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Opportunities for Prefabricated Buildings (PB's) in Pakistan: Lessons from China

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ABSTRACT

This research compares prefabricated building (PB's) practices in Pakistan and China, focusing on opportunities for Pakistan to adopt prefabrication as a sustainable and cost-effective construction approach. By analyzing China's advancements in prefabricated construction, the study identifies strategies that can be adapted to Pakistan's context. Where it traces the development of prefabrication in both countries, highlighting China's achievement in industrialized construction and contrasting it with Pakistan's continued reliance on conventional methods, in Pakistan prefabrication is still in its experimental and initial stage. This research work focuses on the potential of prefabrication in Pakistan to reduce construction time, material waste, and cost and enhance environmental sustainability. This research work highlights the tourism sector, suggesting that eco-friendly and green prefabricated dwellings in Pakistan's colder regions could support sustainable tourism while preserving natural landscapes and context. Recommendations include the implementation of supportive regulations, the promotion of local manufacturing, and the fostering of partnerships between government, academia, and industry to modernize Pakistan's construction sector to promote green prefabrication and a more sustainable built environment.

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1. Introduction

Prefabricated buildings offer valuable insights into the potential for implementing prefabrication in Pakistan, particularly in comparison to China. The study investigated the industrialization of design and construction, along with the crucial part that prefabrication plays in building processes (Hamza et al., 2023). Prefabrication is a construction method where building components are manufactured in controlled environments before being shipped and assembled on site. This strategy has the advantages of reducing waste and saving money and time. (Zhong et al., 2017). China's extensive prefabrication expertise and advancement could benefit Pakistan in the field of green prefabrication, cost-effectiveness, and efficiency. Industrialized building has a long history, but its implementation and adaptability in Pakistan are limited to temporary or experimental projects, instead of long-term advancements and uses. As prefabricated buildings were used as emergency shelters after the 2005 earthquake in northern Pakistan. CO2 emissions mitigation, cost saving, and waste reduction are some of the major issues facing Pakistan's construction sector. Because Pakistan lacks comprehensive policies, standard codes, and an industrial infrastructure, which can support prefabrication building technology.

Pakistan's building industry futures depend on adopting intelligent and sustainable industrialization (Rasool et al., 2022). Prefabrication may reduce environmental effects, enhance construction quality, and increase energy efficiency, as China's example suggests. However, in Pakistan, these benefits required the active participation of national agencies in developing sustainable regulations. Eco-friendly materials should be given importance, and prefabrication quality should be maintained. Prefabrication should be viewed not only as a construction technique but as a comprehensive approach encompassing long-term sustainability (the responsible use of resources to guarantee that future generations can fulfill their own requirements is known as sustainability) Kuhlman and Farrington (2010) community impact, and innovation in technology. Prefabrication has a big chance to have a beneficial influence on ecotourism, which promotes ethical travel to natural regions to protect the environment and improve the quality of life for residents. Eco-tourism (a type of responsible travel known as ecotourism places a strong emphasis on visiting natural regions to protect the environment and improve the well-being of nearby populations) (Kiper, 2013).

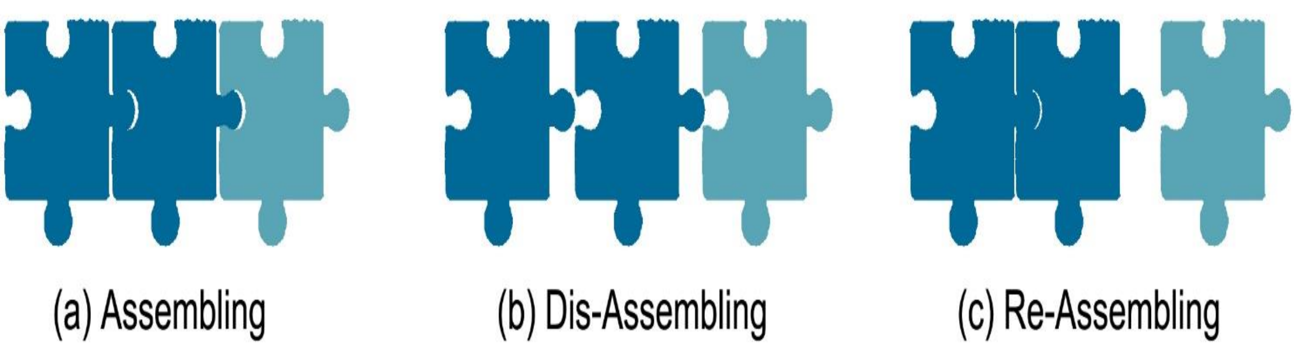
Prefabrication provides a practical and sustainable solution to Pakistan's construction issues, particularly in cold climates like Malam Jabba, Kalam etc. and the tourism industry. Traditional building techniques are resource-intensive and can have negative environmental effects due to growing visitor numbers and inadequate infrastructure. Prefabricated buildings, like mobile homes, are affordable, energy-efficient, and flexible. As observed, in such harsh climatic sites and mountainous ranges, prefabricated buildings are easy to assemble, environmentally friendly, and acceptable to the local communities, where it can preserve the natural landscape and can meet the highest demand of tourism in Kalam, Malam Jabba, and Gabbin Jabba tourist sites. Beyond tourism, in Pakistan, prefabrication has additional potential in the housing sector as well, where it can integrate traditional methods with technological advancements to facilitate housing demand. Which will create standard green codes for dwellings and will fulfil Pakistan’s fast urbanization and requirement of housing demands, along with the promotion of economic growth and utilizing expertise and knowledge from countries like China. Establishing a robust, adaptable, and sustainable building sector in Pakistan requires collaboration between the government, industries, and communities.

2. Literature Review

2.1. Prefabrication & Prefabricated Buildings

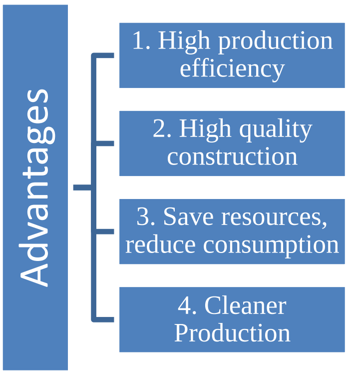
Manufactured from factory-produced components, prefabricated buildings provide consistent quality, quick assembly, and effective transportation. This approach promotes sustainability, reduces pollution, conserves resources, and increases productivity. Prefabrication is a contemporary, environmentally sustainable alternative for faster and more effective building procedures by simplifying construction and reducing environmental impact(Smith, 2016). A portable colonial cottage was designed by Henry John in 1830, which used prefabricated wood and panels for immigrants heading to Australia (Smith, 2016). In the mid-1800s, William Fairbairn pioneered the construction of empty cargo ships, incorporating the method of the first iron steamboats by using riveted plates to create modular components. This innovative construction technique showcased the use of prefabrication in both maritime and residential architecture at that time. The concept was assembling, disassembling, and reassembling. Later, this technology was transferred to build prefabricated iron plate homes and in architectural technology.

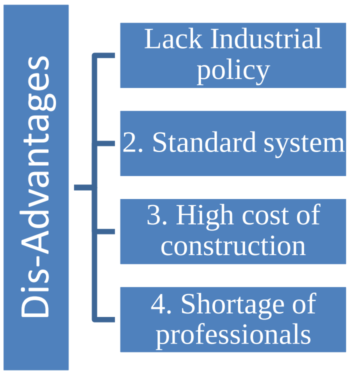
Figure 1 (a), (b) and (c): Showing the process of assembling, disassembling and reassembling of prefabricated architecture



2.2. Advantages and Disadvantages of Prefabricated Architecture

Figure 2 and 3: Showing the Advantages and Dis-Advantages of prefabricated architecture





2.3. Recyclable Architecture: Prefabricated and Recyclable Typologies

The increasing demand for resources and the growing housing shortage, exacerbated by population growth, highlight the challenges faced in addressing housing and environmental concerns. The demolition of buildings also contributes to significant waste generation, emphasizing the need for sustainable solutions in construction and urban planning to manage resources effectively and reduce waste. Here the concept of prefabrication and modular designs will help to resolve the issues where you have a problem of disassembling and reusing the structure. There are three types of prototypes:

- A Slab prototype designed as a shelf structure where wooden housing modules can be plugged in and out.
- A tower prototype allowing for an easy change of layout and use of different floors.
- A demountable prototype characterized by the entire demounting ability of the building.

All the mentioned typologies will incorporate modularity, flexibility, and disassembly to meet the increasing need for versatile spaces, reusability, and efficient construction practices. The design, drawings, plans, and 3D models should be meticulously developed and analyzed to determine the most effective methods for integrating these concepts in both design and construction. This practical approach should prioritize reducing carbon emissions and waste during demolition to enhance sustainability in construction processes (Ferreira Silva, Mário, Lima, and Paiva 2020).

2.4. Terminology used for premade homes

2.4.1. Mobile home

Produced in the company, transported to the site, the site should be temporary or permanent; somehow the authors call it caravans, usually pulled behind long vehicles.

2.4.2. Manufactured housing

Factory made specifically for specific sites, its foundations or placement platforms must be already prepared on site in advance and should be assembled for permanent installation on site.

2.4.3. Modular home

When manufacturing dwelling units or shelters in a factory setting, it is essential to consider local zoning codes and contextual factors throughout the production process (Panjehpour & Ali, 2013).

2.5. Prefabricated Building Concepts and Degrees

The degree of prefabrication in a final structure is determined by the size and complexity of the prefabricated components. Smaller components usually require more onsite construction labor, whereas larger and more intricate components reduce the need for labor. Prefabrication can be classified according to component size and assembly requirements, which in turn affect labor requirements and construction efficiency:

2.5.1. Components

This approach provides a high level of customization and flexibility during the design and execution phases, but it also increases onsite work and requires meticulous labor management. Component systems require multiple joineries and connections, precise alignment, and quality checks. Examples include staircases, gable ends, roof trusses, wall frames, wood kits, and precast concrete, all of which are single prefabricated elements.

2.5.2. Panelized Structures

To increase efficiency and convenience, 2D panels such as partition walls, metal frames, and structural insulated panels (SIPs) are used to build structural walls, floors, roofs, and columns. The 30-story hotel in Dongting Lake in Hunan, China, which was built in 15 days with these effective panel technologies, is a noteworthy example.

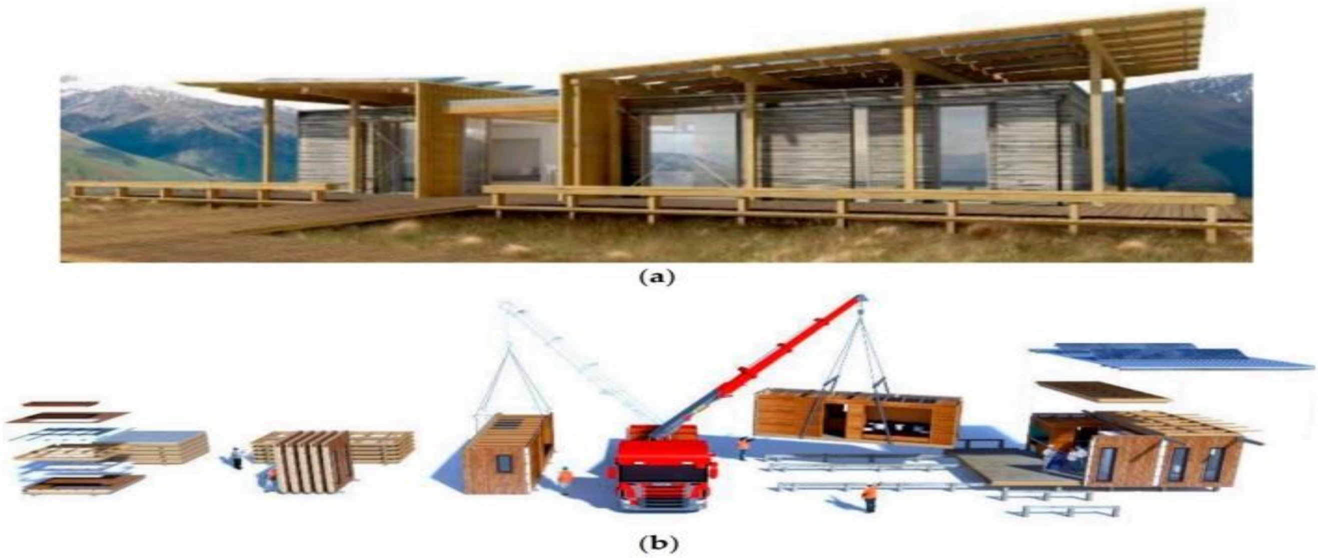
2.6. Modular Structures

3D volumetric modules, including exterior and interior finishes, are used in modular construction and are 80–90% finished in the factory. These portable, lightweight modules enable speedy on-site assembly in contrast to panelized systems. Mobile houses, which provide efficiency, convenience, and streamlined construction with minimal on-site work, are the perfect example of modular prefabrication. Notable examples include Japan's Nakagin Capsule Tower and the Mini Sky City skyscraper, which was erected in a mere 19 working days.

2.7. Hybrid Structures

An example of combining panel and modular prefabrication systems is the Meridian First Light House. This net-zero energy dwelling is designed to optimize climate-based energy efficiency using both active and passive energy strategies. The house includes wooden decking and six independent prefabricated modules that interconnect to form a biophilic environment, blending seamlessly with its surroundings to enhance sustainability and ecological design.

Figure 4 and 5 Showing: Hybrid structure–First Light House: completely installed building (a) and installation procedure (b).



2.8. Unitized Whole Buildings

Compared to components, panels, modular, and hybrid systems, this approach offers a more standardized building unit with the highest level of finish. Manufactured within a controlled industrial environment, it involves precise instructions to ensure maximum quality and adherence to timelines. However, the structure's heavy nature can make transportation and assembly challenging at times (Boafo, Kim, & Kim, 2016).

2.9. Prefabrication Technology Adoption for Sustainable Supply

Developed and developing nations have embraced prefabrication technology to address the growing demand for housing in a sustainable manner. Sweden, for example, initiated the Million Program (1965-1974), a ten-year prefab housing project, and in 2014, they exceeded their targets by producing hundreds of units, thanks to advancements in prefabrication techniques. Japan, known for its well-established prefab industry, manufactured 892,261 units in 2014, although these units were more expensive than traditional onsite construction due to long-term warranties and service benefits. In Malaysia, prefabrication has been used for low-cost housing since the 1960s, but private developers have been slow to adopt this technology, with most low-cost public housing projects still being managed by the government.

Table 1: Prefabrication Technologies Production

S. No	Countries	Year start	Annual Production
1	Sweden	1960	29164 unit on year 2014 (38)
2	Japan	1940	892261 unit on year 2014 (38)
3	Malaysia	1960	No formal record. However, IBS manufacturer such as Gamuda IBS capable to produce 20000 units apartment a year (43)

2.10. Shipping Container Architecture in Cold regions as a Modular Design strategy

In cold regions, the modular design approach is crucial for building with shipping containers, which function as both a standard module and a sturdy structural element. The container serves not only as a building block but also as a key structural component because of its durability. Design considerations extend beyond spatial organization, with a strong emphasis on BIM analysis customized for the particular environment. The significance of modular strategies for using shipping containers in cold regions lies in their versatility, efficiency, and resilience to extreme weather conditions:

- The mechanism of modular design simplifies the design process; architects can solve specific problems with modular logic by applying the serialized modules.
- Modularity is an advanced form of standardization with higher; the shipping container architecture in cold regions will be more integrated and diversified by applying multi-functional composite modules.
- The application of modular design strategy in shipping containers is not only up to the design process, but it helps throughout the execution as well.

2.11. Classification of the modular design strategy

Utilizing modular design strategies is crucial for advancing architectural industrialization, characterized by design standardization, factory production, and prefabrication. This approach represents a significant advancement in cold-region architecture, where modular shipping container designs incorporate adaptive techniques for energy efficiency, sustainability, and mobility. The strategy operates as a comprehensive system, with modules for roofs, panels, windows, and floors within the building envelope subsystem, emphasizing adaptive design, insulation, and joinery. Supporting equipment includes solar power systems, energy storage, and water treatment facilities. Modules for prefabrication, transport, construction management, and municipal pipe interfaces create a self-sufficient, passive, high-performance architectural system focused on sustainability through serialization, recycling, and integrated green solutions (Sun, Mei, & Ni, 2017).

2.12. Off-Site Construction

- Off-site construction involves the process of planning, designing, fabricating, transporting, and assembling building elements for rapid site assembly to a higher finish than in traditional methods of on-site construction.
- Off-site building includes a range of materials, scales, and systems; digital software; methods of manufacture and fabrication; and innovations in social and technological integration.
- Off-site outputs include componentized, panelized, and modularized elements deployed in the service of structural, enclosure, service, and interior partition systems.
- An optimizing strategy of off-site is to integrate these systems and supply chain through research, design, testing, and prototyping. The modular industry consists of two distinct industry segments:

Relocatable modular, also known as temporary modular, are structures that meet temporary space needs and can be leased in a short-term agreement. E.g., job site trailers, temporary classrooms, communication pods, and show rooms.

Permanent modular construction (PMC), comparable to site-built structures meeting the International Building Codes (IBC), the difference being that it is simply manufactured within a factory.

2.13. Disadvantages of Off-Site construction:

- Transportation restrictions limit module and panel size.
- Spans and configurations of design are somewhat restricted.
- Lack of transparency in overhead, profit margin, transport, setting (cranes), and associated increase in designer fees if new to the process.
- Flexibility and changeability of structures through future renovations become more difficult (Smith, 2016).

2.14. Prefabricated houses and opportunities in Pakistan

Prefabricated homes are gaining popularity in Pakistan due to their efficient construction process. These homes are built using prefabricated materials in standardized components that are easy to transport and assemble. With the growing demand for housing, especially in the tourism sector, Pakistan needs a comprehensive strategy to boost its construction industry and promote prefabrication. This may require the implementation of federal regulations. Unlike some neighboring countries, Pakistan has an abundance of human resources. Developing its industries can create job opportunities, reduce unemployment, and potentially attract support from China for research and development projects. China is actively supporting Pakistan through the China-Pakistan Economic Corridor (CPEC) to strengthen its industrial base. In high-altitude regions like popular tourist destinations, shipping containers are being repurposed as cafes and restaurants. Additionally, camping pods, which are durable prefabricated structures designed to withstand harsh weather conditions, are being used as accommodations for visitors (Li et al., 2020).

- **Logistical Ease**

Traveling to job sites can be challenging due to congestion in densely populated urban areas or the remoteness of sparsely populated rural regions. In this scenario, prefabricated homes present a promising solution to lower construction costs and accelerate the building process in Pakistan.

Figure 6 and 7: Transportation and movement of prefab elements/walls and materials

- **Efficiency**

Prefabricated homes are built more quickly because they are constructed in a controlled environment, leading to shorter production cycles. In comparison, traditional site-built homes usually take over three months to complete.

- **Safety**

The construction of prefabricated homes offers a safer working environment, significantly reducing the risk of accidents for workers and construction sites. Trained specialists handle the installation of prefabricated components, ensuring a higher level of safety and efficiency throughout the process.

- **Cost Saving**

The concept of constructing houses and other structures using prefabricated components is inspired by the huge production of modern industrial economies; additionally, prefabricated building technology offers the benefit of cost savings in different construction projects.

- **Quality Assurance**

High material standards are ensured by strict quality control throughout the manufacturing process of prefabricated components. In addition to providing long-term durability and resilience, modern equipment and technologies improve efficiency and precision while protecting structures from extreme conditions and natural calamities.

- **Waste Disposal**

This creative approach effectively reduces construction waste disposal costs. The manufacturing facility manages most of the waste produced by prefabricated homes, where it can be recycled or disposed of appropriately.

- **Sustainability**

An increasing advantage of prefabricated dwellings is their contribution to environmental sustainability. Compared to traditional on-site construction, prefabrication significantly reduces waste, pollution, and disruptions. The installation and assembly of prefabricated components are more efficient than conventional methods. Additionally, these components can be recycled, allowing for the implementation of regenerative design principles that promote a circular economic model throughout the prefab installation process. In Pakistan, the popularity of prefabricated homes is rising due to these compelling benefits (Graana, n.d.).

2.15. Prefab Houses in Pakistan

Prefabricated homes, available in various sizes, are designed using set parameters and algorithms for precise measurements and area calculations. A popular model, the 3K12K6P, measures 5.62 m x 22 m x 5.7 h, with two floors covering a total area of 289.89 m2. It can be transported as a complete set in a 40'HQ container, capable of holding between 280 and 320 m2. The primary structure uses “C” section steel, while EPS/IEPS/glass wool sandwich panels form the walls and roof. With six workers, 100 square meters can be assembled in a single day.

- **Use of Prefabricated Houses**

Temporary Site Offices, Labor Camps, Temporary Schools, Resettlement Houses, Government Projects

Figure 8-10: Prefabricated office buildings, dormitory, residential and commercial units installed in Pakistan

- **Prefabricated Houses Technical Parameter**

1. Wall panel: V950 EPS sandwich panel 50mm thickness, steel plate: 0.3mm
2. Partition plate: V950 EPS sandwich panel 50mm thickness, steel plate: 0.3mm
3. Roof board: V950 EPS sandwich board 50mm thickness, steel plate: 0.3mm
4. Two-layer plywood floor with a thickness of 16mm
5. Rain shed: a layer of color steel plate with a thickness of 0.45mm
6. Window PVC sliding window 0.93mx1.715m
7. Door: Sandwich panel door 0.85mx2.1m
8. General bolts: different sizes
9. Grounding channel: C-shaped steel C80x40x15x2.0
10. Double column: C-shaped steel (2C80x40x15x2.0)
11. welding
12. The second layer beam: steel frame 2C80x40x15x2.0, L40x4 welding
13. Roof support: angle steel L40x4

2.16. Benefits of Prefab Housing

- **Structurally sound**

It can withstand winds of 110 km/h.

- **Perfect anti-corrosion performance**

Cold-formed galvanized steel, which has higher corrosion resistance, is used in the structure.

- **Rapid processing**

Machines are produced in large quantities, making the cycle of processing quicker.

- **Excellent sealing performance**

To preserve a smooth connection with the tongue and groove system, the structure is concealed in the home and exterior panels.

- **Simple to assemble**

The framework is joined together using bolts and nuts rather than any welding, which drastically reduces the amount of time needed for building.

- **Flexible design**

It may be altered to meet customer requirements.

- **Energy situation in Pakistan: options and issues**

Pakistan is grappling with a severe energy shortage as its domestic resources fall short of meeting the demand, resulting in a heavy dependence on imported fossil fuels. A reliable energy supply is crucial for economic development, but due to limited industrial capacity, Pakistan needs significant energy inputs to drive and maintain progress (Douggar, 1995).

- **Do industrialization, energy importations, and economic progress influence carbon emission in Pakistan**

As environmental impacts escalate, enhancing living standards and boosting the economy are crucial challenges. Shifting towards renewable energy sources provides a way to meet rising energy needs while minimizing environmental damage. This analysis examines data from 1971 to 2019 to assess the correlation between CO_2 emissions and factors like industrialization, energy imports, carbon intensity, economic growth, and gross capital formation. The Pakistani government must take proactive steps to curb carbon emissions from industries that drive climate change, promoting both environmental sustainability and economic development (Rehman, Ma, and Ozturk 2021).

2.17. History of Pre-fabrication in China

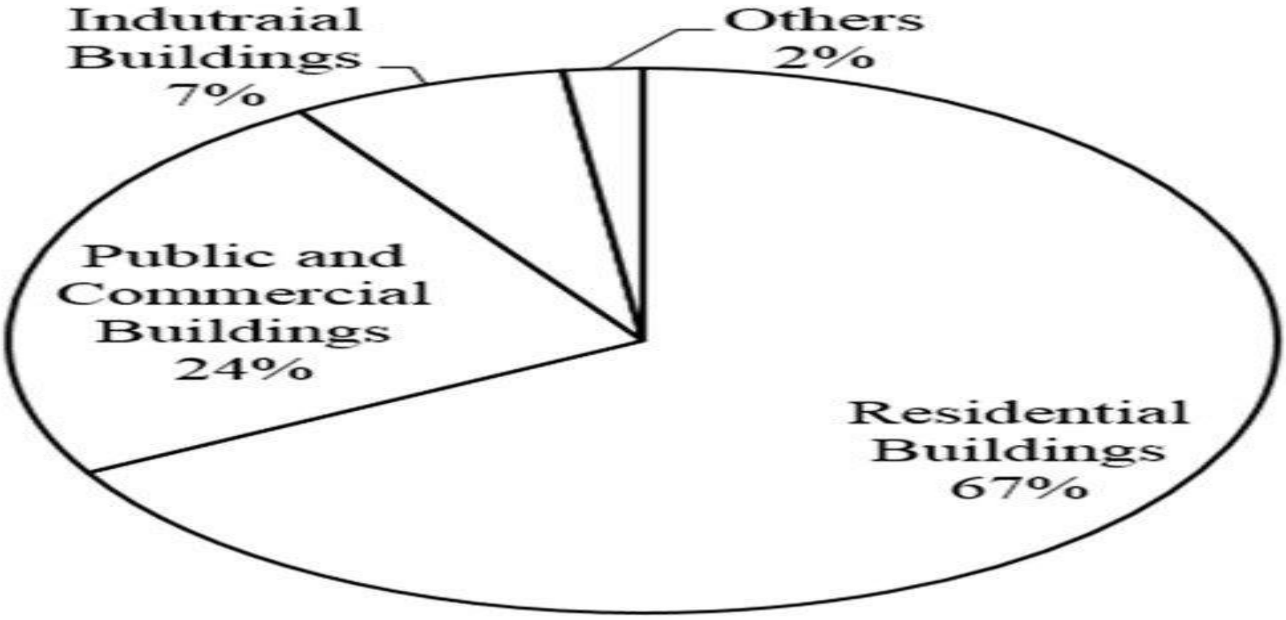
In the 1950s, China began developing prefabrication technology. The 1980s were a period of experimentation and initial implementation of prefabricated buildings, while the 1990s witnessed the widespread adoption of cast concrete in housing construction. The rapid economic growth of the 2000s revealed significant challenges in the construction industry associated with traditional cast-in-place methods, leading to a renewed focus on the development and adoption of prefabricated building solutions (Ahmed, Azhar, & Mohammad; Dler M Ahmed, Z Azhar, & Aram J Mohammad, 2024; Dler Mousa Ahmed, Zubir Azhar, & Aram Jawhar Mohammad, 2024; Mohammad, 2015a, 2015b; Mohammad & Ahmed, 2017).

- **Construction Industrialization in China**

China is Redefining the industry and creating the new era of building construction, to identify the progress and status of construction industrialization, a survey in China is conducted in 19 provinces and municipalities to collect information on construction industrialization to analyze various aspects:

Industrialized building floor area is profiled while using map, showing the different stages/levels of construction industrialization in China in 2014. Typologies of structures and buildings are analyzed for industrialized construction and it is found that RCC structures are predominant, accounting for 77 percent of the total floor area of industrialized construction (Ji et al., 2017).

Figure 11: Analyzed industrialized construction distribution by building type



- **Brief introduction of Construction Industrialization in China**

China’s construction industry has seen remarkable growth, with revenue soaring from 2003 to 2014 to around USD 2,568 billion, achieving an impressive annual growth rate of 30.12%. As a key economic player in the industrial sector, the construction industry also grapples with significant challenges, including limited technological advancement, high levels of waste, quality and safety risks, and a shortage of skilled labor. The main issue stems from constraints on sustainable development. To tackle these pressing challenges, the immediate adoption of innovative technologies and best practices is crucial. A factory-based prefabrication approach—manufacturing in a controlled environment for on-site assembly—can offer a solution. Unlike traditional construction, this industrialized method speeds up project timelines, enhances quality standards, reduces waste, improves safety, lowers carbon emissions, and promotes eco-friendly practices to safeguard the environment (Ji et al., 2017). Research indicates a consistent annual growth rate of 30.12% in China's construction industry over the past decade, with projections indicating a further 10% increase in the coming year, potentially doubling growth by 2024. However, with this rapid expansion come challenges such as industrial waste and labor shortages that are on the rise. To address these issues, a proactive and structured approach is crucial. Solutions should align with established frameworks rather than operating outside of them. The development of a cohesive national policy with comprehensive codes and legislation is urgently required to steer the industrialization of the construction sector, promoting sustainable growth and environmental responsibility.

- **Model of green prefabricated building (A Case Study of Solar Ark 3.0) China**

The Ark project is a continuous effort to enhance human well-being and environmental sustainability. Version 3.0 represents a significant technical advancement in the Solar Ark house series, emphasizing a product-oriented architectural approach that combines state-of-the-art energy solutions with technology. This innovative design promotes sustainable development and demonstrates the seamless integration of energy efficiency into architecture.

Figure 12 and 13: Team Solar Ark 3.0, design and executed a Multi energy house along with energy sharing satuon functional at De sheng village, Zhangjiakou, Hebei Province, China.

Project overview based on UHPC shell architectural design components are:

Restrictions/constraints of the Project: Time and cost, shell should be prefab, No use of concrete.

Achievement: Prefabricated construction technology UHPC materials are used, manufactured in 5 days and the whole project has been executed in 20 days. parametric design to achieve smooth connection of hyperboloid and ensure consistency of shell form and structure.

Advantages of UHPC shell: Structural performance significance, one-third the amount of traditional concreting, easily transported + the whole structure can be moved in parts.

Installation of photovoltaic panels: Arranged according to solar path east-west direction, maximize the no of panels to increase energy about 10%, to keep in mind day timings, overhead thing on ground by assembling 18.2mX18.2mX1.4m PV grids on ground.

Large space multi-functional residence design: An interior space having size of 10.8mX10.8m, services space is placed east, and west, universal space has placed north-south. Bamboos has used as carbon fixing material and for furniture, spatially arranged with Living, home mode, leisure & display.

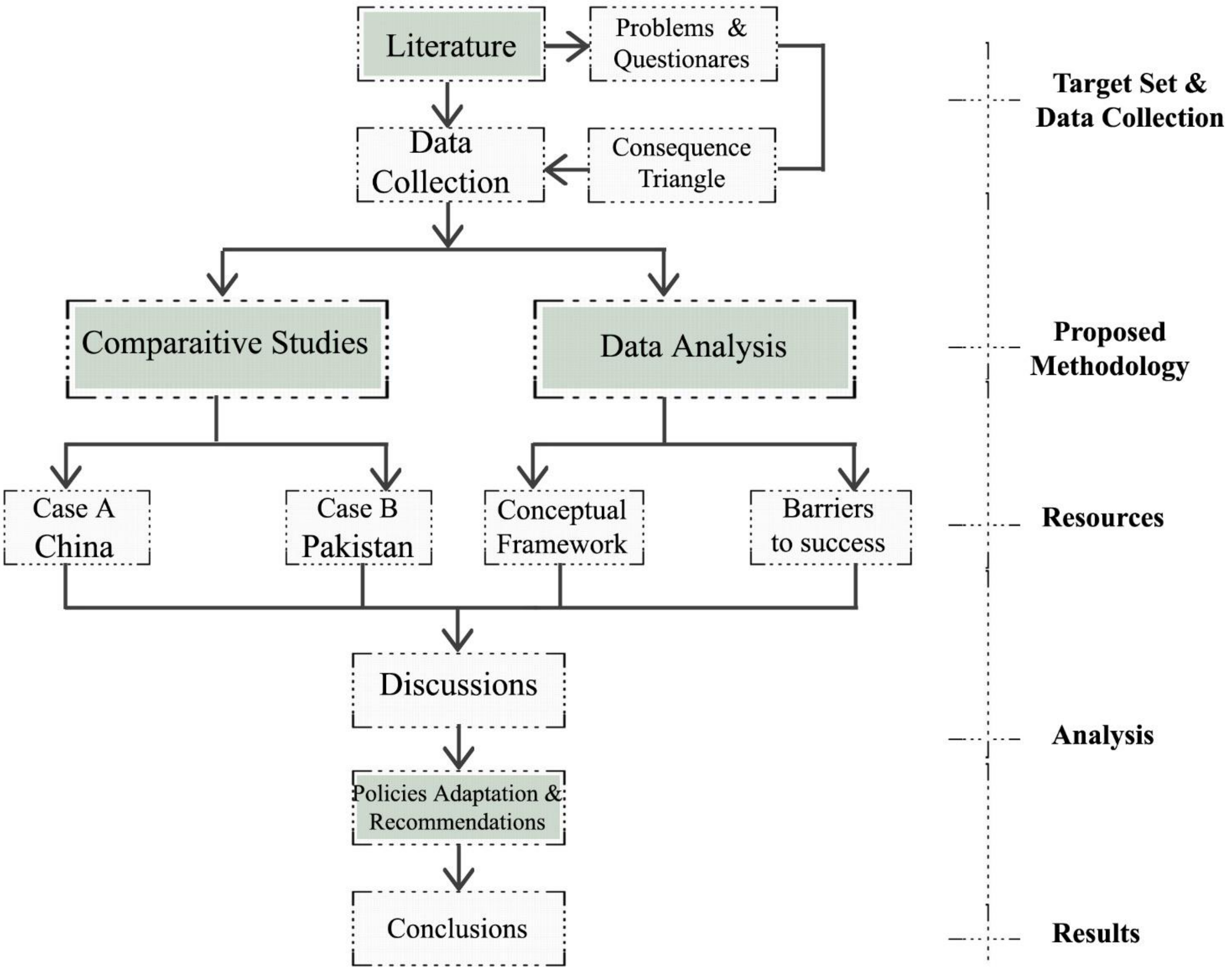
Market potential: Theme was based on sustainable design; integration of low carbon and healthy intelligent building technology (IBT), major aspect was utilization of natural energy (Li et al., 2022).

3. Research Methodology

3.1. Proposed Paths and Methodology

This research work employs a structured methodology to develop sustainable architectural solutions tailored to specific environmental and user needs. The target set, and data collection phase begins with a literature review to identify gaps and establish a research foundation, leading to the creation of questionnaires that address issues in sustainable prefabrication. Data collection uses a "Consequence Triangle" model, treating the site, materials, and users as interdependent elements in an ecological cycle. This approach ensures that design strategies respond to programmatic, climate, and environmental needs, fostering sustainable outcomes. Data was primarily collected through literature reviews, questionnaires, and interviews. A key limitation in this research was the challenge of conducting industrial investigations into prefabricated manufacturing. In the proposed methodology phase, comparative studies are conducted on cases in China and Pakistan, focusing on sustainable and prefabricated building design practices and material usage. This allows for the assessment of diverse environmental and cultural contexts and informs the adaptation of strategies to each site. Data analysis then builds a conceptual framework to identify and address barriers to implementation, supporting solutions that align with local conditions and prefabrication principles. The Resources phase investigates sustainable, prefabricated materials from local and external sources. Insights gathered through professional consultations, surveys, and interviews with locals and visitors help tailor material choices and design to the site context. During analysis, findings from the comparative studies and data analysis are discussed, highlighting key insights and addressing research limitations. The results recommend policies for sustainability and site-specific prefabrication methods and conclude the value of environmentally responsive and contextually relevant architectural solutions.

Figure 14: Proposed Path and Methodology



4. Data Analysis and Discussions

4.1. Conceptual Frame work

This research work introduces a conceptual framework that focuses the use of prefabricated building technology, which should be practical and work in harsh climatic conditions, where the framework incorporates the social, cultural, and climatic factors to create comfortable and environmentally friendly spaces that should be acceptable to both inhabitants and tourists while respecting local norms and ecological standards. The core of research is the integration of industrial and traditional methods while combining the effectiveness of prefabrication with reliable, adaptable-to-the-context, and the strategy offers a novel way to enhance building performance in the variated climatic conditions; haphazard, non-sustainable development should be avoided to boost tourism, industry in the rich cultural heritage sites while promoting prefabricated architecture to create a development paradigm and harmony amongst users, sites, and programs. The research has its roots in a thorough literature review, which also identifies key issues, permits comparative analysis, and offers contextual data to provide a norm for sustainable development by harmonizing environmental, structural, cultural, climatic, and social demands.

4.2. Barriers to Success

Extreme winter conditions can make it difficult to capture and analyze on-site, which can impact progress, safety, and accommodations. Additional delays could result from a lack of human and financial resources. Enough funds must be set beforehand for transportation and documentation while visiting industrial sites, especially those in China that use prefabrication. For smooth visits and precise data collection, language difficulties must be addressed by working with local guides and translators. External experts are required to run specialized equipment essential for evaluating material sustainability and environmental impact while analyzing sustainable materials in local and industrial environments. Their expertise ensures dependable outcomes and technical accuracy. Establishing a Memorandum of Understanding (MoU) with local agencies and authorities is essential to addressing issues, especially in site documentation, to expedite processes and promote project success. This agreement will help secure financial support, on-site accommodations, and access to relevant statistical data for the targeted region. Effective communication with community members as a local resident of the proposed area can facilitate fieldwork operations. However, the success of the research will also depend on close supervision from the Project manager. Regular guidance and feedback from the site supervisor, particularly in a laboratory setting, will be essential for maintaining work progress and ensuring that the research meets academic standards.

4.3. Discussion

As a developing country, Pakistan looks to China for inspiration and guidance, especially through the strengthened ties of the China-Pakistan Economic Corridor (CPEC). Memorandums of understanding (MOUs) have been signed at both government and private levels with various industries to introduce prefabricated dwellings, with units already in place in the tourism sector. In Pakistan, shipping containers have been transformed into tea shops, cafes, and restaurants in colder regions like Murree, Kalam, and Malam Jabba, popular tourist destinations. Camping pods have also emerged as innovative accommodations for tourists, designed to withstand harsh weather conditions. These units offer a potential solution to the housing shortage in the country.

Figure 15 and 16: ***Tourist Camping Pods, Prefab Modular units, installed at Northern areas of Pakistan, district Swat***


Given Pakistan’s rapid population growth and the increasing demand for housing, especially with the rise in tourism, it is crucial for the government to implement a comprehensive policy to support and promote the prefabrication and construction sectors. Establishing national codes and regulations for these industries is a necessary step towards modernizing construction practices and can greatly benefit Pakistan’s economy by fostering industrialization. Pakistan has a significant human resource pool compared to its neighboring countries, with many nationals currently working in more developed regions nearby. By expanding its industries, Pakistan can create local job opportunities and address unemployment issues. Moreover, Pakistan can collaborate with the People’s Republic of China for research and development, leveraging China's expertise and support, particularly in industrial development. The partnership between China and Pakistan Economic Corridor (CPEC) initiative will help the construction industry in Pakistan.

4.3.1. Economic Impact of Prefabrication in Pakistan

Prefabricated buildings have significant economic potential in Pakistan, especially collaborating with China under the CPEC project. Both the private and public sectors can reduce the cost while constructing prefabricated components because Prefabrication reduces time, material waste, and cost in a context that is expanding and urbanizing, which could result in a large saving (Hassan, 2021). Pakistan can solve the housing issues by implementing prefabrication for public infrastructure, government housing, and tourists' lodgings. Where we can see the successful examples in tourism industry like the installations in Murree, Kalam and Gabbin Jabba, where one can see the shipping containers and camping pods which are weather resistant, supporting the local community in terms of economy by attracting tourists. A national level policy needs to promote prefabricated building and technology along with codes and regulations, which could help Pakistan's economy, tourist's industry and modernize the construction industry. China's achievements in this area provide valuable insights. For example, the "C-House" project in Nanjing, China, uses digital techniques like Building Information Modeling (BIM) and modular components manufactured in controlled conditions to enhance energy efficiency. With a 40% reduction in building time and a 25% reduction in carbon emissions during its lifespan, this approach demonstrated how prefabrication can significantly enhance cost and sustainability (Carrasco-Beltrán et al., 2024). Similarly, Chengdu's affordable housing project for low-income families demonstrated how modular prefabrication may address the housing shortage while keeping costs down (Botti, 2023). These are some inspirational models that we can implement in Pakistan's housing and tourism industry as energy-efficient materials and designs.

Additionally, the growth in this sector could help Pakistan's large labor pool by generating employment and reducing dependency on overseas labor markets. Enhancing local skills and paving the path for low-carbon, energy-efficient buildings would be possible by collaborating with China on research and development, especially in the areas of sustainable building technologies and digital construction tools like Building Information Modeling (BIM) (Irfan, 2022). The possibility for building sturdy houses in isolated, frigid areas is demonstrated by China's success employing prefabricated housing in harsh climates, such as the Tibetan Plateau. Pakistan may solve the severe weather in regions like Swat and Gilgit-Baltistan while simultaneously promoting ecotourism and sustainable development by putting similar techniques into practice. The adaptability of such strategies will achieve the sustainability objectives in terms of housing, the tourism sector, and economic-financial demands.

4.3.2. Environmental Benefits of Prefabrication in Pakistan

Prefabrication can have a significant positive impact on Pakistan's environment, especially in terms of lowering CO2 emissions and material waste. Pakistan could see comparable outcomes to China, where prefabricated construction has demonstrated a 20–30% reduction in CO_2 emissions when compared to conventional methods. Because prefabrication minimizes on-site building, less energy is used, less heavy machinery is used, and less transportation is required, all of which help to reduce carbon emissions. Prefabricated structures made of modular components can cut construction waste by 60%, according to Chinese studies, which lowers greenhouse gas emissions from waste treatment procedures. Furthermore, prefabricated parts made in controlled manufacturing settings usually require 30% fewer raw materials, which helps to save natural resources. By implementing these strategies, Pakistan may be able to significantly lower emissions throughout its building industry, which would be in line with both domestic and international sustainability objectives. Environmental advantages can be increased by incorporating renewable energy technology, such as solar panels, into prefabricated buildings. Prefabricated buildings in Northern Pakistan have the potential to function as almost energy-zero units, lowering dependency on non-renewable energy sources, according to pilot research. Pakistan may become a leader in South Asia's sustainable building methods thanks to its combined emphasis on prefabrication and renewable energy. These measurable environmental advantages highlight how important it is to put national prefabrication regulations that support environmentally friendly building methods into effect. The adoption of low-carbon building solutions in Pakistan might be accelerated by collaborating on research and technology exchange with nations like China.

4.3.3. Lessons from Global Prefabrication in Cold Regions

Prefabrication is being used for ecotourism in Pakistan's colder regions, which is in line with worldwide trends where similar tactics have been effectively used to combat adverse weather conditions and advance environmentally friendly travel. Prefabricated units are the crucial part of winter tourism in the remote regions of Finland, Norway, and Sweden. Setting the standards for these units has the potential to face severe weather conditions by utilizing advanced technologies, like triple-glazed windows, insulated panels, and energy-efficient heating system for their thermal comfortability. These prefabricated units are famous for its durability and sustainability in the northern area of Canada (Skoghagen & Danneholm, 2018). Another project of prefabricated housing has aided in the Himalayan range of India and Nepal, providing affordable, weather-resistant accommodation. These units are frequently built using indigenous building materials, preserving the environment and carbon emissions (Shrestha, 2001). Similar if we can apply the solutions in Pakistan, issues relevant to transportation, community involvement, and climatic adaptability must be taken into consideration. Without the involvement of locals and avoiding local climatic conditions, culture, and landscape, it is not possible to implement the strategies. Here it has been concluded that technology can be integrated with traditional terms and conditions to evolve and implement prefabricated buildings and technologies. The adaptability of international achievement, Pakistan can resolve the relevant issues and improve strategies to optimize the economic and ecological advantages of prefabrication in different climatic conditions. While promoting ecotourism, this tactic provides creative answers to housing demands in difficult-to-reach places.

4.4. Policies and Recommendations for the adoptability and implementation in Pakistan's context

Instances of rules and regulations that have been effectively adopted in China about prefabricated buildings and digital construction techniques can be used as models for such initiatives in Pakistan. As follows, these examples offer beneficial opportunities for adaptation in the Pakistani context. The intelligent construction of prefabricated buildings has become an important transforming way of the construction industry in China (Ho et al., 2024; Ullah et al., 2024). As China continues to advance and implement policies on digital economy and digital transformation, the level of digital technology in China will continue to improve. The maturity and application of digital technology will reconstruct the construction model of the industry (Ullah et al., 2024; Wang et al., 2024). For example. BIM was used to assess carbon emissions in prefabricated buildings at Southeast University, Nanjing, China, demonstrating the potential of digital tools to promote sustainable construction and prefabricated building practices (Carrasco-Beltrán et al., 2024; Ullah et al., 2024). Ullah et al. (2024), investigates the building performance optimization strategies based on BIM digital technology, with a focus on assessing carbon emissions in prefabricated buildings through digital means with a detailed case study on C-House at Southeast University, Nanjing, China. Highly accurate BIM models help you study building performance and calculate carbon emissions during the design, production, construction, operations and maintenance phases. This study takes C-House, a building with multiple life cycle stages, as a case study to construct a component-based BIM model for comprehensive carbon emission calculations. The results show that CO2 emissions are significantly reduced by extending the life cycle of the building and improving the durability of parts. This highlights the importance of long-term environmental sustainability in decision-making, and the potential for digital tools such as BIM to support smart green building approaches to achieve low-carbon, energy-efficient and socially sustainable buildings (Ullah et al., 2024).

In a study conducted in Pakistan, concluded that there are important indigenous approaches to improve sustainability and energy efficiency is:

1. Solar energy is collected by photovoltaic (PV) panels.
2. Integration of local practices and digital strategies: Traditional methods are combined with modern technological tools to generate your own energy at home and reduce your carbon impact. To further integrate these local approaches into the Pakistani context, it is recommended that future research include thorough carbon assessment using BIM simulations and advanced digital methods.

4.4.1. Importance of Stakeholder Collaboration in Prefabrication Adoption

Government, business leaders and the community must work closely together to successfully introduce precast in Pakistan. To encourage prefabrication, governments must establish regulations, provide incentives, and establish policies. To ensure quality and consistency, national standards for prefabricated components must be developed and approval procedures simplified. Public-private partnerships (PPPs) can help spread the financial risk of prefabricated projects and encourage innovation. The infrastructure and technical know-how required to develop large-scale prefabrication relies heavily on the construction sector. Investing in precast manufacturing plants can reduce dependence on imports while increasing local production capacity through training programs for engineers, architects and workers. Collaborations with research groups and academic institutions can also drive technological advances, such as integrating digital technologies such as Building Information Modeling (BIM) into pre-production procedures. Local communities are crucial for prefabricated projects to achieve social acceptance and sustainable development. In addition to addressing issues such as aesthetics, cultural fit, and environmental impact, involving the community in the planning stages helps foster a sense of ownership. Similar experiments around the world have shown that using local materials or designs can increase acceptance of prefabricated buildings by residents. These stakeholders can leverage their respective capabilities to work together to create a collaborative framework to help solve Pakistan's pre-production challenges. By encouraging collaboration, Pakistan can create a robust prefabricated ecosystem that addresses the housing shortage while promoting sustainability and economic growth.

5. Conclusions

The report highlights how prefabrication can revolutionize Pakistan’s construction industry by addressing inefficiencies, cost overruns, environmental damage and housing shortages. Pakistan can transform its construction industry by implementing prefabrication technology influenced by developments in China. This will shorten construction schedules, reduce material waste and promote sustainable development. These observations are consistent with the growing demand for affordable housing in Pakistan, especially in urban and tourist areas.

5.1. Expected Results

The goal of this research is to accelerate the use of prefabricated components on construction sites to increase productivity, reduce costs and ultimately provide more accessible housing. Cooperation with China through the China-Pakistan Economic Corridor initiative is expected to strengthen local capabilities and foster industrial growth by promoting research, development and technology transfer. The use of digital tools such as Building Information Modeling (BIM) is expected to help achieve sustainability goals by improving performance assessments, producing more accurate results, and reducing carbon emissions.

5.2. Contributions to Pakistan’s Needs

By promoting mass production of affordable housing, prefabricated homes will help alleviate the severe housing crisis. In addition to strengthening the local economy, prefabricated solutions for tourist destinations will provide resilience to adverse weather events. Expansion of the industry will create jobs and improve socioeconomic conditions by reducing dependence on foreign labor markets.

5.3. Future Research Directions

Research is underway to combine prefabrication techniques with traditional architecture to improve cultural adaptability. We research cutting-edge digital strategies for optimizing just-in-time construction processes, including machine learning and IoT sensors. Life cycle assessment is required to determine the long-term viability of prefabricated buildings in different climate zones of Pakistan. By putting these recommendations into practice, Pakistan can pave the way for a stronger, more sustainable and industrialized future. This will help meet the country's growing housing and urbanization needs while supporting economic and environmental sustainability.

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