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RESEARCH ARTICLE

Life Cycle Costing as a Decision-Making Tool for Construction Product Design: A Comparative Assessment of Cost-in-Use

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ABSTRACT

The growing emphasis on sustainable construction has shifted attention from minimizing initial construction costs to optimizing total costs incurred over the service life of buildings. This study evaluates the effectiveness of life cycle costing (LCC) as a decision-making tool for construction product design by examining how design decisions influence the cost-in-use of construction products. A comparative case study approach was adopted using roofing materials as representative building components. Data were obtained from market surveys, published literature, construction professionals, and quantity surveying firms. Comparative life cycle cost analysis was employed to evaluate initial costs, maintenance requirements, replacement frequency, service life, and overall life cycle costs over a 60-year study period. The findings indicate that construction products with relatively higher initial acquisition costs often produce lower maintenance and replacement costs throughout their service life, resulting in superior long-term economic performance. The study further demonstrates that integrating Life Cycle Costing, Building Information Modelling (BIM), and Life Cycle Assessment (LCA) provides a comprehensive framework for evaluating design alternatives and improving investment decisions. It concludes that design decisions made during the conceptual stage substantially determine the whole-life cost performance of construction projects. The study therefore recommends the institutionalization of life cycle costing principles in project planning and procurement, together with greater integration of BIM-supported cost planning to enhance value for money and sustainable construction practices.

Keywords: *Life cycle; Cost-in-use; Construction products; Design decisions; Whole-life costing; Sustainability*

1. INTRODUCTION

The construction industry has traditionally focused on minimizing initial construction costs during project procurement. However, increasing concerns regarding sustainability, operational efficiency, and asset performance have shifted attention toward evaluating the total costs incurred throughout the service life of buildings. Consequently, Life Cycle Costing (LCC), commonly referred to as whole-life costing or cost-in-use analysis, has become an essential decision-support tool for assessing the long-term economic performance of construction projects. Rather than considering only acquisition costs, life cycle costing evaluates the cumulative costs associated with operation, maintenance, repair, replacement, and disposal over the useful life of a facility (Seeley, 1996; Kirk & Dell'Isola, 1995; Jin et al., 2025). Recent studies have shown that a substantial proportion of a building's total life cycle cost is determined during the conceptual and detailed design stages, where critical decisions concerning materials, structural systems, energy performance, durability, and maintainability are made (McNeil-Ayuk & Jrade, 2024; Jin et al., 2025; Vitkova & Vitasek, 2024). These early design decisions significantly influence future operating and maintenance expenditures, as well as the overall economic performance of construction projects. Consequently, selecting construction products solely based on their initial purchase price often results in increased maintenance costs, frequent replacement, higher operational expenditures, and reduced value for money over the building's lifespan (Umdu et al., 2024; Samarasekara et al., 2024).

Material selection is among the most influential design decisions affecting the cost-in-use of construction products. High-performance materials generally require higher initial investment but often provide longer service life, lower maintenance requirements, and improved environmental performance (Arab et al., 2025; Theilig et al., 2024). Similarly, building designs that incorporate adaptability, durability, and energy-efficient technologies contribute significantly to reducing operational costs while improving the sustainability of the built environment (Adu-Duodu et al., 2025; Umdu et al., 2024). The growing adoption of Building Information Modelling (BIM), Life Cycle Assessment (LCA), and Whole-Life Costing (WLC) has further enhanced designers' ability to evaluate alternative construction products before project implementation. These technologies enable professionals to integrate economic, technical, and environmental considerations into the decision-making process, thereby improving value for money and supporting sustainable procurement practices (McNeil-Ayuk & Jrade, 2024; Vitkova & Vitasek, 2024). Nevertheless, despite these technological advances, the practical application of life cycle costing remains limited in many developing countries, including Nigeria, where procurement decisions continue to emphasize minimum initial cost rather than long-term economic performance (Ikwueze & Onuegbu, 2025). The consequences of prioritizing initial cost over whole-life performance are evident in the increasing maintenance burden, premature deterioration of building components, and escalating operational costs experienced by many public and private buildings. These challenges underscore the need for greater integration of life cycle costing principles into construction planning and design. By evaluating the long-term financial implications of alternative design decisions, stakeholders can achieve more sustainable investments, improve asset performance, and optimize resource utilization throughout a building's service life (Samarasekara et al., 2024; Jin et al., 2025). Life Cycle Costing (LCC) has been widely recognized as an effective approach for evaluating the long-term economic performance of construction projects. Previous studies have demonstrated the importance of whole-life costing, sustainable material selection, and the integration of Building Information Modelling (BIM) and Life Cycle Assessment (LCA) in improving construction decision-making (McNeil-Ayuk & Jrade, 2024; Samarasekara et al., 2024; Jin et al., 2025). Similarly, studies by Vitkova and Vitasek (2024) and Umdu et al. (2024) have highlighted the influence of durability, maintenance requirements, and operational performance on the total life cycle cost of buildings. Despite these advances, there remains a limited number of empirical studies that compare the life cycle costs of alternative building components commonly used in residential construction, particularly in developing countries such as Nigeria. Most existing studies have focused on general life cycle costing frameworks, sustainability assessment, or digital technologies without providing detailed comparative evaluations of specific construction products used in building design.

Furthermore, few studies have examined how design decisions relating to window systems and roofing materials influence cost-in-use over the service life of residential buildings using locally relevant cost data.

This study addresses these gaps by undertaking a comparative life cycle cost analysis of alternative window systems and roofing materials within the Nigerian construction context. By evaluating both initial and long-term costs over a 60-year study period, the study provides empirical evidence on how design decisions influence the cost-in-use of construction products. The findings are expected to support architects, quantity surveyors, engineers, and clients in making more informed, sustainable, and cost-effective design decisions. Against this background, this study aims to evaluate the effectiveness of Life Cycle Costing (LCC) as a decision-making tool for construction product design by examining how design decisions influence the cost-in-use of selected construction products. The specific objectives of the study are: to examine the concept and significance of Life Cycle Costing in construction product design, to evaluate the influence of design decisions on the cost-in-use of selected construction products, to compare the life cycle costs of alternative window systems used in residential buildings, to compare the life cycle costs of alternative roofing systems used in residential buildings, to assess the effectiveness of Life Cycle Costing as a decision-making tool for sustainable construction product selection.

2. LITERATURE REVIEW

Concept of Cost-in-Use

Cost-in-use, commonly referred to as life cycle costing (LCC) or whole-life costing (WLC), is a systematic approach to evaluating the total expenditure associated with a building or construction product throughout its service life. Unlike conventional cost estimation, which primarily emphasizes the initial capital investment, cost-in-use considers all costs incurred from acquisition to disposal, including operation, maintenance, repair, replacement, energy consumption, and end-of-life disposal. This approach enables project stakeholders to make informed investment decisions based on long-term economic performance rather than initial purchase price alone (Seeley, 1996; Kirk & Dell'Isola, 1995; Samarasekara et al., 2024). The concept of cost-in-use has evolved considerably over the past few decades due to increasing concerns about sustainability, resource efficiency, and value-based procurement. According to Okereke (2013), cost-in-use provides a framework for comparing alternative design solutions by evaluating both their immediate and future financial implications. Similarly, Guha (2009) explained that cost-in-use comprises the initial construction cost together with the expected costs of maintenance, repairs, renewal, operation, taxation where applicable, and eventual replacement during the anticipated service life of a facility. The Royal Institution of Chartered Surveyors (RICS, 1999) defines whole-life costing as the systematic assessment of all relevant costs associated with acquiring, owning, operating, maintaining, and disposing of an asset over its entire life cycle. Likewise, the Building Research Establishment (BRE) describes whole-life costing as an evaluation of the overall performance and total cost of an asset throughout its service life, taking into account the initial capital cost as well as future operational, maintenance, replacement, and disposal costs. Consequently, life cycle costing has become an indispensable tool for designers, quantity surveyors, and facility managers seeking to achieve optimum value for money while maintaining functional performance and sustainability.

Recent studies further emphasize that life cycle costing provides a more comprehensive basis for investment appraisal than traditional cost estimation methods because it captures the long-term financial consequences of design decisions. Samarasekara et al. (2024), through a systematic review of whole-life cost estimation practices, identified maintenance requirements, durability, service life, operational efficiency, and replacement frequency as some of the principal variables influencing total life cycle cost. Similarly, Jin et al. (2025) demonstrated that life cycle costing provides a holistic framework for evaluating engineering structures and supports more sustainable investment decisions by considering costs incurred throughout the asset's operational life.

Mathematically, the life cycle cost of a construction product may be expressed as:

LCC = IC + OC + MC + RC + DC

Where:

LCC = Life Cycle Cost, IC = Initial Cost, OC = Operating Cost

MC = Maintenance Cost, RC = Replacement Cost, DC = Disposal Cost

Although simplified, this expression demonstrates that the total cost of a construction product extends far beyond its acquisition cost. Consequently, products with relatively high initial costs may ultimately prove more economical if they require less maintenance, consume less energy, and possess longer service lives than lower-cost alternatives (Vitkova & Vitasek, 2024; Umdu et al., 2024).

Design Decisions in Construction

Design decisions constitute one of the most influential determinants of the economic performance of construction projects because they establish the physical characteristics, functionality, durability, and operational efficiency of buildings. These decisions are made predominantly during the conceptual and detailed design stages, where architects, engineers, quantity surveyors, and clients collectively determine the form, materials, structural systems, building services, and construction methods to be adopted. McNeil-Ayuk and Jrade (2024) observed that nearly 80% of a building's life cycle costs are committed during the early stages of design, even though only a small proportion of the total project expenditure has been incurred at that stage. Construction design decisions extend beyond aesthetics and structural integrity to include considerations relating to maintainability, adaptability, constructability, environmental performance, and long-term operational efficiency. Consequently, inappropriate design choices often result in increased maintenance expenditure, higher energy consumption, premature deterioration, and costly renovations throughout the building's service life (Vitkova & Vitasek, 2024). Several broad design decisions have consistently been identified in the literature as having substantial implications for project cost. These include building height, storey height, circulation space, plan configuration, building size, internal layout, level of prefabrication, constructability, redundancy in design, and material selection (Seeley, 1996; Ashworth & Perera, 2018). Although each project possesses unique characteristics, these design variables significantly influence both initial construction costs and long-term operational expenditures. For instance, building height affects construction cost through increased structural requirements, larger circulation cores, more extensive service installations, and longer construction durations. Similarly, storey height influences the quantity of materials required for walls, columns, staircases, mechanical services, and vertical transportation systems. Plan configuration also affects cost efficiency because compact building shapes generally minimize external envelope costs, whereas complex or irregular layouts increase wall areas, roofing requirements, and construction complexity (Ashworth & Perera, 2018). Building size equally influences economic performance through economies of scale. Larger projects often achieve lower unit costs because fixed overhead costs, temporary works, and procurement expenses are distributed across greater floor areas. Furthermore, repetitive construction activities enhance labour productivity and reduce production costs through learning-curve effects (Flanagan & Tate, 1997). Modern construction practices also emphasize constructability and standardization as important design considerations. Prefabrication, modular construction, and standardized building components improve productivity, minimize material waste, reduce construction time, and lower overall life cycle costs. However, successful implementation requires careful planning, higher initial coordination efforts, and integration among project stakeholders (McNeil-Ayuk & Jrade, 2024).

Major Design Factors Influencing Cost-in-Use of Construction Products

The economic performance of construction projects is largely determined by decisions made during the design stage. Although initial construction costs are important, design choices relating to material selection, durability, maintainability, energy efficiency, adaptability, and constructability have far greater implications for the total cost incurred throughout a building's service life. Consequently, life cycle costing emphasizes evaluating these factors collectively to achieve optimum value for money rather than minimizing initial expenditure alone (Jin et al., 2025; Samarasekara et al., 2024). Material selection remains one of the most critical determinants of cost-in-use because construction materials directly influence durability, maintenance requirements, replacement frequency, operational efficiency, and environmental performance. The selection of inappropriate materials often results in premature deterioration, increased maintenance expenditure, and reduced service life. Conversely, high-performance materials, although typically associated with higher acquisition costs, generally provide superior long-term economic benefits by reducing maintenance interventions and extending building lifespan (Arab et al., 2025). Theilig et al. (2024) further argued that material selection should be based on multi-criteria decision-making frameworks that simultaneously consider economic, environmental, technical, and functional performance throughout the product life cycle. Closely related to material selection is durability, which refers to the ability of construction products to withstand environmental exposure, mechanical loading, weathering, and aging while maintaining their intended performance. Durable construction materials require fewer repairs and replacements, thereby reducing whole-life expenditure. Vitkova and Vitasek (2024), in their life cycle cost assessment of residential buildings, demonstrated that durable building technologies consistently produced lower life cycle costs despite requiring greater initial investment. Their findings reinforce the principle that higher capital expenditure at the design stage can generate substantial long-term financial savings. Maintainability is another important design consideration influencing life cycle cost.

Maintainability refers to the ease with which building components can be inspected, cleaned, repaired, replaced, and serviced throughout their operational life. Construction products designed for easy maintenance reduce labour requirements, minimize service interruptions, and lower maintenance expenditure. According to Samarasekara et al. (2024), maintainability is one of the most influential variables affecting whole-life cost estimation because buildings that facilitate efficient maintenance generally experience lower operating costs and improved asset performance throughout their service life. Energy efficiency has equally become a major consideration in contemporary construction due to increasing energy costs and growing environmental concerns. Design decisions relating to thermal insulation, roofing systems, glazing, ventilation, lighting, and building services significantly affect operational energy consumption. Umdu et al. (2024) demonstrated that incorporating energy-efficient technologies during the design stage can substantially reduce carbon emissions and operational costs without significantly increasing construction expenditure. Consequently, energy-efficient design not only enhances environmental sustainability but also improves long-term economic performance by lowering utility costs throughout the building's operational life. Adaptability and flexibility have also emerged as essential characteristics of sustainable buildings. Adaptable buildings are capable of accommodating future changes in occupancy, technology, or functional requirements with minimal structural modification. This flexibility reduces renovation costs, extends service life, and delays building obsolescence. Adu-Duodu et al. (2025) emphasized that adaptable construction systems support circular economy principles by facilitating reuse, refurbishment, and recovery of building components, thereby improving both environmental and economic sustainability. Constructability, often referred to as buildability, also contributes significantly to life cycle cost optimization. The concept describes the extent to which building design facilitates efficient construction while satisfying the functional requirements of the completed facility. Good constructability minimizes construction complexity, reduces material waste, shortens project duration, improves quality, and lowers both initial and future maintenance costs (CIRIA, 1983; Ashworth & Perera, 2018). Ferguson (1989) further observed that integrating construction knowledge into the design process improves project outcomes by enhancing cost efficiency, reducing delays, and increasing the quality of completed facilities. Overall, these design factors are highly interrelated and collectively determine the long-term financial performance of construction projects. Decisions regarding materials, durability, maintainability, adaptability, energy efficiency, and constructability should therefore be evaluated simultaneously during the design stage using life cycle costing techniques. Such an integrated approach enables project stakeholders to identify design alternatives that provide the lowest whole-life cost while satisfying technical, functional, and environmental requirements (McNeil-Ayuk & Jrade, 2024; Jin et al., 2025).

Relationship between Design Decisions and Cost-in-Use

The relationship between design decisions and cost-in-use is fundamental to life cycle costing because the majority of future building expenditures are committed during the early stages of project development. Although construction costs are incurred during project execution, decisions made during planning and design largely determine future maintenance requirements, operational efficiency, replacement frequency, and asset longevity. Consequently, inappropriate design decisions may result in buildings with low initial costs but significantly higher operational expenditures throughout their service lives (Olanrewaju & Abdul-Aziz, 2020). Life cycle costing provides a systematic framework for evaluating alternative design solutions by considering all costs expected during the economic life of a building rather than focusing solely on capital expenditure. McNeil-Ayuk and Jrade (2024) demonstrated that integrating Building Information Modelling (BIM) with Life Cycle Cost Analysis enables project teams to compare multiple design alternatives during the conceptual stage and predict their long-term financial implications before construction begins. Similarly, Vitkova and Vitasek (2024) reported that investing moderately higher amounts in durable construction technologies significantly reduced maintenance, repair, and operational costs over the building's life cycle. Recent advances in digital construction technologies have further strengthened the relationship between design decision-making and life cycle performance. The integration of BIM, LCA, and LCC enables designers, quantity surveyors, architects, and engineers to optimize material selection, energy performance, and maintenance planning simultaneously. This integrated approach improves decision-making by balancing economic, environmental, and functional objectives, thereby delivering greater value for money and enhancing the sustainability of construction projects (Theilig et al., 2024; Arab et al., 2025). Overall, the literature demonstrates that cost-in-use is largely a consequence of design quality. Projects that prioritize durability, maintainability, energy efficiency, and adaptability during the conceptual design stage consistently achieve lower life cycle costs, improved operational performance, and greater long-term value than projects that focus primarily on minimizing initial construction expenditure. These findings provide the theoretical basis for the comparative life cycle cost analysis undertaken in this study.

Role of Quantity Surveyors in Design Decision-Making

Quantity Surveyors play a critical role in ensuring that construction projects achieve optimum value for money throughout their life cycle. Traditionally, their responsibilities have focused on cost planning, budgeting, tender documentation, procurement, and financial control. However, contemporary construction practice increasingly requires Quantity Surveyors to participate actively during the conceptual design stage, where their expertise contributes to evaluating alternative design solutions based on whole-life economic performance rather than initial construction cost alone (Ashworth & Perera, 2018).

Early involvement of Quantity Surveyors enables project teams to integrate life cycle costing into design development by assessing the long-term financial implications of material selection, construction methods, building services, and maintenance strategies. Through value engineering and cost planning, Quantity Surveyors assist clients in identifying design alternatives that achieve the desired functional performance at the lowest whole-life cost without compromising quality or sustainability (Flanagan & Tate, 1997).

The emergence of Building Information Modelling (BIM), Life Cycle Assessment (LCA), and digital cost management tools has further expanded the role of Quantity Surveyors in construction decision-making. McNeil-Ayuk and Jrade (2024) demonstrated that integrating BIM with Life Cycle Cost Analysis enables Quantity Surveyors to estimate future operational, maintenance, and replacement costs during the conceptual design stage, thereby improving investment decisions and enhancing project sustainability. Consequently, modern Quantity Surveyors have become strategic advisers who contribute not only to cost control but also to sustainable asset management and value optimization throughout the project life cycle.

Theoretical Framework

This study is anchored in the Life Cycle Costing Theory and the Value Management Theory, both of which provide a theoretical foundation for evaluating design alternatives based on long-term economic performance.

Life Cycle Costing Theory posits that the true economic value of a construction project cannot be assessed solely by its initial construction cost but rather by considering all costs incurred throughout its operational life. These costs include acquisition, operation, maintenance, repair, replacement, and disposal. The theory therefore provides a comprehensive framework for comparing competing design alternatives and selecting those that minimize total ownership costs while maximizing long-term value (Kirk & Dell'Isola, 1995; Jin et al., 2025).

Complementing this perspective is Value Management Theory, which emphasizes achieving the optimum balance between function, quality, performance, and cost. Rather than seeking the cheapest design solution, value management encourages project teams to maximize functional performance relative to the total resources invested. According to Ashworth and Perera (2018), effective value management requires multidisciplinary collaboration during the design stage to eliminate unnecessary costs without compromising the client's functional requirements.

The integration of these two theories provides a comprehensive basis for this study. While Life Cycle Costing Theory explains how design decisions influence long-term economic performance, Value Management Theory provides the decision-making framework for selecting construction products that deliver optimum value throughout the building's life cycle. Together, they justify the adoption of life cycle costing as an effective decision-support tool for construction product design.

3. MATERIALS AND METHODS

Research Design

This study adopted a comparative case study research design to evaluate the effectiveness of life cycle costing as a decision-making tool for construction product design. The case study approach was considered appropriate because it facilitates an in-depth evaluation of how alternative design decisions influence the long-term economic performance of construction products under real-life conditions. According to Yin (2018), case studies are particularly suitable for investigating contemporary phenomena within their natural contexts where the boundaries between the phenomenon and its environment are not clearly distinguishable. The study specifically compared alternative roofing materials commonly used in residential buildings to determine how differences in durability, maintenance requirements, replacement frequency, and service life influence their cost-in-use over an extended operational period.

Study Area and Case Study

The study was conducted using a typical residential building located in Owerri, Imo State, Nigeria, as the case study. A comparative life cycle cost analysis was undertaken using two major building components: windows and roofing systems, because these components constitute significant elements of the building envelope and have considerable influence on construction cost, durability, maintenance requirements, replacement frequency, weather resistance, and long-term operational performance.

For the window component, two commonly used alternatives were investigated:

Louvre windows

Aluminium windows

Similarly, for the roofing component, the following alternatives were evaluated:

Corrugated galvanized steel roofing sheets

Aluminium roofing sheets

These building components were selected because they exhibit substantial differences in initial acquisition cost, durability, maintenance requirements, replacement intervals, and expected service life. Such variations make them suitable for comparative life cycle cost analysis and provide a reliable basis for assessing how design decisions influence the cost-in-use of construction products. By comparing alternative window and roofing systems over a 60-year study period, the research evaluates whether products with higher initial costs provide superior long-term economic performance through reduced maintenance and replacement costs.

Variables Considered

The comparative life cycle cost analysis considered five principal variables that significantly influence the long-term economic performance of the selected window and roofing systems. These variables comprised initial cost, maintenance cost, replacement cost, service life, and cost-in-use (life cycle cost). The initial cost represents the acquisition and installation cost of each construction product. Maintenance cost refers to the expenditure incurred on routine servicing, repairs, repainting, and other maintenance activities required to maintain the functional performance of the windows and roofing materials throughout their service life. Replacement cost represents the cost of replacing a construction product at the end of its useful life. Service life refers to the expected period during which the product performs satisfactorily under normal operating conditions before replacement becomes necessary. Finally, cost-in-use (life cycle cost) represents the cumulative expenditure incurred throughout the study period, including initial cost, maintenance cost, and replacement cost. These variables were selected because they provide a comprehensive basis for evaluating the long-term economic implications of alternative design decisions involving both window systems and roofing materials.

Analytical Framework

The study employed Life Cycle Costing (LCC) as the principal analytical tool for evaluating the long-term economic performance of alternative window systems and roofing materials. Life Cycle Costing provides a systematic approach for estimating the total expenditure associated with a construction product throughout its operational life, thereby facilitating objective comparison of competing design alternatives (Kirk & Dell'Isola, 1995; Jin et al., 2025).

The analytical model adopted for this study is expressed as:

$$LCC = IC + MC + RC$$

Where:

LCC = Life Cycle Cost, IC = Initial Cost, MC = Maintenance Cost, RC = Replacement Cost

The comparative analysis was conducted over a 60-year study period, representing the assumed economic life of a typical residential building. Separate life cycle cost analyses were undertaken for the selected window systems (louvre and aluminum windows) and roofing systems (corrugated galvanized steel and aluminum roofing sheets). The construction product with the lower cumulative life cycle cost over the study period was considered to provide superior long-term economic value and lower cost-in-use.

Comparative Cost Analysis

A comparative life cycle cost analysis was undertaken to evaluate the economic implications of selecting alternative window systems and roofing materials for residential building construction. For the window systems, the analysis compared louvre windows and aluminum windows based on their initial installation costs, maintenance requirements, replacement frequency, and cumulative life cycle costs over the 60-year analysis period. Similarly, for the roofing systems, the study compared corrugated galvanized steel roofing sheets and aluminum roofing sheets using the same life cycle costing criteria. The comparison incorporated initial construction cost, maintenance expenditure, replacement intervals, expected service life, and cumulative life cycle cost. The results obtained from the analyses provided the basis for evaluating how design decisions relating to the selection of windows and roofing materials influence the cost-in-use of construction products. The comparative approach further enabled the study to determine whether construction products with relatively higher initial costs ultimately provide lower whole-life costs through reduced maintenance and replacement requirements.

Assumptions

The life cycle cost analysis was conducted based on the following assumptions:

The analysis period was 60 years, representing the assumed economic life of the building, All alternative window and roofing systems were exposed to identical environmental and operating conditions throughout the study period, Installation of all construction products was carried out in accordance with manufacturers' specifications and accepted construction practices, Maintenance activities were performed at the recommended intervals throughout the service life of each construction product, Labour costs were assumed to remain relatively constant throughout the analysis period, Inflation, interest rates, and discount rate fluctuations were excluded from the analysis to facilitate direct comparison of the alternative construction products, The expected service lives and maintenance schedules adopted in the analysis were based on manufacturers' recommendations and published literature.

Reliability and Validity

To enhance the reliability of the study, cost information was obtained from multiple independent sources, including registered contractors, quantity surveying firms, construction material suppliers, manufacturers' publications, and peer-reviewed literature. Expected service life, maintenance intervals, and replacement schedules adopted in the analysis were similarly validated using manufacturers' specifications and findings reported in previous empirical studies. The triangulation of multiple information sources improved the consistency, credibility, and validity of the comparative life cycle cost estimates generated in this study.

4. RESULTS AND DISCUSSION

Comparative Life Cycle Cost Analysis of Selected Building Components

This section presents the results of the comparative life cycle cost analyses conducted on selected building components. The analyses evaluate the influence of design decisions on the long-term economic performance of window systems and roofing systems by comparing their initial costs, maintenance requirements, replacement costs, and total life cycle costs over a 60-year study period. The findings provide empirical evidence on the effectiveness of Life Cycle Costing (LCC) as a decision-support tool for selecting construction products that deliver optimum value for money.

Comparative Life Cycle Cost Analysis of Window Systems

Window systems are important components of the building envelope because they influence construction cost, maintenance expenditure, durability, thermal performance, and occupants' comfort. Two commonly used window alternatives, louvre windows and aluminum windows, were analyzed using the Life Cycle Costing (LCC) technique to determine their long-term economic performance.

Table 1. Life Cycle Cost Analysis of Louvre Windows

Cost Component	Present Value (₦)
Initial Cost	404,430.00
Redecoration (5 Years)	15,670.40
Redecoration (10 Years)	12,278.20
Redecoration (15 Years)	9,620.20
Renewal (20 Years)	265,485.58
Redecoration (25 Years)	5,906.00
Redecoration (30 Years)	4,627.40
Redecoration (35 Years)	3,625.80
Renewal (40 Years)	142,669.24
Redecoration (45 Years)	2,225.80
Redecoration (50 Years)	1,744.80
Redecoration (55 Years)	1,366.40
Total Life Cycle Cost	**869,649.82**

Table 2. Life Cycle Cost Analysis of Aluminum Windows

Cost Component	Present Value (₦)
Initial Cost	739,500.00
General Repairs (30 Years)	57,842.50
Total Life Cycle Cost	797,342.50

Tables 1 and 2 indicate that louvre windows have a significantly lower initial installation cost than aluminum windows. However, because louvre windows require frequent redecoration and two major renewals within the 60-year analysis period, their cumulative life cycle cost is substantially higher. In contrast, aluminum windows require a higher initial investment but incur minimal maintenance and repair costs throughout their service life, resulting in a lower overall life cycle cost.

The findings suggest that selecting window systems solely based on initial acquisition cost may lead to poor long-term economic outcomes. Rather, construction professionals should consider the total ownership cost throughout the building's operational life. These findings agree with those of Jin et al. (2025), Samarasekara et al. (2024), and McNeil-Ayuk and Jrade (2024), who concluded that durable construction products generally provide superior long-term economic performance despite their relatively higher capital costs.

Comparative Life Cycle Cost Analysis of Roofing Systems

Roofing systems constitute one of the most critical components of a building because they protect the structure from environmental exposure and significantly influence maintenance costs, durability, and service life. To evaluate the influence of roofing material selection on cost-in-use, a comparative life cycle cost analysis was undertaken for corrugated galvanized steel roofing sheets and aluminum roofing sheets.

Table 3. Life Cycle Cost Analysis of Corrugated Galvanized Steel Roofing Sheets

Cost Component	Present Value (₦)
Initial Cost	269,000.00
Maintenance (10 Years)	18,417.30
Maintenance (20 Years)	11,306.40
Replacement (30 Years)	154,786.53
Maintenance (40 Years)	4,261.20
Maintenance (50 Years)	2,616.00
Total Life Cycle Cost	460,387.43

Table 4. Life Cycle Cost Analysis of Aluminum Roofing Sheets

Cost Component	Present Value (₦)
Initial Cost	447,300.00
General Repairs (30 Years)	6,941.10
Total Life Cycle Cost	797,342.50

Tables 3 and 4 reveal that corrugated galvanized steel roofing sheets require a considerably lower initial investment than aluminum roofing sheets. However, due to periodic maintenance requirements and complete replacement during the analysis period, the total life cycle cost of galvanized roofing sheets exceeds that of aluminum roofing sheets. Although aluminum roofing sheets have a higher acquisition cost, their superior durability and lower maintenance requirements result in reduced expenditure throughout the building's service life. Consequently, aluminum roofing sheets provide greater long-term economic value than galvanized roofing sheets. These findings support the principles of life cycle costing and demonstrate that long-term financial performance should be prioritized over initial construction cost when selecting roofing materials.

Discussion of Findings

Table 5. Summary of Comparative Life Cycle Cost Analysis

Building Component	Alternative	Initial Cost Ranking	Life Cycle Ranking	Preferred Alternative
Windows	Louvre Windows	Lower	Higher	Aluminum Windows ✓
	Aluminum Windows	Higher	Lower	
Roofing	Corrugated Galvanized Steel	Lower	Higher	Aluminum Roofing ✓
	Aluminum Roofing	Higher	Lower	

The comparative analyses demonstrate that the choice of construction products during the design stage has a significant influence on the long-term economic performance of buildings. For both window systems and roofing materials, products with higher initial acquisition costs consistently recorded lower total life cycle costs because of their superior durability, reduced maintenance requirements, and longer service lives. These findings provide strong empirical evidence that initial construction cost alone is an inadequate criterion for selecting construction products. Instead, project teams should adopt Life Cycle Costing (LCC) to evaluate the total cost implications of competing design alternatives over their expected service lives. By incorporating maintenance, repair, replacement, and operational costs into the decision-making process, construction professionals can identify alternatives that maximize value for money and promote sustainable asset management. The findings are consistent with the principles of Life Cycle Costing Theory, which advocates evaluating investments based on total ownership cost, and Value Management Theory, which seeks to optimize the relationship between cost, function, quality, and performance. They also corroborate the findings of McNeil-Ayuk and Jrade (2024), Vitkova and Vitasek (2024), Samarasekara et al. (2024), and Jin et al. (2025), all of whom reported that durable and well-designed construction products achieve lower whole-life costs despite requiring higher initial investment.

Limitations of the Study

Despite providing valuable insights into the application of Life Cycle Costing (LCC) as a decision-making tool for construction product design, this study has certain limitations that should be acknowledged. First, the analysis was limited to two building components, window systems and roofing systems, using a residential building in Owerri, Imo State, Nigeria, as the case study. Consequently, the findings may not fully represent the life cycle cost performance of other building components such as doors, floor finishes, wall finishes, ceilings, structural elements, or mechanical and electrical services.

Second, the comparative life cycle cost analysis focused primarily on initial costs, maintenance costs, and replacement costs over a 60-year study period. Other economic variables, including inflation, discount rates, fluctuations in material prices, interest rates, salvage values, and taxation, were not incorporated into the analysis to facilitate direct comparison between the selected construction products. The inclusion of these variables could influence the estimated life cycle costs under different economic conditions.

Furthermore, the study concentrated primarily on the economic dimension of sustainability and did not explicitly evaluate environmental and social performance indicators such as embodied carbon, greenhouse gas emissions, energy consumption, occupant comfort, or end-of-life recycling potential. Integrating Life Cycle Assessment (LCA) with Life Cycle Costing (LCC) would provide a more comprehensive evaluation of sustainable construction product selection.

Notwithstanding these limitations, the study provides useful empirical evidence on the influence of design decisions on the cost-in-use of construction products and demonstrates the value of Life Cycle Costing as a practical decision-support tool for improving long-term economic performance in the construction industry.

Future studies should extend the analysis to additional building components, different building types, and multiple geographical locations. Researchers are also encouraged to incorporate discounted cash flow techniques, sensitivity analysis, inflation, and integrated Life Cycle Assessment (LCA) to enhance the robustness and applicability of life cycle cost evaluations.

5. CONCLUSION

This study evaluated the effectiveness of life cycle costing as a decision-making tool for construction product design by examining the relationship between design decisions and the cost-in-use of construction products. The findings demonstrate that decisions made during the conceptual and detailed design stages significantly influence the long-term economic performance of buildings. In particular, material selection, durability, maintainability, adaptability, energy efficiency, and constructability were found to be major determinants of life cycle cost. The comparative analyses of alternative window systems and roofing materials revealed that construction products with relatively higher initial acquisition costs generally produce lower maintenance, repair, and replacement costs over their operational life. Consequently, these products achieve lower total life cycle costs and provide greater value for money than alternatives selected solely based on minimum initial expenditure. The study therefore confirms that cost-in-use is largely determined by design quality and that early design decisions have long-term financial implications for building owners and facility managers. Furthermore, the study highlights the importance of integrating Life Cycle Costing (LCC), Building Information Modelling (BIM), and Life Cycle Assessment (LCA) into construction planning and procurement. These tools enable project teams to evaluate competing design alternatives comprehensively by considering economic, functional, and environmental performance simultaneously. Their adoption promotes sustainable construction practices and supports informed investment decisions that optimize long-term asset performance. Overall, the findings reinforce the principles of Life Cycle Costing Theory and Value Management Theory by demonstrating that construction projects should be evaluated based on total ownership cost rather than initial construction expenditure. Accordingly, greater emphasis should be placed on whole-life economic performance during project planning to achieve sustainable development, improved building performance, and optimum value for money.

Based on the findings of this study, the following recommendations are made:

Construction clients should incorporate life cycle costing into project briefs and procurement strategies to ensure that investment decisions are based on whole-life economic performance rather than initial construction costs alone.

Quantity Surveyors should integrate Building Information Modelling (BIM), Life Cycle Costing (LCC), and Life Cycle Assessment (LCA) into cost planning and value engineering processes to facilitate more accurate evaluation of alternative design solutions.

Architects and engineers should prioritize durable, maintainable, adaptable, and energy-efficient construction products during the design stage to minimize long-term operational and maintenance costs.

Government agencies and professional regulatory bodies should develop policies and practice standards that encourage the adoption of whole-life costing principles in both public and private sector construction projects.

Institutions of higher learning and professional bodies should strengthen education and continuing professional development programs on life cycle costing, digital construction technologies, and sustainable procurement to improve industry-wide implementation of whole-life cost management.

Future researchers should extend this work by evaluating additional building components, incorporating discounting, inflation, sensitivity analysis, and environmental performance indicators into life cycle cost models to provide more comprehensive decision-support tools**.**

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6. COMPETING INTERESTS

None to declare

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