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Development of Sustainable and Cost-effective Housing Designs for low-income communities in Sri Lanka; An Analysis of Materials and Construction Costs

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ABSTRACT

Access to adequate housing is a fundamental human need and essential for individual and community well-being, much like food and water. Global housing developments, however, have made serious problems with the economy, society, and environment worse. Since sustainable housing can address these issues, it has become a major concern for governments, academic institutions, and business leaders. To succeed, sustainable housing must be technically feasible, socially acceptable, environmentally responsible, and economically viable. This study focuses on developing sustainable and cost-effective housing designs that focus on the specific needs of low-income communities in Sri Lanka. The approach begins with a comprehensive review of previous literature to identify key principles of sustainable construction. Based on these findings, the study proposes a housing design that integrates environmentally friendly materials for the foundation, flooring, walls, and roof. Multiple design scenarios will be evaluated based on the existing studies, and the associated costs calculated to determine the most viable and cost-effective option. The results of the study introduced sustainable and cost-effective building designs intergerning cost effective while environment-friendly materials for the foundation, external and internal walls, floor and roof to utilized. The estimated total cost of the most sustainable and cost-effective housing design across all the scenarios found that its around Rs 417,610. The outcomes of this research will offer valuable insights and guide recommendations for launching low-income housing projects. These solutions aim to address the housing crisis by promoting affordable and sustainable living environments within vulnerable communities in Sri Lanka.

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1. INTRODUCTION

The construction industry is one of the most significant consumers of environmental resources worldwide and one of the biggest industries responsible for giving rise to large amounts of waste (Meyer, 2009).

Over its lifespan, the construction

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industry consumes 30% to 40% of all natural resources and primary energy, contributing 30% of global greenhouse gas (GHG) emissions and 6% of global GDP (Hatfield-Dodds et al., 2017). Despite the sector's importance to the global economy, the UN estimates that about one billion people worldwide still live in inadequate buildings or are homeless (The Sustainable Development Goals Report, 2019). An internationally recognized fundamental human right that plays a significant role in society and provides people with a sense of dignity and security is access to adequate housing (Hohman, 2019). In Sri Lanka, only 5.2 million of 6 million families have access to some type of housing. More than 800,000 families currently live in poor housing with inadequate access to sanitary facilities and adequate drinking water (Ahmed et al., 2007). The housing deficit mainly affects low-income communities with lack of access to adequate housing. To mitigate this social problem, the government of Sri Lanka has launched several housing programs, targeting low-income families who do not have a permanent house or permanent income source (National Housing Development Authority, 2023), for instance, the 'Housing for All' program, which seeks to build 500,000 housing units by 2025. Low-income communities in the country frequently struggle with inadequate housing and a lack of fundamental amenities like access to sanitary facilities and clean water.

Most of the houses of these communities are constructed without proper design or materials, which can lead to issues with structure, health risks and social problems (Osumanu et al., 2018) . In addition, Sri Lanka's construction industry encounters difficulties like scarce materials, high costs, and a shortage of skilled labor (Shelter et al., 2022). Therefore, development of buildingmodels that are affordable, energy-efficient, and sustainable while offering suitable living conditions for the people has become a social necessity (Golubchikov et al., 2012). This requires creative thinking, thorough research, and coordination across different stakeholders, including the government sector, the private sector, and local communities and development of sustainable and affordable building models to address the housing issue, enhance the living conditions of low-income people, and promote the expansion of Sri Lanka's construction industry.

This research aimed to develop sustainable and cost-effective housing designs for low-income communities inSri Lanka that are tailored to the specific needs and challenges of these communities. The objectives of this study are,

- To identify the most cost-effective and sustainable materials for housing construction in Sri Lanka.
- To identify the design features that can be incorporated to reduce construction costs without compromising quality and safety.
- To propose housing designs that are made more accessible to low-income families through innovative financing options.

The study on the development of sustainable and cost-effective housing models for low-income communities in Sri Lanka holds significant value for various reasons. For low-income families who struggle to access adequate accommodation, this study directly addresses the ongoing housing crisis, offering affordable, safe, and durable housing solutions. The 'Sustainable Cities and Communities' is the one of Sustainable development goals (London et al., 2023) that Sri Lanka has committed to achieving which aligns with this study and promotes sustainable development efforts in the country. These housing models lead to reduced housing costs, increase energy efficiency, and contribute to local economic growth in terms of economically. In particular to the socially, it provides affordable and durable housing which results in enhancing overall quality of life, improves children's health and educational outcomes, and fosters social stability in the country. By encouraging innovation, enhancing the quality of buildings, and generating employment opportunities, the development of sustainable and low-cost housing models can assist the expansion of the construction industry in Sri Lanka. Overall, the significance of the study rests in its ability to address Sri Lanka's housing issue, enhance living conditions, enhance sustainable development, and assist the development of the country's construction sector.

2. LITERATURE REVIEW

2.1 Definition of Sustainability and Sustainable Housing

A document published in 1987 by the UN World Commission on Environment and Development (WCED) and titled "Our Common Future," also referred to as the Brundtland Report, introduced the idea of sustainable development (Lele et al., 1991). The Brundtland Report characterizes sustainable development as a *"Development that meets the needs of the present without compromising the ability of the future generations to meet their own needs"* (WCED, 1987). It emphasizes the importance of finding a balance between economic, social, and environmental goals. In terms of sustainable housing Meroni (2007) has explained that the concepts of sustainable housing include caring for people by making sure they live in an environment that is productive, healthy, and in balance with the surrounding environment. According to Choguill (2007), sustainable housing needs to be both technically and socially feasible as well as environmentally acceptable and economically viable. Sustainable housing, according to Habitat, (2013), is made up of environmentally and socially beneficial residential practices that are incorporated into larger settlement systems. Similar to this, Premius (2005) has defined "Sustainable housing" as housing designed to satisfy present-day needs without compromising the potential of future generations to satisfy their own needs. After examining several definitions, Arman et al. (2009) developed the following conceptual definition of sustainable housing: housing that satisfies current needs and demands without compromising the capacity of future generations to satisfy their own needs and demands in housing. There are significant and interconnected economic, social, and environmental components to affordable and sustainable housing. The definition provided by Premius (2005) strengthens the explanation by Arman et al., (2009). Numerous scholars have reviewed that the integration of environmental, social, and economic aspects is imperative for sustainable housing practices, as it plays a significant role in promoting human health, sustainability, and safety. Programs for sustainable housing must continually assess their economic viability, sociocultural acceptability, technical feasibility, and environmental compatibility to remain in place. However, these definitions often lack consensus on balancing affordability with sustainability, particularly in low-income contexts. While economic constraints are frequently mentioned, there is limited discussion on how policy frameworks can reconcile cost efficiency with environmental sustainability.

2.2. Importance of Sustainable Housing for Low Income Communities

Numerous scholars have reviewed that Sustainable housing for low-income communities is of paramount importance due to its potential to address various social, economic, and environmental challenges. Ilesanmi (2010) has explained that the concept of Sustainable Housing (SH) emphasizes how crucial it is to take ecological and social factors into account in addition to economic ones when developing new housing. In the context of housing development, integrating Sustainable Housing would not only give people a place to live but also have a significant positive influence on their health and overall well-being. Park et al. (2015) has mentioned that since most low-income households have limited access to cheap housing, it is clear that the aim of affordable housing must be sustainable in order to address the housing deficit. Turner et al. (2012) have reviewed that Sustainable housing can break the cycle of poverty by providing affordable and energy-efficient homes. This empowers low-income families economically by reducing long-term housing costs and creating opportunities for financial stability. similarly, Krieger (2019) has reviewed that Sustainable housing contributes to improved health outcomes by providing better indoor air quality, reduced exposure to environmental hazards, and access to green spaces. This positively impacts the overall well-being of low-income residents.

2.3. Challenges in Providing Sustainable Housing for Low-Income Communities

The provision of sustainable housing for low-income communities is a pressing global challenge that intersects social, economic, and environmental dimensions. As the world grapples with increasing urbanization and economic disparities, the need for affordable and sustainable sound housing solutions becomes paramount. Aghimien et al., (2018) has studied the key challenges of Sustainable Low-income housing delivery in Zimbabwe and the study has been able to determine the key challenges and measures to improve low-income housing in the country. The study concludes that Zimbabwe's main challenges to sustainable low-income housing delivery are inadequate budget allocation, lack of development funds, outdated policies, insufficient housing delivery programs, and high interest in capital finance. Muhammad et al., (2015) has also reviewed similar facts and findings to Aghimien et al., (2018) through his study and explored that inadequate funding, high mortgage interest rates, lack of well-developed mortgage institutions, inadequate institutional capacity and political interference are the key challenges of delivering sustainable low-income housing. Table 1 shows a list of challenges of providing Sustainable Housing for Low-income communities. Search highlights of previous research studies show several challenges in delivering Sustainable Housing for Low-income communities.

Table1: Challenges of providing Sustainable Housing for Low-income communities

Reference	High interest in capital finance	Inadequate funding	High cost of construction materials	Weaknesses of policies
(Richardson & Lynes, 2007)	x		x	
(Chan et al., 2009)				x
(Salleh,2008)		x		
(Araji et al., 2020)		x		
(Muhammad et al., 2015b)				x
(Ayedun et al., 2011)	x			
(Ugonabo et al., 2020)		x		x
(Chan et al., 2018)	x		x	
(Seneviratne et al.,2017)		x	x	x
(Bardhan et al., 2018)			x	x

2.4. Sustainable Building Materials

Building materials can make up to 80% of the total cost of a basic residential building, making them frequently the most significant tangible input (Zuraida et al., 2023). Housing, even affordable housing, must always be constructed using high- quality materials. High-quality materials, among other things, last a long time, have attractive qualities, and need minimal maintenance. 'Basic durability' could be used to describe this. A house must offer defense against the effects of the local climate, including cold and heat, wind and rain, etc. Common building materials like iron, cement, and concrete are typically not manufactured sustainably. These materials result in comparatively significant quantities of greenhouse gas emissions during production and transportation. As an alternative, there are locally manufactured and used building materials that do not produce a lot of CO_2 (Olanrewaju et al., 2018). Table 2 provides various building materials identified by scholars through their studies.

Table 2: Sustainable Building Materials

Materials	Building Components	Source
Daub, mud blocks, rammed Earth, Cement rammed earth, stabilized soil-cement blocks, waste recycled materials	Wall	(Gama et al.,2012)
Trombe Wall	Wall	(Jovanović et al., 2020)
Hollow Blocks	Wall	(SALGADU M.D.R.S,2020)
Bamboo scrimpe and laminated bamboo	Wall	(SALGADU M.D.R.S,2020)
Wattle and grass	Roof	(Mpakati-Gama et al., 2012)
Mud Concrete Block	Wall	(Udawattha et al.,2017)

2.5. Sustainable Materials Selection for Housing

An interdisciplinary approach called the Life Cycle Sustainability Assessment (LCSA) assesses the effects of products and processes simultaneously from an environmental, social, and economic standpoint (Onat et al.,2017). LCSA is produced by fusing three key processes: i) the environmental dimension is represented by the Life Cycle Assessment (LCA) (Zielinska, 2022); ii) The social dimension is represented by the Social Life Cycle Assessment (S-LCA) (Diego Alexis Ramos Huarachi, 2020); and iii) the economic component is described through life cycle costing (LCC) (Chaudhari et al.,2020). The following equation can be used to illustrate LCSA: LCSA = LCA + S-LCA + LCC. The most popular methodology for assessing a product's effects throughout its entire life cycle is still life cycle assessment (LCA) (Nawarathna et al., 2021). Takano, (2015) investigated the impact of material selection on a building's energy balance using LCA. Social Life Cycle Assessment (S-LCA) is a systematic approach that considers all effects on society during a product's life (Martin-Gamboa et al., 2020). The S-LCA approach addresses both societal positive and negative aspects (Goedkoop et al., 2022). Various social effects, including effects on worker safety, a fair wage, and access to resources, can be investigated in relation to the application of this strategy in the construction sector (Dong & Ng, 2015). A method for calculating the total cost of a project or design is called life cycle costing (LCC). It makes it easier for decision-makers to choose the course of action that will have the lowest overall cost without compromising functionality and quality (Llatas et al., 2020).

2.6. Building Information Modelling (BIM)

Building information modelling (BIM), which involves creating virtual models with parametric parts, has completely changed how building projects are conceptualized. It enables a continuous, dynamic update of the project (Gao et al.,2019). It gives professionals the knowledge they need to conduct successful analysis. With the use of Using BIM software, experts can monitor building schedules, minimize costs, and find errors in design (Figueiredo et al.,2021). Recently, there has been a noticeable surge in the adoption of BIM. BIM is widely used to enhance decision-making by reducing the amount of labor necessary to analyze different options in the early design stages (Chen, 2016). BIM is also seen to be a useful technology to support building life cycle analysis (Obrecht et al.,2020).

2.7. Multi Criteria Decision Making

When making decisions about specific project components, for example, those related to quality, security, ethics, finances, and human resources, it is crucial to take into account the various perspectives of the stakeholders involved. As a result, multiple criteria made during the design phase of a project include several factors, which must be analyzed to ensure a decision is made in the most optimal manner (Figueiredo et al., 2021). Several MCDM techniques have been proposed over the past few decades, each having advantages and limits (Taherdoost et al., 2024). The Analytic Hierarchy Process (AHP) stands out among them for having the benefits of simplicity of use, reproducibility, and reliability of results (Büyüközkan et al., 2021), and as a result, it gained prominence and is today one of the most used MCDM methodologies by academics and industry in general (Bhadra et al., 2022).

Through comparisons between criteria and priorities, Qualitative evaluations are converted into quantitative comparisons by the process, assisting decision-makers in finding the ideal solution to an MCDM problem (Bhadra et al., 2022). However, despite its widespread use, traditional AHP has limitations because its use depends directly on the ranking of criteria determined by professionals and decision-makers, who may have potential for bias (Sherif et al., 2022). Therefore, traditional AHP might not accurately represent the views of people participating in the decision-making process. Researchers developed fuzzy AHP (FAHP) to address the issue by combining AHP with fuzzy logic (Sherif et al., 2022). The FAHP produces more accurate results (Nazam et al., 2020), reducing the process' subjectivity so that it has no influence on the decision of the ideal method of action. Currently, FAHP is regarded as a tool that is more effective than traditional AHP (Akkaya et al., 2015).

2.8 Life Cycle Costing (LLC) in Sustainable Housing

For the determination of building's overall cost of ownership over time, life Cycle Costing (LCC) is a well-established economic assessment method. This focuses only on initial construction expenses compared to the traditional cost analysis, LCC considers long-term financial implications, including maintenance, operational costs, and end-of-life expenses (Fuller & Petersen, 1996) This method provides a holistic view of cost efficiency which making it an essential tool in sustainable housing development. Several studies emphasize the importance of LCC in optimizing construction material selection and reducing long-term financial burdens**.** For instance, (Jewell et al., 2005) highlight that choosing cost-effective**,** durable materials can lead to significant savings in maintenance and energy consumption**.** Similarly, Stephan et al., (2016) demonstrate that energy-efficient materials, despite their higher initial costs, result in lower life cycle expenses due to reduced operational costs. For low-income housing projects, affordability remains a key priority. However, short-term cost-cutting measures often result in higher long-term expenses due to poor material quality and high maintenance costs(Goh et al., 2015). LCC provides an effective solution by enabling decision-makers to select building materials and construction methods that balance affordability and sustainability. Studies on low-income housing in developing countries show that implementing LCC principles can enhance housing durability, reduce repair costs, and improve energy efficiency (Nanayakkara et al., 2022). In Sri Lanka, where a significant portion of the population faces economic constraints, adopting an LCC approach can help ensure that housing remains affordable not just at the construction stage but throughout its entire lifecycle. By integrating LCC into housing design decisions, this study identifies the most cost-effective and sustainable solutions for low-income households in Sri Lanka.

3. METHODOLOGY

This research addresses the optimized use of materials in foundation, floors, walls and roof in a residential house for Low-income communities in Sri Lanka. Alternative configurations are evaluated and compared. This study has used qualitative method to collect and analyse the data to achieve the research objectives. A detailed literature review is done in the first phase to identify the sustainable and cost-effective building materials used for low-income communities in Sri Lanka and identify the design features for low-cost housing in Sri Lanka. In the second phase, a housing design is proposed based on the analysed data from the previous literatures. The proposed housing design is based on 2D AutoCAD drawings and 3D model is developed using Autodesk Revit software. Scenarios are developed by using the selected construction materials for foundation, floor, walls and roof. Next, the material costs are calculated for each scenario and select the most cost-effective and sustainable combination for the proposed housing design.

3.1. Materials Selection

The focus on sustainable and cost-effective materials is driven by the need to address the housing and infrastructure challenges faced by low-income communities, while also considering environmental sustainability and affordability. The research in this area encompasses various aspects including the development of eco-friendly construction materials, innovative building techniques, and the impact of sustainable materials on the overall well-being of low-income communities.

Selecting cost-effective and sustainable materials is a crucial aspect of various fields including engineering, architecture, and construction. The process involves studying previous research to identify materials that meet both economic and environmental criteria. By analyzing the data from previous studies, the author has finalized the building materials for this study. The following table 3, 4, 5 and 6 presents the information gathered from the previous research about materials used for roofing, walls, floor and foundation in respectively and these are based of the low-cost building materials used for low-income housing in Sri Lanka.

Table 3: Sustainable and cost-effective material selection for roofing

	Material	**Environmental Impact**	**Durability**	**Cost**	**Source**
1	Asbestos sheet	High	High	Initial and maintenance cost is low	(Jayawardana et al., 2021)
2	Clay tiles	Low	High	Low	(Liyanage et al.,2022)
3	Concrete	Low	High	Initial land maintenance cost is high	(Liyanage et al.,2022)
4	Cement Fiber sheet	Low	High	Low	(Ministry of Urban Development and Housing,2020)
5	**Metal sheets**	**Low**	**High**	**Low**	**(Ministry of Urban Development and Housing, 2020)**

Table 4: Sustainable and cost-effective material selection for walls

	Material	Environmental Impact	Durability	Cost	Source
1	Cement Blocks	Low	High	Low	(Wickramaratne & Kulatunga, 2020)
2	Mud Concrete Block	Low	High	Low	(Udawattha et al., 2016)
3	Mud and Wattle	Low	Low	Low	(Dayaratne, 2008)
4	**Compressed Stabilized Earth Blocks (CSEB)**	Low	High	Low	(Dayaratne., 2008)

Table 5: Sustainable and cost-effective material selection for floor

	Material	Environmental	Durability	Cost	Source
1	Concrete	Low	High	Low	(Wickramaratne & Kulatunga, 2020)
2	**Tiles**	Low	High	**Initial cost is high**	(Wickramaratne & Kulatunga, 2020)

Table 6: Sustainable and cost-effective material selection for foundation

	Material	Environmental Impact	Durability	Cost	Source
1	Rubbe masory work	**Low**	**High**	**Low**	(Wickramaratne & Kulatunga, 2020)

3.2 Case Study Housing Design Description

After conducting a comprehensive literature review on low-income housing in Sri Lanka, key characteristics including size, construction materials, and housing components were identified. A cost-effective single-story housing model was developed based on these findings featuring two bedrooms, a bathroom, and a kitchen integrated with the living and dining area. The design prioritizes affordability while maintaining functionality and was developed in consideration of the minimum legal standards for housing in Sri Lanka. For the instance each bedroom has a minimum floor area of 10*12 sqft and the bathroom features a minimum floor area of 4*9 sqft, adhering to the standards specified for sanitation and hygiene (UDA, 2018). The decisions were made regarding appropriate construction materials for the foundation, walls, flooring, and roofing, Informed by the literature. The proposed design consists of a total floor area of 441 square feet, accommodating two bedrooms, combined living, dining, and kitchen space, and a separate bathroom with a shower. As shown in Figure 1 and 2 the layout of the case study house is illustrated.

Figure 1: Basic figures of the house

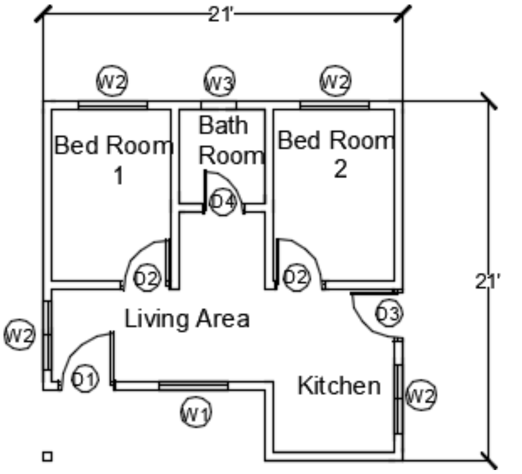


Figure 2: 3D View of the house

As informed by the literature, the decisions were made regarding appropriate construction materials for the foundation, walls, flooring, and roofing as represented in following tables. The foundation of the house is a Random Rubble Foundation that consists of irregularly shaped and randomly placed stones or rocks. The volume of the foundation is 590 Cubic Feet. The literatures explore several advantages (Ching et al.,2014), including Cost-effectiveness, good load bearing capacity, natural insulation and durability.

In the total house floor area is 441 Sq.ft with the open verandah. Concrete and tiles (1'*1') are used for the floor of the house. The wall area consists of external and internal wall. Both walls are Concrete Blocks (200mm), Clay Bricks (200mm) and Mud Concrete Blocks (MCB). Total wall volume of the house is 525 Cubic Feet. The total roof area is 720 Sq.ft with 30o pitch. Calicut tiles, Asbestos sheets and Fiber Cement sheets are used for the roof of the model house. Visual representation of materials proposed for floor, walls and roof are illustrated in figure 3, 4 and 5 in respectively.

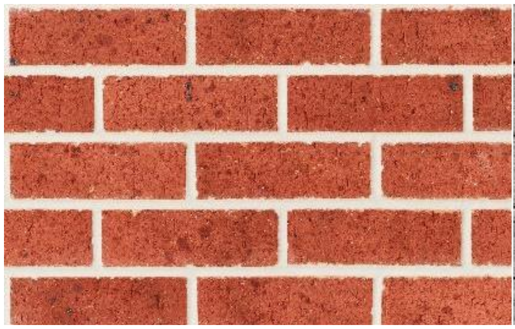
Figure 3: Materials used for Floor

(a). Concrete Floor

(b). Tiled Floor

Figure 4: Materials used for walls

(a). Clay Bricks



(b). Concrete Blocks

(c). Mud Concrete Blocks

Figure 5: Materials used for roof

(a). Calicut Tiles

(b). Asbestos sheets

(c). Fiber Cement sheet

Following an extensive review of the available literature on low-income housing in Sri Lanka, a meticulous selection of specific materials has been made for the foundational, flooring, walling, and roofing components of the proposed housing design. The choice of these materials is underpinned by a nuanced understanding of the prevalent challenges and characteristics identified in the literature. This deliberate selection aims to address both structural and economic considerations, ensuring a judicious balance between sustainability, cost-effectiveness, and local appropriateness. The incorporation of these materials reflects a strategic response to the unique requirements and constraints observed within the context of low-income housing in Sri Lanka, contributing to the development of a purposeful and contextually relevant housing solution.

4. ANALYSIS AND DISCUSSIONS

4.1. Scenario Development

Building upon the carefully chosen materials for the foundation, floor, wall, and roof identified through our literature review, five distinct scenarios have been meticulously developed for the proposed housing design. The purpose of exploring multiple scenarios is to assess the potential outcomes and optimize the design to align with the overarching goals of sustainability, affordability, and suitability for low-income communities in Sri Lanka.

4.1.1. Scenario 01

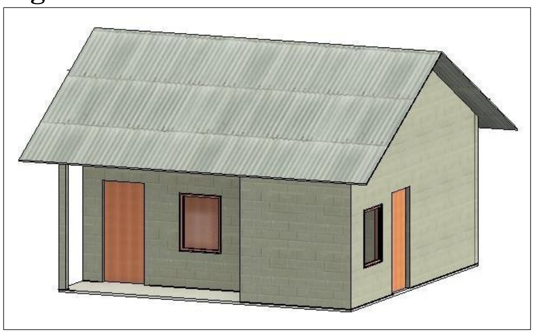
Scenario 01 of the proposed housing design is characterized by a specific set of construction materials carefully chosen to address key considerations including sustainability, affordability, and adaptability. The construction materials for the foundation, floor, wall, and roof are detailed in Table 7, providing a visual representation of the strategic choices made in the development of this scenario the 3D representation has been visually articulated in Figure 6.

Table 7: Material details of the foundation, floor, wall and roof of scenario 01

	Foundation	Floor	Wall	Roof
1	Rubble masonry foundation	Concrete	Clay bricks	Calicut tiles

Source: Author (2023)

Figure 4: 3D view of scenario 01



4.1.2. Scenario 02

The construction materials for the foundation, floor, wall, and roof associated with Scenario 02 are elucidated in Table 8. This visual representation offers a detailed insight into the material choices made for this scenario, contributing to a comprehensive understanding of the design variations explored in response to the unique needs of low- income communities in Sri Lanka. The 3D representation of the Scenario for the proposed housing design has been visually articulated in Figure 7.

Table 8: Material details of the foundation, floor, wall and roof of scenario 02

	Foundation	Floor	Wall	Roof
2	Rubble Masonry foundation	Tiled	Concrete bricks	Asbestos sheets

Source: Author (2023)

Figure 7: 3D view of scenario 02

4.1.3. Scenario 03

The construction materials for the foundation, floor, wall, and roof associated with Scenario 03 are Rubble masonry foundation, salvaged materials, mud concrete blocks and Fiber cement sheets and they are elucidated in Table 9. The 3D representation of the Scenario for the proposed housing design has been visually articulated in Figure 8.

Table 09: Material details of the foundation, floor, wall and roof of scenario 03

	Foundation	Floor	Wall	Roof
3	Rubble masonry foundation	Salvaged Materials	Mud concrete block	Fiber Cement sheets

Source: Author (2023)

Figure 8: 3D view of scenario 03

4.1.4. Scenario 4

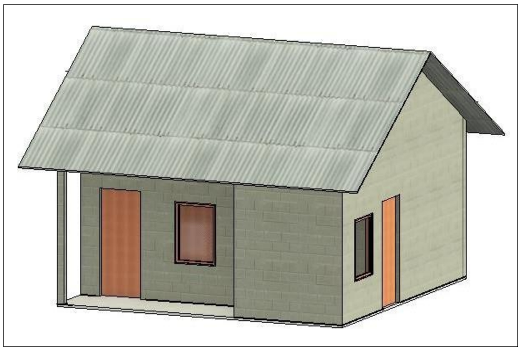
Scenario 04 of the proposed housing design is characterized by a distinct set of construction materials, as delineated in Table 10 and 3D representation in Figure 9.

Table 10: Material details of the foundation, floor, wall and roof of scenario 04

	Foundation	Floor	Wall	Roof
4	Rubble masonry foundation	Tiled	Concrete bricks	Asbestos sheets

Source: Author (2023)

Figure 9: 3D view of scenario 04



4.1.5. Scenario 5

The fifth scenario of the proposed housing design exhibits a unique combination of building materials, as illustrated in the diagram provided as Table 10. The 3D representation of the Scenario for the proposed housing design has been visually articulated in Figure 10.

Table 11: Material details of the foundation, floor, wall and roof of scenario 05

	Foundation	Floor	Wall	Roof
5	Rubble masonry foundation	Concrete	Clay bricks	Fiber Cement sheets

Source: Author (2023)

Figure 5: 3D view of scenario 05

The previously outlined scenarios, denoted as Scenario 01, Scenario 02, Scenario 03, Scenario 04, and Scenario 05 represent distinct instances among the five scenarios systematically developed for the proposed housing design.

4.2. Cost Analysis

The cost analysis for the proposed housing design encompasses a meticulous calculation of expenses associated with the foundation, floor, wall, and roof components. This computation is based on systematically collected and analyzed data, ensuring a thorough assessment of the financial implications of the chosen construction materials. In order to provide a detailed examination of the financial implications associated with each housing scenario, the material costs have been meticulously calculated and are presented in the following table 12, 13, 14, 15 and 16. Each table corresponds to a specific scenario, delineating the individual costs for the foundation, floor, wall, roof, labour, and miscellaneous expenses. This approach allows for a focused analysis of the unique cost structures associated with each scenario, facilitating a nuanced understanding of the financial considerations integral to the proposed housing designs. The quantity of the materials was calculated by using BOQ and unit cost is computed by using collected data and analysed data.

Table 12: Cost calculation for scenario 01

ITEM	UNIT	QUANTITY	COST PER UNIT (RS)	TOTAL COST (RS)
FOUNDATION				
1.Cement for foundation	Bags (50kg)	33	20	**76,560**
2. Sand for foundation	Cube	2	23,500	**47,000**
3. Aggregate for foundation	Cube	0.21	20,000	**4,200**
FLOOR				
4.Cement	Bags (50kg)	28	20	**64,960**
5. Sand	Cube	0.66	23,500	**15,510**
6. Aggregates	Cube	0.21	23,000	**4,830**
WALL				
7. Clay bricks	No.	8671	38	**329,498**
8. Cement for mortar	Bags (50kg)	13	2,320	**30,160**
9. Sand for mortar	cube	0.77	23,500	**18,095**
ROOF				-
10. Calicut tiles	No.	940	92	**86,480**
			Total cost	**677,293**

Source: Author (2023)

Table 13: Cost calculation for scenario 02

ITEM	UNIT	QUANTITY	COST PER UNIT (RS)	TOTAL COST (RS)
FOUNDATION				
1. Cement for foundation	Bags (50kg)	33	2,320	**76,560**
2. Sand for foundation	Cube	2	23,500	**47,000**
3. Aggregate for foundation	Cube	0.21	20,000	**4,200**
FLOOR				
4.Cement	Bags (50kg)	11	2,320	**25,520**
5. Sand	cube	0.52	23,500	**12,220**
6. Tiles (1' x 1')	No.	380	680	**258,400**
WALL				
7. Concrete blocks	No	2162	105	**227,010**
8. Cement for mortar	Bags (50kg)	25	2,320	**58,000**
9. Sand for mortar	cube	1.47	23,500	**34,545**
ROOF				
10. Asbestos sheets	No.	35	3600	**126,000**
			Total cost	**869,455**

Source: Author (2023)

Table 4: Cost calculation for scenario 03

ITEM	UNIT	QUANTIT Y	COST PER UNIT (RS)	TOTAL COST (RS)
FOUNDATION				
1.Cement for foundation	Bags (cu.ft)	33	2,320	**76,560**
2.Sand for foundation	Cube	2	0	**47,000**
3.Aggregate for foundation	Cube	0.21	0	**4,200**
FLOOR				
4.Cement	Bags (cu.ft)			-
5. Aggregates	m3			-

WALL				
6. Clay bricks	No.	2905	38.00	**110,390**
7.Cement for mortar	Bags (kg)	10	2,320.00	**23,200**
8. Sand for mortar	Cube	0.56	0	**13,160**
ROOF				
9.Fibre Cement sheets	No.	270	0	**143,100**
			Total cost	**417,610**

Source: Author (2023)

Table 15: Cost calculation for scenario 04

ITEM	UNIT	QUANTITY	COST PER UNIT (RS)	TOTAL COST (RS)
FOUNDATION				
1. Cement for foundation	Bags (50kg)	33	0	**76,560**
2.Sand for foundation	m3	2	23,500	**47,000**
3.Aggregate	m3	0.21	20,000	**4,200**
FLOOR				
4. Cement	Bags (50kg)	28	0	**64,960**
5. Sand	cube	0.66	23,500	**15,510**
6. Aggregates	m3	0.21	23000	**4,830**
WALL				
7. Clay bricks	No.	8671	38	**329,498**
8. Cement for mortar	Bags (50kg)	13	0	**30,160**
9. Sand for mortar	cube	0.77	0	**18,095**
ROOF				
10. Asbestos sheets	No.	35	0	**126,000**
			Total cost	716,813

Source: Author (2023)

Table 16: Cost calculation for scenario 05

ITEM	UNIT	QUANTITY	COST PER UNIT (RS)	TOTAL COST (RS)
FOUNDATION				
1. Cement for foundation	Bags (50kg)	33	2,320	**76,560**
2. Sand for foundation	Cube	2	23,500	**47,000**
3. Stones for foundation	Cube	0.21	20,000	**4,200**
FLOOR				
4.Cement	Bags (50kg)	28	2,320	**64,960**
5. Sand	Cube	0.66	23,500	**15,510**
6. Aggregates	Cube	1.3	23000	**29,900**
WALL				
7. Clay bricks	No.	8671	38	**329,498**
8. Cement for mortar	Bags (50kg)	13	2,320	**30,160**
9. Sand for mortar	cube	0.77	23,500	**18,095**
ROOF				
10. Fiber Cement sheets	No.	3270	530	**143,100**
			Total cost	**758,983**

Source: Author (2023)

The above table shows the cost of each scenario and Table 17 shows the Total Material Costs Breakdown for Each Housing Design.

Table 17: Costs Breakdown for Each Housing Design (in Rs.)

Category	Scenario 01	Scenario 02	Scenario 03	Scenario 04	Scenario 05
Foundation	127,760	127,760	127,760	127,760	**127,760**
Floor	85,300	296,140	0	85,300	**85,300**
Wall	377,753	319,555	146,750	377,753	**377,753**
Roof	86,480	126,000	143,100	126,000	**143,100**
Total Cost	**677,293**	**869,455**	**417,610**	**716,813**	**758,983**

Source: Author (2023)

In comparing the costs of different scenarios, Scenario 02 shows a higher overall cost due to the use of tiles for flooring. In contrast, Scenario 03 records the lowest cost by utilizing salvaged materials for the floor, demonstrating a more balanced cost distribution across all components. Based on this analysis, Scenario 03 emerges as the most sustainable and cost-effective housing design.

Based on the analysis a comprehensive exploration of sustainable and cost-effective housing designs for a low-income community in Sri Lanka has been undertaken. The research involved an extensive review of existing literature, identifying common characteristics of low-income housing in the region, including considerations of size, construction materials, and housing components. This literature review informed the development of five distinct scenarios, each integrating specific construction materials for the foundation, floor, wall, and roof.

A meticulous cost analysis was conducted, presenting a detailed breakdown of material costs for each scenario. Unexpected costs and challenges encountered during the cost estimation process were discussed, demonstrating an awareness of potential complexities in the implementation phase and strategies employed to mitigate these challenges. The overall costs of each design were compared, highlighting variations in material and labor expenses.

Furthermore, visual representations, including 3D models and figures, were employed to enhance the clarity of the proposed housing designs. The integration of community feedback, where applicable, was also considered in refining the designs to align with local preferences and needs.

Through this multifaceted analysis, the research aims to contribute valuable insights into the development of sustainable and cost-effective housing solutions tailored to the specific context of low-income communities in Sri Lanka. The synthesis of literature, scenario development, cost analysis, and visual representation collectively forms a robust foundation for informed decision-making and future directions in the field of affordable housing.

5. CONCLUSION

The research embarked upon an exploration into the identification of the most sustainable and cost-effective construction materials, coupled with design features, tailored for housing solutions within low-income communities in Sri Lanka. With a focus on Sri Lanka, where economic constraints often intersect with environmental considerations, the study endeavors to bridge the gap between sustainability and affordability in the realm of housing. The significance of this research lies in its potential to inform policy, guide architectural practices, and contribute to the development of housing solutions that transcend economic limitations while prioritizing environmental responsibility. The pressing nature of housing inadequacy within low-income communities underscores the need for targeted and pragmatic research that directly addresses the unique contextual challenges faced by these communities.

The primary purpose of this study is to unearth insights into construction materials and design features that strike a delicate balance between sustainability and cost- effectiveness. By doing so, the research aspires to provide a foundation for the conceptualization and implementation of housing designs that not only withstand economic constraints but also contribute to the broader objectives of sustainable development and community resilience. Conducted through a meticulous review of existing literature, exploration of sustainable development principles, and scenario-based design development, the research methodologically draws from both theoretical foundations and practical considerations. The integration of community engagement and participation further enhances the depth of the study, ensuring that the proposed housing designs align with the lived experiences and preferences of the intended beneficiaries.

This study fulfilled the objective one by identifying locally available and environmentally sustainable materials that minimize costs while maintaining durability and efficiency. These materials, evaluated through literature analysis and scenario-based assessments, highlight the feasibility of using alternative resources for instance agro-industrial waste and recycled materials. As a next objective achievement, this study examined various design strategies that optimize space, improve thermal comfort, and reduce energy consumption, thereby lowering construction and long-term maintenance costs. The incorporation of passive design techniques and modular construction methods ensures affordability without compromising safety and quality. By analyzing cost of the housing designs this research provided five housing projects that are made more accessible to low-income households through innovative financial options.

The major findings of this research are anticipated to contribute a nuanced understanding of the optimal interplay between sustainable construction materials and design features, elucidating the pathways to develop housing solutions that are both economically viable and environmentally responsible. These findings are poised to offer valuable insights for policymakers, architects, and stakeholders involved in the creation of housing solutions for low-income communities, not only in Sri Lanka but also serving as a reference for similar contexts globally.

5.1. Research Implications

The implications of this research extend across multiple domains, encompassing environmental, social, economic, and policy considerations. By exploring the optimal synergy between sustainable construction materials and design features for housing in low-income communities in Sri Lanka, the research generates insights that can influence practices, policies, and perceptions in the field of affordable and environmentally conscious housing. The research underscores the potential to reduce the environmental footprint associated with housing construction. By identifying and promoting sustainable construction materials, the environmental impact of housing projects can be mitigated. This includes minimizing resource depletion, lowering energy consumption, and addressing issues related to waste management. The integration of eco-friendly design features contributes to creating living spaces that harmonize with the natural environment, promoting biodiversity and overall ecological health.

At its core, the research strives to enhance the quality of life for residents in low-income communities. By designing housing solutions that are sustainable and cost-effective, the social implications are profound. Access to safe, affordable, and environmentally conscious housing can positively impact the health and well-being of community members. Additionally, by incorporating community engagement in the design process, the research promotes a sense of ownership and pride among residents, fostering a more inclusive and participatory approach to housing development. The economic implications of the research are twofold. Firstly, by identifying cost- effective construction materials and design features, the study contributes to reducing the financial burden on both residents and developers. Affordable housing solutions align with economic realities, ensuring that low-income communities can access safe and sustainable living spaces. Secondly, the research has the potential to stimulate economic activity by promoting the use of locally sourced materials and labor, thus contributing to community development and resilience.

The findings of this research carry implications for policymakers involved in urban planning and housing development. By highlighting the benefits of sustainable construction practices, policymakers can be informed to create supportive frameworks and regulations. This may involve incentivizing the use of environmentally friendly materials, streamlining approval processes for sustainable designs, and integrating sustainable practices into broader urban development strategies. Ultimately, the research can influence the formulation of policies that foster sustainable and inclusive urban environments. For architects and design practitioners, the research provides a valuable resource for informed decision-making in the creation of housing designs. It encourages a departure from conventional approaches toward innovative, context-specific solutions. By incorporating sustainable materials and design features, architects can contribute to the evolution of design practices that prioritize not only aesthetics but also the long-term well-being of inhabitants and the surrounding environment.

The research places a strong emphasis on community engagement and participation throughout the design process. This approach has the potential to empower communities, allowing them to actively shape the spaces they inhabit. Empowered communities are more likely to sustainably manage and maintain their living environments, fostering a sense of community pride, resilience, and social cohesion. While rooted in the context of Sri Lanka, the research's implications extend globally. The principles and insights derived from this study can be adapted and applied in various low-income settings facing similar challenges. The research thus contributes to a broader global dialogue on sustainable development and affordable housing, with potential applications in diverse geographical and cultural contexts.

5.2. Limitation of the Study

This research, despite its comprehensive approach and valuable contributions to the field of sustainable and cost-effective housing designs for low-income communities in Sri Lanka, is not without its limitations. The study focuses on low-income communities in Sri Lanka, and while the findings may offer insights into similar contexts, they might not be directly applicable to different geographical or cultural settings. Generalizing the results to a broader global context may require additional research and considerations. The depth and breadth of the study might be constrained by available resources, including time, and access to specific data. These constraints could impact the comprehensiveness of the literature review, the scale of community engagement, and the scope of the proposed housing designs. Also, socioeconomic conditions within low-income communities are dynamic and subject to change. The study captures a snapshot of these conditions, but shifts in economic factors, government policies, or community dynamics could impact the feasibility and sustainability of the proposed housing designs.

The cost analysis is based on assumptions and estimations, as actual costs can vary based on market fluctuations, regional differences, and unforeseen circumstances during the construction process. The accuracy of the cost projections is contingent on the availability of real-time data and the stability of economic conditions.

Furthermore, this study primarily focuses on identifying cost-effective and sustainable construction materials and design features, however, it does not comprehensively assess the impact of climate change and disaster risk reduction strategies in housing construction. Given that many low-income communities in Sri Lanka reside in disaster-prone or environmentally sensitive areas, future research should incorporate a detailed analysis of climate resilience and foundation design adaptations to mitigate risks like floods, landslides, and erosion.

5.3 Future Direction of the Study

- Conduct longitudinal studies to assess the long-term performance, durability, and adaptability of sustainable housing designs.
- Investigate emerging construction technologies and materials to stay abreast of advancements in sustainable and cost-effective building practices.
- Implement Community-Based Participatory Research methodologies to involve community members more actively in the research process. Engaging communities in a collaborative manner can ensure that housing designs are culturally sensitive, address community needs, and foster a sense of ownership and sustainability.
- Develop models that assess the affordability of sustainable housing designs over the life cycle of the buildings.
- Evaluate the impact of existing policies and regulations on the implementation of sustainable and cost-effective housing designs.

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