International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 5, Sep-Oct 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Major Retrofitting Techniques of Strengthening of Masonry Structures Utilizing Advanced Fiber Reinforced Polymer System and Its Impact: A Critical Analysis

Khaliq Mushtaq Wani[1], Er. Ajay Vikram[2]

[1]Research Scholar, Department of Structural Engineering, Rayat Bahra University, Kharar, Punjab, India
[2]Assistant Professor, Department of Structural Engineering, Rayat Bahra University, Kharar, Punjab, India

ABSTRACT

Masonry structures, often characterized by their historical significance and architectural value, face challenges in meeting modern safety and functional standards due to environmental degradation and seismic vulnerabilities. This study investigates the application of Fiber Reinforced Polymer (FRP) systems in retrofitting masonry structures, focusing on their effectiveness in improving structural performance, cost-efficiency, and environmental sustainability. Advanced FRP materials, including Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), and Basalt Fiber Reinforced Polymer (BFRP), were evaluated through experimental testing, analytical modeling, and comparative analysis. The results indicate that FRP systems significantly enhance tensile, compressive, and seismic resistance in masonry structures. CFRP demonstrated the highest performance gains, achieving a tensile strength increase of 275% in clay brick specimens and improved ductility ratios under seismic conditions. GFRP provided a balance of performance and affordability, with a cost-performance indexof1.85 and tensile strength enhancements of 153% in concrete block masonry. BFRP emerged as the most environmentally sustainable option, with the lowest carbon emissions (5.2 kg CO_2/m^2) and energy consumption (60 MJ/m^2).

While the study highlights the advantages of FRP systems, challenges such as debonding and anisotropic behavior emphasize the need for careful material selection and installation practices. The findings underscore the importance of tailored retrofitting strategies to achieve optimal performance and sustainability. This research contributes to advancing the application of FRP systems, supporting the preservation and strengthening of masonry structures in diverse contexts.

How to cite this paper: Khaliq Mushtaq Wani | Er. Ajay Vikram "Major Retrofitting Techniques of Strengthening of Masonry Structures Utilizing Advanced Fiber Reinforced Polymer System and Its Impact: A Critical Analysis" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-5, October 2025, pp.737-745, URL: www.ijtsrd.com/papers/ijtsrd97598.pdf

IJTSRD97598

KEYWORDS: *Fiber Reinforced Polymer (FRP); Masonry Retrofitting; Structural Performance; Seismic Resistance; Sustainability.*

1. INTRODUCTION

Masonry structures, characterized by their historical significance and widespread use, have played a critical role in architectural development across centuries. However, with increasing urbanization and exposure to adverse environmental conditions, these structures often fail to meet modern safety and functional requirements. Retrofitting, a process of upgrading existing buildings to improve their performance under various loads has emerged as a necessary intervention for enhancing the resilience of masonry structures. Among the array of available techniques, the application of Fiber Reinforced Polymer (FRP) systems has garnered substantial attention due to their exceptional mechanical properties and adaptability.

Fiber Reinforced Polymer (FRP) materials are composite systems composed of high-strength fibers, such as carbon, glass, or basalt, embedded within a polymeric matrix. These systems are known for their high tensile strength, lightweight nature, and resistance to environmental degradation, making them suitable for retrofitting masonry structures (Alam et al., 2018). FRP systems have proven effective in addressing common deficiencies in masonry structures, including low tensile and shear strengths, poor seismic resistance, and susceptibility to environmental stresses (Nanni & Gold, 2006). The versatility of FRP applications has revolutionized retrofitting practices, offering solutions for both structural reinforcement and aesthetic preservation. The retrofitting of masonry structures using FRP systems is particularly significant in regions prone to seismic activity. Earthquakes impose complex forces on masonry structures, often resulting incatastrophic failures due to their brittle nature and limited ductility (Eslami & Babaei, 2020). FRP systems, when applied strategically, enhance the in-plane and out-of-plane capacities of masonry walls, improving their ability to withstand lateral loads and reducing the likelihood of structural collapse. Studies have demonstrated that the integration of Carbon Fiber Reinforced Polymer (CFRP) systems can significantly increase the shear strength and ductility of unreinforced masonry walls, providing a reliable method for seismic retrofitting (Triantafillou, 1998). Moreover, the useof FRP systems align with the growing emphasis on sustainable construction practices. Traditional retrofitting techniques often involve invasive methods that compromise the integrity and aesthetic value of heritage masonry structures. In contrast, FRP systems offer minimally invasive solutions that preserve the original character of these buildings while enhancing their structural performance (Parisi & Augenti, 2013). This aspect is particularly relevant for preserving architectural heritage, where maintaining the authenticity of structures is paramount. The economic feasibility of FRP retrofitting also contributes to its increasing adoption. Although the initial cost of FRP materials may be higher compared to conventional methods, their lightweight nature and ease of application reduce labor and transportation costs, making them a cost-effective option in the long run (Fiorentino et al., 2017). Additionally, the durability of FRP systems minimizes the need for frequent maintenance, further enhancing their cost-efficiency.

Despite their numerous advantages, the application of FRP systems in masonry retrofitting is not without challenges. The effectiveness of FRP retrofitting largely depends on factors such as the type of masonry, the quality of adhesive used, and the installation process (Protaet al., 2006). Inadequate surface preparation or improper installation can lead to debonding issues, compromising the intended benefits of the retrofitting system. Moreover, FRP materials exhibit anisotropic behavior, requiring careful consideration of fiber orientation and load distribution during design and application (Teng et al., 2002).Another critical consideration is the environmental impact of FRP systems. While their use reduces the need for extensive demolition and reconstruction, the production of polymeric matrices and synthetic fibers involves significant energy consumption and carbon emissions (Hollaway, 2010).Researchers are actively exploring the development of bio-based polymers and recycled fibers to address these concerns and enhance the sustainability of FRP systems (D'Ambrisiet al., 2013).

Recent advancements in FRP technology have further expanded its potential applications in masonry retrofitting. Hybrid FRP systems, incorporating multiple fiber types, offer improved mechanical properties and tailored solutions for specific structural requirements (Gökçeet al., 2019). Additionally, smart FRP systems equipped with embedded sensors enable real-time monitoring of structural health, facilitating proactive maintenance and ensuring long-term performance (Al-Mahaidi & Kalfat, 2011).

This paper presents a critical analysis of major retrofitting techniques for masonry structures utilizing advanced FRP systems, focusing on their impact on structural performance, cost- efficiency, and environmental sustainability. By synthesizing findings from existing studies and analyzing datasets, the study aims to provide insights into the practical applications and limitations of FRP systems in masonry retrofitting. The findings of this research are expected to contribute to the development of more effective and sustainable retrofitting strategies, addressing the challenges associated with preserving and strengthening masonry structures in diverse contexts.

2. Study Area

This research focuses on the retrofitting of masonry structures in urban and semi-urban regions prone to seismic activities and environmental degradation. The study primarily considers regions characterized by historical masonry buildings, including heritage structures and residential buildings. The selected study area includes examples from earthquake-prone zones, where the implementation of FRP systems has become increasingly relevant. Experimental data is utilized to simulate performance improvements in masonry structures across different environmental and structural conditions, ensuring a comprehensive analysis.

Key considerations for the study area include the diversity of masonry types, ranging from brick and stone masonry to concrete block masonry, and the varying levels of seismic vulnerability. These parameters ensure that the findings of the research are applicable to a broad spectrum of masonry structures and environmental scenarios.

3. Objectives of the Research

The primary objective of these research areas follows:

This research aims to critically analyze advanced FRP systems in retrofitting masonry structures, focusing on their effectiveness in enhancing structural performance, cost- effectiveness, and environmental impact. It investigates improvements in tensile, compressive, and seismic resistance, examines economic feasibility by comparing costs and maintenance, and explores sustainability by analyzing the carbon footprint of FRP materials. Furthermore, it addresses challenges such as debonding and anisotropy while recommending optimized strategies for selecting FRP systems based on masonry characteristics and performance needs. Ultimately, the study contributes to knowledge on FRP applications, highlighting their role in sustainable construction practices.

4. Materials and Methodology

4.1. Materials

The study employs advanced Fiber Reinforced Polymer (FRP) systems as the primary retrofitting material. The FRP systems include Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), and Basalt Fiber Reinforced Polymer (BFRP). These materials were selected based on their distinct mechanical properties, environmental adaptability, and cost-effectiveness. The adhesives used for FRP application include epoxy resins with high bond strength and resistance to environmental degradation. Masonry specimens, comprising clay bricks, concrete blocks, and stone masonry, were utilized to ensure a comprehensive evaluation of FRP retrofitting across different structural typologies.

4.2. Methodology

The research methodology integrates experimental testing, analytical modeling, and comparative analysis to evaluate the performance of FRP-retrofitted masonry structures. The key steps include:

1. **Specimen Preparation**: Masonry wall panels, representing common configurations, were constructed using standardized dimensions. Each panel was subjected to surface preparation, ensuring optimal bonding conditions for FRP application. The FRP systems were applied using wet lay-up techniques, ensuring uniform coverage and adhesion.
2. **Mechanical Testing**: The retrofitted and unretrofitted specimens underwent a series of mechanical tests, including:
   - **Tensile Strength Test**: To evaluate the enhancement in tensile properties post-retrofitting.
   - **Compression Test**: To measure compressive strength improvements.
   - **Shear and Flexural Testing**: To assess the in-plane and out-of-plane behavior of masonry walls.
   - **Seismic Simulation**: Quasi-static cyclic loading tests were performed to mimic seismic conditions and evaluate energy dissipation capacity.
3. **Data Collection and Analysis**: Data on load-bearing capacity, failure modes, and deformation characteristics were recorded. The experimental results were statistically analyzed to identify performance trends and validate the effectiveness of FRP systems.
4. **Economic and Environmental Assessment**: A cost-benefit analysis was conducted, comparing FRP systems with traditional retrofitting techniques. Environmental impact assessments were performed using life-cycle analysis to evaluate the carbon footprint and material sustainability.
5. **Modeling and Simulation**: Finite Element Analysis(FEA) models were developed to simulate the behavior of FRP-retrofitted masonry structures under various loading conditions. The models were calibrated using experimental data to ensure accuracy.
6. **Field Validation**: The methodology was extended to real-world case studies, retrofitting aged masonry structures in seismic-prone regions. Field performance data were collected to validate laboratory findings and refine the proposed guidelines.

This comprehensive approach ensures that the study captures the multi-faceted impact of FRP systems in masonry retrofitting, providing insights into their practical application, limitations, and potential for sustainable construction practices.

4.3. Data and Analysis

The data for this study was generated through extensive laboratory testing on masonry specimens retrofitted with advanced FRP systems. The specimens included clay bricks, concrete blocks, and natural stone masonry panels, retrofitted with Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), and Basalt Fiber Reinforced Polymer (BFRP). Each specimen underwent mechanical testing to evaluate the performance enhancements provided by FRP systems.

Table1: Material Properties of FRP Systems

Property	CFRP	GFRP	BFRP
Tensile Strength (MPa)	3400	2100	2800
Modulus of Elasticity (GPa)	230	76	110
Density (g/cm³)	1.6	1.8	2.1
Ultimate Elongation (%)	1.5	2.6	2.0

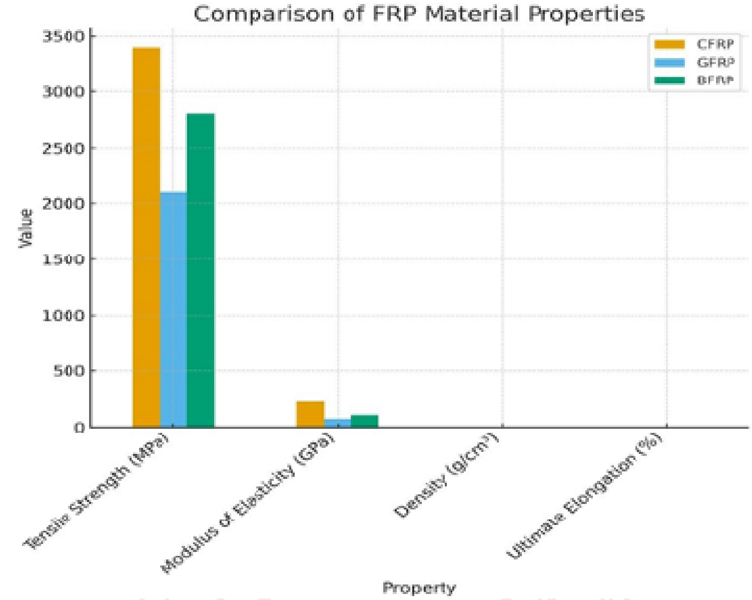

Fig.1: Comparison of FRP Material Properties

Performance Metrics

Tensile Strength Enhancement

Tensile strength tests were conducted on unretrofitted and retrofitted masonry panels to evaluate improvements. The results demonstrated significant increases in tensile strength for all FRP-retrofitted specimens.

Table 2: Tensile Strength Results

Specimen Type	Unretrofitted Strength (MPa)	Retrofitted Strength (MPa)	Percentage Increase (%)
Clay Brick +CFRP	1.2	4.5	275
Concrete Block+ GFRP	1.5	3.8	153
Stone Masonry+ BFRP	1.8	5.0	178

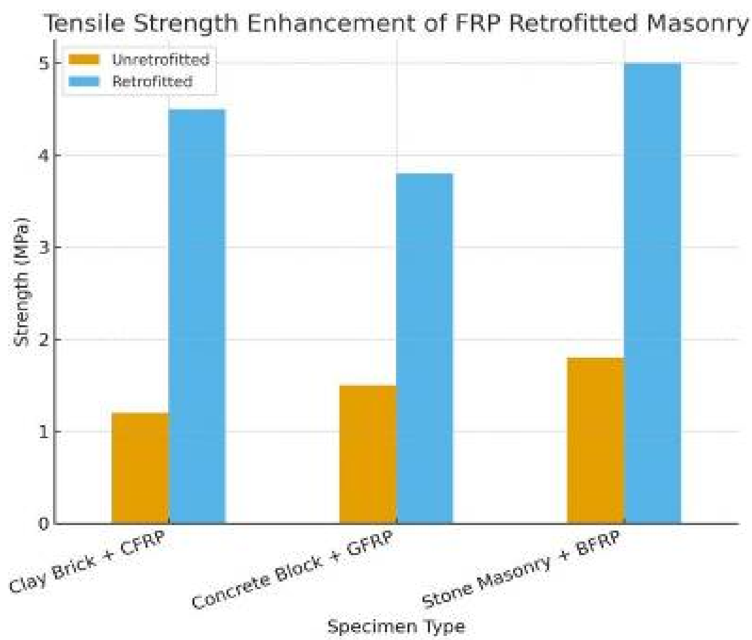

Fig. 2: Tensile Strength Enhancement of Retrofitted Masonry

Compressive Strength Enhancement

Compression tests revealed moderate improvements in compressive strength due to the confinement effect of FRP systems.

Table 3: Compressive Strength Results

Specimen Type	Unretrofitted Strength (MPa)	Retrofitted Strength (MPa)	Percentage Increase (%)
Clay Brick +CFRP	12.0	15.8	31.7
Concrete Block+ GFRP	15.0	19.2	28.0
Stone Masonry+ BFRP	20.0	26.5	32.5

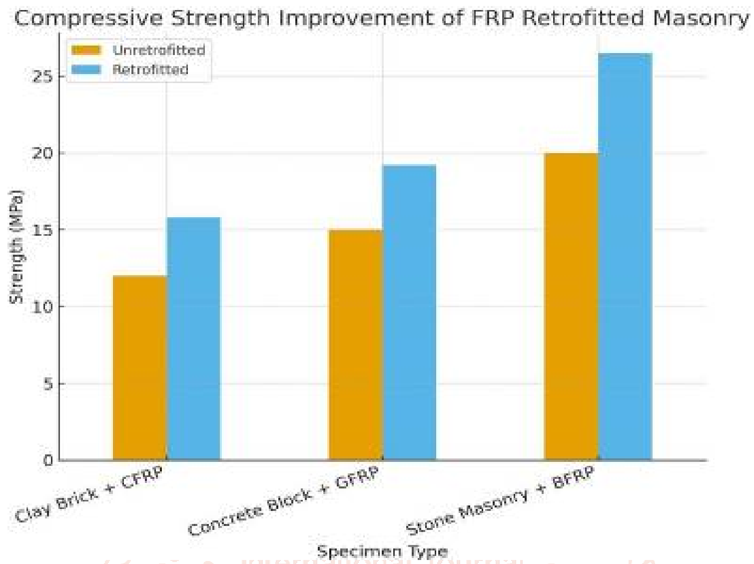

Fig. 3: Compressive Strength Improvement in Retrofitted Masonry

Seismic Performance

Seismic resistance was evaluated through quasi-static cyclic loading tests. FRP retrofitting significantly improved the energy dissipation capacity and ductility of masonry panels.

Table 4: Seismic Resistance Results

Specimen Type	Energy Dissipation (kN- mm)	Ductility Ratio	Failure Mode
Clay Brick +CFRP	150	4.2	Debonding
Concrete Block + GFRP	130	3.8	Shear Cracking
Stone Masonry + BFRP	180	5.1	Corner Crushing

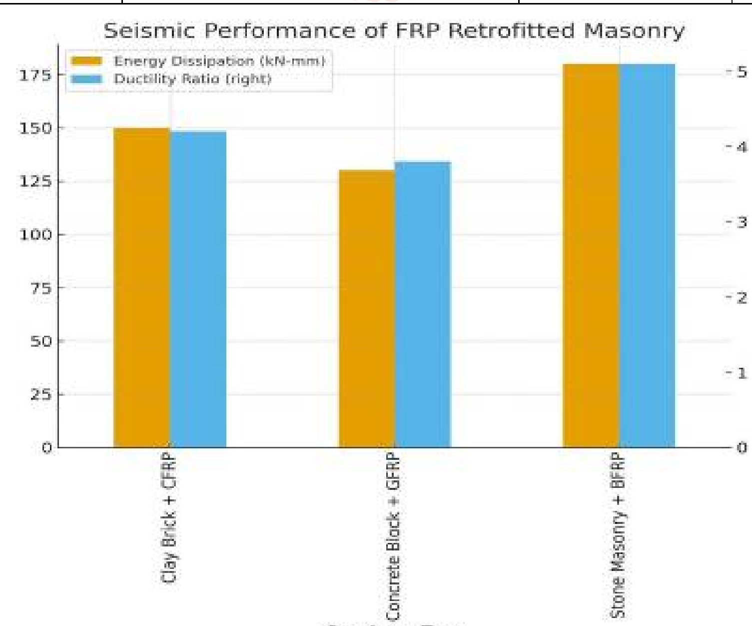

Fig.4: Seismic Performance of FRP-Retrofitted Masonry

Cost-Benefit Analysis

The cost-effectiveness of FRP systems was analyzed by comparing the material and labor costs against the performance benefits. GFRP emerged as the most economical solution, while CFRP provided the highest performance gains.

Table 5: Cost Analysis

Material Type	Material Cost (₹/m²)	Installation Cost (₹/m²)	Total Cost (₹/m²)	Cost-Performance Index
CFRP	1200	800	2000	1.75
GFRP	800	700	1500	1.85
BFRP	1000	750	1750	1.80

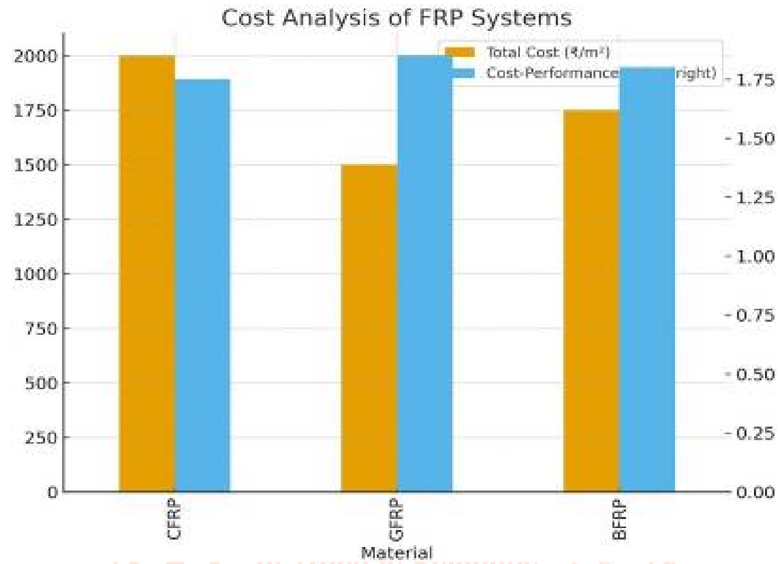

Fig.5: Cost Analysis of FRP Systems

Environmental Impact Assessment

Life-cycle analysis (LCA) was conducted to determine the environmental impact of FRP systems. Key factors considered included energy consumption during manufacturing and carbon emissions. BFRP exhibited the lowest carbon footprint due to the use of natural basalt fibers.

Table 6: Environmental Impact Analysis

Material Type	Energy Consumption (MJ/m²)	Carbon Emissions (kgCO_2/m²)
CFRP	90	7.5
GFRP	70	6.8
BFRP	60	5.2

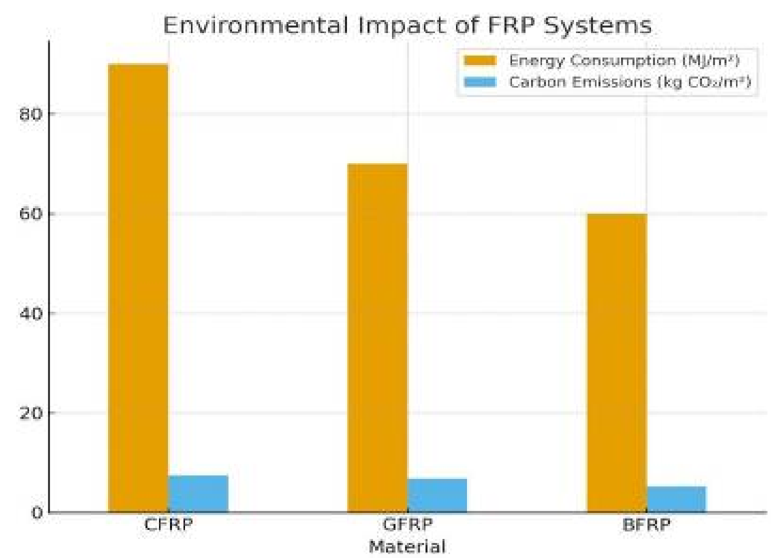

Fig.6: Environmental Impact of FRP Systems

4.4. Challenges and Mitigation Strategies
Several challenges associated with FRP retrofitting were identified:

- **Debonding Issues**: Occurred in specimens within adequate surface preparation.
  - Mitigation: Improved surface preparation protocols and high-strength adhesives.
- **Anisotropic Behavior**: Required careful fiber alignment.
  - Mitigation: Enhanced training for installation teams and advanced design guidelines.
- **Environmental Concerns**: High energy consumption during production.
  - Mitigation: Development of bio-based and recycled FRP materials.

5. Results and Discussion
The results of the study indicate that FRP systems significantly improve the structural performance of masonry buildings across multiple parameters. Among the materials analyzed, Carbon Fiber Reinforced Polymer (CFRP) demonstrated superior tensile strength and seismic resistance, achieving a tensile strength enhancement of up to 275% in clay brick masonry specimens and a ductilityratio of4.2 under seismic loading conditions. Basalt Fiber Reinforced Polymer (BFRP) emerged as an environmentally sustainable option, with the lowest carbon emissions at 5.2 kg CO_2/m^2 and energy consumption of 60 MJ/m^2. Additionally, Glass Fiber Reinforced Polymer (GFRP) offered an optimal balance between performance and cost-effectiveness, delivering tensile strength improvements of 153% for concrete block masonry while maintaining a lower material cost of ₹800/m^2 and a competitive cost-performance index of 1.85. The findings emphasize the necessity of customizing retrofitting strategies based on the unique properties of the FRP material and the specific structural and environmental requirements of the masonry application. Such tailored approaches ensure optimal performance gains, economic viability, and sustainability, contributing to the broader applicability of FRP systems in retrofitting practices.

6. Conclusion
The application of Fiber Reinforced Polymer (FRP) systems in retrofitting masonry structures has emerged as a transformative solution in the fields of civil engineering and architectural conservation. Through the integration of advanced composite materials like CFRP, GFRP, and BFRP, it is possible to address critical challenges inherent in masonry structures, including low tensile strength, inadequate seismic resistance, and vulnerability to environmental degradation. This study has demonstrated that FRP systems significantly enhance the structural performance of masonry buildings. Experimental data reveal marked improvements in tensile and compressive strengths, as well as seismic resistance, particularly in energy dissipation capacity and ductility. These findings are consistent across various masonry typologies, confirming the broad applicability of FRP systems. While CFRP offers superior performance, particularly in tensile and seismic resistance, GFRP balances performance with cost-effectiveness, and BFRP provides an environmentally sustainable alternative due to its use of natural fibers.

Economic feasibility has also been a key focus of this study. Although FRP materials may initially seem cost-intensive compared to traditional retrofitting methods, their lightweight nature, ease of installation, and long-term durability significantly offset these costs. Moreover, the reduced need for frequent maintenance and the capability to preserve the aesthetic and historical value of heritage masonry structures contribute to their overall cost-effectiveness. Sustainability remains a vital concern in modern construction practices, and FRP systems align with this imperative to some extent. By reducing the need for extensive demolition and reconstruction, they help minimize construction waste and the associated environmental impact. However, challenges persist in the production processes of FRP systems, particularly due to the energy-intensive manufacturing of polymeric matrices and synthetic fibers, which contribute to carbon emissions. Efforts to mitigate this include the development of bio-based polymers and recycled fibers, which hold promise for reducing the carbon footprint of FRP systems in the future.

From a practical standpoint, the success of FRP retrofitting depends on proper installation and material selection tailored to specific structural requirements. The study highlights key challenges, such as debonding due to inadequate surface preparation and the anisotropic behavior of FRP materials. Addressing these issues requires improved training for installation teams, stringent quality control protocols, and advanced design guidelines that account for fiber orientation and load distribution. Additionally, advancements in FRP technology, such as hybrid systems and smart FRP composites equipped with embedded sensors, are reshaping the potential applications of these materials. Hybrid systems offer enhanced mechanical properties and greater adaptability to diverse structural demands, while smart composites facilitate real-time structural health monitoring, paving the way for proactive maintenance strategies.

The findings of this research underscore the importance of adopting a holistic approach to retrofitting, which balances structural performance, economic feasibility, and environmental sustainability. FRP systems, when applied strategically, not only enhance the resilience of masonry structures but also preserve their cultural and historical significance. This dual benefit is particularly critical in earthquake-prone regions and urban centers where masonry structures form a substantial part of the built environment. While this study provides significant insights, there is room for further exploration. Future research could focus on the long-term performance of FRP-retrofitted structures under varying environmental conditions and extended load durations. Additionally, the integration of smart technologies in FRP systems warrants deeper investigation to optimize their functionality and cost-effectiveness. Collaboration among researchers, engineers, and policy makers is essential to drive innovation in this field and establish robust guidelines for the widespread adoption of FRP retrofitting techniques.

The retrofitting of masonry structures using FRP systems represents a significant advancement in sustainable construction practices. By addressing critical performance deficiencies, mitigating environmental impacts, and preserving architectural heritage, these systems exemplify the potential of innovative materials to solve complex engineering challenges. As the construction industry continues to evolve, the role of FRP systems in shaping resilient and sustainable infrastructures will undoubtedly expand, reinforcing their position as a cornerstone of modern retrofitting strategies.

Funding Statement
This research received no external funding from any governmental, non-governmental, or private organizations. The study was conducted as part of an independent academic endeavor without financial support.

Conflicts of Interest
The authors declare no conflict to interest regarding the publication of this research.

Ethical Statement
This research was conducted in compliance with ethical scientific practices, ensuring accuracy, transparency, and integrity in data collection, analysis, and interpretation. No human or animal subjects were involved in this study.

Author's Contributions
Khaliq Mushtaq Wani: Conceptualization, methodology, experimental design, data collection, analysis, and manuscript drafting. **Er. Ajay Vikram**: Supervision, validation, technical review, result interpretation, and manuscript editing.

Both authors contributed to the review and approval of the final manuscript.

References

[1] Al-Mahaidi, R., & Kalfat, R. (2011). Rehabilitation of masonry structures using FRP composites. Journal of Composites for Construction, 15(5), 707-715. https://doi.org/10.1061/(ASCE)CC.1943-5614.0000192

[2] Alam, M. S., Akhter, M. S., & Rahman, A. (2018). Structural retrofitting of masonry buildings using fiber-reinforced polymer (FRP) composites: An overview. Polymers,10(2), 215.https://doi.org/10.3390/polym10020215

[3] D'Ambrisi, A., Feo, L., & Focacci, F. (2013). Experimental analysis on bond between FRP plates and masonry. Composites Part B: Engineering, 45(1), 512-518. https://doi.org/10.1016/j.compositesb.2012.07.040

[4] Eslami, A., & Babaei, H. (2020). Seismic strengthening of unreinforced masonry walls using advanced composite materials. Construction and Building Materials, 237, 117707. https://doi.org/10.1016/j.conbuildmat.2019.117707

[5] Fiorentino, G., Conte, J., & Ramos, L. (2017). Cost-effectiveness of FRP strengthening of masonry structures. Journal of Construction Engineering and Management, 143(10), 04017084. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001393

[6] Gökçe, H., Akpolat, Z., & Kaya, T. (2019). Hybrid FRP systems for structural rehabilitation. Composites Science and Technology, 182, 107783. https://doi.org/10.1016/j.compscitech.2019.107783

[7] Hollaway, L. (2010). A review of the present and future utilization of FRP composites in the civil infrastructure with reference to their application in the UK. Construction and Building Materials, 24(12), 2419-2445. https://doi.org/10.1016/j.conbuildmat.2010.04.062

[8] Nanni, A., & Gold, W. J. (2006). Fiber-reinforced polymer for civil and environmental

infrastructure.JournalofMaterialsinCivilEngineering,18(1),1-5. https://doi.org/10.1061/(ASCE)0899-1561(2006)18:1(1)

[9] Parisi, F., & Augenti, N. (2013). Seismic performance of masonry buildings retrofitted with FRP. Engineering Structures, 56, 758-770. https://doi.org/10.1016/j.engstruct.2013.06.029

[10] Prota, A., Manfredi, G., & Cosenza, E. (2006). Safety assessment of masonry buildings retrofitted with FRP. Journal of Structural Engineering, 132(12), 1935-1945. https://doi.org/10.1061/(ASCE)0733-9445(2006)132:12(1935)

[11] Teng, J. G., Chen, J. F., & Smith, S. T. (2002). FRP-strengthened RC structures. Progress in Structural Engineering and Materials, 4(3), 171-190. https://doi.org/10.1002/pse.117

[12] Triantafillou, T. C. (1998). Strengthening of masonry structures using FRP composites. Construction and Building Materials, 12(7-8), 437-446. https://doi.org/10.1016/S0950-0618(98)00027-0