences.

Research Gap and Conceptual Framework

The review reveals that, although the performance, barriers and policy aspects of modular construction have been explored in the international context, there is limited evidence in Pakistan. Existing research has not looked at the perceived

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performance level and organisational and technological readiness simultaneously and not assessed the moderating effect of regulatory and policy support in Pakistan context. The conceptual framework suggests that the perceived performance benefits and the perceived organisational and technological readiness have a positive link with the adoption intention, and that the support from regulatory and policy can reinforce the relationship between perceived performance benefits and perceived organisational and technological readiness.

H1: Perceived performance benefits significantly and positively affect adoption intention.
H2: Organisational and technological readiness significantly and positively affects adoption intention.
H3: Regulatory and policy support moderates the relationship between perceived performance benefits and adoption intention, such that the effect is stronger when support is higher.
H4: Regulatory and policy support moderates the relationship between organisational and technological readiness and adoption intention, such that the effect is stronger when support is higher.

This framework combines the perceptions of the demand side, the capabilities of the building industry and institutional support to account for the adoption of modular construction in the housing and building industry in Pakistan.

RESEARCH METHODOLOGY

Design and Research Philosophy

The type of research philosophy used in this research was positivist and research design used was quantitative, non-experimental and cross sectional survey. According to positivism, social phenomena can be studied objectively and social relationships between variables can be tested by means of measurable observations (Farooqui et al., 2008). As per this approach to research, the study followed a deductive research methodology, in which theoretical concepts and literature informed the conceptual framework and research hypotheses, which were then tested with primary quantitative data gathered from construction professionals in Pakistan.

Population and Sampling

The target population involved professionals who are actively involved in the building construction industry in Pakistan such as developers, contractors, architects, structural engineers, project managers, consultants and regulatory

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professionals. The study was conducted in two metropolitan cities, namely Islamabad – Rawalpindi and Lahore, which are the main and major centres of formal construction activity for the country, and Karachi which serves as the headquarters of the major construction organisations. Because of the lack of a broad-based sampling frame of construction professionals, non-probability purposive and convenience sampling methods were used. Individuals were chosen for their industry applicability, and were limited to those with at least three years of experience in the construction industry and in the selection of construction methods and/or project delivery decisions. Based on the recommendations of Structural Equation Modelling (SEM), that usually requires a minimum sample of 30 individuals for each parameter being estimated, a target sample of 300 valid responses was determined. Data screening and validation were performed and 312 questionnaires were retained for final analysis.

Instrumentation

A structured self-administered questionnaire was used to gather the primary data which had three sections. The first section collected the demographic and professional data, and the second section was the phases of the study constructs, with 27 items that were rated on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The last part of the questionnaire required respondents to rate the factors that inhibit and facilitate the use of modular construction in Pakistan. The content validity and reliability of measurement items were based on the adaptation of the items previously validated. Specifically, those items measuring perceived performance benefits were adapted from Blismas et al. (2006) and Hamza et al. (2023), organisational and technological readiness from Mao et al. (2015) and Wuni and Shen (2020), regulatory and policy support from Steinhardt and Manley (2016), and adoption intention from Davis (1989) and Venkatesh and Davis (2000). The questionnaire was pre-tested for clarity of items, content validity and reliability with 30 respondents before the main survey and was revised to make small adjustments.

Demonstrates the ability to collect and analyze data.

The survey was administered online and onsite and data collection took place for a period of 10 weeks during the first half of 2026 in order to achieve the highest possible response rates and ensure the best possible response quality. The questionnaires were sent out electronically via an online survey tool and onsite at construction companies and professional industry functions. Data collected were analysed by SPSS version 26 and AMOS. Data screening, coding and data preparation were done as preliminary steps in the analytical procedure, and descriptive statistical analysis was performed to sum up the characteristics of the respondents. The Cronbach's alpha was used to test the reliability, and Confirmatory Factor Analysis (CFA) was conducted to test the convergent and discriminant

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validities of the measurement model. A correlation analysis was then performed to study the correlations among the study variables. The result of the hypotheses test has a direct relationship between the constructs tested by using the method of Structural Equation Modelling (SEM) and a moderating relationship between the constructs was examined through hierarchical moderated regression analysis. Ethical principles were fully respected throughout the research process, including obtaining informed consent from all participants, ensuring their voluntary participation, maintaining anonymity and confidentiality and using suitable methods to protect their security and privacy when collecting the data.

ANALYSIS

Descriptive Statistics and Reliability

The final sample (N=312) comprised predominantly male (90.1%) experienced professionals: 44.2% aged 26-35; 30.1% aged 36-45. Professional roles included civil/structural engineers (25.0%), project/construction managers (20.5%), architects (15.7%), developers (13.8%), consultants (13.1%), contractors (8.3%), and regulatory officials (3.5%). Majority held bachelor's (54.8%) or master's (39.7%) degrees. Experience distribution: 30.8% (3-5 years), 37.8% (6-10 years), 19.6% (11-15 years), 11.9% (16+ years). Organisation types: private contractor/builder (33.3%), consultancy/design firm (28.5%), real-estate developer (21.5%), public-sector/authority (16.7%). Geographic distribution: Lahore (40.4%), Karachi (33.3%), Islamabad-Rawalpindi (26.3%). Prior exposure: awareness only (56.4%), direct project experience (22.8%), no prior exposure (20.8%).

Category	Sub-Category	%
Gender	**Male/female**	90.1 / 9.9
Age	25 or under / 26-35 / 36-45 / 46+	10.9 / 44.2 / 30.1 / 14.8
Role	Engineer / Manager / Architect / Developer / Consultant / Contractor / Officia	25.0 / 20.5 / 15.7 / 13.8 / 13.1 / 8.3 / 3.5

Qualification	Bachelor's / Master's / Diploma	54.8 / 39.7 / 5.4
Exoerenice	3-5 yrs / 6-10 yrs / 11-15 yrs / 16+ yr	30.8 / 37.8 / 19.6 / 11.9
Organisation	Contractor / Consultancy / Developer / Public	33.3 / 28.5 / 21.5 / 16.7
City	Lahore / Karachi / Islamabad-Rawalpind	40.4 / 33.3 / 26.3
Exposure	Awareness Only / Direct Experience / No Exposur	56.4 / 22.8 / 20.8

Construct means followed pattern: perceived performance benefits (M=3.91, SD=0.62) highest; adoption intention (M=3.38, SD=0.74); organisational and technological readiness (M=3.16, SD=0.71); regulatory and policy support (M=2.58, SD=0.79) lowest and only construct below scale midpoint.

Reliability assessment revealed all constructs exceeded conventional thresholds: Cronbach's alpha (0.84-0.90), composite reliability (0.85-0.91), average variance extracted (0.57-0.64). Confirmatory factor analysis confirmed measurement model fit: $\chi^2/df=2.04$; CFI=0.951; TLI=0.944; RMSEA=0.046; SRMR=0.041; GFI=0.918. Discriminant validity confirmed via Fornell-Larcker criterion: diagonal values (square roots of AVE) exceeded off-diagonal correlations. Correlation analysis showed all constructs positively correlated at $p<.01$: PPB-AI (r=0.55); OTR-AI (r=0.50); RPS-AI (r=0.42); PPB-OTR (r=0.46).

Hypothesis Testing

Structural equation modelling tested direct-effect hypotheses. Structural model fit was good: $\chi^2/df=2.18$; CFI=0.943; TLI=0.935; RMSEA=0.052; SRMR=0.048; GFI=0.911.

Table 2: Structural Path Estimates for Direct-Effect Hypotheses

Path	β (std.)	S.E.	t-value	p	Decision
PPB → AI (H1)	0.41	0.06	6.79	<.001	Supported

OTR → AI (H2)	0.34	0.06	5.62	<.001	Supported

Note: Dependent variable: adoption intention. Model R^2 = 0.42. β values are standardised regression weights.

Path estimates confirmed H1: perceived performance benefits significantly and positively affected adoption intention (β=0.41, t=6.79, p<.001). H2 confirmed: organisational and technological readiness significantly and positively affected adoption intention (β=0.34, t=5.62, p<.001). Together predictors explained 42% variance in adoption intention (R^2=0.42). Hierarchical moderated regression tested moderation hypotheses. Step 1 (main effects): PPB (β=0.39, p<.001), OTR (β=0.32, p<.001), RPS (β=0.21, p<.01), R^2=0.46. Step 2 (adding interaction terms): PPB×RPS (β=0.17, p<.01, ΔR^2=0.031); OTR×RPS (β=0.14, p<.05, ΔR^2=0.024); total R^2=0.51. Both interaction terms positive and significant, confirming H3 and H4.

Table 3: Hierarchical Moderated Regression Predicting Adoption Intention

Predictor	β (Step 1)	β (Step 2)	p
PPB	0.39	0.37	<.001
OTR	0.32	0.31	<.001
RPS	0.21	0.20	<.01
PPB × RPS	_	0.17	<.01
OTR × RPS	_	0.14	<.05
Model Summary	R^2 = 0.46	R^2 = 0.51	ΔR^2 = 0.055

Ranking of Barriers and Enablers

Barriers ranked by mean importance: high initial capital cost (4.28); absence of financing recognising factory-stage work (4.16); lack of code recognition (4.09); immature local supply chains (3.97); shortage of skilled workforce (3.85); transport/logistics constraints (3.71); design inflexibility perceptions (3.44). Top three barriers were financial/institutional rather than technical.

Table 4: Ranking of Perceived Barriers to Modular Construction Adoption

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Rank	Barrier	Mean	SD
1	High initial capital cost of modular manufacturing capacity	4.28	0.66
2	Absence of financing recognizing factory- stage work in progress	4.16	0.71
3	Lack of recognition of volumetric systems in building codes/approval	4.09	0.74
4	Immature local supply chains and component manufacturer	3.97	0.78
5	Shortage of skilled modular design and assembly workforce	3.85	0.80
6	Transportation and logistics constraints for oversized modules	3.71	0.83
7	Perceptions of design inflexibility and standardization	3.44	0.88

Table 5: Ranking of Perceived Enablers of Modular Construction Adoption

Rank	Enabler	Mean	SD
1	Guaranteed public- sector demand through government housing programmes	4.31	0.63
2	Speed and schedule compression relative to conventional methods	4.22	0.68
3	Recognition of modular systems in building codes and standards	4.11	0.72
4	Fiscal incentives and tariff relief for manufacturing investment	4.03	0.75
5	Reduced construction waste and environmental impact	3.92	0.77

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6	Improved and predictable quality through factory production	3.88	0.79
7	Improved site safety through relocation of labour to factories	3.69	0.84

Table 6: Summary of Hypothesis Testing Results

Hypothesis	Statement	Estimate	Decision
H1	PPB → Adoption Intention (direct effect)	β = 0.41***	Supported
H2	OTR → Adoption Intention (direct effect)	β = 0.34***	Supported
H3	RPS moderates PPB → Adoption Intention	β = 0.17**	Supported
H4	RPS moderates OTR → Adoption Intention	β = 0.14*	Supported

*Note: ***p<.001; **p<.01; p<.05

DISCUSSION AND CONCLUSION

Discussion

Findings are consistent with international literature while extending understanding of adoption determinants in developing-economy institutional context. The strong effect of perceived performance benefits (β=0.41) aligns with Diffusion of Innovations theory emphasising relative advantage (Rogers, 2003) and Technology

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Acceptance Model's perceived usefulness mechanism (Davis, 1989). It confirms Hamza et al.'s (2023) Pakistani finding that perceived usefulness shapes modular adoption intention. However, highest mean for perceived benefits (3.91) indicates awareness barrier is not as strong as often believed—binding constraints are capability and institutions, not belief. This reframes adoption problem from advocacy to capability building and institutional reform.

The significant effect of organisational and technological readiness (β=0.34) reiterates barrier literature findings that supply-chain immaturity, fragmented industry structures, and skills shortages are recurring barriers (Mao et al., 2015; Wuni & Shen, 2020; Pan et al., 2007). Moderate mean for readiness (3.16) significantly lower than perceived benefits suggests Pakistani firms value modular approaches but lack current capability. This aligns with Farooqui et al.'s (2008) and Khahro et al.'s (2019) descriptions of industry dominated by conventional, labour-intensive, in-situ practices, and Pervez et al.'s (2022) risk assessment where inadequate skills and manufacturing capacity emerged as most critical risks.

The most theoretically distinctive contribution lies in moderation findings. Both interaction effects significant, demonstrating regulatory and policy support conditions strength of benefit and readiness pathways. This supports conceptually (Pan & Hon, 2020; Steinhardt & Manley, 2016) that institutional environment decisively shapes whether intrinsic advantages are realised. Regulatory and policy support rating lowest (2.58) and below midpoint has considerable analytical significance: strengthening institutional environment likely yields disproportionately large returns, raising adoption intention directly and magnifying effects of existing benefits and capabilities. This interpretation reinforced by barrier/enabler rankings where code recognition and public-sector demand appear at top of both lists. Convergence of three independent evidence strands—descriptive (lowest-rated construct), moderation (conditions strength), and ranking (institutional levers top both lists)—lends robustness to conclusion. Barrier rankings align with international research identifying upfront capital and financing constraints as commonly reported barriers (Goodier & Gibb, 2007; Rahman, 2014), and code recognition as important barrier in less mature markets. Enabler rankings align with international evidence from Hong Kong and Singapore public housing programmes (Jaillon & Poon, 2008; Generalova et al., 2016) showing government procurement and demand aggregation played key roles where modular construction has gained scale.

Conclusion

Perceived performance benefits are significant determinant of modular construction adoption intention in Pakistan and strongest determinant examined. Pakistani

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construction professionals recognise time, cost-certainty, quality, and waste advantages, and this recognition translates directly into stronger adoption disposition.Organisational and technological readiness is also significant determinant, operating independently of perceived benefits. Capability is binding constraint in its own right: belief in value is necessary but not sufficient, and moderate industry readiness limits translation of belief into adoption. Regulatory and policy support significantly moderates both benefit and readiness pathways. Institutional environment conditions whether advantages and capabilities convert into adoption intention, and is currently weakest element of adoption system. Institutional environment is decisive leverage point: strengthening both raises adoption intention directly and amplifies effect of other determinants. Financial and institutional constraints are major challenges, not technical. Most critical constraints are upfront capital cost, lack of supportive financing, and lack of code recognition. Most powerful enablers are credible public-sector demand pipeline, speed of modular construction, and code recognition. Institutional constraints perceived to unlock adoption are same as those limiting it—targeted institutional reform is most efficient way to accelerate modular construction.

Recommendations

For Government and Policymakers: Develop and promulgate building-code provisions and technical standards specific to modular and volumetric construction; establish credible sustained public-sector demand pipeline by committing defined share of public/affordable housing and post-disaster reconstruction projects to modular delivery; introduce targeted fiscal instruments including tax incentives, import-duty relief on manufacturing equipment, and catalysing modular-appropriate financing and mortgage products. For Housing Authorities and Development Agencies: Pilot modular delivery on defined portfolio of public and affordable housing schemes; document cost, time, and quality outcomes transparently; use results to build evidence base and institutional confidence; reconstruction programmes following floods and earthquakes represent particularly appropriate setting for pilots, combining urgent demand for speed with strong public interest in resilient, engineered housing.

For Developers, Contractors, and Consultants: Invest deliberately in capabilities modular construction requires—design-for-manufacture-and-assembly competence, early-stage design-production integration, supply-chain relationships with component manufacturers, upskilling technical and site personnel; begin with hybrid and partial applications (prefabricated bathroom/service modules or panelised components) before progressing to fully volumetric systems to build capability incrementally while managing risk. For Future Research: Employ longitudinal design to follow evolution of adoption intention to actual adoption behaviour as institutional environment evolves; broaden focus to secondary cities and rural reconstruction environments, include regulators, financiers, and end users; supplement quantitative model with qualitative case studies of pioneering modular projects to illuminate implementation mechanisms; examine generalisability of moderated model in other developing economies; expand model by adding constructs like cost perception, environmental orientation, and client demand. The study demonstrates technology is seen as beneficial, industry capability and institutional setting are limiting factors, and institutional change is most effective way to speed diffusion. By identifying where most powerful levers lie, the study provides practical basis for government, industry, and researchers to achieve faster, more affordable, and more sustainable housing and reconstruction in Pakistan's construction sector.

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