Sustainable Earthen Housing System For Forcibly Displaced Population And Disaster Affected Areas

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Abstract - Forced displacement is the most critical developmental and humanitarian challenge around the world, predominantly affecting developing nations. Solutions are required from all sectors to help millions of refugees from forcibly displaced communities and disaster-affected areas. Accordingly, the highest life-sustaining essential vital for a displaced population is shelter. Thus, providing sustainable housing is crucial for better living standards and the global goal of sustainability. Sustainable housing must comply with several economic and ecological demands. The utilization of earth as a building material is one of the prehistoric and the most common construction technique widely used by a large percentage of populations in developing nations. The application of earth for housing is sustainable since it is pollution-free, natural, and versatile. Furthermore, the utilization of earthen housing satisfies the three pillars of sustainability; economic, environmental, and social sustainability. Finally, implementing earthen housing for the resettlement of vulnerable groups is a sustainable approach that benefits humans and nature.

Keywords - Sustainable Material, Resettlement, Earthen Housing, Sustainability

I. Introduction

Currently, around the world, over 61 million peoples are reportedly displaced. Including 21 million refugees, many of whom are driven from their homes by the rise in conflict and violence. Africa comprises more than 15.5 million internally displaced peoples and one-third of the global forcibly displaced population[1]. Additionally, natural disasters have given rise to increased demand for resettlement and sustainable housing. Adequate housing solutions are universally provided for affected inhabitants through international and humanitarian assistance. The right to adequate shelter is one aspect of the right of every person to enjoy a suitable standard of living.

Sustainable buildings are structures constructed to satisfy the environmental pillar of sustainability by life cycle use of materials and protection of the health of the society. Economic advancement in the building industry, with minimum impact on the environment, is realized by sustainable building construction practice[2].

Rammed earth has several qualities that make it stand out from other building materials. Some of the distinct properties are high thermal mass, high fire resistance, and its availability around the world. Earth is natural, versatile, durable, and of stable value when used as a building material. The cost for the construction of reamed earth housing can be less than two-thirds of a standard frame house[4]. Strew is used to prevent shrinkage and cracking during drying, which is dependent on the composition. Straw is an agricultural waste product that has no use; thus, it is a secondary-agricultural product. Stabilizing the rammed earth mix with cement or lime can improve its material strength. Rammed earth has been widely used for thousands of years and still today. According to the United Nations, about one-third of the world population lives in earthen housing. Also, it is an effective and economical form of housing construction[3].

II. Sustainability Framework

Sustainability is based on environmental, social, and economic pillars and their interaction. The primary concept of sustainability in the housing sector is constructing buildings to be environmentally friendly, economically feasible while ensuring a healthy environment for its occupants. Sustainable construction in buildings consists of various approaches projects that comprise environmental protection with the recycling of waste for the manufacturing of construction materials[5].

Sustainability is defined as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” [6]. Enhanced quality of life is when people are enabled to live in a healthy environment with better social, economic, and environmental conditions. Thus, with an objective of resource conservation and cost-efficiency [2].

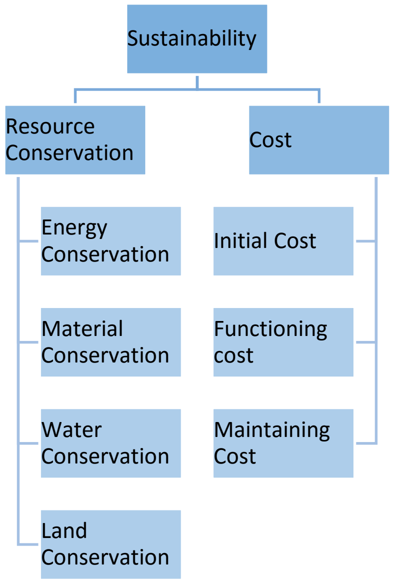

Figure 1 Sustainability Framework

A. *Energy Conservation*

Resource conservation is the proper utilization of natural resources to satisfy the current generation while preserving the amount needed for future generations [2]. Energy and resource consumption in buildings ranges from material manufacturing to construction, operation, and demolition.

Energy conservation aims to reserve nonrenewable resources by increasing the consumption of renewable resources. Accordingly, by choosing materials and construction methods that are important to reduce energy consumption, energy is conserved. Thus, the amount of embodied energy in construction materials will aid in selecting materials with less energy consumption over mining, processing, manufacturing, and transporting. Furthermore, designing for energy-efficient deconstruction and recycling of materials is critical for resource and environmental conservation. Thus, choosing construction materials suitable for reuse and recycling, based on the amount of hazard, biobased, quality, and recyclability, will create a green and sustainable environment.

B. *Material Conservation*

The ecosystem is affected due to the mining and use of natural resources as building materials. Accordingly, the large percentage consumption of raw materials is from non-renewable resources [2]. Consequently, the consumption of non-renewable materials is reduced by;

- Using durable materials.
- Using local materials
- Adopting waste minimization.
- Designing for pollution prevention.
- separating non-toxic or less-toxic materials

III. SUSTAINABLE HOUSING

The classification of vulnerable groups generally includes children, immigrants, refugees, and senior citizens [6]. Sustainable, environmentally conscious, and affordable housing for vulnerable groups, can be achieved through principles and related rationales from the basis of sustainable housing practices. Thus, contributing to minimizing the carbon footprint of buildings throughout the lifecycle from material source, manufacturing, construction, use, maintenance, restoration, finally demolition [7]. Some of the measures of sustainable building are;

a) Conservation of the environment

b) Economic efficiency

c) Social participation

d) Cultural adequacy

A. *Conservation of the enviroment*

Currently, the major environmental problem around the globe is climate change. Global climate change causes environmental, social, and economic losses. Some of the impacts are the increase in temperatures, flooding, storms, and landslides. Thus, sustainable housing needs to become resilient to extreme weather events caused by climate change.

B. *Economic Effectiveness*

The housing industry influence the economic capacity of a nation. The building sector shall satisfy its occupants' demand and the economic growth of a country. Hence, the production of housing stock, based on the selection of local materials and solutions, will achieve economic effectiveness. Consequently, using local materials and solutions for the life cycle of a building from design, construction, refurbishment, and maintenance contribute to local employment opportunities.

C. *Social Participation*

The building sector shall satisfy the social pillar of sustainability, which includes public participation and community inclusiveness. Consequently, addressing the need for adequate, healthy, safe, and affordable housing through state support by creating access to utilities and services to marginalized and vulnerable groups. Furthermore, creating housing solutions for people affected by natural and human-made disasters.

D. *Cultural Adequacy*

Housing strategy shall satisfy issues regarding cultural uniqueness and value. Housing strategies shall protect landscapes, historical and cultural heritages that have a significant cultural and territorial impact.

IV. SUSTAINABLE DESIGN

Sustainable buildings lessen their ecological impact and improve the welfare of their residents. Thus, to achieve building sustainability is to address the environmental problem in the early design stage, where the durability and safety of buildings are evaluated [5]. Sustainable housing is a building that is ecological during the entire life cycle. The complete life cycle of a building involves stages from site selection to demolition, shown on figure 2 below.

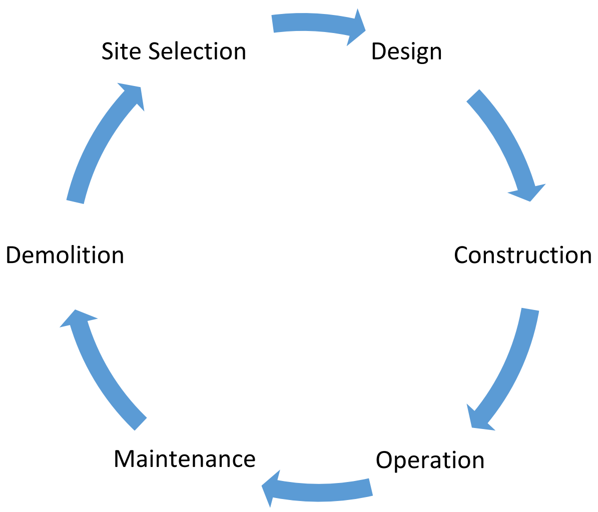

Figure 2 Life Cycle of Building

The life cycle of a building starts at site selection and rages till demolition, where recycling and disposal reduce waste associated with demolition [2]. All parties involved in the design and construction of a building project play a vital role in minimizing the environmental impact of buildings by applying the principle of sustainability during the design stage. "The stages of sustainable structural design are pre-design; concept design; schematic design; detail design and post-occupancy evaluation, with the basic goal of achieving the expected structural performance and environmental protection [3]."

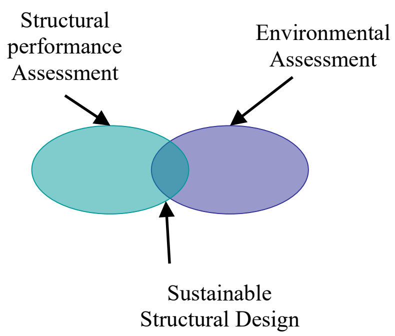

Figure 3 Sustainable Structural Design

V. GREEN BUILDINGS

Globalization harms the environment. Thus, applying green building design, construction, and operational practices decrease the impact. The three pillars of sustainability and green building design have a common goal of addressing the environmental impact of buildings. Accordingly, the basis for the selection of materials is resource usage, energy consumption, amount of waste, environmental, social, and cultural issues.

Green buildings utilize non-renewable resources such as; a metallic element, minerals, fuels, water, land, timber, fertile soil, clean air, and biodiversity in an efficient manner. The environmental impacts of materials over their life cycle from resource manufacturing to recycling, are addressed through Life Cycle Assessment (LCA) [5]. The sustainability performance of green is assessed not only for the design stage but also for operation and maintenance.

VI. EARTHEN BUILDING SYSTEMS

Most of the ancient and historic earthen buildings have a lifespan of more than 100 years. Earth can be used, for a variety of applications in walls, façades, roofs, gardens, terraces, and open spaces. Earthen building materials are stable and durable. Thus, earthen materials have a favorable life cycle impact [8]. Adobe rammed earth, cob, are used for the structural and nonstructural application of earthen house.

A. Rammed Earth Based Housing

The most common use of Unstabilized earth in developing nations is for the construction of many historical buildings and numerous houses. Rammed earth has good strength in compression but poor strength in shear and tension [7]. As a result of the development of rammed earth technology, cement stabilizes the mix to gain high strength and durability. Rammed earth is environmentally friendly and has a significant thermal comfort. Rammed earth absorbs heat during the daytime and releases the stored heat when the temperature drops. Thus, enabling it to act as a thermal mass like concrete and brick, it performs like a passive heating system, reducing energy consumption for temperature control.

The extraction of the earth for earthen building materials is done well below the topsoil to protect the agricultural capacity of the land. Earth, from two or more quarries, is used to achieve an even particle size distribution. Furthermore, by using stabilizing agents like cement and pozzolans allow the use of a different type of earthen materials. Thus, stabilization modifies the material properties of soils such as; absorption capacity, volume, strength, and durability. The most common advantage of stabilization is higher compressive strength and modulus of rupture to resist the effects of erosion from weathering damage.

Moisture can degrade un-stabilized earthen buildings and cause to lose its structural strength. Earthen building materials shall not be used, for substructure applications such as; foundation, basement walls, and retaining walls. Protective measures such as raising the earthen building material from flood level, coating with renewable earthen plaster, or overhangs of sufficient size provided to deflect wind-driven rain [8]. A small amount of cement stabilization shall be used for a rammed earth wall to decrease its environmental effect. Clay and silt content and particle size distribution, assessed to determine the appropriate amount of cement needed for the mix. Repair of an earthen building carried out using the same material used during the original construction.

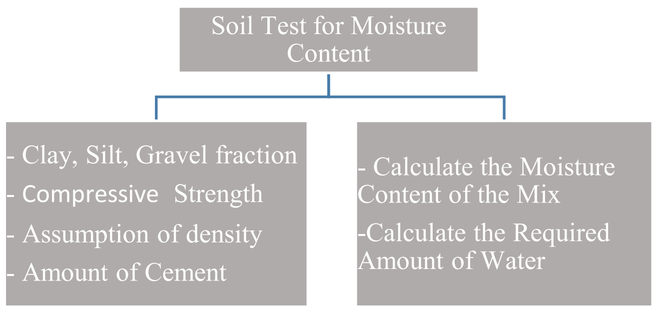

Figure 4 Preparation of Rammed Earth for Construction

In high seismic risk areas, earthen and tile roofs and any other supporting structures shall be lightweight. In such zones, the plan layout of the house shall be regular both in plan and elevation. There shall be a rigid diaphragm connection across intersections to prevent separation during seismic shaking by applying a lateral restraint shall be provided by a diaphragm, bond beam, or other similar structural members. Earthen walls shall be a minimum of 250 mm thick. Unreinforced walls and columns higher than 3.3m and 2.4mm shall have their structural response assessed by an experimental study. In earthen buildings, lateral restraints from timber, steel, and reinforced concrete can be used. Distribution of bracing shall be around the building perimeter to resist out of plane bending and Torsional forces [9].

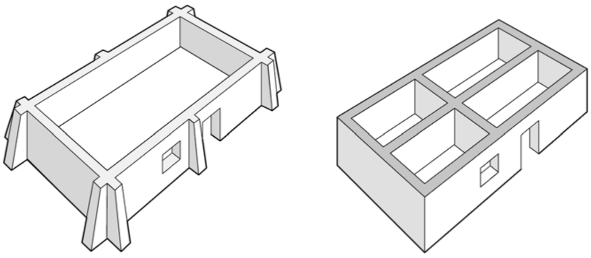

Figure 5 Bracing Element and Dense Wall Systems for Out of Plane Stability

Bracing elements are constructed monolithically with structural members. Various researches have shown that shake table experiments for a rammed earth structure shall be reinforced and interconnected to remain intact and stable under seismic shaking [8]. Reinforcement spacing decreased with higher seismic risk. When reinforced, rammed earth members possess ductility and also resist lateral forces due to an earthquake shaking [10]. Thus, reinforcement placed at weak locations such as wall corners, openings control the stress concentration. Thin reinforcement shall be laid on mortar joints and secured into walls at corners. Additionally, in walls cracking can be reduced with vertical or horizontal reinforcement. Cracking and fall off of wall pieces can be prevented by providing external mesh or mortar joint reinforcement.

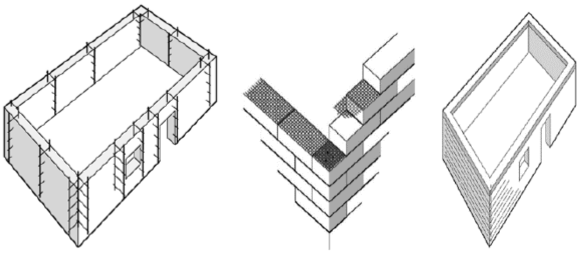

Figure 6 Vertical and Horizontal Reinforcing for Crack Control

B. Material Properties of Rammed Earth

Basic material properties of Rammed earth varies based on the type and the composition of the earth sample. The range for the basic material properties has been computed by various researchers and experiments. The Material properties of rammed earth is specified below are based on NZS 4297 (1998): Engineering design of earth buildings [Building Code Compliance Documents] [8].

- Modulus of Elasticity [8]
  - For silty or poorly graded materials, range between 120 kPa –3 GPa
  - For silty-sandy clays, and poorly graded sands 3 GPa – 7 GPa,
  - silty sands and sandy clays nearer 7 GPa, gravely soils 7 GPa – 20 GPa.
- Compressive strength (flexural, direct compression or bearing) fe = 0.5 (MPa)
- Tensile/flexural bond strength feb = 0.02
- Flexural tensile strength fet = 0.1
- Shear strength of steel reinforced earth fes = 0.35

C. Design of Rammed Earth Building

Design of rammed earth Building is required to satisfy various structural and seismic provisions. The basis for these specifications is centered on various research and experimental procedures listed below [8];

- when the seismic zone factor exceeds 0.6, the recommended maximum ground floor area is;
  - 600 m2 for single-story rammed earth buildings
  - 200 m2 for two-story rammed earth buildings
- Wall height must be less than eight times its thickness and less than six times the wall thickness for medium and high seismic risk areas respectively.
- The total height of the earth wall from the lowest level of foundation to the top level shall not exceed 6.5 m.
- Limit total wall openings to one-third of the total wall length
- Deflections shall be less than h /150, for seismic design under elastic response
- Minimum column dimensions shall be 250 mm square if reinforced, 580 mm square if unreinforced.

D. Sample Analysis of Rammed Earth Building

A simplified model for a rammed earth housing has been done using a finite element software (Etabs 2017). Etabs is an integrated building design software with an extended three-dimensional analysis of building systems. Thus, the model incorporates two basic components, the substructure, and superstructure. Based on conventional construction methods, the superstructure is modeled as a rammed earth wall. Whereas, the substructure has been modeled as a masonry wall. Generally, modeling and material specification had been done based on the design requirements stated in section B and C.

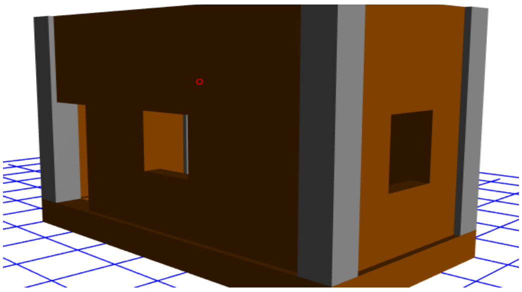

Figure 7 Structural Model

A structural design has been done for gravity and seismic loading conditions. Since the model is a one-story building, equivalent static analysis has been done instead of a dynamic earthquake analysis, where the seismic loads applied in x and y directions.

Table 1 Load Cases Summary

Name	Type
Dead	Linear Static
Live	Linear Static
EQX+	Linear Static
EQX-	Linear Static
EQY+	Linear Static
EQY-	Linear Static

The impact of earthquakes on the design is assessed in accordance with the requirements of prEN-1998-1:2003. The parameters listed below are used in the analysis.

Medium Ductility structural behavior (DCM);

$$q=q_o*k_w\geqslant 1.5 \qquad \textbf{Equation 1- prEN 8- 5.1}$$

Where :- q=Behavior Factor

q_0=Basic value of behavior factor=$3\alpha_u/\alpha_1$ for Ductility medium Frame System

$\alpha_u/\alpha_1=1.1$ for multistory multi-bay frame structure

$k_w=1$ for frame & frame equivalent dual system

$$q=3*1.1*1=3.3\geqslant 1.5 \qquad \text{Use} \qquad q=3.3$$

The behavior factor q is "an approximation of the ratio of the seismic forces that the structure would experience if its response was completely elastic with 5% viscous damping, to the seismic forces that may be used in the design, with a conventional elastic analysis model, still ensuring a satisfactory response of the structure" [11].

During modeling, a fine mesh is needed to obtain a definitive result at corners, openings, and other critical locations. Based on the stress distribution for various modes and load combinations, corer locations shall be designed as rigid and stabilized reinforced rammed earth members. Additionally, there is significant stress between the boundary of masonry and rammed earth layers. Thus, the two layers shall be properly connected to transfer the prospective loads and moments to the substructure.

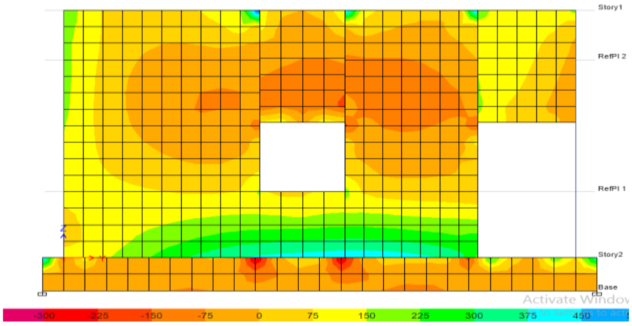

Figure 8 Stress Distribution of Rammed Earth Wall

Based on the analysis results for gravity and seismic loading conditions, the structural response of rammed earth building is assessed for story drift, fundamental pperiod and ffrequency, ddiaphragm CM ddisplacement and base reaction

The analysis result for a single-story building model illustrates that the structural responses are reasonable. While the large moment was observed at;

a. Layers of various building materials should allow the proper transfer of structural load. Consequently, a properly designed and constructed adjoining -layer allows a continuous load transfer.

b. Providing stiff and reinforced members at corners will create a rigid frame system for structural stability.

c. Reinforcing opening corners will decrease the concentration of stress. Additionally, lintels around door and windows will aid to transfer the structural load.

Earth-based building materials are used in seismic zones by adding a stabilizing agent that helps to modify the material properties of the mix. Additionally, by adding lateral load resisting structural elements, the resistance for both gravity and lateral load increase [9].

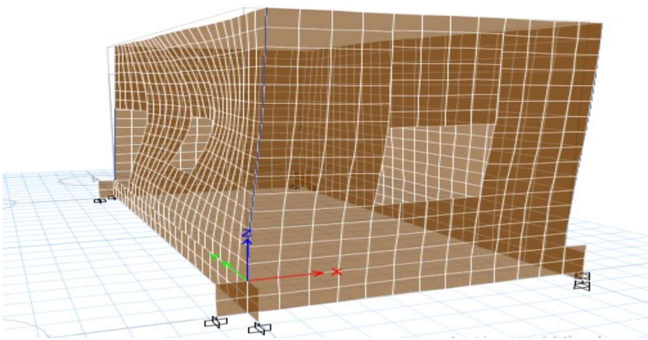

Figure 9 Deformed Shape of the Structural Model

CONCLUSION

Adopting green and sustainable materials and metrologies helps in creating a green and sustainable environment with minimum lifecycle impact. Thus, this study provides a sustainable housing framework based on a sustainable development approach. Earth is a widely available and renewable resource used as the most common building material around developing nations. Rammed earth construction is a traditional technology used for building houses and is being improved due to its valuable properties such as its strength, durability, environmental compatibility, and affordability. Based on the conducted structural analysis, the response of a single-story rammed earth building is adequate. However, when dealing with multiple stories rammed earth structure built on an earthquake zone, reinforcement shall be placed at critical locations to enhance the lateral load-carrying capacity of the building and to prevent crack due to drying. Furthermore, to increase the load-carrying capacity and material strength of earthen structural members, a stabilizer is added. In conclusion, earthen housing is a sustainable, economical, and environmentally friendly approach for resettlement of forcibly displaced communities and disaster-affected areas.

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