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INNOVATIVE ARCHITECTURE AND INDUSTRIALIZATION BUILDING SYSTEM IN THE CONSTRUCTION INDUSTRY OF PAKISTAN

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Abstract
Industrialized Building System (IBS) construction has emerged as a sustainable method for enhancing productivity and mitigating the adverse environmental and social impacts associated with conventional construction practices. While a growing body of research has addressed management issues in prefabricated construction, a systematic summary and strategic framework for its optimization remain underdeveloped. This study aims to develop a framework for optimizing the use of industrialized building construction by integrating innovative architectural approaches and construction waste reduction strategies. Through a comprehensive review of best practices in prefabrication implementation, including adoption rates, construction methods, cost-effectiveness, and performance evaluation, this paper examines effective implementation strategies, industry prospects, and the enabling environment for technological application. Special focus is placed on design, production, transportation, and assembly processes. The findings offer an improved understanding of the critical factors influencing the success of IBS and provide practical guidance for enhancing future adoption, promoting sustainability, and advancing innovation within the construction industry.

INTRODUCTION

The industrialized building system (IBS) has been introduced in the construction industry as early as the 1960s (Ali, M. M., et al, 2018). Housing needs continue to rise very rapidly, particularly in urban areas. While demand for new homes every year has reached up to 800,000 units (Prajapati, M. B., & Patel, R. B., 2024). There is a gap of about 1,350,000 units that must be resolved to fulfill the housing need. One of the ways to speed up the construction of affordable housing is to use the Industrialized Building System (IBS) in construction (Hassan, A.S., & Ali, O. S. 2020). Industrialized Building System is usually associated with sustainable construction, which is described as the ability of the construction system to consider the environmental impact of a building over its entire lifetime, while optimizing its economic viability and the comfort and safety of its occupants (Marzouk, M., Azab, S., & Metawie, M. (2018).

Pre-assembly, prefabrication, modularisation, system building, and industrialised buildings are the terms that have been frequently used to describe the

manufacture of building components that are constructed either on-site or off-site in a factory, covering manufactured, modular and pre-cut or pre-engineered systems (Ayinla, K. et al, 2020).
Innovation in project design is a strategic means of uncompromised pride as the gateway provider and achieving clients' needs better, and even surpassing their expectations of global physical development through the expectations (Albaidhani, I., 2019). Research generally focuses on issues facing on construction industry and the effect of innovative architecture on IBS (Ariffin, H, 2019). As IBS constructions do not have sufficient flexibility to develop varied architectural forms, the main problems facing our construction industry are a serious shortage of skilled construction workers (Jaffar, Y., & Lee, C. K., 2020).

1. Literature Review

Generally, IBS (also known as off-site manufacturing in the UK construction industry) is defined from two perspectives, namely, the system and process of construction (Mehdipoor, A., 2024). IBS is a system that uses industrialised techniques either in the production of components or the assembly of a building, or both (Abd Rashid, M. et al, 2018). Similarly, Trikha (1999) classified IBS as "a system in which concrete components prefabricated at sites or in factories are assembled to form structures under strict quality control and minimum in situ construction activity." (Li, L., et al, 2020).
IBS is also defined as a construction process that utilises techniques, products, components, or building systems that involve prefabricated components and on-site installation (Abd Jalil, 2021). The components of IBS are manufactured either in a factory, on or off site, positioned, and assembled into place with minimal additional site work (Abd Rashid, M., 2019).
Almost similarly, Elliott defined IBS as a mass production of building components either in a factory or at the site according to the stipulated specifications with standard shapes and dimensions, and transported to the construction site to be re-arranged according to a certain standard to form a building (Elliott, K.S. 2017). Table 1 shows the basic structure to use for IBS Classification, depending on the categories typically found in Industrialized Building Systems

Table 1: IBS classification (Grad, 2020).

SNO	CLASSIFICATION	DESCRIPTION
01	Precast concrete-framed buildings	The most common group of IBS products is the precast concrete elements. precast concrete columns, beams, slabs, walls, 3-D components (e.g., balconies, staircases, toilets, lift chambers, refuse chambers), lightweight precast concrete, and permanent concrete frameworks.
02	Formwork system	Considered as one of the low-level or the least prefabricated IBS, as the system generally involves site casting and is subject to structural quality control, the products offer high-quality finishes, and fast construction with less site labor and material requirements.
03	Steel framing system	Commonly used with precast concrete slab, steel columns and beams, steel framing systems have always been a popular choice and used extensively in the fast-track construction of skyscrapers. Recent developments in this type of IBS include the increased usage of light steel stress, consisting of cost-effective profiled cold-formed channels and steel portal frame systems as an alternative to the Heavier traditional hot rolled sections.
04	Prefabricated timber framing system	The system consists of timber building frames and timber roof trusses. While the latter are more popular, timber building frame systems also have their niche market, offering interesting designs from simple dwelling units to buildings requiring high aesthetic values such as chalets for resorts.
05	Blockwork system	The construction method of using conventional bricks has been revolutionized by the development and usage of interlocking concrete masonry units (CMU)

		and lightweight concrete blocks. The usage of these effective alternative solutions greatly simplifies the tedious and time-consuming traditional brick-laying tasks.

IBS was initially implemented to promote systematic construction processes and minimize the number of foreign workers (Akmam & Amtered, 2021). However, impediments to achieving this goal have been widely reported in the literature. The coordination between spatial design and dimensioning of elements was poor and was not appropriately incorporated into the designing of spatial and functional space relations incompatible interfaces between manufacturers, poor coordination between the manufacturers and architects during an early design phase, and limited applications of building materials (i.e., mainly using concrete for fabricating precast beams, columns, and panelized wall systems) are some of the pressing problems that mar IBS constructions (Gurcan Bahadir & Tong 2025).

2.1 Architecture and Industrialization Building System

Architects are unaware of envisioning the incorporation of IBS building components in the architectural design process. The lack of an IBS data repository and inadequate knowledge of IBS among architects has resulted in redundant design flaws during detailed construction documentations, which has further delayed projects (Gunasagaran et al, 2022).

Moreover, the IBS approach has created a negative perception among the architects and customers because of the following factors: it hinders flexibility; it only allows internal flexibility in the layout; it creates jointing problems; it promotes monotonously manufactured building components; it creates repetition in standardized building components and it does not allow varied forms that can yield creative architectural designs (Jaffar, Y., & Lee, C. K. 2020).

Despite these defects, the existing IBS construction practices need to be revitalized in the minds of the designers such that they can efficiently incorporate "system thinking" in the architectural design process (von Furstenberg, G. M., & Kirton, J. J., 2024).

A systematic approach often limits the freedom of designers, notably architects. Design is a key concept within the construction and design world, mostly within architecture, interior design, industrial design, engineering design, graphic design, urban design, information system design, interaction design (software design), and fashion design (Casakin, H., & Wodehouse, A., 2021). It is often said that design is the process that links creativity and innovation (Taura, T., & Nagai, Y., 2017). Hence, designers have strived to make a satisfactory meaning to plan and intention with a strategically creative design for the provision of both physical and mental satisfaction. This has stemmed their hunt for uniqueness through innovative strategies in the construction industry (Andreasen, M., 2015).

2.2 Development of Prefabricated Building Construction

As Prefabrication is the practice of assembling components of a structure in a factory or other manufacturing site, and transporting complete assemblies or sub-assemblies to the construction site where the structure is to be located (Gao, S., 2020).

Whether the building materials are concrete, steel, or timber-based systems, the advantages of Pre-fabricated building systems are clear (Tenório, M., 2024). Attouri in 2022 defines an industrialized way of construction, with the Inherent advantages of:

- High capacity - enabling the realization of important projects
- Factory-made products
- Shorter construction time - less than half of conventional cast-in-situ construction
- Independent of adverse weather conditions during construction
- Continuing erection in wintertime until -20 °C
- Quality surveillance system

At the same time, prefabrication offers clients better performance to fulfil all requirements, such as:

- Fire-resistant material
- Healthy buildings
- Reduced energy consumption through the ability to store heat in the concrete mass
- Environmentally friendly way of building with optimum use of materials, recycling of waste products, less noise and dust, etc.

• Cost-effective solutions

All above mentioned advantages compared with the traditional on-site building erection method can be summarized. As **Table 2 shows Several Significant Benefits Provided by Prefabricated Elements Compared with the Onsite Building Erection Process:**

Table 2: Significant provided by prefabricated elements (Antonina, 2020).

Factor	Prefabrication	On-site
Quality	In a climate-controlled environment using efficient equipment operated by well-trained people.	Uncertain weather can result in less-than-expected construction.
Speed	Speedy process (up to 70% less)	Time-consuming. The process can be delayed by weather or scheduling conflicts.
Cost	Greater control over manufacturing Results dramatically reduce the chance of cost overruns.	Uncontrollable variables such as weather and scheduling can Increase the construction cost
Versatility	Less	More
Site space	Panels arrive on a flat-bed trailer and are installed with sufficient listing plants.	A bigger space is needed. In addition, costly scaffolding is often necessary for installation.
Site refuse	Less waste is generated at the site.	A significant amount of waste is produced and removed from the site, which often adds to the cost.

2.3 Waste Management in IBS

Waste management in construction activities has been promoted to protect the environment in line with the recognition that the wastes from construction works contribute significantly to the polluted environment (Huang, B.,2018). There is an urgent issue on the huge quantities of waste generated in construction. There should not be a lack of environmental support from construction stakeholders (Al-Raqeb, 2023).

The current implementation of prefabrication seems unable to provide satisfactory results to the construction industry (Wu, Z.,2021). The suitability of adopting prefabrication for various project types is also examined. Furthermore, a financial analysis is also conducted by a local case study. It found that waste generation can be reduced up to 100% after adopting prefabrication, in which up to 84.7% can be saved on wastage reduction. (Hu, R., et al, 2022).

2.4 Problem Description

The challenges facing our construction industry are due to a shortage of skilled labour and high construction costs. Therefore, construction using IBS is proposed to reduce our dependency on intensive labor work and reduce the cost of construction. However, changing the traditional construction method to IBS has been delayed due to the reluctance to accept the changes and even resistance to changes.

This study aims to develop a framework for optimizing the use of industrialized building construction in the context of innovative architecture and construction waste.

2. Research Materials and Discussions

This study attempts to find out the measure for optimizing IB construction in the context of innovative architecture, construction cost, and construction work. regarding the need, problems, facilities, and services. Industrialized Building Construction (IBC) is a modern approach to building efficiently, supporting architectural innovation, and minimizing construction waste. Table 3 shows Framework Components, based on optimizing industrialized building construction through innovative architecture and waste reduction.

Table 03. Framework Components

Component	Objective	Key Strategies
Design Integration	Align creativity with modular construction	DfMA, BIM, Mass customization
Advanced Prefabrication	Improve precision and reduce on-site waste	3D printing, modular units, robotic

		assembly
Sustainable Materials	Lower environmental impact and material wastage	Recycled materials, renewable resources, and material reuse
Digital Tools & Monitoring	Track construction progress and waste in real-time	IoT, Digital Twin, waste dashboards
Policy & Regulation	Create supportive regulatory and financial environments	Adaptive codes, green certifications, and innovation incentives
Workforce Development	Build skilled teams for modern construction techniques	Training in IBC systems, collaboration labs
Lifecycle Feedback Loop	Improve future designs based on current project performance	Post-occupancy data, material reuse analysis

Implementing IBC with a strategic framework significantly enhances architectural flexibility, accelerates construction timelines, improves environmental sustainability, and reduces waste generation. Adopting this approach is essential for future-ready, responsible urban development. Table 04 shows that IBC-based construction significantly reduces construction time, material waste, and carbon footprint compared to traditional methods. It also offers higher worker safety, lower cost variability, and greater design flexibility through modular approaches.

Table 04: IBC vs Conventional Construction

Parameter	**Traditional Construction**	**IBC-Based Construction**
Construction Time (avg.)	18 months	9-12 months
Material Waste Reduction	Baseline	50-80% reduction
Cost Variability	High	Low
Design Flexibility	Medium	High with modular elements
Worker Safety	Moderate	Improved (controlled environments)
Carbon Footprint	High	Up to 40% lower

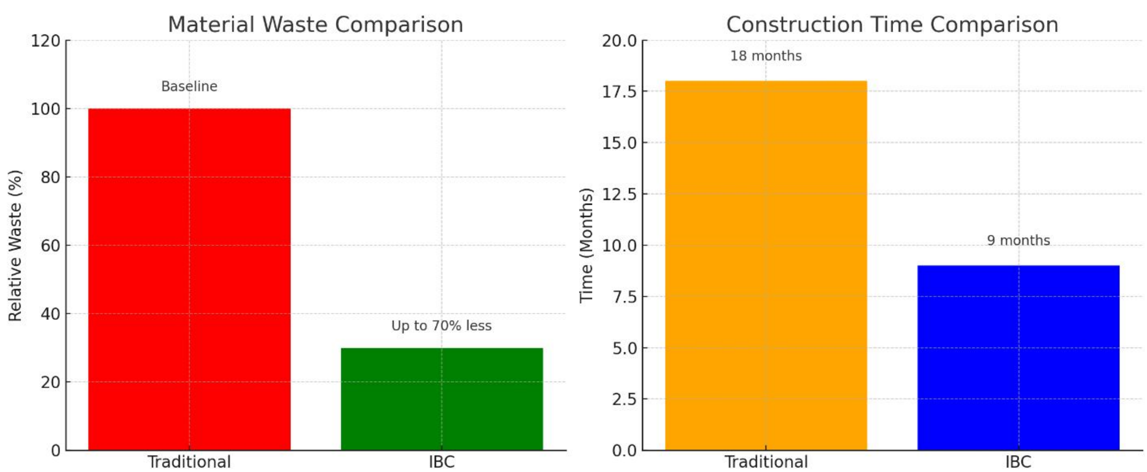

Figure 01: Waste comparison graphs: traditional vs IBC.

Smart prefabrication involves manufacturing building components in controlled factory environments using precise, automated technologies such as 3D printing and robotic assembly, significantly improving quality and reducing on-site waste. Integrated digital dashboards play a crucial role by continuously monitoring construction progress, material usage, and waste generation in real time, enabling data-driven decision-making

Table 5: Comparison Between Industrialized Building Construction (IBC) and Conventional Construction

Aspect	Industrialized Building Construction (IBC)	Conventional Construction
Construction Speed	Faster due to off-site fabrication and parallel site work.	Slower, sequential on-site construction processes.
Quality Control	Higher quality with controlled factory conditions.	Variable quality depending on site conditions and workforce.
Labor Requirement	Reduced; requires fewer on-site workers.	Highly extensive on-site workforce needed.
Material Waste	Minimized through precise production and standardized elements.	Higher waste due to on-site errors and material handling.
Environmental Impact	Lower; less site disturbance, reduced noise, dust, and waste.	Higher, more site pollution and disruption.
Cost Efficiency	Potentially lower overall cost with mass production and reduced time.	Higher costs due to longer timelines and inefficiencies.
Design Flexibility	Moderate; needs careful planning for modular systems.	High flexibility during construction but can cause inefficiencies.
Weather Dependency	Minimal; fabrication occurs indoors, reducing weather delays.	High construction progress is highly affected by weather.
Safety	Safer; most work is done in controlled environments.	More hazards: labor-intensive site activities.
Technology Integration	High often incorporates BIM, automation, and advanced management systems.	Low to moderate; traditional practices dominate.

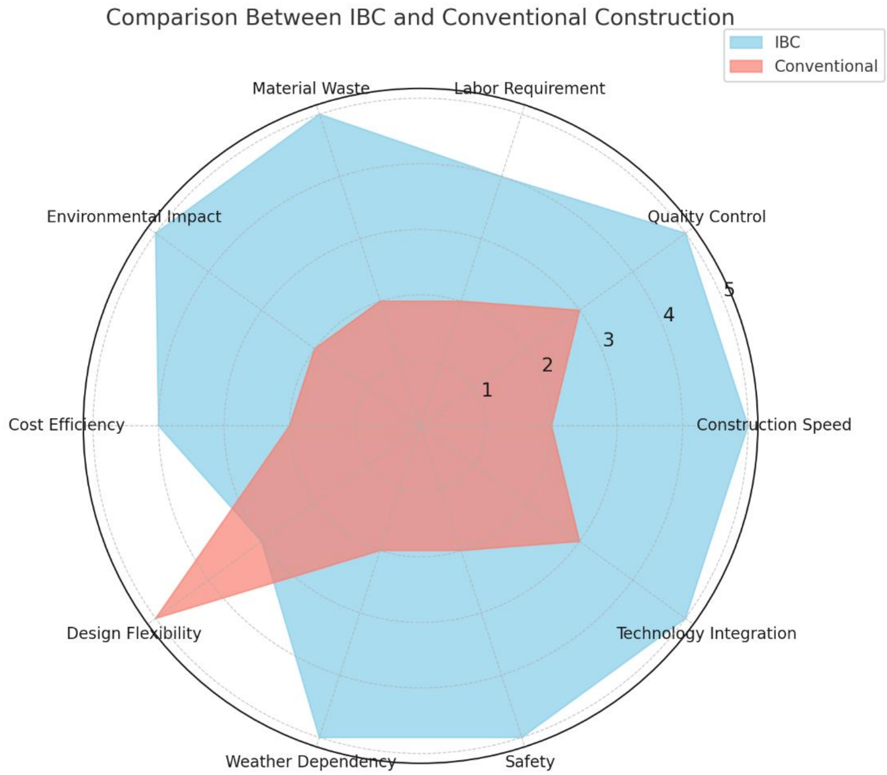

Figure 02: Radar Chart of Industrialized Building Construction (IBC) and Conventional Construction

Figure 02 shows the comparison between Industrialized Building Construction (IBC) and Conventional Construction across key factors. When comparing waste levels, traditional methods often result in excessive off-cuts and inefficiencies, whereas IBC systems can reduce waste by up to 80% due to exact production and standardized modules. Moreover, flexible architectural designs are increasingly achievable with modular systems, allowing architects to creatively combine prefabricated units to produce customized, high-performance buildings without compromising on aesthetics or functionality.

3.1 Material Waste Reduction

Waste (Traditional)=10,000×0.20=2,000 kg

Waste (IBC)=10,000×0.05=500 kg

Waste Reduction=2,000−500=1,500 kg

Percentage Reduction = (1,500/2,000) ×100=75%

By using Industrialized Building Construction (IBC), material waste can be reduced from 20% down to just 5%, meaning for every 10,000 kg of material, 1,500 kg less waste is generated, a 75% reduction.

3.2 Construction Time Reduction

Time Saved=18−9=9 months

Percentage Reduction = (9/18) ×100=50%

In terms of time, IBC projects are completed in about 9 months instead of 18 months, cutting construction time by 50%.

3.3 Cost Savings from Waste Reduction

Traditional Waste Cost:2,000×2=4,000 USD

IBC Waste Cost:500×2=1,000 USD

Cost Saved:4,000−1,000=3,000 USD

Additionally, if the material costs around $2 per kilogram, this waste reduction results in a cost saving of about $3,000 per project.

3. Conclusion

The results highlight the substantial advantages of implementing Industrialized Building Construction (IBC). Material waste decreases by 75%, reducing from 20% to just 5%, which means 1,500 kg less waste is generated for every 10,000 kg of material. Additionally, construction timelines are significantly shortened, with projects completed in just 9 months instead of 18, reflecting a 50% reduction in duration. This decrease in waste also leads to considerable cost savings, amounting to approximately $3,000 per project when the material price is $2 per kilogram. Overall, these outcomes emphasize the enhanced efficiency, cost savings, and sustainability that IBC offers, affirming its important role in driving innovation within the construction industry.

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