Evaluation of Carbon Fiber Reinforced Polymer Usage in Apartment Building Strengthening to Enhance Stakeholder Preference

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ABSTRACT : *Apartment building strengthening requires appropriate material selection to ensure structural safety and long-term building sustainability. Carbon Fiber Reinforced Polymer (CFRP) has potential as a strengthening material due to its functional advantages and ease of application. This study aims to analyze the factors influencing Stakeholders' preferences for using CFRP in apartment building strengthening projects in the Jabodetabek region. Data were collected through a Likert-scale questionnaire distributed to 30 respondents and analyzed using descriptive analysis, validity and reliability tests, and Geometric Mean calculations, followed by expert validation. The results indicate that functional capability is perceived as the most dominant factor with a GM value of 4.486; however, only the environmental friendliness variable satisfies the validity (calculated r 0.472) and reliability (Cronbach's Alpha 0.6) criteria and can therefore be used as the primary basis for hypothesis testing. Time and cost factors contribute as supporting factors rather than primary determinants. Furthermore, the analysis was extended to the development of strategic recommendations, which were assessed by experts as feasible but still requiring further reinforcement through additional research to ensure consistent and measurable implementation of CFRP.*

KEYWORDS - *Apartment Building Maintenance, Carbon Fiber Reinforced Polymer, Geometric Mean Analysis, Material Selection, Statistical Analysis.*

1. INTRODUCTION

Apartment building maintenance is a critical aspect in ensuring occupant safety and comfort, as well as in preserving the long-term value of property assets. Proper maintenance not only sustains the functional performance of buildings in accordance with their intended use but also contributes significantly to the protection and enhancement of asset value over time. According to the Regulation of the Minister of Public Works of the Republic of Indonesia No. 24 of 2008 on Guidelines for Building Maintenance and Repair, building maintenance is defined as activities aimed at repairing and/or replacing building components, materials, and supporting facilities to ensure that the building remains fit for use (curative maintenance).

In the management of apartment buildings, safety and security constitute primary concerns. One of the most significant risks is fire hazards, which are commonly caused by electrical short circuits or the use of unsafe equipment. Consequently, an effective and comprehensive maintenance system is required to mitigate potential risks that may endanger occupants and building assets.

In practice, apartment building maintenance must also prioritize occupational health and safety for maintenance workers. Stakeholders are required to minimize high-risk maintenance activities and establish effective coordination with other key organizational functions. Poor maintenance management—characterized by delayed response actions, inefficient decision-making processes, and limitations in staff competence—can negatively affect maintenance performance. Furthermore, maintenance management has a substantial impact on the operational costs incurred throughout the building's service life.

The use of conventional materials such as steel and iron in construction and maintenance also presents several challenges. One major issue is corrosion resulting from exposure to varying environmental conditions, which can degrade structural performance and compromise safety. From an economic perspective, although steel and iron are relatively accessible materials, their prices tend to fluctuate and may become costly depending on market supply and demand.

Based on the background, the selection of appropriate alternative materials, such as Carbon Fiber Reinforced Polymer (CFRP), represents a strategic solution for apartment building maintenance. The application of CFRP has the potential to enhance structural safety, improve occupant health and comfort, and increase occupational safety during maintenance activities, thereby supporting more effective and sustainable apartment building management.

Based on the literature review conducted (1-30), several studies have examined the application of Carbon Fiber Reinforced Polymer (CFRP) both in Indonesia and internationally. However, the analytical review indicates that previous studies have predominantly focused on experimental investigations of the functional performance and structural strength of CFRP, as well as its sustainability in various industrial and construction applications. These studies have not specifically addressed the supporting and inhibiting factors that may influence contractors' interest in adopting CFRP for apartment buildings in the Indonesian context.

Research on material preferences has also been conducted by various scholars; nevertheless, studies that specifically examine preferences for CFRP as a material in apartment building projects remain limited. Existing studies have identified a range of factors that support or hinder material selection in construction projects; however, a focused analysis of the determinants influencing the selection of CFRP for apartment buildings has yet to be comprehensively explored.

Despite the numerous advantages of Carbon Fiber Reinforced Polymer (CFRP), its application in apartment building projects in Indonesia has not yet become a primary choice. In several countries, including Indonesia, there is still a lack of clear standards or regulatory frameworks governing the use of CFRP in construction. The limited availability of data related to CFRP applications in Indonesia further indicates that this material has not been widely adopted. These conditions pose challenges for engineers in designing and implementing CFRP-based solutions in an optimal and systematic manner (31, 32).

An in-depth understanding of stakeholders' material selection preferences enables a more structured and effective decision-making process. Consideration of technical priorities, cost constraints, and operational requirements facilitates the alignment of material selection strategies with the diverse interests of relevant stakeholders, thereby minimizing potential conflicts and fostering the adoption of innovative materials such as Carbon Fiber Reinforced Polymer (CFRP). Accordingly, the analysis of stakeholder preferences constitutes a strategic foundation for optimizing the implementation of CFRP and enhancing overall project performance in terms of schedule, cost efficiency, and structural quality. The outcomes of this study are expected to provide a strategic framework for increasing the adoption of CFRP in apartment buildings and to serve as a preliminary reference for the future development of CFRP-related regulatory guidelines in Indonesia.

The novelty of this study lies in its focus on the application of Carbon Fiber Reinforced Polymer (CFRP) as a maintenance material for apartment buildings, with particular emphasis on increasing contractors' interest in its adoption. Unlike previous studies that predominantly concentrate on the experimental performance and structural capacity of CFRP, this research examines the supporting factors influencing contractors' material selection decisions in the context of apartment building maintenance. Specifically, this study seeks to empirically validate the hypothesis that time performance and cost efficiency are the primary factors encouraging the selection of CFRP, based on qualitative questionnaire data collected from contractors.

The outcomes of this research are expected to serve as a new reference framework for CFRP-based maintenance practices in apartment buildings in Indonesia. Furthermore, the proposed framework can be adapted to suit specific project requirements and potentially be applied to other types of buildings or similar urban environments.

Based on the research background and problem identification, the research questions of this study are "What factors influence the use of Carbon Fiber Reinforced Polymer (CFRP) for apartment building maintenance in the Jabodetabek region?".

In accordance with the research questions, the objectives of this study are to identify the factors influencing the use of Carbon Fiber Reinforced Polymer (CFRP) in apartment building maintenance in the Jabodetabek region, and to analyze the factors and their interrelationships that underlie the selection of CFRP for apartment building maintenance from the perspective of local stakeholders, including contractors, consultants, and project owners. By identifying these factors, this study aims to provide empirical support for the proposed research hypotheses.

II. LITERATURE REVIEW

According to the Kamus Besar Bahasa Indonesia (Indonesian Dictionary), a gedung (building) is defined as a large structure used as a place for human activities. Buildings may be classified into office buildings, meeting halls, commercial facilities, performance venues, sports facilities, and others. In the context of Indonesian law, the definition of a building is regulated under Law No. 28 of 2002 concerning Buildings. Article 1, paragraph (1) defines a building as: "A physical form resulting from construction work that is integrated with its location, partially or entirely situated above and/or below ground and/or water, and functions as a place where humans carry out activities, whether for residential purposes, religious activities, business activities, social and cultural activities, or other specific purposes." (translated from: "Wujud fisik hasil pekerjaan konstruksi yang menyatu dengan tempat kedudukannya, sebagian atau seluruhnya berada di atas dan/atau di dalam tanah dan/atau air, yang berfungsi sebagai tempat manusia melakukan kegiatannya, baik untuk hunian maupun tempat tinggal, kegiatan keagamaan, kegiatan usaha, kegiatan sosial, budaya, maupun kegiatan khusus.")

Considering that every citizen has the right to a prosperous life, both materially and spiritually, to adequate housing, and to a healthy living environment as basic human needs, these rights play a fundamental role in shaping national character and identity, and in realizing a complete, independent, and productive Indonesian society. National development, as mandated by the 1945 Constitution of the Republic of Indonesia, fundamentally aims to enhance public welfare through comprehensive human development and overall societal progress. Accordingly, the state bears responsibility for protecting its citizens by providing adequate housing, particularly livable multi-story residential buildings.

Government Regulation No. 16 of 2021 classifies buildings based on their function—such as residential, religious, commercial, socio-cultural, and special-purpose buildings—as well as based on specific criteria including complexity, permanence, fire risk, location, height, and ownership. Classification by height includes super-tall buildings, skyscrapers, high-rise buildings, mid-rise buildings, and low-rise buildings. High-rise buildings are defined as structures exceeding eight stories in height. Apartment buildings fall within the category of high-rise buildings.

More than fifty thousand types of materials have been utilized in the design and production of various engineering applications (13). These materials range from those that have existed for centuries—such as copper, cast iron, and brass—to newly developed advanced materials, including composites, ceramics, and high-performance steels. Advances in concrete technology have positioned concrete as the primary material in modern construction. The selection of construction materials has encouraged researchers and engineers to develop external reinforcement systems for concrete structures (27). Such reinforcement systems are considered essential, particularly for contemporary construction demands that emphasize practicality and efficiency without compromising concrete performance. The evolution of external reinforcement techniques has introduced innovative designs for strengthening reinforced concrete columns.

Materials used in corrosive industrial environments are required to exhibit high strength, high specific stiffness, effective vibration damping capacity, and low coefficients of thermal expansion (8). Composite materials have successfully replaced traditional materials in numerous applications requiring lightweight structures combined with high strength (16). In addition, these materials must demonstrate wear resistance and dimensional stability (8). Composite materials are defined as combinations of two or more distinct micro-constituents with different physical forms and chemical compositions. The purpose of combining these elements is to exploit the advantages of each constituent while minimizing their individual limitations (16).

Fiber Reinforced Polymer (FRP) composite materials have been widely used across various fields for several decades due to their high strength-to-weight and stiffness-to-weight ratios (21,23). Bakelite was the first type of Fiber Reinforced Plastic (FRP) developed by Dr. Leo Baekeland. This material was officially introduced during a scientific meeting organized by the American Chemical Society on February 5, 1909.

Carbon Fiber Reinforced Polymer (CFRP) is regarded as one of the most advanced composite materials for engineering applications; however, its primary limitation is its relatively high cost (33). Despite this limitation, the use of CFRP has continued to increase across various sectors. In practice, engineers are required to evaluate trade-offs and develop strategic approaches to balance performance and cost efficiency within project environments, thereby creating opportunities for cost reduction. CFRP strengthening systems are designed to repair and enhance the structural capacity of building elements—such as concrete, masonry, timber, and hybrid materials—that experience performance degradation due to aging, functional changes, or increased loading demands. The application scope of CFRP strengthening systems includes columns, beams, slabs, walls, wall openings, cylindrical structures, pier caps, piles, prestressed and post-tensioned concrete structures, as well as composite elements involving steel, masonry, and timber.

Carbon Fiber Reinforced Polymer (CFRP) is a composite material characterized by high strength and low weight, which has led to its extensive use in high-performance sectors such as aerospace engineering and high-speed transportation systems. However, the complex manufacturing processes associated with CFRP components introduce a relatively high risk of production defects, which may result in structural damage or operational hazards during fabrication and application (Ardiansyah, 2022).

CFRP may pose health hazards to humans, particularly in the form of fine dust or fragments generated during cutting, sanding, or recycling processes (34-35). Inhalation of CFRP dust can cause respiratory tract irritation, coughing, pulmonary inflammation, and, over prolonged exposure, may contribute to serious lung diseases such as fibrosis or even cancer, exhibiting effects comparable to asbestos exposure. Fine CFRP particles that penetrate deep into the lungs are extremely difficult for the body to eliminate (34). Consequently, special protective measures are required when working with CFRP materials, including the use of specialized respiratory masks and adequate ventilation systems.

Direct contact with CFRP dust may cause skin irritation, redness, itching, or dermatitis due to the abrasive nature of the fibers and the chemical sizing agents used in their production (35), CFRP dust or fragments entering the eyes may result in irritation or minor ocular injury. The resin matrices commonly used in CFRP, such as epoxy resins, may also be corrosive, and repeated skin exposure can lead to irritation or allergic reactions. In general, CFRP-related hazards primarily arise from dust exposure during manufacturing and recycling processes; therefore, preventive measures and the use of appropriate personal protective equipment (PPE) are essential to safeguard worker health and the surrounding environment (36).

III. Methods

This study adopts a mixed-methods approach by integrating quantitative and qualitative methods through a respondent questionnaire for data collection. The quantitative component is conducted using a Likert-scale measurement, while the qualitative component employs descriptive analysis of respondents' questionnaire feedback.

Research Question	Input	Process	Output
What factors influence the use of CFRP for apartment building maintenance in the Jabodetabek region?	Literature review on CFRP applications and material selection factors	Development of research instrument (questionnaire), data collection, data analysis using descriptive and statistical tests	Identification of the most influential factors affecting CFRP use, leading to the determination of key supporting factors for hypothesis testing
What are the recommended strategies for increasing interest in the use of CFRP for the reinforcement of apartment buildings in the Greater Jakarta area among stakeholders? interviews.	Data from RQ1, interviews with experts and literature related to strategies for the implementation of innovative materials.	Analysis of RQ1 results, development of strategies based on research findings and validation through expert	Strategy recommendations based on literature and analysis results to increase interest in and implementation of CFRP for the reinforcement of apartment buildings in the Jabodetabek area.

Table 1 Research Operational Model

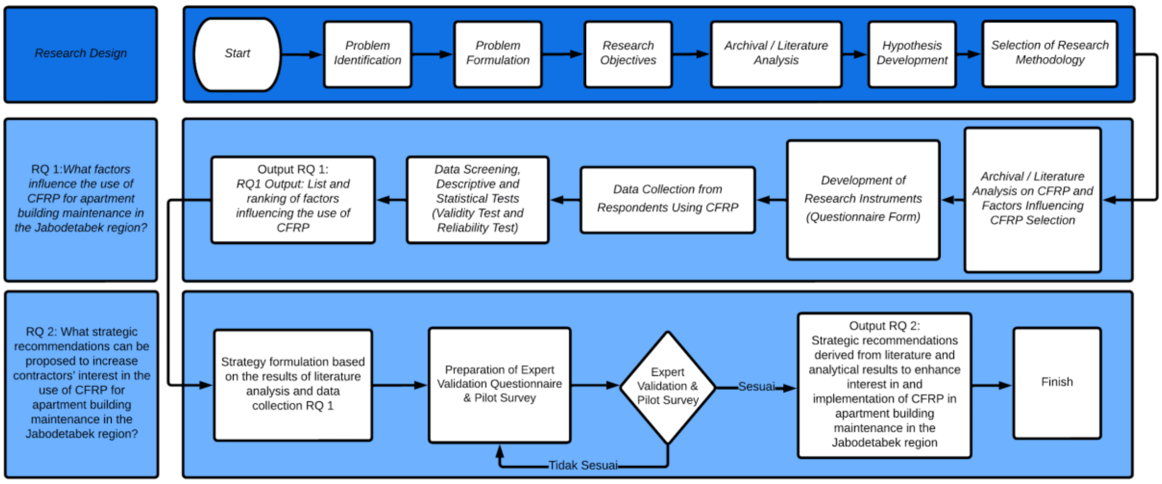
Figure 1 Research Flowchart

A systematic process was applied to explore the implementation of CFRP in apartment buildings in Indonesia. The process began with problem identification and formulation, followed by the establishment of research objectives and an analysis of relevant literature. This stage was further refined into more specific problem statements to construct a clear research framework. Subsequently, research objectives were formulated to define the expected outcomes, followed by archival and literature analysis to obtain an initial understanding of the research context. The study

was then focused on two main research questions (RQs).

Literature analysis was conducted prior to the development of the research instrument. Once finalized, the research instrument was distributed for data collection. The collected data were subsequently screened and processed for analysis.

Data analysis was conducted using descriptive and statistical tests to ensure that the data met eligibility and quality requirements. Through Geometric Mean (GM) analysis, the study identifies



the main factors that support or inhibit the use of CFRP, thereby providing a basis for hypothesis testing. The variable with the highest GM value is interpreted as having the strongest influence on the selection of CFRP for apartment building maintenance in the Jabodetabek region.

3.1. Research Variables

Based on the literature review, the study identifies risks and considerations that act as supporting or inhibiting factors in the use of CFRP for apartment building maintenance. These factors are defined as independent variables (X variables), as presented in Table 2.

Table 2 Independent Variables (X)

Code	Variable	References
X1	Cost Affordability	(1, 2, 20) (11, 17, 25, 29)
X2	Environmental Performance	(37-48)
X3	Aesthetic Value	(2, 10, 20)
X4	Functional Performance	(6, 7, 10, 15, 18)
X5	Fire Resistance	(10, 11)
X6	Structural Strength	(3-5, 9, 20, 30)
X7	Installation Technique	(6, 9, 20)
X8	Time Efficiency	(1, 2, 20)

Table 3 Dependent Variable (Y)

Code	Category	Indicator	Reference
Y	Strategic recommendations to increase interest in and implementation of CFRP for apartment building maintenance in the Jabodetabek region	Increased adoption of CFRP	Expert Validation

3.2. Target Respondents

To address the research problem, data were collected using random sampling, targeting key stakeholders—namely contractors, consultants, and project owners—who possess direct experience in using CFRP for apartment building maintenance in the Jabodetabek region. This selection aimed to obtain relevant and comprehensive data concerning CFRP implementation, benefits, and challenges, thereby enabling the identification of factors influencing material selection. The estimated number of respondents ranged from 30 to 35 participants, with a minimum of 10 respondents per stakeholder category, based on the principle of information saturation to ensure data quality and depth. This approach allows the study to capture diverse technical, economic, and social perspectives influencing CFRP adoption decisions, while also providing a robust basis for analysis and strategy formulation for more effective material implementation.

3.3. Hypothesis Testing

The hypotheses proposed in this study are as follows:

1. H0: Time performance and cost factors support contractors' preference for using CFRP but are not the primary influencing factors.
2. H1: Time performance and cost factors are the primary factors supporting increased stakeholder preference for using CFRP.

Hypothesis testing was conducted through six systematic analytical stages to ensure that the conclusions drawn are valid, consistent, and scientifically defensible. The first stage involved testing the homogeneity of respondent characteristics, including work experience, education level, and duration of CFRP usage, to ensure respondent relevance and comparability. The second stage applied data adequacy testing using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's Test of Sphericity, which assess sample adequacy and inter-variable correlation structure. The third stage consisted of validity and reliability testing to evaluate the measurement quality of each variable; variables failing to meet the required criteria were excluded from further analysis. The fourth stage involved respondent preference analysis using the Geometric Mean method to determine the relative importance of each variable and to identify dominant and supporting factors influencing contractors' preferences toward CFRP. The fifth stage applied qualitative descriptive analysis of Likert-scale responses to interpret respondents' perceptions and experiences. The final stage involved hypothesis decision-making, integrating all analytical results; the hypothesis is accepted if time performance and cost emerge as the two most dominant factors supporting increased contractor preference for CFRP.

IV. RESULT AND DISCUSSION

Data collection was conducted by distributing a Google Form questionnaire (attached) to identify the variables that most strongly influence the selection of Carbon Fiber Reinforced Polymer (CFRP) for apartment building maintenance in the Jabodetabek region.

4.1. Results Research Question 1

Data collection in this study involved 30 respondents selected according to predefined criteria. This number was considered sufficient to meet the minimum sample size required to obtain a representative overview of the research object. The data were collected using a questionnaire developed based on the indicators of the research variables and distributed to respondents over a specified period. All questionnaires were successfully returned and deemed suitable for analysis; therefore, a total of 30 valid responses were processed.

4.1.1 Respondent Distribution

The distribution of respondents based on work experience is presented in Table 4.

Table 4 Distribution of Respondents' Work Experience

Category	Work Experience
0-3 years	1
3-5 years	4
5-10 years	8
> 10 years	17
Total	30

The distribution of respondents based on educational background is shown in Table 5.

Table 5 Distribution of Respondents' Educational Level

Category	Education
Diploma (D3)	2
Bachelor's degree	13
Master's degree	15
Total	30

The distribution of respondents based on the number of years using CFRP is presented in Table 6.

Table 6 Distribution of Years of CFRP Usage

Category	Years of CFRP Usage
0-1 year	19
1-2 years	6
2-5 years	1
> 5 years	4
Total	30

4.1.2 Descriptive and Geometric Mean Analysis

Descriptive analysis was conducted to provide a general overview of the characteristics of the research data obtained from respondents. This analysis identifies data distribution patterns and the degree of response variability, thereby offering an initial empirical understanding of the research object prior to advanced statistical analysis. The descriptive statistics are presented in Table 7.

Table 7 Descriptive Statistics of Research Variables

Var.	N	Mean	Std. Deviation	Min.	Max.
X1	30	4,0667	0,78492	2,00	5,00
X2	30	3,8333	0,91287	1,00	5,00
X3	30	3,8333	1,01992	1,00	5,00
X4	30	4,5333	0,62881	3,00	5,00
X5	30	4,0333	0,71840	2,00	5,00
X6	30	4,2667	0,82768	2,00	5,00
X7	30	4,2667	0,94443	1,00	5,00
X8	30	4,4667	0,81931	2,00	5,00

The collected data were further analyzed using Microsoft Excel to calculate the Geometric Mean (GM) values, as presented in Table 8.

Table 8 Results of Geometric Mean Analysis

Variabel Code	Variable	Geomean	Ranking
X3	Aesthetic Value	3,654	8
X2	Environmental Performance	3,691	7
X5	Fire Resistance	3,956	6
X1	Cost Affordability	3,984	5
X7	Installation Technique	4,102	4
X6	Structural Strength	4,174	
X8	Time Efficiency	4,374	
X4	Functional Performance	4,486	

The Geometric Mean values (Geomean) represent the relative importance of each variable in influencing preferences for CFRP use in apartment building maintenance. Higher Geomean values indicate a stronger perceived influence.

4.1.3 Homogeneity Analysis

Homogeneity testing was conducted to determine whether the research data exhibited equal variances across respondent groups. This test is a prerequisite for further statistical analyses, as the fulfillment of the homogeneity assumption ensures that subsequent analytical results are reliable and statistically valid. In this study, homogeneity analysis was performed based on respondents' work experience, educational level, and years of CFRP usage. The results are presented in the following tables.

Table 9 Homogeneity Test Based on Work Experience

	X1	X2	X3	X4	X5	X6	X7	X8
Kruskal-Wallis H	3,686	1,596	0,817	2,105	3,169	4,050	0,898	1,581
df	3	3	3	3	3	3	3	3
Asymp. Sig.	0,297	0,660	0,845	0,551	0,366	0,256	0,826	0,664

a. Kruskal Wallis Test

b. Grouping Variable: Work Experience

Based on these results, it can be concluded that differences in respondents' work experience do not have a statistically significant effect on the evaluations of variables X1 through X8. This indicates that respondents from different work experience groups exhibit relatively similar perceptions of the examined variables.

Table 10 Homogeneity Test Based on Education Level

	X1	X2	X3	X4	X5	X6	X7	X8
Kruskal-Wallis H	2,271	4,726	0,257	2,440	3,415	1,535	0,645	0,147
df	2	2	2	2	2	2	2	2
Asymp. Sig.	0,321	0,094	0,879	0,295	0,181	0,464	0,725	0,929

a. Kruskal Wallis Test

b. Grouping Variable: Education Level

The results indicate that respondents' education level does not significantly influence their assessments of variables X1 to X8. Therefore, perceptions of these variables remain relatively consistent across different educational backgrounds.

Table 11 Homogeneity Test Based on Years of CFRP Usage

	X1	X2	X3	X4	X5	X6	X7	X8
Kruskal-Wallis H	2,235	2,194	3,607	1,247	4,779	1,306	0,765	1,084
df	3	3	3	3	3	3	3	3
Asymp. Sig.	0,525	0,533	0,307	0,742	0,189	0,728	0,858	0,781

a. Kruskal Wallis Test

b. Grouping Variable: Years of CFRP Usage

These findings indicate that there are no statistically significant differences in variables X1 through X8 based on respondents' years of CFRP usage. In other words, the length of experience using CFRP does not significantly affect respondents' perceptions of the evaluated variables. Overall, respondents demonstrate homogeneous characteristics across all tested groups.

4.1.4 Sample Adequacy Analysis

The adequacy of the sample size in this study was evaluated using the Kaiser–Meyer–Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity. A dataset is considered adequate for further analysis if both the KMO value and Bartlett's test significance are equal to or greater than 0.5. Conversely, values below this threshold indicate insufficient sample adequacy.

Table 12 KMO and Bartlett's test results

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0,589
Bartlett's Test of Sphericity	Approx. Chi-Square	68,745
	df	28
	Sig.	0,000

Based on the KMO and Bartlett's test results, the obtained value exceeds the minimum threshold of 0.5. Therefore, it can be concluded that the number of respondents in this study is sufficient, and further data analysis can be appropriately conducted.

4.1.5 Validity and Reliability Analysis

Validity testing was conducted to evaluate the extent to which the research instrument accurately measures the intended variables. The validity test was performed at a 95% confidence level with a significance level (α) of 0.05 using a two-tailed test. With 30 respondents, the degree of freedom (df) was calculated as $N - 2 = 28$. Based on the Pearson Product–Moment correlation table, the critical r value for df = 28 at a 5% significance level is 0.361. An item is considered valid if its calculated r value exceeds 0.361. Accordingly, questionnaire items with a calculated correlation coefficient (r count) greater than 0.361 are considered valid, while items with r count values equal to or less than 0.361 are deemed invalid and excluded from further analysis.

Reliability testing was then conducted to evaluate the consistency of the measurement instrument. Cronbach's Alpha was used as an indicator of internal consistency, with the following criteria:

1. Cronbach's Alpha ≤ 0,6 indicate that the research instrument is not reliable or lacks internal consistency.
2. Cronbach's Alpha ≥ 0,6 indicate that the instrument is reliable and demonstrates acceptable internal consistency.

The results of the validity and reliability analyses, conducted using SPSS version 25, are presented as follows:

Table 13 Validity Test Results

Var.	Corrected Item-Total Correlation	r tabel	Description
X1	-0,078	0,361	Not Valid
X2	0,472	0,361	Valid
X3	0,123	0,361	Not Valid
X4	0,350	0,361	Not Valid
X5	0,339	0,361	Not Valid
X6	0,523	0,361	Valid
X7	0,615	0,361	Valid
X8	0,614	0,361	Valid

Table 14 Reliability Test Results

Var.	Cronbach's Alpha if Item Deleted	Nilai Cronbach's Alpha	Description
X1	0,725	0,663	Reliable
X2	0,600	0,663	Reliable
X3	0,702	0,663	Not Reliable
X4	0,637	0,663	Reliable
X5	0,637	0,663	Reliable
X6	0,589	0,663	Reliable
X7	0,555	0,663	Reliable
X8	0,565	0,663	Reliable

Overall, the results of the validity and reliability tests indicate that not all items in the research instrument met acceptable measurement criteria. Items that demonstrated both validity and reliability were retained for further analysis, whereas items that failed to satisfy these criteria were revised or eliminated. This step is essential to ensure that the research instrument possesses adequate accuracy and internal consistency in empirically measuring the study constructs.

Table 15 Summary of Validity and Reliability Test Results

Variabel	**Validitas**	**Reliabilitas**	**Keputusan**
X1	❌ Not Valid	❌ Not Reliable	Eleminated
X2	✅ Valid	✅ Reliable	Retained
X3	❌ Not Valid	❌ Not Reliable	Eleminated
X4	❌ Not Valid	✅ Reliable	Eleminated
X5	❌ Not Valid	✅ Reliable	Eleminated
X6	✅ Valid	✅ Reliable	Retained
X7	✅ Valid	✅ Reliable	Retained
X8	✅ Valid	✅ Reliable	Retained

Based on these results, variables X1 and X3 were removed from the research instrument because they did not meet the validity criteria. They were also found to reduce the instrument's reliability, as determined by the Cronbach's Alpha if Item Deleted test. Although items X4 and X5 showed an adequate level of reliability, they were removed because they did not meet the validity test requirements. Items X2, X6, X7, and X8 met the validity and reliability criteria and were retained for the subsequent study analysis.

The study results indicate that the respondents were homogeneous in terms of their work experience, educational background and duration of CFRP use. The collected data met the required standards of adequacy and were suitable for further analysis. Following validity and reliability testing, variables X2 (environmental performance), X6 (structural strength), X7 (installation technique) and X8 (time efficiency) were identified as valid and reliable. Geometric mean analysis showed that all the variables had positive perception scores above 3.5. Time efficiency (X8) had the highest score and was the dominant factor, followed by structural strength and installation technique. While time was found to influence stakeholder preferences regarding CFRP usage, the cost factor did not meet the required validity and reliability criteria and could therefore not be considered a primary factor. Hypothesis H1, which posits time and cost as the main influencing factors, is rejected, while hypothesis H0, which considers them as supporting but not dominant factors, is accepted. This indicates that stakeholders' preference for CFRP implementation is influenced more by time efficiency than cost considerations.

4.2. Results Research Question 2

The second stage of this research focuses on developing strategies based on the results of the analysis and testing the research hypotheses. The key findings from the previous stage are analyzed and interpreted in greater depth at this stage to formulate appropriate and practical strategies. This process not only tests the validity of the proposed hypotheses but also ensures that the resulting strategies are empirically sound and relevant to real-world conditions in the field. Thus, Research Question 2 is a crucial bridge between the results of quantitative analyses and strategic recommendations that can inform decision-making.

4.2.1 Strategic Recommendations Based on the Literature

Through a comprehensive literature analysis, the researcher identified that one of the primary challenges in the implementation of Carbon Fiber Reinforced Polymer (CFRP) lies in its relatively high material cost compared to conventional strengthening methods. Consequently, numerous studies have emphasized the importance of optimizing raw material resources and production processes in order to reduce CFRP costs, thereby enhancing its economic competitiveness and feasibility for widespread application in construction projects (1-2, 20).

In addition to cost-related concerns, sustainability has also emerged as a significant issue in CFRP development and application. The literature highlights that CFRP production should incorporate environmentally friendly technologies and adopt life cycle assessment approaches to minimize environmental impacts throughout the product's life cycle, in line with the principles of sustainable development (11,17,29).

From a design perspective, the literature suggests that visually appealing CFRP designs, which are adaptable to the aesthetic requirements of various construction projects, can improve stakeholder acceptance, particularly in existing buildings with specific visual constraints (39-43,46-38). In line with these aesthetic considerations, the development of CFRP technical specifications capable of meeting diverse functional requirements and project standards has become a key factor in ensuring material performance and compatibility under various field conditions (1-2, 20).

Structural safety represents another crucial aspect in the application of CFRP, particularly in high-rise buildings. The literature emphasizes the importance of improving CFRP fire resistance through material innovation and safety testing based on international standards to ensure occupant safety (10-11,15,18). Furthermore, the structural strength of CFRP must be continuously validated through advanced research and consistent quality testing to ensure that the material can optimally support various loading conditions and structural applications (10-11).

The successful implementation of CFRP in practical applications is also highly influenced by implementation-related factors. The literature indicates that the availability of efficient and user-friendly installation guidelines, supported by technical training, can significantly improve construction quality and reduce the likelihood of implementation errors (3-5,9,20,30). Moreover, the integration of CFRP into project management strategies has been shown to accelerate project execution without compromising work quality, thereby providing overall benefits in terms of project time and cost efficiency (6,9,20).

The proposed strategic recommendations derived from the literature analysis were subsequently integrated with the analytical results and findings of the present study.

4.2.2 Strategic Recommendations Based on the Analysis

Based on the results of the analysis conducted, the proposed strategic recommendations to enhance the implementation of Carbon Fiber Reinforced Polymer (CFRP) in apartment buildings within the Greater Jakarta (Jabodetabek) area were identified and systematically summarized. Subsequently, these strategic recommendations were carried forward to the expert validation stage to evaluate their appropriateness, practicality, and potential effectiveness prior to implementation.

Based on the results of expert validation, the experts generally accepted and agreed with the findings of the validity and reliability tests, which indicated that most of the research variables had not yet fulfilled the required statistical criteria. According to the experts, these findings reflect the actual conditions in the field, where the implementation of Carbon Fiber Reinforced Polymer (CFRP) still faces limitations in terms of standardized evaluation parameters and the clarity of measurement scales, particularly for non-technical and perception-based variables.

The experts explained that variables categorized as unreliable yet valid indicate that the respondents' answers were relatively consistent; however, the indicators used were not fully capable of representing the complexity of the constructs being measured. This condition is influenced by the absence of a standardized evaluation framework that can be uniformly applied to assess aspects such as functional perception, implementation efficiency, and cost considerations in the context of CFRP application. Therefore, the invalidity of these variables was considered a reasonable methodological consequence rather than a substantial weakness of the research.

Furthermore, regarding variables categorized as valid but unreliable, the experts considered that this condition reflects the high variation in respondents' perceptions, which are influenced by project experience, professional background, and the characteristics of each type of work. Time, cost, and CFRP implementation factors were considered highly contextual and project-specific, making it difficult to achieve high consistency in responses in the absence of standardized implementation procedures and uniform cost references.

The variables that fulfilled both validity and reliability criteria, namely time, structural strength, installation techniques, and environmental friendliness, were considered feasible and ready for further empirical testing. These four variables possess relatively clear indicators that can be consistently understood by respondents from both technical and operational perspectives. In particular, the environmental aspect was considered to have the most established evaluation framework due to the support of material life-cycle assessment approaches and sustainability standards that have been widely implemented in construction practices. Therefore, the experts agreed that these four variables could be retained as the basis for hypothesis testing, with time identified as the dominant factor influencing preferences for CFRP utilization.

Overall, the experts emphasized that the validity and reliability test results, which led to the elimination of most variables, do not weaken the objectives of the study. Instead, they strengthen the position of this research as an exploratory study. These findings highlight the existing gaps in standardized measurement parameters and provide a basis for recommendations for future studies to develop more standardized instruments and evaluation indicators for CFRP implementation in the future.

Furthermore, the proposed strategic recommendations were also subjected to expert validation. In general, the experts expressed agreement with the developed strategies, stating that they had fulfilled the aspects of conceptual clarity, relevance, technical feasibility, and compatibility with practical field conditions. The feedback provided by the experts primarily served to strengthen and refine the strategies, particularly regarding cost aspects, empirical data support, technical standards, and opportunities for further development through future research.

Based on the experts' suggestions and input, revisions and improvements were subsequently made to the proposed strategic recommendations. The refinement process focused on improving the clarity of implementation, strengthening the technical basis of the strategies, and enhancing their applicability to real construction project conditions. After the revisions had been completed, the improved strategies were revalidated by the experts to ensure that the recommendations had become more comprehensive, feasible, and aligned with practical and academic considerations.

The results of the second expert validation confirmed that the revised strategies were considered more comprehensive and applicable. Consequently, the experts concluded that the proposed strategies are feasible, acceptable, and ready to be utilized as a basis for further research development and practical implementation, with additional refinement and future studies recommended to support broader standardization of CFRP applications.

Table 16 The Final strategic recommendations to enhance the implementation of Carbon Fiber Reinforced Polymer (CFRP) in apartment buildings within the Greater Jakarta (Jabodetabek) area

No.	Variable	Strategy Code	Proposed Strategic Recommendation	Basis of Strategy	Responsible Party	References
1	X1 – Cost Affordability	X.1.1	Implementing Life Cycle Cost Analysis (LCCA) in project planning to evaluate CFRP not only in terms of initial cost, but also based on maintenance cost savings, reduced repair frequency, and long-term corrosion resistance.	Stage 1 Data Collection Results (Questionnaire) and Statistical Testing	Cost Consultant	
		X.1.2	Applying CFRP selectively based on critical structural requirements in order to reduce material costs without compromising structural strength (ranked 3rd) and the functional performance of the building.	Stage 1 Data Collection Results (Questionnaire)	Design Consultant, Cost Consultant	
2	X2 – Environmental Friendliness	X.2.1	Utilizing environmental friendliness as a stable and consistent variable to support policy and regulatory justification for CFRP implementation, including the preparation of guidelines, internal building management	Stage 1 Data Collection Results (Questionnaire) and Statistical Testing Results	Project Owner	

			standards, and building strengthening policies.			
3	X3 – Aesthetics	X.3.1	Developing CFRP design planning based on standardized aesthetic criteria and adapting it to the visual requirements of different apartment areas. This strategy ensures that aesthetic variables possess clear limitations and measurable indicators, considering that aesthetic perception is subjective and varies among individuals.	Stage 1 Data Collection Results (Questionnaire)	Consultant	
4	X4 – Functional Capability	X.4.1	Developing CFRP technical specifications to fulfill functional requirements in accordance with diverse construction project standards.	Literature Analysis	Consultant	(2,10,20)
		X.4.2	Establishing CFRP functional capability as the primary criterion in selecting building strengthening methods within material selection technical specifications for apartment buildings. Measurable indicators should	Stage 1 Data Collection Results (Questionnaire) and Statistical Testing	Project Owner, Consultant	

			emphasize structural capacity enhancement without disrupting space functionality, architectural design, and occupant activities.		
		X.4.3	Enhancing dissemination and technical standards of CFRP to ensure equal understanding among all stakeholders, thereby supporting effective, efficient, and sustainable structural performance.	Stage 1 Data Collection Results (Questionnaire)	Consultant
5	X5 – Fire Resistance	X.5.1	Clarifying within technical guidelines that CFRP application must be accompanied by fire protection systems to protect polymer components and adhesives from high-temperature exposure.	Stage 1 Data Collection Results (Questionnaire)	Project Owner and Design Consultant
		X.5.2	Developing standardized guidelines for CFRP selection and application to achieve more consistent user perceptions and increase confidence in CFRP performance related to fire resistance in building strengthening.	Statistical Testing Results	Project Owner and Design Consultant

6	X6 – Structural Strength	X.6.1	Ensuring superior structural strength of CFRP through research and quality testing to support applications across various project types.	Literature Analysis and Stage 1 Data Collection Results (Questionnaire)	Project Owner, Design Consultant	(10-11)
		X.6.2	Preparing Technical Guidelines and CFRP Application Standards related to structural strength aspects, including limitations on effective layer quantities, calculation methods, and successful case examples. This strategy aims to improve the understanding of building owners, contractors, and apartment management regarding CFRP structural performance, thereby overcoming doubts and neutral perceptions caused by limited field experience.	Stage 1 Data Collection Results (Questionnaire) and Statistical Testing	Project Owner and Design Consultant	
7	X7 – Installation Technique	X.7.1	Designing and preparing installation guidelines and standard operating procedures (SOPs) for efficient and user-friendly CFRP installation to support field implementation, including: assessment of	Literature Analysis and Stage 1 Data Collection Results (Questionnaire)	Design Consultant	(3-5,920,20)

	existing structural conditions, selection of CFRP type and specifications, surface preparation and resin application, and environmental condition control (temperature, humidity, and chemical exposure). This standardization aims to ensure strengthening quality and minimize technical failures in the field.		
X.7.2	Improving contractor competency and certification through technical training and installation certification programs. Such competency and certification programs are expected to encourage the use of certified contractors and applicators, as well as the involvement of experienced structural consultants in CFRP installation implementation.	Contractor	
X.7.3	Conducting continuous quality control and evaluation in every project to ensure consistency of	Statistical Testing Results	Project Owner and Construction Management/Supervision Consultant

			results and long-term performance.			
8	X8 – Time	X.8.1	Preparing Technical Guidelines and Standards related to CFRP installation duration integrated with work methods or installation techniques. This aims to achieve shorter implementation periods with minimum and maximum time limitations for strengthening apartment buildings that remain operational, without reducing work quality.	Literature Analysis, Stage 1 Data Collection Results (Questionnaire), and Statistical Testing Results	Project Owner and Construction Management/Supervision Consultant	(6,9,20)

V. CONCLUSION

Overall, this study demonstrates that although the respondent data satisfied the requirements of homogeneity and sampling adequacy, measurement quality emerged as the key determinant in hypothesis testing. Time and cost factors were perceived as important by respondents; however, they could not be empirically confirmed as primary factors because they failed to meet the statistical criteria of validity and reliability. Consequently, these factors function as supporting variables rather than dominant determinants in enhancing contractors' preferences for the use of CFRP.

Based on the findings of this study, several conclusions can be drawn. The results of the validity and reliability tests indicated that only the variables of Time Efficiency (X8), Structural Strength (X6), Installation Technique (X7), and Environmental Performance (X2) were considered suitable for further analysis. The Geometric Mean analysis revealed that Time Efficiency (X8) was the most dominant variable influencing contractors' preferences toward the use of Carbon Fiber Reinforced Polymer (CFRP), followed by Structural Strength (X6) and Installation Technique (X7). Meanwhile, Environmental Performance (X2) showed the lowest relative influence among the validated variables.

Although Environmental Performance (X2) remained an influential factor, the findings indicate that material selection preferences were predominantly driven by technical considerations, particularly implementation time, structural strength, and ease of installation. This condition may be associated with the application requirements of CFRP, which involve the use of special filter masks (M3) during installation and its common application in open areas, such as building façades and floor slabs, which are subsequently covered by finishing materials.

Furthermore, the expert validation results concluded that the proposed strategic recommendations developed in this study were considered appropriate, feasible, and relevant to the investigated variables. However, further refinement is still required through additional studies and the development of standardized references and measurable technical guidelines aligned with official regulations, including Indonesian National Standards (SNI), Ministerial Regulations of Public Works and Housing (PerMen PUPR), and ASTM 1164. Such improvements are necessary to ensure that CFRP implementation can be carried out consistently, safely, and systematically.

Based on the findings obtained, several recommendations are proposed. Future studies are recommended to improve the questionnaire instrument by incorporating more specific and measurable indicators, particularly for variables with subjective characteristics, such as Functional Performance (X4), Aesthetic Value (X3), Cost Affordability (X1), and Time Efficiency (X8). This improvement is expected to capture respondents' perceptions more consistently and enhance compliance with validity and reliability requirements.

In addition, future research should consider integrating quantitative and qualitative approaches, such as in-depth interviews or project case studies, to provide a more comprehensive understanding of dominant factors that are perceptually important but have not been optimally represented within quantitative instruments.

Moreover, subsequent studies are recommended to investigate Cost Affordability (X1) and Time Efficiency (X8) using life cycle cost and service life analysis approaches. This would enable the economic evaluation of CFRP to extend beyond initial costs and include long-term efficiency, durability, and sustainability considerations associated with its implementation.

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