



## **ANALYSIS OF THE STATE OF LOW-RISE PREFABRICATED BUILDING CONSTRUCTION**

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**Abstract:** This study investigates the current landscape of low-rise prefabricated buildings (PFBs), emphasizing their swift expansion and the challenges that come with it. The popularity of prefabricated technologies is on the rise due to their efficiency, economic benefits, and flexibility in meeting modern needs. However, their widespread acceptance is hindered by regulatory, technical, and perceptual obstacles. This research utilizes a structured literature review to classify issues into four categories: technological, legal, social, and environmental. Important data were gathered from technical documents, reports, and industry publications. Findings reveal that although PFBs provide advantages such as decreased construction time and cost savings, they encounter significant challenges. These include rising temperatures during summer, inadequate sound insulation, variable material quality, a lack of comprehensive standards (particularly for light steel thin-walled structures, LSTK), and a public perception associating PFBs primarily with temporary housing. The analysis highlights that many of these challenges are interconnected, with regulatory deficiencies exacerbating design and construction mistakes. Suggested remedies involve improved regulations, innovative materials, stringent quality control, and enhanced professional training. It is crucial to tackle aesthetic limitations and shifting public perceptions for wider acceptance. The study concludes that addressing these challenges through integrated reforms can position PFBs as a sustainable and resilient option in the global construction industry, especially in light of climate change and urban housing shortages.

**Key words:** Prefabricated buildings (PB), Low-rise construction, Light steel thin-walled structures (LSTS), Modular construction, Regulatory gaps, Energy efficiency, Sustainable development

### **1. Introduction**

#### **Overview and Evolution of Prefabricated Buildings**

Prefabricated buildings (PFBs), which can be frame or frameless, are notable for their rapid construction that is often unaffected by weather, as they utilize pre-manufactured components and modules. This building technology emerged in the mid-20th century and evolved in two principal ways: the development of wooden modular structures for temporary housing and the manufacture of block containers for various technical uses. Following World War II, the USA and Canada led in the widespread adoption of this technology, emphasizing quick assembly and

disassembly, resulting in its application across many sectors, such as residential housing, retail spaces, and warehouse facilities.

Once viewed as makeshift or supplementary solutions, PFBs have significantly transformed. They now provide "unprecedented opportunities for any business – to build quickly, qualitatively, and profitably". Contemporary prefabricated structures effectively rival permanent buildings, being utilized not just for residential projects, but also in commercial, administrative, and industrial sectors. This evolution reflects a substantial shift in both perception and functionality of PFBs. No longer merely temporary fixes, they are now recognized as robust, competitive alternatives to conventional building methods. This transition modifies market expectations, necessitates stricter regulations, and raises various challenges concerning durability, aesthetics, and long-term operational efficiency that were previously less pressing.

### **Definition and Classification of Low-Rise Prefabricated Buildings**

In the context of this analysis, low-rise prefabricated buildings are typically defined as structures up to three stories high. There are several key types of such buildings, each with its own characteristics:

**Container Buildings:** Comprised of pre-fabricated modules created in a factory and assembled on-site on a prepared foundation. They are commonly utilized as temporary housing, retail spaces, or mobile healthcare facilities. Their lifespan can reach up to 50 years, although they offer limited architectural variety.

- **Volumetric Block Houses:** Generally more comfortable than container buildings, but at a higher cost. Each block features a metal frame encased in OSB, chipboard, and other materials, with siding and thermal insulation for added comfort. Their lifespan also extends to 50 years, but transporting and maintaining the aesthetics of the finished blocks can pose difficulties.

- **Large-Panel Buildings:** Constructed with sandwich panels, which deliver excellent sound and thermal insulation. These buildings can be assembled quickly and do not require welding.

- **Frame Buildings:** Composed of a wood or metal frame, which is then covered with panels and insulation. This method allows for buildings to be designed in a variety of shapes and architectural styles.

- **Permanent Formwork:** Involves initially erecting permanent formwork that is filled with concrete. These buildings are strong and offer good thermal insulation, although they are slower to construct compared to other methods.

- **Modular Buildings:** Structures made of prefabricated block modules assembled at the production facility. These modules may also include integrated utilities and finished interiors. They are transported to the building site and assembled on a prepared foundation, with maximum dimensions typically limited to transportation specifications (around 4x15x3.8 m).

- **Light Steel Thin-Walled Structures (LSTK):** This technique employs thin (3-4 mm) galvanized steel profiles as load-bearing components. LSTK is recognized for rapid assembly and minimal metal usage, leading to significant cost savings in construction.

The wide variety of construction technologies under the label "prefabricated" means that, although they generally offer advantages like speed and cost-efficiency, each has its own distinct material composition, assembly techniques, and operational features. Consequently, the "issues"

with PFBs are not uniform; rather, specific challenges—such as gaps in the regulatory framework for LSTK, design constraints of modular buildings, or toxicity concerns with sandwich panels—are closely associated with particular technologies. This fragmentation hinders the establishment of a cohesive and comprehensive regulatory framework, which is a significant element of the current issue. Therefore, effective solutions must be tailored to the unique characteristics of each technology.

**Table 1: Main Types and Characteristics of Low-Rise Prefabricated Buildings**

<b>Building Type</b>	<b>Main Materials</b>	<b>Assembly Method</b>	<b>Typical Applications</b>	<b>Key Advantages</b>	<b>Key Disadvantages</b>
<b>Container</b>	Ready-made modules	Assembly of finished modules on foundation	Temporary housing, retail pavilions, medical centers	Fast installation, mobility, up to 50 years of operation	Limited architectural variety
<b>Volumetric Block Houses</b>	Metal frame, OSB/chipboard, insulation	On-site block assembly	Residential buildings	Comfort, up to 50 years of operation	Difficulties with transportation, maintaining exterior appearance
<b>Large-Panel</b>	Sandwich panels	Panel connection with lock joints	Industrial, warehouse, commercial	Optimal sound and thermal insulation, high-speed assembly without welding	Maximum height 2 stories, need for ventilation
<b>Frame (wood/metal)</b>	Wooden/metal frame, panels, insulation	Frame assembly, then cladding and insulation	Residential, commercial, industrial	Variety of configurations and architecture, energy efficiency, lightweight foundation	Full-scale construction work on site, low sound insulation, assembly complexity
<b>Permanent Formwork</b>	Permanent formwork, concrete mix	Concrete pouring into formwork	High-strength buildings	High strength, good thermal insulation properties	Slower construction speed

<b>Modular</b>	Ready-made block modules (often SIP panels)	Assembly of finished modules on foundation	Temporary/permanent residential, commercial, industrial	High speed, "turnkey" house, mobility, cost-effectiveness, no construction waste	Limited room size and design projects, need for ventilation
<b>LSTK</b>	Galvanized steel profiles (up to 3-4 mm)	Bolted connection of profiles	Industrial, commercial, residential	High assembly speed, minimal metal consumption, lightweight foundation	Lack of regulatory framework (historically), low strength of thin profiles

Export to Sheets

### Significance and Growing Role in Modern Construction

Prefabricated buildings are acknowledged as "advanced construction technology," delivering a distinctive blend of speed, quality, and economic advantages. They present "unprecedented opportunities for any business – to build quickly, qualitatively, and profitably." Their importance goes beyond mere construction efficiency; they serve as a strategic resource for tackling global challenges. For instance, they are crucial in addressing housing shortages and fostering sustainable urban development, particularly in developing areas.

The rapid construction capability of PFBs is vital in the fight against climate change. With the rising occurrence of natural disasters, such as floods, fires, and hurricanes, prefabricated buildings facilitate the swift restoration of damaged infrastructure and provide housing for affected communities. This elevates PFBs beyond a construction method to a significant asset for adapting to climate change and bolstering societal resilience. Their strategic significance in an ever-evolving world highlights the necessity for a comprehensive approach to fully harness their potential.

### Problem Statement: Overview of Challenges in Low-Rise Prefabricated Building Construction

Despite numerous advantages, the widespread adoption and optimal operation of prefabricated buildings are hindered by a number of interconnected problems. These include:

- **Regulatory and Legal Gaps:** The absence of a comprehensive regulatory framework, particularly for multi-story buildings and specific technologies such as LSTK, creates uncertainty and risks.
- **Technological and Operational Limitations:** These include issues related to material properties (e.g., susceptibility to pests, potential toxicity of certain panels), as well as operational drawbacks such as high energy consumption in summer (overheating) and poor sound insulation. Furthermore, ensuring consistent quality during production and assembly remains a significant challenge, requiring highly qualified personnel.

- **Social Perception and Architectural Limitations:** The historical association of PFBs with temporary structures, as well as limitations in the architectural variety of some modular designs, hinder their full societal acceptance.

These problems are not isolated; they are interconnected and can worsen each other. For instance, inadequate regulation can lead to a decline in material and assembly quality, which, in turn, worsens issues with energy efficiency or sound insulation. Therefore, analyzing the state of the problem necessitates a comprehensive approach that considers all aspects and their interconnections.

## Objectives of the Analysis

This analysis pursues the following objectives:

- To identify and systematize the primary challenges associated with the construction and widespread implementation of low-rise prefabricated buildings.
- To conduct an in-depth analysis of the root causes and potential consequences of the identified problems, relying on the provided data to form substantiated conclusions.
- To identify and evaluate existing solutions, best practices, and innovative developments capable of mitigating or eliminating these challenges.
- To formulate practical recommendations for construction industry participants and regulatory bodies to promote sustainable development, improve quality, and expand recognition of this construction method.

## 2. Methods

### Data Collection and Synthesis Approach (Literature Review)

This analysis stems from a thorough and methodical review of the provided information snippets. These snippets come from various sources, including articles, industry reports, and official regulatory documents about prefabricated buildings, particularly regarding their use in low-rise construction. Relevant information addressing the question was meticulously extracted, organized, and synthesized. This process entailed pinpointing crucial definitions, historical context, outlined advantages, acknowledged disadvantages, specific issues, current market trends, existing regulatory frameworks, and the latest technological innovations in the field.

### Criteria for Problem Identification and Categorization

Problems were identified based on explicit mentions of "disadvantages," "challenges," "problems," "limitations," or "destruction factors" within the textual content of the information snippets. A structured categorization system was used to group the identified problems by their inherent nature:

- **Technological and Operational:** Covering issues directly related to construction materials, manufacturing processes, on-site assembly, and the functional characteristics of completed structures.
- **Regulatory and Legal:** Pertaining to gaps, inconsistencies, or inadequacies in existing standards, building codes, and legislative frameworks governing PFB construction.
- **Social and Perceptual:** Addressing issues of public acceptance, market perception, and inherent architectural or aesthetic limitations.
- **Environmental:** Focused on the environmental impact of PFBs, including aspects of

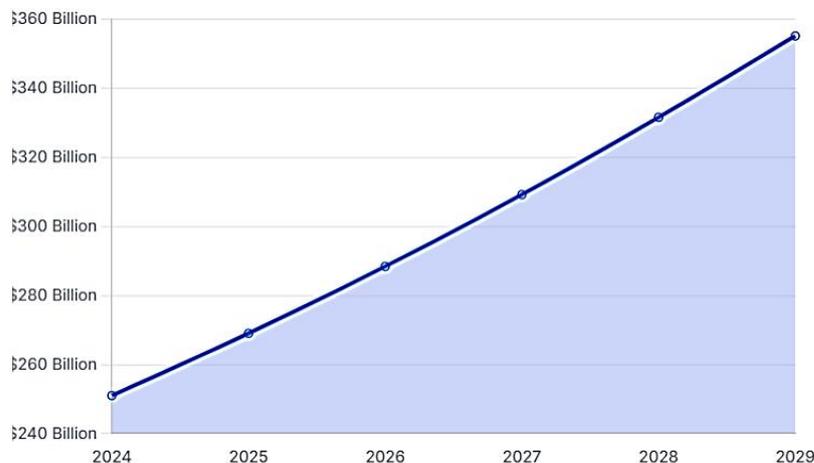
energy consumption, waste generation, and climate change adaptation.

### Analytical Framework for Problem Assessment

The analysis adopts a comprehensive and critical approach. Each identified issue is explored regarding its unique characteristics, recognizable root causes (whenever possible based on available data), and its potential implications for the PFB sector in both the short and long term. Special focus is given to uncovering and emphasizing the connections and dependencies among various problem categories. This method seeks to offer a complete and integrated view of the "state of the problem," going beyond simply listing issues. Existing solutions, proven best practices, and new innovations are rigorously assessed against the identified challenges to evaluate their current effectiveness and future potential for thoroughly addressing the problems.

## 3. Results

### Global Market on the Rise



*Figure 1* The prefabricated buildings market shows steady growth, driven by demand for affordable housing, urbanization, and businesses' desire to optimize costs. North America remains the largest market, while the Asia-Pacific region exhibits the fastest growth.

**Economic Advantages and Driving Forces:** The economic viability of PFBs is the primary catalyst for their increasing adoption:

- **Construction Speed:** PFBs are built significantly faster than traditional buildings, typically 2-3 times quicker. Project completion times can range from a few weeks to several months, with some modular projects completing in just 2-3 weeks. Such rapid project execution directly leads to reduced overall timelines and associated costs.
- **Cost-Effectiveness:** PFBs are significantly more economical, being 40-60% cheaper than traditional buildings. This advantage stems from lower material costs, reduced labor and equipment needs, and optimized logistics. The continuous increase in traditional construction costs is a key factor driving the PFB market.
- **Lightweight Structures:** The low weight of PFB structures minimizes the need for massive and complex foundations, resulting in substantial savings in time, materials, and labor during the foundation phase. Some small structures can even be erected without a foundation.
- **All-Season Construction:** The absence of "wet processes" (e.g., concrete pouring, extensive masonry) in PFB assembly enables construction work to proceed efficiently, regardless

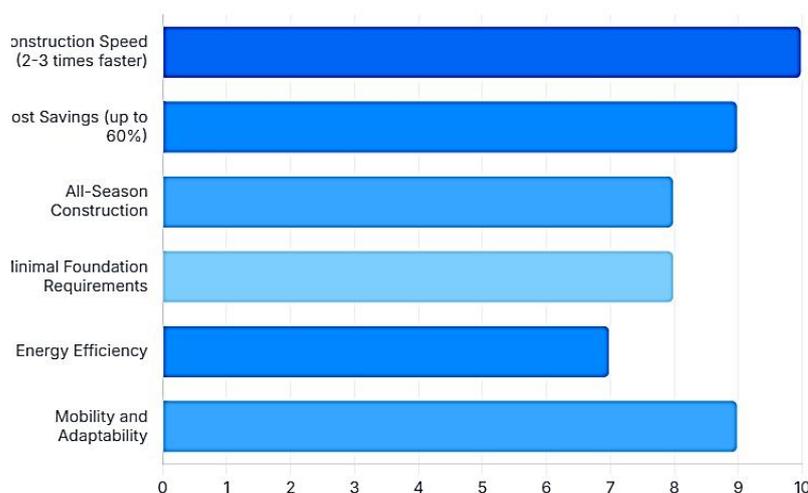
of temperature or adverse weather conditions, ensuring project continuity.

**Diversity of Applications and Versatility:** The inherent versatility of PFBs allows for their successful use in a wide range of applications, extending far beyond traditional residential construction:

- **Industrial and Warehouse Facilities:** Including factories, large warehouses, hangars, boiler houses, and various service centers.
- **Commercial and Exhibition Spaces:** Such as shopping centers, hypermarkets, car dealerships, sports complexes, and fast-food restaurants.
- **Agricultural Facilities:** Covering livestock complexes, poultry farms, specialized storage for vegetables, fruits, and grains, as well as large greenhouse complexes.
- **Other Applications:** Including temporary housing, mobile medical units, and various municipal facilities.
- **Mobility and Adaptability:** Many types of PFBs, especially modular and container structures, offer a clear advantage in their ability to be dismantled and relocated, providing flexibility in land use and asset management.
- **Architectural Flexibility:** While some modular designs may have inherent limitations, frame structures, for example, provide significant scope for diverse configurations and architectural solutions.

Despite various challenges and limitations, which will be examined in detail later, the prefabricated building (PFB) market is experiencing notable growth, leading to widespread utilization across multiple sectors. Key factors driving this trend include significant advantages in speed and cost efficiency. The rising expenses associated with traditional construction methods further establish PFBs as a more appealing and economically sensible alternative. This strong financial incentive serves as a powerful driver for the ongoing expansion of PFB usage, even amidst unresolved technological and regulatory challenges. Therefore, any comprehensive strategy aimed at addressing the "state of the problem" must not only prioritize improvements in quality and performance but also focus on sustaining and enhancing the economic viability that supports market growth and appeal.

### Undeniable Advantages



*Figure 2 Economic viability and operational efficiency make prefabricated buildings an increasingly attractive alternative to traditional construction.*

## Technological and Operational Challenges

### Material-Specific Issues:

- **Pest Susceptibility:** Certain insulation materials, such as inexpensive foam plastic, are prone to rodent infestations, creating durability and hygiene issues. However, the industry is increasingly adopting alternatives, such as ecowool, which provides better pest resistance.
- **Potential Toxicity:** A critical concern for residential buildings is the potential toxicity of some sandwich panels. This requires careful material selection and adherence to health and safety standards during the design and construction of residential homes.
- **Inconsistent Material Quality:** Problems can arise due to the "low quality of the material itself – panels," indicating deficiencies in the manufacturing process or material supply.

### Energy Efficiency Issues:

- **Summer Overheating:** Lightweight wall structures, particularly those with metal frames, can heat up significantly in the summer. While air conditioning can solve this problem, its use is expensive, undermining the overall economic benefit.
- **"Thermos Effect":** Sandwich panel buildings, despite excellent thermal insulation, can create an airtight environment similar to a thermos. This necessitates the installation of a high-quality, often forced, ventilation system to ensure adequate air circulation and prevent condensation, as well as poor indoor air quality.
- **Dependence on Insulation Quality:** The stated energy efficiency of PFBs largely depends on the quality, type, and thickness of the insulation used. Suboptimal insulation can lead to significant heat loss or overheating, negating expected savings.

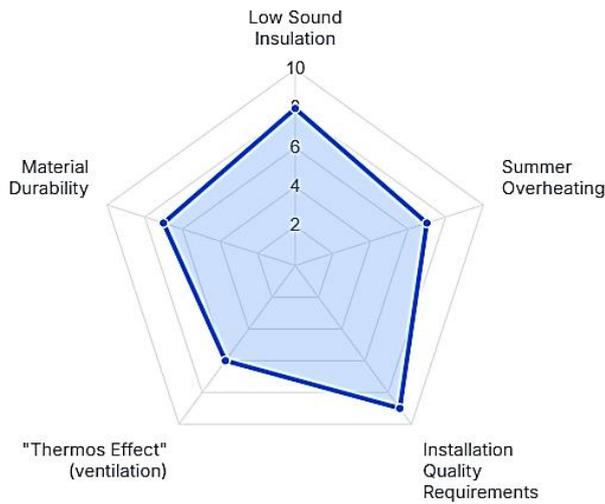
### Acoustic Characteristics (Sound Insulation):

- **Low Sound Insulation:** A common drawback, especially in residential PFBs, is the relatively thin nature of their walls, which can lead to "noisy" interiors and poor sound insulation from external sources or adjacent rooms.
- **Dependence on Panel Material:** The level of sound insulation directly depends on the specific materials and thickness of the cladding panels chosen for the structure.

### Quality Control in Production and On-Site Assembly:

- **Design and Assembly Errors:** Even minor inaccuracies or serious errors during the design, transportation, storage, or on-site assembly stages can result in significant problems with the finished structure.
- **Structural and Aesthetic Defects:** Errors made by builders can manifest as cracks at the joints of structural elements or peeling of cladding, compromising both structural integrity and aesthetic appearance.
- **High Qualification Requirement:** Despite the pre-manufacturing of elements, the assembly of PFBs, especially for complex projects, requires high qualification, precision, and experience from construction workers. The high precision of factory-made elements means minimal need for on-site fitting, but any assembly errors are critical and can have cascading consequences.

## Technological and Operational Issues



*Figure 3 Despite progress, a number of operational characteristics require special attention during design and construction to ensure long-term comfort and quality.*

Prefabricated buildings, while offering speed and cost benefits, often encounter operational issues such as inadequate acoustics and overheating. These challenges often arise from the use of lightweight materials and construction techniques, which are designed for quick assembly and cost savings. For instance, the "thermos effect" results from effective thermal insulation, which, in the absence of proper ventilation, leads to an undesirable airtight condition. In addition to material attributes, frequent references to quality control problems and the crucial need for skilled builders suggest that the "human factor" is a major exacerbating issue. Even with precision-engineered factory components, improper high-precision assembly or assembly on site can significantly compromise the structural integrity, longevity, and expected operational efficiency of the completed building. Tackling these technological hurdles demands material innovations to address intrinsic limitations, along with strict adherence to quality assurance practices throughout the supply chain, from production to final assembly. Additionally, it requires substantial investments in professional training and ongoing supervision to reduce the widespread effects of human errors that can detract from even the most sophisticated prefabricated systems.

## Regulatory Gaps

### Absence of Comprehensive Standards for Specific Technologies (e.g., LSTK):

- The primary and critical reason for the deformation and destruction of LSTK buildings in Russia is the explicit absence of legally established and comprehensive design standards specifically developed for such structures.
- Existing Russian Building Codes and Regulations (SNIps) currently apply only to metal structures thicker than 4 mm. This leaves LSTK structures, which use profiles and corrugated sheets 3-4 mm thick, without clear, mandatory regulatory guidance.
- As a consequence, designers are often forced to work without a defined regulatory framework, leading to arbitrary calculations and design decisions. This lack of clear regulatory

constraints can result in incorrect load calculations, structural deformation during operation, and, in serious cases, even complete building collapse.

- Recognizing this critical gap, the Russian Union of Metal Product Suppliers actively advocates for the development of specific Russian SNiPs for LSTK, proposing to use one of the well-established Eurocodes as a basis.

### **Consequences of Inadequate Regulatory Frameworks:**

- **Increased Risk:** The main consequence is an increased risk of structural failure and deformation, posing significant safety and economic risks.
- **Dependence on Individual Experience:** In the absence of clear norms, the reliability and safety of PFBs largely depend on the individual professional qualities, experience, and responsibility of designers and manufacturers, rather than on standardized, verifiable processes.
- **Limited Adoption:** The lack of regulatory certainty directly limits the widespread adoption and scaling of certain PFB technologies. For example, multi-story LSTK buildings are "practically not built in Russia" precisely due to the absence of relevant norms.

### **Social Perception and Architectural Limitations**

Public Perception and Association with Temporary Structures: The historical use of PFBs as temporary housing and functional technical facilities has inadvertently shaped a lasting public perception. This association often results in PFBs being seen as temporary or inherently lower-quality solutions, despite their significant technological advancements and proven capability to compete directly with traditional capital construction. Such perception can act as a barrier to broader market acceptance, particularly in the residential and high-value commercial sectors.

### **Design and Aesthetic Limitations:**

- **Limited Architectural Variety:** Certain types of PFBs, such as container buildings and volumetric block houses, are explicitly noted as "not differing in a wide variety of architectural solutions". This inherent standardization, while contributing to speed and cost-effectiveness, can limit unique aesthetic expression.
- **Modular Limitations:** Modular homes inherently face "limitations in design project possibilities, based on the production capabilities for module manufacturing." Furthermore, "limitation of room size by the dimensions of component modules" can restrict internal spatial planning and design flexibility.
- **Trade-off with Customization:** While some PFB technologies, such as frame buildings, allow for a wider range of configurations and architectural solutions, the fundamental principles of prefabrication and modularity often inherently prioritize standardization and efficiency over individual architectural customization, creating a tension that needs to be addressed for broader appeal.

The analysis indicates that PFB issues extend beyond just technical or regulatory flaws; they are also tied to a notable "image problem" and aesthetic concerns. The effectiveness and cost-efficiency of PFBs often stem from standardization and modularity, which consequently restrict distinctive architectural expression and spatial adaptability. This leads to a clear trade-off between the fundamental benefits of PFBs and the aesthetic standards of traditional construction. Historically viewed as temporary housing, PFBs encounter a "perception lag," where societal views and acceptance fail to match the swift technological progress and enhanced capabilities of contemporary PFBs. For PFBs to reach their full potential and achieve broader acceptance, especially in the residential and upscale commercial sectors, it is vital to proactively tackle these aesthetic challenges and strategically influence public perception, in conjunction with resolving

technical and regulatory obstacles. This necessitates a transition from solely functional designs to more holistic architectural solutions.

## Environmental Aspects

### Waste Minimization and Energy Efficiency in Production/Operation:

- **Reduced Construction Waste:** PFBs inherently lead to a significant reduction in construction waste due to the precision of their factory production and assembly processes. This sharply contrasts with the substantial volume of waste often generated in traditional on-site construction.
- **Optimized Energy Consumption:** These buildings are designed to integrate energy-efficient systems and can easily incorporate renewable energy sources, such as solar panels.
- **Material-Specific Efficiency:** Common materials, such as sandwich panels, contribute to a significant reduction in heating insulation costs and indoor climate maintenance, leading to lower operational energy consumption.
- **Resource Conservation:** The factory production process ensures stricter quality control and more efficient material utilization, resulting in overall resource savings compared to less controlled on-site construction methods.
- **Reduced Site Impact:** Prefabrication and rapid assembly minimize the use of heavy machinery and reduce the volume of construction waste generated directly at the construction site, thereby positively impacting the local ecology.

### Adaptability to Climate Change:

- **Universal Adaptation:** PFBs demonstrate high adaptability to various climatic conditions and diverse social needs, offering a flexible and affordable solution for housing construction and infrastructure development.
- **Disaster Response Capability:** The high speed of their construction is a critical advantage for rapid recovery and reconstruction in regions affected by natural disasters (e.g., floods, fires, hurricanes), phenomena that are becoming increasingly frequent and intense due to global warming. This makes them a vital tool for enhancing disaster resilience.
- **Increased Structural Resilience:** Modern PFBs, utilizing advanced materials and construction technologies, demonstrate increased resistance to extreme weather events such as strong winds, floods, and earthquakes.

While prefabricated buildings encounter energy efficiency challenges, such as overheating in summer, they offer considerable environmental advantages, including significant waste reduction and the natural energy efficiency of some materials. Prefabricated buildings are well-positioned amid the "climate changes caused by global warming," highlighting their ability for the "rapid restoration of destroyed infrastructure" and their "increased resilience to phenomena" like severe weather events. This elevates the significance of prefabricated buildings from being merely an effective construction method to becoming a vital element in strategies for adaptation and resilience against climate change. The environmental challenges for prefabricated buildings are therefore more complex than just a shortfall; they present an opportunity to enhance their energy performance while capitalizing on their inherent benefits in waste reduction and swift response capabilities. This reassessment underscores their potential as a sustainable and resilient solution in a time of growing environmental instability.

### Table 2: Comparative Analysis of Advantages and Disadvantages of Prefabricated Buildings

Category	Advantages	Disadvantages
<b>Construction Speed</b>	2-3 times faster than capital construction (weeks-months) .	-
<b>Cost</b>	40-60% cheaper than traditional buildings due to materials, labor, logistics.	-
<b>Foundation Requirements</b>	Lightweight structures do not require massive foundations; lighter options possible (pile, columnar, shallow strip) .	-
<b>Mobility</b>	Possible to dismantle and relocate to a new site .	Module delivery can be expensive.
<b>Architectural Possibilities</b>	Wide range of shapes and layouts (especially frame structures).	Limited architectural variety for container and volumetric blocks ; limitation of design project possibilities and room sizes for modular.
<b>Seismic Resistance</b>	High seismic resistance (up to 9 points on MSK-64 scale).	-
<b>Energy Efficiency</b>	High energy efficiency indicators with sandwich panels and insulation result in reduced heating costs.	High energy consumption in summer (overheating of lightweight structures, need for air conditioning); "thermos effect" requires quality ventilation.
<b>Sound Insulation</b>	-	Low sound insulation (thin walls).
<b>Regulatory Framework</b>	-	Lack of a regulatory framework for multi-story and LSTK buildings in Russia.
<b>On-site Work</b>	Absence of "wet processes," possibility of construction at any time of year; absence of full-scale construction and construction waste for modular.	Full-scale construction work on site for frame structures.
<b>Material Specifics</b>	Resistance to rodents, chemical/biological influences (sandwich panels).	Susceptibility to rodents (cheap foam plastic); potential toxicity of some panels for residential buildings; low quality of panels themselves.
<b>Assembly/Finishing Quality</b>	Precision manufacturing and ease of assembly of elements.	High demands are placed on finishing work quality and builder qualifications; errors can lead to cracks and peeling.
<b>Object Readiness</b>	"Turnkey" house with finished interior and utilities for modular.	Delivery of the object in "shell and core" condition for frame structures.

**Table 3: Categorized Problems and Challenges in Low-Rise Prefabricated Building**

## Construction

Problem Category	Specific Problem	Brief Description/Impact	Sources
<b>Technological and Operational</b>	Low Sound Insulation	Thin walls lead to noise transmission, making houses "noisy".	
	Summer Overheating	Lightweight wall structures on metal frames heat up significantly in summer, requiring expensive air conditioning.	
	"Thermos Effect"	The airtightness of sandwich panels requires a high-quality ventilation system.	
	Pest Susceptibility	Some insulation materials (foam plastic) can be susceptible to rodents.	
	Potential Material Toxicity	Some sandwich panels can be toxic for residential buildings.	
	Material/Panel Quality Issues	The low quality of the panels themselves can lead to defects.	
	High Demands on Installer Qualification	Assembly complexity and the need for technology adherence require high qualifications and experience from builders.	
<b>Regulatory and Legal</b>	Design and Installation Errors	Inaccuracies or serious errors can lead to cracks, peeling cladding, and reduced strength.	
	Lack of a Comprehensive Regulatory Framework for LSTK	In Russia, there are no legally established design norms for LSTK buildings, resulting in arbitrary calculations and an increased risk of destruction.	
	Limitations of Existing SNiPs	SNiPs apply only to metal structures thicker than 4 mm, excluding LSTK.	
	Absence of Norms for Multi-Story PFBs	The lack of a regulatory framework for multi-story buildings hinders their construction in the Russian Federation.	
<b>Social and Perceptual</b>	Association with Temporary Structures	Historical use for temporary housing creates a perception of PFBs as less permanent or of lower quality.	
	Limited Architectural Variety	Container and modular buildings may not offer a wide variety of architectural solutions, limiting design possibilities.	
<b>Environmental</b>	Need for Ventilation	Airtightness of structures requires ventilation installation to ensure a comfortable microclimate.	
	Energy Costs for Air Conditioning	The problem of summer overheating leads to additional air conditioning costs.	

## 4. Discussion

## Synthesis of Interconnected Problems and Their Root Causes

The analysis clearly indicates that the challenges encountered by low-rise prefabricated buildings are not isolated events, but rather a complex network of interrelated issues. For instance, the notable lack of a strong regulatory framework for LSTK stands as a primary root cause, leading to widespread quality control problems and serious structural integrity concerns. This regulatory gap compels designers and builders to work without defined, standardized guidelines, which heightens the impact of the "human factor" and raises the probability of mistakes.

These basic structural and quality challenges often worsen technological operational difficulties. For example, if materials aren't specified or installed accurately due to regulatory ambiguity or human mistakes, it can result in poor sound insulation and reduced energy efficiency. The "thermos effect" issue, which stems from effective insulation, illustrates that even benefits can lead to secondary operational challenges that need extra solutions, such as enforced ventilation.

The traditional view of PFBs as temporary structures, along with the architectural constraints of certain modular designs, hinders broader public acceptance. This occurs even as the economic benefits promote market expansion. This situation produces a vicious cycle where an essential regulatory deficiency erodes quality, performance, and public confidence, despite the notable economic advantages and rapid construction time associated with PFBs. To disrupt this cycle, coordinated efforts in regulation, quality assurance, and public education are necessary.

## Assessment of Existing Solutions and Best Practices

Despite the identified problems, solutions and best practices aimed at mitigating them exist and are actively being developed:

- **Addressing Sound Insulation Issues:** To improve sound insulation, special sound-insulating materials can be used, such as vibro-acoustic panels, sandwich panels with rock wool, thick plaster layers, gypsum board coverings, acoustic door seals, sound-permeable curtains, and even "white noise".
- **Enhancing Energy Efficiency:** The application of high-quality insulation (e.g., Eco wool instead of foam plastic for pest protection), the installation of mechanical ventilation systems to counteract the "thermos effect", and chemical cleaning of heating systems contribute to improved thermal performance.
- **Mitigating Material-Specific Risks:** Replacing pest-susceptible materials and ensuring proper ventilation are essential steps to address potential toxicity issues.
- **Ensuring Quality Control:** Special attention is paid to the need for highly qualified builders, ordering products from reliable manufacturers, and selecting qualified contractors. Strict adherence to technology is crucial for maintaining building airtightness.
- **Best Practices in Design and Construction:** These include modularity and layout variability, precise structural calculations for strength and stability, ensuring required thermal performance indicators, considering geo-engineering conditions, and the technology of element manufacturing and assembly. The use of non-combustible materials, fire-bioprotective treatment of wooden elements, and the installation of fire alarm systems are also important.

The existence of solutions for various issues (such as sound insulation materials, ventilation systems, and quality control measures) does not guarantee their widespread use. The challenge now revolves around "lack of consistent application" rather than the "lack of a solution." Factors contributing to this gap include economic issues (like the high cost of air conditioning for cooling needs and the expense of quality materials), limited awareness, or insufficient compliance with current standards. Therefore, the focus should be on closing this

implementation gap. Achieving this requires ongoing research and development to improve existing solutions, as well as providing financial incentives, enforcing quality standards more rigorously, and implementing comprehensive training programs for the workforce to normalize these best practices instead of treating them as exceptions.

## **Analysis of Innovations and Their Potential to Address Challenges**

Innovations play a key role in overcoming existing challenges and transforming the PFB sector:

- **Advanced Materials:** The development of innovative insulation panels (e.g., vacuum-based), low-emissivity windows, and "smart" facades that adapt to temperature changes significantly enhances energy efficiency. The emergence of self-healing concrete presents new opportunities for enhanced durability.
- **Digital Technologies:**
  - **BIM (Building Information Modeling):** Applied in PFB design, increasing accuracy and coordination, which reduces errors and improves quality.
  - **3D Printing:** Applied in construction, offering new possibilities for design and material use, which can address architectural limitations and accelerate production.
  - **"Smart Homes" and Automation Systems:** Integration into PFBs to enhance functionality and energy consumption management, which can mitigate overheating problems and increase comfort.
- **Advances in Prefabrication and Modularity:** Increasing the factory readiness of components, such as pre-installed windows, doors, and electrical wiring, minimizes on-site work and improves quality. For example, German technology provides ready-made house kits.
- **New Construction Technologies:** Beyond traditional frame/panel methods, approaches such as "Canadian assembly" (SIP panels) and "German technology" (pre-assembled panel kits) offer faster and more integrated solutions.

Innovations are not just incremental improvements; they are potentially game-changing factors. They can fundamentally alter the cost-benefit analysis, enhance operational performance, and possibly overcome aesthetic and perceptual barriers. The spread of these innovations will largely determine the future "state of the problem" for PFBs, pushing them further into the mainstream of high-quality construction.

## **Future Development Directions and Opportunities**

- **Increased Industrialization:** A stronger emphasis on factory production of modules and components will lead to improved quality and accelerated assembly.
- **Enhanced Energy Efficiency and Sustainability:** Continued work on "green building" concepts, integration of renewable energy sources (solar panels), and heat recovery and rainwater harvesting systems.
- **Regulatory Harmonization:** Development of comprehensive national standards for all types of PFBs, especially for LSTK, possibly based on international best practices (e.g., Eurocodes).
- **Architectural Versatility:** Innovations in design and production to provide greater aesthetic flexibility and customization, overcoming the perception of "boxy" buildings.
- **Smart Integration:** Further integration of "smart home" technologies, automation, and digital twins to optimize design, construction, and operation phases.
- **Disaster Resilience:** Continued development of PFBs for rapid deployment in disaster-affected areas, leveraging their speed and reliability.

The successful development of these directions will not only address existing problems but also elevate PFBs from a niche, economically advantageous solution to a mainstream, high-performance, and sustainable construction method, fundamentally transforming their role in the built environment.

## Gaps in Current Research and Practice

Despite significant progress, key gaps remain in research and practice that require attention:

- **Long-Term Performance Data:** While some sources mention service life, more extensive long-term studies on durability, material degradation, and operational performance in various climatic conditions are needed, especially for new material combinations.
- **Comprehensive LSTK Norms:** Despite recent progress in fire resistance, the overall absence of a comprehensive regulatory framework for LSTK remains a critical gap that requires urgent attention.
- **Economic Impact of Quality Solutions:** A detailed cost-benefit analysis is necessary to justify investment decisions, examining the economic benefits of implementing higher-quality materials (e.g., eco-wool versus cheaper insulation), advanced ventilation systems, and improved sound insulation.
- **Public Perception Studies:** Empirical research on how the public's perception of PFBs changes with technological advancements and regulatory improvements can aid in developing effective marketing and policy strategies.
- **Standardization of Digital Workflows:** While BIM is mentioned, the standardization of BIM workflows and digital twins, specifically for PFB lifecycle management, requires further development and implementation.
- **Training and Certification Programs:** There is a gap in widespread, standardized training and certification programs for PFB installers, which is crucial given the high-quality requirements.

## Conclusion

### Summary of Key Findings on the State of the Problem

Low-rise prefabricated buildings have become a significant force in modern construction, driven primarily by their **unprecedented speed and economic efficiency**, making them economically competitive with traditional capital structures. Their versatility enables their use in various sectors, including industrial, commercial, residential, and agricultural applications.

However, their widespread adoption and full potential are limited by several interconnected problems. **Technological and operational challenges** include material-specific issues (e.g., susceptibility to pests, potential toxicity), performance gaps in energy efficiency (overheating, "Thermos effect"), and, notably, low acoustic insulation. Crucially, consistent **quality control** at all stages of production and on-site assembly remains a challenge that requires high professional qualifications.

A critically important and overarching problem is the **fragmented and incomplete regulatory framework**, particularly evident in the absence of comprehensive standards for Light Steel Thin-Walled Structures (LSTK), which directly impacts structural reliability and the confidence of designers. Although progress is observed in standards for modular buildings, the uneven regulatory landscape creates uncertainty.

**Social perception** continues to struggle with the historical association of PFBs with temporary structures, and **architectural limitations** in some modular types hinder design flexibility. Despite these challenges, PFBs offer significant **environmental advantages** in waste

minimization and adaptability to climate change, positioning them as a valuable tool for sustainable development.

### Implications for Industry and Policy

For the industry to grow further, it must strategically shift towards enhancing quality assurance at every phase, from selecting materials to assembly, while also focusing on improving operational attributes like acoustics and thermal comfort to align with changing consumer expectations. Investing in specialized training for professional PFB construction is essential. For regulatory bodies, there is a pressing need to standardize and finalize the regulatory framework for all PFB technologies, particularly LSTK, to guarantee safety, reliability, and encourage innovation. This effort involves establishing clear design standards, quality control measures, and possibly performance-based regulations.

Both the industry and regulatory bodies must collaborate to **bridge the perception gap**, demonstrating the long-term viability, quality, and environmental benefits of modern PFBs.

### Recommendations for Sustainable Development and Problem Resolution

To ensure sustainable development and effective problem resolution in the field of low-rise prefabricated building construction, the following recommendations are proposed:

- **Regulatory Framework Development:** Prioritized development and implementation of comprehensive, legally binding national standards for all prefabricated building technologies, especially for LSTK, utilizing international best practices (e.g., Eurocodes).
- **Quality Assurance and Control:** Implement stringent quality control measures throughout the entire lifecycle, from factory production of components to on-site assembly. This should include mandatory inspections and third-party certification.
- **Research and Development:** Investing in R&D to create advanced materials and technologies that enhance acoustic insulation, improve thermal performance (especially in hot climates), and provide greater architectural flexibility without compromising cost or speed.
- **Professional Training and Certification:** Establishment and promotion of standardized training and certification programs for designers, manufacturers, and installers specializing in prefabricated building technologies to ensure a high level of competence and reduce human errors.
- **Public Education and Marketing:** Launching initiatives to inform the public and stakeholders about the advancements, advantages, and long-term viability of modern prefabricated buildings, challenging outdated perceptions.
- **Digital Technology Integration:** Encouraging wider adoption and standardization of BIM, 3D printing, and "smart building" technologies to optimize design, construction, and operation phases, leading to increased efficiency and quality.

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