Journal of Mines, Metals and Fuels, *73(2): 307-320; 2025. DOI: 10.18311/jmmf/2025/47416*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Exploring the Quality and Safety Aspects of LGSF -Ferron Modular Construction in Indian Context

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Abstract

The Indian construction industry is grappling with an affordable housing crisis, prompting the exploration of alternative construction methods. Traditional techniques, such as brick and concrete, are increasingly labour-intensive and costly. This paper investigates the potential of Light Gauge Steel Frame (LGSF) construction, particularly when combined with Ferron, a composite material that enhances structural integrity while reducing costs and construction time. The LGSF-Ferron system eliminates the need for formwork and offers benefits like increased fracture resistance and sustainability, positioning it as a viable alternative to reinforced concrete. Despite its advantages, the adoption of LGSF-Ferron in India remains in its early stages, with critical quality and safety challenges that must be addressed. High-quality assurance and safety management standards are essential to mitigate risks such as financial losses and injuries during on-site construction. This study emphasises the importance of stringent quality control measures, including material quality checks, precision manufacturing, structural engineering compliance, and ongoing quality assurance throughout construction. Through a comprehensive analysis of the benefits, challenges and solutions associated with LGSF-Ferron modular construction, this research aims to provide insights into its role in promoting sustainable and affordable housing in India. Key findings highlight the necessity for pre-engineered components, rigorous on-site inspections and adherence to regulatory standards to ensure successful implementation. By addressing quality and safety concerns, LGSF-Ferron technology can significantly contribute to more efficient building practices and help alleviate the ongoing housing crisis in India. The paper's findings show that LGSF-Ferron is a sustainable, cost-effective alternative, requiring better quality control, safety, and workforce training for adoption in India.

Major Findings: *The study identifies LGSF-Ferron modular construction as a sustainable, cost-effective solution to India's housing crisis, emphasizing the need for rigorous quality control, safety standards, and skilled workforce training for effective adoption.*

Keywords: *LGSF Ferron, Modular Construction, Quality Control, Safety, Sustainability*

1.0 Introduction

1.1 Background of the Study

While many traditional industries, such as manufacturing, textiles, food, and agriculture, have evolved by embracing new technologies, the construction industry has been slow to adapt, focusing mainly on machinery to reduce labour and time. The construction industry in India is facing a significant challenge in addressing the affordable housing crisis. As traditional building methods, such as brick and concrete structures, become increasingly labour-intensive and cost-prohibitive, alternative construction technologies are being explored[1]. Modular technologies

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are widely utilised in low-rise buildings, including office spaces, residential units, warehouses, sanitary facilities and special-purpose premises. Recently, these technologies have also been adopted for multi-storey and high-rise construction projects. Modular construction integrates different technologies that adhere to rapid construction principles, offering efficient and versatile building solutions. One such promising alternative is Light Gauge Steel Frame (LGSF) construction, which offers a cost-effective and efficient solution for building structures. LGSF utilises high tensile steel cold-formed to tailored profiles, creating a robust framework that is both lightweight and durable [2].

The LGSF-Ferron system boasts several advantages, including reduced costs, lighter weight and the elimination of formwork, which significantly accelerates the construction process. Moreover, the increased specific surface area of reinforcement in Ferron leads to enhanced fracture resistance, making it an ideal material for sustainable and resilient building solutions[3]. Despite these benefits, the widespread adoption of LGSF-Ferron modular construction in India is still in its nascent stages, with various quality and safety aspects requiring thorough examination. Quality control in construction is paramount, as defects and malfunctions on-site can lead to substantial financial losses, delays, and even serious injuries or fatalities. Ensuring high-quality standards and robust safety measures is essential for the successful implementation of LGSF-Ferron construction technologies[4].

1.2 Previous Research Work

The literature review focuses on various applications of LGSF technology across different construction areas. Key

Table 1. Summary of previous research work

Sr. No.	Focus Area	Key Findings	Application	Reference
1	Energy efficiency in LGSF	Discusses resilience and recyclability of LGSF systems.	Nearly-Zero Energy Buildings (NZEBs)	7
2	General LGSF application	Highlights advantages in construction processes.	Various construction types.	8
3	Seismic Performance	Evaluates effectiveness in seismic regions.	Seismically vulnerable areas	9
4	Modular Construction	Discusses efficiency and sustainability of modular designs.	Modular Buildings	10
5	Residential Projects	Highlights energy efficiency and cost-effectiveness.	Residential Applications	11
6	Renewable Energy Integration	Examines the benefits of integrating photovoltaics in LGSF.	Energy-efficient Buildings	12
7	High-rise Construction	Investigate new LGSF designs for tall structures.	High-rise Buildings	13
8	Sustainability	Discusses innovations for sustainable building practices.	Sustainable Projects	14

findings highlight its energy efficiency, resilience and recyclability, especially in nearly zero-energy buildings. LGSF offers significant advantages in construction processes across various building types, with proven seismic performance in vulnerable areas. Modular construction benefits from LGSF's efficiency and sustainability, while residential projects emphasise energy efficiency and cost-effectiveness. Integration with renewable energy, like photovoltaics, enhances energy-efficient buildings and new LGSF designs support high-rise construction. Finally, innovations in LGSF contribute to sustainable building practices. The integration of LGSF and Ferron presents a promising opportunity to revolutionise the construction industry in India[5]. By addressing the quality and safety concerns associated with this method, the construction sector can move towards more sustainable, and cost-effective building practices, ultimately contributing to the alleviation of the affordable housing crisis in the country[6]. Table 1 summarises key findings from previous research on LGSF-Ferron construction, highlighting advancements, challenges and gaps in its adoption.

1.3 Objective of the Study

This research paper aims to explore the quality and safety aspects of LGSF-Ferron modular construction, emphasising the importance of stringent quality assurance processes and effective safety management strategies. By examining the benefits, challenges, and potential solutions associated with this innovative construction method, the study seeks to provide a comprehensive understanding of how LGSF-Ferron can contribute to the development of sustainable and affordable housing in India. The findings will highlight the critical role of pre-engineered steel components, on-site quality inspections and compliance with regulatory standards in ensuring the success of LGSF-Ferron modular construction projects.

2.0 Methodology

Figure 1 illustrates the flowchart of the methodology. The research begins by selecting a topic focused on quality management within RCC and LGSF Ferron construction. An in-depth literature review is conducted to gather existing knowledge and practices related to quality

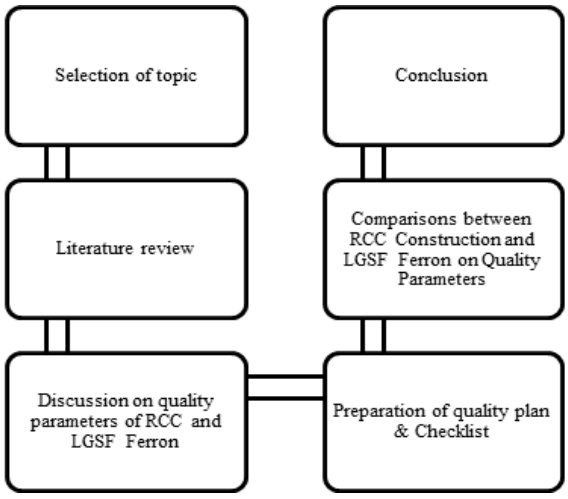


Figure 1. Research methodology flow chart.

standards in both construction methods. The study then identifies key quality parameters, which are discussed in detail to develop a practical quality plan and checklist tailored for each construction type. A comparative analysis is performed to highlight the differences in quality between Reinforced Cement Concrete (RCC) and LGSF Ferron construction. Finally, the research concludes by summarising the findings and offering recommendations aimed at enhancing quality management practices in the construction industry.

3. Overview of LGSF-Ferron Composite Construction

As the demand for eco-friendly construction grows, building sturdy and durable structures has become crucial. In this evolving industry, LGSF stands out as a game changer, offering resilient structures that enhance building durability. Light gauge steel construction is quite like wood-framed buildings in that thin steel sections are used in place of the wooden framing components. The sections that are employed here are referred to as "cold-formed sections," which denote that they are shaped or produced at room temperature. Forms made of galvanised light-gauge steel, often known as forms, are created by cold-forming galvanised steel. The origins of LGSF can be found in the late 19th century, a time when steel gained prominence as a key building material in the annals of construction history[15].



Figure 2. LGSF-Ferron panel composite construction.

New industrialisation was ushered in by the development of innovative steel production methods, most notably the Bessemer process, which made steel more widely available and cheaply feasible. But even with these revolutionary developments, the use of steel in buildings was still mostly restricted to large-scale projects like skyscrapers and bridges because of the constraints that construction methods still imposed[16].

Figure 2 shows a photo of the LGSF-Ferron composite construction from the site located in Pune. LGSF technology underwent a period of constant invention and improvement in the middle to late 20th century. The development of corrosion-resistant coatings and increased manufacturing precision in the steel industry opened the door for the widespread use of LGSF systems. These developments, in conjunction with standardised components and expedited building methods, enabled the broad use of LGSF in a variety of construction projects[17].

Light gauge steel framing is a strong substitute for traditional building techniques and a living example of the construction industry's continuous legacy of innovation[18]. Its popularity in modern construction techniques is highlighted by its intrinsic features, which include durability, insect and fire resistance, and accelerated construction timelines[19]. The cost and weight of the structure rise with the conventional (RCC) technique or LGSF with RCC wall panels, however, with the composite technique, RCC wall panels can be exchanged for precast ferrocement wall panels in LGSF to allow for more affordable and quicker construction[20]. Additionally, Ferrocement wall panels are simple to erect and lessen the structure's dead load. Bolts in the LGSF frames aid in the assembly of the ferro cement wall panels. The material is reusable for additional projects, and the LGSF frames are simple to disassemble. Ferrocement and LGSF are both long-lasting materials, and the composite method has a longer lifespan[21].

Because of structural steel's affordability, strength, longevity, adaptability and recyclability, it is the material of choice for an increasing variety of construction-related applications[22]. Building is completed quickly thanks to precisely manufactured steel frame components, which maximises the amount of work needed. Termites cannot consume steel and it will not burn or ignite. Moisture build-up is not a problem for walls or floors. When all the ferrocement wall panels are properly aligned and piped, steel framing is attached to the floor structure through the bottom plate. Ferrocement is an extremely cooperative substance that works well with steel, bricks, stones and other building elements[23]. Light gauge steel framing is mostly made of steel that is recycled[24]. Steel from demolished steel-framed buildings can be recycled. Steel buildings can be taken down and rebuilt somewhere else if they are no longer needed where they are now[25].

The LGSF panel construction process involves designing the building layout using software. LGSF and Ferron panels are pre-fabricated. Steel coils are cold-formed into structural profiles, while Ferron panels are moulded and cured[26]. These components are assembled in a factory or on-site, with the steel frames erected first, followed by attaching Ferron panels using fasteners or adhesives. The structure is then finished with insulation, utilities and final coatings. This system, known for its lightweight, high strength and fast-track construction, offers excellent thermal insulation, soundproofing and sustainability benefits, making it ideal for modern projects.

3.1 Quality Parameters for LGSF -Ferron Material

Ensuring the quality of LGSF with Ferron material requires attention to various critical factors, from selecting the right materials to overseeing the entire construction process. These factors are essential to ensure the structure's safety, stability and durability, all of which depend on strict compliance with engineering and manufacturing standards. Key quality parameters to focus on include the following:

Dimensional accuracy guarantees correct fitting and alignment throughout construction, which has an immediate effect on overall performance and structural integrity. Furthermore, confirming the quality of LGSF Ferron materials requires strict adherence to industry certifications and regulations. Figure 3 indicates quality parameters LGSF-Ferron quality factors include material composition that complies with requirements. To guarantee the structural integrity and durability of LGSF constructions, sustainability in terms of recyclability and environmental impact, as well as fire resistance for safety, are essential factors.

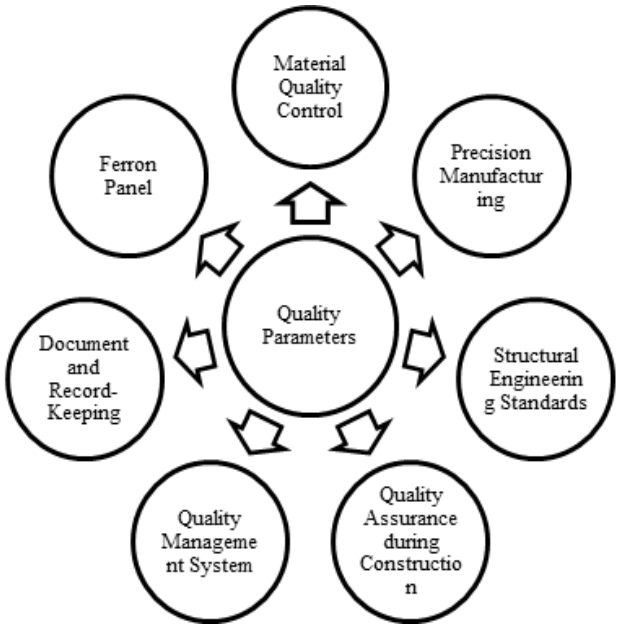


Figure 3. Quality parameters for LGSF-ferron material.

- **Material Quality Control** - Steel frame components play a major role in LGSF construction. It is important to ensure the standards of these resources. This involves buying steel from reliable vendors, inspecting delivered materials for quality and making sure all applicable standards are met (such as ASTM International standards for steel).
- **Precision Manufacturing** - For LGSF construction, accuracy in the production of steel components is crucial. Any departure from the prescribed dimensions may result in structural problems and endanger safety. To guarantee accuracy and consistency in the creation of components, quality management procedures should be in place during the manufacturing process.
- **Structural Engineering Standards** - For LGSF structures to be stable and safe, structural engineering standards must be followed in the letter. To make sure that the design satisfies safety criteria, engineers must abide by norms and standards unique to light gauge steel construction.
- **Quality Assurance During Construction** - Quality assurance procedures must be implemented throughout the building process. This entails routine checks to ensure that parts are assembled properly, connections are tight and craftsmanship meets standards. Any deviations or inadequacies should be fixed to avoid safety hazards.
- **Quality Management System (QMS)** - It is possible to monitor quality metrics, support continuous improvement initiatives and expedite processes by putting in place a strong QMS that is customised to the unique needs of LGSF construction. Activities related to quality assurance, planning, control and improvement should all be included in this system.

- **Document and Record-Keeping** - In LGSF construction, accurate record-keeping and documentation are crucial to quality and safety management. To guarantee accountability and traceability throughout the project lifetime, this entails keeping records of material certifications, inspection reports, construction drawings, modification orders and other pertinent documents.
- **Ferron Panel** - Ferron panel quality is ensured through a multi-step process. Raw materials are inspected, dimensions and assembly are monitored, curing conditions are controlled and finished panels undergo visual checks and may involve non-destructive testing for hidden flaws.

4.0 Factors Affecting LGSF -Ferron Construction in India

Figure 4 states the factors that influence the adoption and performance of LGSF construction with Ferron components in India. India's construction of LGSF is influenced by several elements, especially when the Ferron system is employed.

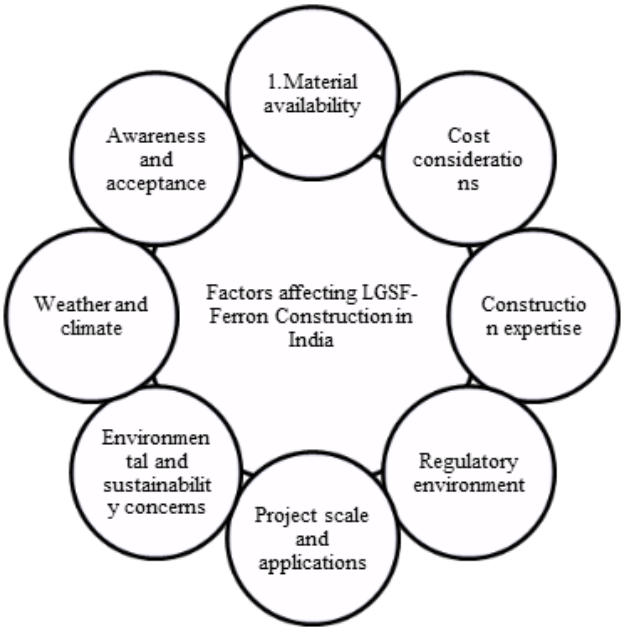


Figure 5. Factors affecting LGSF Ferron construction in India.

These factors include:

1. **Material Availability**
   - Steel Production: India has a robust steel manufacturing industry, but the availability of quality light gauge steel for LGSF projects may vary regionally, affecting costs and project timelines.
   - Ferron Components: Access to Ferron components, a crucial element in LGSF construction, depends on local suppliers and manufacturers. Any shortage or inconsistency in supply can impact project execution.

2. **Cost Considerations**
   - Initial Costs: While LGSF offers advantages in terms of speed and precision, the initial setup cost for machinery and specialised materials (including Ferron) can be high.
   - Lifecycle Costs: Although LGSF-Ferron structures can lead to long-term savings in maintenance, energy efficiency and construction time, the cost-effectiveness needs to be carefully evaluated against traditional methods, especially in smaller projects.

3. **Construction Expertise**
   - Skill Gaps: LGSF technology is relatively new in India compared to traditional methods. The construction workforce needs to be adequately trained in using Ferron components and LGSF techniques, creating challenges in project execution.
   - Design Expertise: Architects and engineers must be familiar with LGSF-Ferron design principles, including load-bearing considerations and integration with other materials.

4. **Regulatory Environment**
   - Building Codes: Indian building codes are evolving to accommodate newer technologies like LGSF. However, local regulations may lag, creating challenges in approvals and compliance for projects using Ferron components.
   - Seismic and Wind Standards: LGSF systems need to meet seismic and wind resistance standards, particularly in regions prone to earthquakes or

cyclones. Ferron components must be designed to meet these structural requirements.

5. **Project Scale and Application**
   - Residential vs. Commercial: LGSF with Ferron components is well-suited for low to mid-rise buildings, especially in residential and institutional projects. However, for larger commercial or industrial projects, the scalability and adaptability of the system may be tested.
   - Customisation: Ferron components need to be customised based on the specific structural needs of each project, which can add complexity to project planning.

6. **Environmental and Sustainability Concerns**
   - Sustainability: LGSF-Ferron construction is often promoted for its eco-friendly attributes, such as minimal waste and recyclability of steel. However, the environmental benefits must be assessed against the carbon footprint of steel production in India.
   - Energy Efficiency: LGSF-Ferron systems can enhance energy efficiency due to better insulation properties, contributing to India's push for green buildings.

7. **Technological Adoption**
   - Automation and Prefabrication: The use of prefabricated Ferron components in LGSF construction can significantly reduce construction time, but the adoption of prefabrication technology in India is still in the early stages.
   - BIM Integration: Building Information Modelling (BIM) plays a crucial role in optimising LGSF construction. The integration of Ferron components within BIM workflows can improve accuracy and project management but requires digital expertise.

8. **Weather and Climate**
   - Durability in Harsh Conditions: Ferron components and LGSF structures must be designed to withstand India's diverse climatic conditions, including high humidity, monsoons and extreme heat, which can affect material performance.
   - Corrosion Resistance: In coastal regions, corrosion of steel components can be a concern, requiring additional protective measures for Ferron materials.

9. **Awareness and Acceptance**
   - Market Awareness: The awareness and acceptance of LGSF construction and Ferron components among developers, contractors and clients are crucial for wider adoption. Misconceptions about steel frame construction, particularly regarding strength and durability, can slow down its acceptance.
   - Cultural Preferences: Traditional construction methods, such as brick and mortar, have cultural significance in India. Convincing stakeholders to shift to LGSF with Ferron components can be challenging.

5.0 Proposed Inspection Plan and Checklist

This checklist summarises a comprehensive inspection plan for a ferrocement panel installation project. It ensures quality control by assigning specific responsibilities for various activities. Key steps include worker health, equipment fitness and electrical safety inspections. The checklist also covers material handling, staging, testing of frames and panels, installation of various components like frames, exterior panels, service conduits, interior panels and final void filling. The designated personnel involved include Quality Control Point (QCP), Quality Hold Point (QHP), internal Witness (W) and consultant Reviewer (R). Table 2 presents the proposed inspection plan and checklist, detailing systematic procedures for ensuring quality and safety in LGSF-Ferron construction.

6.0 Proposed Checklist (During Construction Stage)

Before commencing ferrocement panel installation, this comprehensive checklist ensures a safe and efficient process. It emphasises crucial aspects like workplace safety, proper site preparation, meticulous panel and frame inspection, secure connections and support systems and

Table 2. Proposed inspection plan and checklist

Sr. No.	Description of Activity	QCP	QHP	Internal Check (W)	Consultant Check (R)	Remark
1	Workmen Health Inspection.					
2	Equipment Fitness Inspection.					
3	Electrical Safety.					
4	Unloading of LGS-frames and Ferro-panels from the trailer.					
5	Staging.					
6	Test of frame material before installation.					
7	Test of panel material before installation.					
8	Installation of LGS-frames.					
9	Installation of exterior panels.					
10	Installation of service conduits.					
11	Installation of interior Ferro-panels.					
12	Void packing with filler.					



Figure 5. Two-way panel fixation work execution on site.

achieving precise panel alignment and finishing. Table 3 outlines the proposed checklist for the construction stage, focusing on critical tasks to ensure quality, safety and compliance.

This procedure usually starts on-site with the panels being aligned to make sure they are plumb and level. The panels are fastened to the vertical and horizontal structure by workers using brackets or clips. For increased strength, screws or welds are frequently used. To guarantee a level basis and alignment with the structural framework, the process starts with site preparation. To ensure accuracy and safety, there are various essential processes involved in executing two-way panel fixation on-site. Figure 5 illustrates the execution process of two-way panel fixation on-site, showcasing the systematic alignment and installation of prefabricated panels.

Important safety parameters in LGSF – FERRON modular precast construction.

Table 3. Proposed checklist (during the construction stage)

Checklist			
Work: Ferrocement Panel Installation			
Project:		**Date:**	
Site In-Charge:		**Time:**	
Sr. No.	**Inspection Notes**	**Response**	
		Yes	**No**
1	All electrical equipment is tested and tagged.		
2	Pre-start checks are complete.		
3	Is the floor slab clear to allow safe operation of installation?		
4	Are any contributing hazards impacting safe panel installation?		
5	ST-Screw set out and packer locations are as per approved drawings?		
6	Frames and panel finish are correct and as per approved drawings?		
7	The panel is straight and free from twists, bulges, edge deterioration, etc.		
8	Do LGSF Frame numbers and location match approved drawings?		
9	The number of screw connections is as per the approved drawings.		
10	Panel Props are secure and all connections are tight to prevent dislodgement of the ST-Screw.		
11	Ferrocement panels are plumbed /aligned as per approved drawings?		
12	Is the filler material provided with a compact and smooth finish?		
Remark:			

- Material Selection: Use of high-quality, certified LGSF steel with appropriate corrosion resistance. Proper selection of Ferron mix design and materials for strength and durability.
- Design Safety Factor: Engineers compute and include a safety factor in the design of LGSF structures, much like they do with RCC construction. To guarantee that the structure can sustain a range of stresses, this factor takes into consideration uncertainties in material qualities, construction techniques and loading circumstances.
- LGSF Frame Installation: Qualified personnel for handling and installing LGSF frames. Proper anchoring of LGSF frames to the foundation to ensure stability. Verification of correct frame connections and load distribution.
- Ferron Panel Installation: Safe lifting and manoeuvring of heavy Ferron panels using appropriate equipment. Secure support systems

for panels during installation to prevent tipping or collapse. Following proper safety procedures for drilling, cutting and grouting activities related to Ferron panels.

- Connections and joints: Ensuring that connections and joints are designed to absorb and dissipate seismic energy without compromising structural integrity.
- Inspections: Following construction, quality control inspections ensure proper installation and adherence to safety standards. Additionally, periodic maintenance checks monitor LGSF frames and Ferron panels for any signs of damage or wear, guaranteeing long-term structural integrity.
- Worker Training: Workers should be equipped with the necessary skills through comprehensive safety training, covering proper material handling and safe installation procedures.

7. Comparisons Between RCC Construction and LGSF Ferron on Quality Parameters

LGSF-Ferron construction offers an intriguing alternative to traditional RCC. While RCC boasts superior strength

Table 4. Comparisons between RCC construction and LGSF Ferron on quality parameters

Sr no	Parameters	RCC Construction	LGSF Ferron Construction
1	Material Quality	Compliance with applicable norms.	It is important to adhere to manufacturing standards and specifications.
2	Structural Integrity	Requirements for structural design are important for ensuring structural integrity.	Strong connections, correct alignment, precise assembly and precision in manufacture are crucial.
3	Design Accuracy	satisfy safety and performance requirements, structural design, detailing and reinforcement placement must be precise.	Achieve the desired building performance, precise production of steel framing components, and accurate architectural and engineering drawings.
4	Construction Quality Control	It is crucial to implement quality control procedures during mixing, pouring, curing, and installing formwork.	Dimensional correctness, weld quality, and standard compliance are all dependent on quality control during the steel manufacturing process.
5	Fire Resistance and Safety	Concrete's ability to withstand fire is dependent on its thickness and composition.	Steel frame components' fire resistance can be increased by fire-resistant coatings and assemblies.
6	Durability and Maintenance	maintenance procedures are some of the elements that affect how long concrete structures last.	Steel framing's capacity to withstand corrosion is dependent on coatings, galvanization, and routine maintenance procedures that stop rust and degradation over time.
7	Environmental Impact	Environmental impacts of concrete production are considered, including resource depletion, energy usage, and greenhouse gas emissions.	Steel's capacity for recycling, the energy used in the production of steel, and the possibility of reducing building waste through prefabrication are all considered.

Table 5. Comparative study of various types of construction methods

Sr. No.	Parameter	Conventional Construction	MIVAN Construction	Precast Construction	Prefabricated Construction	LGSF Panel Construction
1	Construction Speed	Slow (time-consuming due to manual labour and site activities)	Fast (aluminium formwork system reduces cycle time)	Fast (factory-produced units assembled on-site)	Fast (components are pre-made and assembled on-site)	Very Fast (lightweight, factory-made panels assembled quickly)
2	Labor Requirement	High (skilled and unskilled labour needed on-site)	Moderate (skilled labour for formwork, less unskilled labour)	Low (most work done off-site in a controlled environment)	Low (off-site fabrication reduces on-site labour)	Very Low (majority of construction done off-site)
3	Quality Control	Variable (on-site conditions affect quality)	High (precision formwork ensures consistency)	Very High (controlled factory environment ensures quality)	Very High (manufactured in a factory with strict controls)	Extremely High (factory-fabricated under strict controls)
4	Cost	Moderate (depends on labour and material fluctuations)	Moderate to High (formwork is expensive but reusable)	Moderate to High (factory setup and transport costs)	Moderate (cost of transportation and specialized assembly)	Moderate (initial material cost higher, but lower labour costs)
5	Waste Generation	High (waste from material handling and cutting on-site)	Low (precise formwork reduces material wastage)	Low (waste is minimized in factory production)	Low (most production is done off-site, reducing on-site waste)	Very Low (factory-controlled production limits waste)
6	Structural Strength	High (depends on the material and design used)	Very High (concrete structures are durable and strong)	Very High (precast concrete is robust and durable)	High (depends on the material used; generally sturdy)	High (lightweight but strong, especially for non-heavy loads)
7	Sustainability	Low (high energy use, large carbon footprint)	Moderate (less material waste, but concrete has high emissions)	Moderate (concrete production has high emissions, but efficient usage reduces impact)	High (reduced energy and materials used during construction)	Very High (recyclable materials, reduced energy use, lower carbon footprint)
8	Foundation Requirements	Standard foundations (depends on building height and soil type)	Standard foundations	Requires strong foundation (due to weight of precast panels)	Requires adaptable foundations depending on site conditions	Light foundation due to lightweight panels

9	Flexibility in Design	High (customizable on-site adjustments possible)	Low (standardized formwork limits flexibility)	Moderate (standardized panels limit design freedom)	High (prefabrication allows for modular flexibility)	High (flexible design options, especially for modular builds)
10	Durability	High (depends on materials and maintenance)	Very High (concrete structures are long-lasting)	Very High (precast concrete is highly durable)	High (durability varies with material choice)	High (steel structures are corrosion-resistant and durable)
11	Seismic Performance	Moderate to High (depends on design and materials)	High (monolithic concrete structures are earthquake-resistant)	High (precast units can be designed for seismic resistance)	High (lightweight and modular structures perform well in seismic zones)	Very High (lightweight yet strong, ideal for seismic zones)
12	Time to Erect	Long (on-site activities take more time)	Short (standard formwork accelerates construction)	Short (prefabricated units reduce on-site time)	Short (quick on-site assembly)	Very Short (quick installation of panels)
13	Material Transportation Cost	Moderate (on-site transportation of materials required)	Low (formwork reduces the need for continuous material supply)	High (heavy precast panels require special transport)	Moderate (requires transport of prefab components)	Low (lightweight materials easy to transport)
14	Weather Dependency	High (construction progress dependent on weather conditions)	Moderate (formwork protects some areas from weather impact)	Low (most work is done in factories, reducing weather delays)	Low (off-site fabrication reduces weather dependency)	Very Low (off-site production; quick on-site assembly minimizes weather impact)

and durability, it suffers from slower construction times, higher dependence on skilled labour and greater weather impact. LGSF-Ferron construction counters these drawbacks with faster assembly, consistent quality due to prefabrication and potentially lower environmental impact. However, long-term performance data and fire resistance require more attention. Selecting the optimal method hinges on project specifics like structural needs, speed requirements, budget constraints, sustainability goals and skilled labour availability. Careful evaluation of these factors alongside quality considerations is crucial for choosing the most suitable building approach.

Based on their respective material properties and building techniques, LGSF and RCC systems each have unique characteristics. Table 4 shows the comparisons between RCC and LGSF Ferron construction, RCC is well-known for its compressive strength, weather and fire resistance and longevity, which makes it perfect for heavy-duty constructions. But its heavier weight and longer curing times can make building take longer and complicate logistics. By comparison, LGSF requires less foundation and can be assembled more quickly because of its lightweight design.

The examination of different construction techniques, including traditional masonry, RCC, LGSF, modular construction and Aluminium Formwork System (MIVAN) construction, Table 5 demonstrates the unique benefits of each method. LGSF panel construction

stands out due to its fast construction speed, low labour requirements and high-quality control. The lightweight nature of the panels makes them easy to transport and quick to assemble, reducing on-site time and costs. It also offers excellent sustainability since the materials used are recyclable and the energy consumption is lower compared to traditional methods like precast or conventional concrete. Additionally, it performs exceptionally well in seismic zones due to its lightweight yet strong structure, making it a robust solution in earthquake-prone areas. Though initial material costs can be slightly higher, the overall savings in labour, time and waste make LGSF panel construction the most efficient and cost-effective solution, particularly for fast-track and environmentally sensitive projects.

8.0 Future Scope

Future research on LGSF-Ferron modular construction should focus on long-term performance assessments, including durability, lifecycle costs and maintenance compared to RCC structures. Investigating fire resistance, environmental impact and recyclability is essential for establishing safety standards and promoting sustainability. The development of regulatory frameworks, along with training and certification programs, will ensure quality and safety. Integrating smart technologies like IoT sensors for real-time monitoring can enhance maintenance and safety while expanding studies to commercial and institutional buildings can demonstrate the versatility of LGSF-Ferron technology. Addressing these areas will aid in the broader adoption of this construction method, particularly in regions with housing challenges.

9.0 Conclusion

This study highlights the transformative potential of LGSF construction integrated with the Ferron panel to tackle India's affordable housing crisis. As traditional building methods become increasingly labour-intensive and costly, LGSF-Ferron emerges as a lightweight, durable and cost-effective alternative. Key advantages include reduced construction time, enhanced structural integrity, and significant cost savings. However, successful implementation requires stringent quality control and safety management. The research identifies challenges to widespread adoption, such as material availability, initial investment costs and the need for specialised construction expertise. To facilitate the integration of LGSF-Ferron technology, the study emphasises robust quality assurance throughout the construction lifecycle. This involves meticulous material selection, precise manufacturing, adherence to structural engineering standards, and thorough on-site inspections. Additionally, the integration of pre-engineered components and compliance with regulatory standards are vital for project success. The study advocates for increased awareness and training within the construction workforce to address skill gaps related to LGSF technology. By focusing on these quality and safety issues, LGSF-Ferron can contribute significantly to sustainable building practices in India. This innovative construction method holds great promise not only for alleviating the housing crisis but also for promoting environmentally friendly practices within the construction sector. The study calls for further exploration into technological advancements and regulatory frameworks to support the growth of LGSF-Ferron in India, paving the way for efficient, resilient, and cost-effective building solutions.

10.0 References

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