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CATENARY BASED THIN SHELL:LOW EMBODIED ENERGY FOR AFFORDABLE HOUSING

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ABSTRACT

Affordable housing developments are distinguished predominantly by urbanization and rising demand. The choice of materials used in construction should be appropriate for the environment. in order to enhance the standard of life of those most in need through the construction of new buildings or the renovation of existing ones.

The goal of this paper is to figure out the embodied energy index and environmental impact of different alternative materials that can be used on a daily basis, as well as to study and compare the CO2 emissions of wall and roofing components using traditional and alternative materials. While this study aims to address a wide range of factors influencing the usage of techniques and procedures for building materials and construction, the focus was on the impact of building materials on the construction and manufacturing of inexpensive housing models in rural areas.

Keywords: Embodied energy, Materials, Forms, environment, Construction technique

INTRODUCTION

The construction industry accounts for about 40 percent of the world's primary energy use, which makes it the single most energy-intensive sector. India's construction industry accounts for the largest share of CO2 emissions (24 percent) in the atmosphere and nearly 41 percent of primary energy consumption. Approximately 80% of the above emissions come from four energy-intensive construction materials, namely cement, burnt clay bricks, lime and steel, predominantly from industrial/production processes.

In other words, development in urban areas is a key user of energy, a fundamental result of pollution in environment, and it is therefore important to evaluate the relationship amongst many factors, such as manufactured and natural building materials and renewable energy sources, and depleted energy sources. Since the green building is still based on the 3R principle (reduce, reuse and recycle), it doesn't matter what technology is being implemented.

The review of environmental consequences of the built environment employs a variety of approaches, depending on the study's scope. At the construction material scale and at the individual building scale, LCA stands for life cycle assessment, which is a widely acknowledged scientific process for assessing materials/buildings over their whole lifetime while accounting for upstream effects

1.1 LIFE CYCLE ASSESSMENT OF BUILDING MATERIALS:

Assessment of the life cycle has become an important method for assessing the effect of materials and goods on the environment. In the course of its life cycle, it is often useful to evaluate the effect a structure has. The International Organization of Standardization's 14040 series explains how to conduct a systematic life cycle assessment in which a building's materials, design, use, and demolition are quantified in embodied energy and carbon dioxide equivalents, as well as representations of resource use and released emissions. These findings are relevant to architects, structural engineers, constructors, and building owners who want to forecast environmental implications during the life of a structure.

Several methodologies are present for evaluating the environmental and ecological implications of components and materials in the building industry.

Figure 1 Stages int he life-cycle of a product considered in LCA

LCA is a technique for constructing a product's environmental features and potential consequences by analysing impacts on environment, enchanting inputs and outputs of a product system and interpretation of impact assessment and inventory analysis phases, according to ISO 14040.

1.2 MAIN PHASES OR STAGES IN LIFE CYCLE ASSESSMENT-

Scope and Goal- Life, cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation are the four steps in a typical LCA, as shown in Fig. 2. These phases are dependent on one another, thus the outputs from one act as inputs for the next.

Goal and Scope- The establishment of geographical boundaries that explains the position of the study area is another important step in this phase, as LCAs can be influenced by the conditions of the site, such as the electricity mix, the presence of distinct procedures for collecting or precuring minerals, the status of technology in various countries or locations, or the actual requirements.

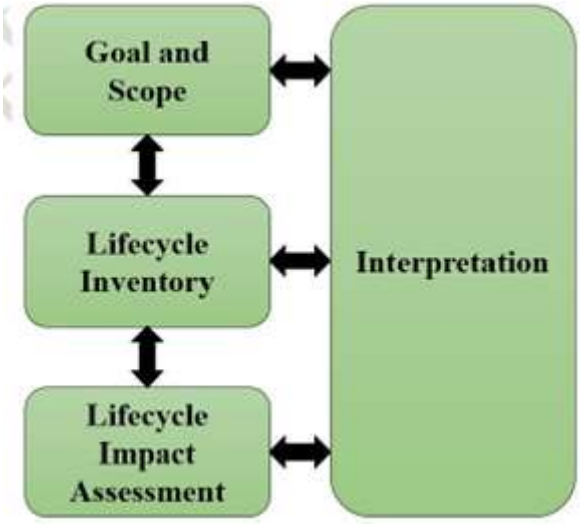

Figure 2 Main Phases of Life Cycle Assessment

Inventory Analysis- Inventory Analysis- The LCI keeps track of the outputs and inputs for each process all over the life cycle of a product. As a result, the LCI includes products such as raw materials, water and energy as inputs, as well as outputs to the water, air, and land.

The following are the four major groups of flows in LCAs (Guinée. Jeroen B & Heijungs, 2010).

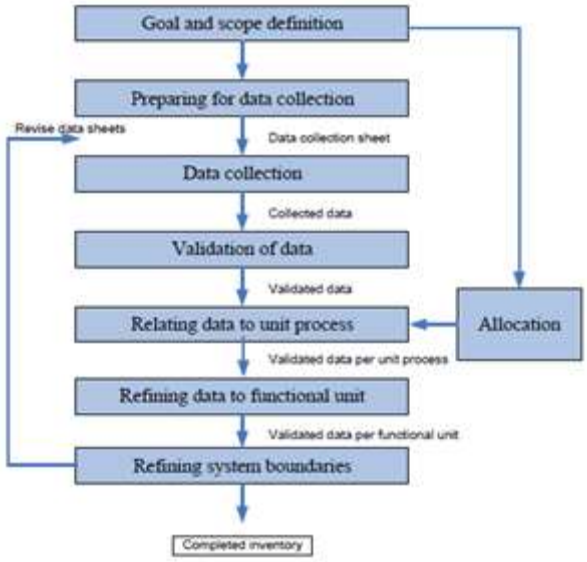

Figure 3 Simplified procedures for inventory analysis

- Inflows of money, such as the energy and cement needed to make concrete.
- Inflows into the environment, such as the fuel used in the manufacturing of concrete.
- Economic outflows: a sample of concrete made by combining cement, water and aggregates together.
- Environmental outflows, such as transaction to the water and air resulting from concrete production.

Life Cycle Assessment- It entails transforming LCI-identified inputs and outputs into the effects they cause, which may then be assessed at the midpoint and endpoint stages. The damage to three primary protection areas: human health, the environment, and resource availability is calculated at the endpoint level. Human toxicity, climate change and ozone depletion are examples of environmental fluxes that fall halfway between the endpoint level and the LCI, and the midpoint level's scope is largely concerned with evaluating them. Both approaches have their own set of benefits and drawbacks: The mid-point implications are more certain than the endpoint impacts, which are easier to comprehend. (Hauschild & Huijbregts, 2015)

Interpretation- The last phase of the LCA is interpretation, which involves summarising and assessing the results acquired in the preceding processes in connection to the study's purpose and scope in order to draw conclusions. Some

strategies for reducing uncertainty, or at the very least being aware of its magnitude and existence, are given below:

i. **Scientific approach**: It entails broadening the area of the study in order to gather more accurate data and/or models. Although this would be the best strategy for reducing uncertainty, due to data availability, it is not always practical to use.
ii. **Social approach**: Stakeholders are consulted about the technique and data utilised in the study in order to reach a consensus.
iii. **Statistical approach**: Rather of removing uncertainty, this strategy uses a number of statistical techniques such as Monte Carlo methods to include it into the study. The preceding step in the interpretation phase is to derive inferences that are consistent with the LCA's goal, as well as make suggestions for future use of the study's results, while emphasizing any limits that were discovered throughout the process.

1.3 LOW EMBODIED ENERGY: ECO FRIENDLY BUILDING MATERIALS AND THEIR ALTERNATIVES

Numerous materials and alternative technologies generated by research institutions, manufacturers, and entrepreneurs in India can be employed in the construction of houses. As part of this study, several different methodologies were evaluated, and the results are reported in the following sections.

1.3.1 STRUCTURAL MATERIALS

A. Pozzolana Material (fly ash/ calcined clay /slag) as Blending Material with Cement- Depending on structural considerations, approximately 35 percent of acceptable and matched fly ash can be used directly as a mixing cement material. Fly ash addition improves quality and durability of final concrete greatly. Blended cement is currently widely used all over the world because to its durability and environmental benefits. The benefits of using mixed cement concrete are well-known: reduced hydration heat, improved workability and pump-ability, improved microstructure results in decreased permeability, stronger strength, good performance in demanding conditions (Sulphates, Chlorides, etc.), less danger of alkali silica interaction, and reduced reinforcement corrosion are just a few of them. A lime pozzolana mixture can save up to 70% of the energy used by Portland pozzolana cement.

i. **Recycled Steel Reinforcement**- Scrap iron that has been recycled can be used to make steel reinforcement. Appliances, autos, and steel-reinforced constructions such as reinforced concrete bridges, pavements, and buildings include this material. Scrap rails, defense trash, or vehicle scrap, steel plant faults, scrap from shipbreaking or demolished structures, tested billets and ingots from small and large steel manufacturers can all be used to reinforce steel bars. Because of its importance in the international steel industry, recycled steel has become a strategic raw resource with a global market price. Verifiable recycled content claims of 40% or more may be made on galvanized studs, roofing panels, cladding, and tube assemblies, among other steel goods. Non-combustibility with the increased benefit of not giving toxic gases when exposed to high temperatures, Uniform and Efficient application, good bond strength and durability, resistance to atmospheric erosion, and termite infestation resistance are all benefits.

ii. **Precast and Ferro Cement Components**- Precast Components are 85 percent recyclable, produce less CO2, and consume less energy. The products are cost-effective, ecologically friendly, and simple for installation. Due to a reduced water cement ratio, precast components reduce waste during operations, eliminate the need for curing, and make constructions impermeable. They also reduce the requirement for inside slab plastering, and the components are corrosion resistant. In comparison to cast-in-situ constructions, the components are also stronger, have a longer life, and have a larger load bearing capability.

iii. **Precast R.C.C/Ferro-cement Frames**- Concrete frames with welded reinforcing are known as precast RCC frames. These are made to Indian specifications. They're affordable, environmentally friendly, and long-lasting. Termites, fire, and corrosion don't bother them. There is no bending or warping, twisting, shrinkage, or cracking. They are better than other door frame materials on the market and have a built-in high-quality drop hold protection. They require little upkeep and are simple to install on-site. They also have two distinct types of hinges mounting methods to meet a variety of needs.

B. Bricks and Blocks

i. **Fly ash – lime--sand bricks**- lime--sand bricks- Fly ash-lime-sand bricks can be used to fill a large gap in the brick supply and increase the reuse of fly ash waste. These bricks have the advantage of availability in a variety of bearing grades, which saves money on mortar plastering and allows for the building of aesthetic brickwork.

ii. **Coal Washery's Bricks Rejects** - Newly mined coal is get washed for removing impurities before being used or processed. This residual waste from washeries is a concern to the nature, and it must be destroyed of or handled in a manner that minimizes the environment. This coal washery reject material can be used to make blocks and bricks similar to those created with fly ash using a binder such as lime or cement. These bricks are waste-free and environmentally friendly. They reduce pollution of the air, land, and water, as well as being cost and effective energy efficient.

iii. **Building Blocks getting from Industrial Waste material and Mine Waste material** - It is environmentally beneficial, makes use of trash, and lowers pollution in the air, land, and water. It is both cost-effective and energy-efficient. The vast majority of businesses and thermal power plants produce significant amounts of solid waste. For decades, red mud, slag, coal ash, fly ash, and other similar wastes have sat unused.

iv. **Brick**- The C-brick Machine, which was invented by CBRI, was used to produce these bricks. The machine, which can produce high-quality bricks from sand, fly ash, and lime, as well as fly ash, sand, and cement-sand aggregate, is sold by BMTPC. Among the features of the bricks produced are good compressive strength i. e. 40-80 kg/sq.cm and less water absorption around 20%.

C. Plaster

i. **Calcium Silicate Plaster**- Calcium silicate kilns are often constructed from silicate-bearing minerals or calcium silicates which are hornblende, diopside, and epidotic, together with

dolomite, wollastonite, or calcite for good measure. Calcium silicate which is a naturally occurring from Wollastonite that is generally used as a filler.

ii. **Portland cements-** Portland cement also contains calcium silicate (CS). CS plasters are cost-effective, environmentally friendly, produce low amount of waste, and have a wide range of uses, provide a professional finish, require less energy, dangerous fumes or gases, and are recyclable. They're easy to use and handle, don't require specialized labour, dry rapidly, last a long time, and consume minimal water.

iii. **Fiber reinforced clay plaster**- Fibres can be added to clay plaster to improve its adhesive capabilities. Plant fibres (cellulose) or synthetic polypropylene fibres can be employed. Plant fibres operate as reinforcement and form voids in fibre reinforced plaster, preventing micro-cracks because of thermal movement and drying shrinkage. Dried plaster is low brittle in nature and can sustain mild substrate movement. Fibers produced completely of virgin polypropylene fibres can likewise be utilised to attain the same results.

D. Roofing

i. **Micro concrete roofing tiles-** For sloping roofs, MCR tiles are a long-lasting, aesthetically beautiful, and cost-effective choice. MCR tiles include precise amounts of sand, cement, fine stone aggregate and water. MCR tiles are subjected to enhanced quality controls at every stage of production. They must pass a number of tests to ensure that they are watertight, sturdy, and the correct size and shape. MCR technology is the culmination of years of development and study on a global scale. TARA, Development Alternatives, collaborates with SKAT agency of Switzerland to promote MCR as a technology in India.

ii. **Clay tiles-** These tiles are more uniform, fire resistant, durable, environmentally beneficial, energy efficient and less expensive than traditional tiles. Rather than promoting Mangalore design clay tile for roofing, regionally available clay tiles should be promoted. Fiber reinforced clay tile is a fantastic optional material that is both attractive and durable.

1.4 LOW EMBODIED ENERGY: CONSTRUCTION AND MAINTENANCE TECHNIQUES

Proper housing is one of humanity's most fundamental requirements. Currently, millions of individuals are without a basic roof over their heads. The world requires low-cost, ecologically friendly, long-term housing to house the millions of people who are homeless in both rich and developing countries. The construction uses primarily local natural materials with minimal high-energy processing, lowering the construction's embodied energy. Because the approach is particularly suited to rural locations and has potential applicability in underdeveloped countries, it just requires basic building skills in addition to using local resources.

1.4.1 TYPES OF CONSTRUCTION

i. Heavy weight constructions-

- When utilised in conjunction with passive design and excellent insulation, it improves thermal comfort and saves operational energy use.
- Has a higher embodied energy in general.
- Should be avoided on remote sites with a significant transportation component (e.g., Darwin). (Robert, 1993)
- Is frequently quarried or processed in a high-impact manner.

ii. Light weight constructions-

- Can have lower embodied energy
- It is recommended on remote sites with a high materials transportation component because it has a lower embodied energy.
- In cold to mild regions (where solar access is possible), uses more heating and cooling energy than heavyweight construction with equivalent levels of insulation and passive design.

1.4.2 COST-EFFECTIVE HOUSING MODELS

i. **Jack Art Unit-** Jack arch roofing is used as an optional roofing method to R.C.C roofing. It is a structural element that provides support at the openings of masonry. The Jack arch is not semi-circular in form instead they are flat in profile and sometimes used over as lintels.

They are suitable and easy to construct for non-climatic conditions. The raw materials like brick, clay, concrete and mortar are used. Advantages of jack roofing are thar it is constructed in small pieces unlike lintel which is monolithic. Decorative patterns and elements like keystones, steeped or arched top profiles and contrasting colours are used.

Figure 4 Example of Jack Art

ii. **Rat Trap Bond Brick Wall-** This cost-effective design typography is given by Laurie baker. The approach is centred on selecting structural designs and materials with care. Rat-Trap Bond brick walling with a Filler-Slab roof can be used to create hexagonal shaped rooms. The Rat Trap Bond cavity walling system is a hollow walling technique that maximizes the utilization of bricks and cement mortar.

Figure 5 Rat Trap Bond Brick Wall

iii. **Stone Masonry House-** In rural India, the majority of homes are composed of masonry. The masonry walls are built with either burned clay bricks or natural stone masonry. It is especially widespread in mountainous areas, such as the Himalayan region, where there are many different sorts of stones. There are two stories in this design, each with its own

entrance. The first storey has a hillside entrance, while the bottom floor has a ground level entrance. Due to the geography of the area, both levels are independent of one another. A cow shed may be found on the bottom floor. The first level has huge rooms that are utilised as living rooms.

Figure 6 A Stone house in Himalayan Area

iv. **Bamboo House-** In India's rural patchwork, indigenous bamboo house has been distinctive. Bamboo huts have long been popular among rural residents because of its low cost, availability, fast construction and also it is a cheap and safe alternative of plastic, cement, mud and wood house. bamboo buildings are appropriate for earthquake and flood-prone areas. It is a low-cost, light-weight, environmentally beneficial, and self-sustaining material that may be found in various places of the country. Bamboo groves are simple to establish in the backyards of rural residences. In the North-East, bamboo is the typical shelter material. These dwellings are self-sustaining and environmentally beneficial, as well as providing employment possibilities in rural regions. (Lechner, 2015)

Figure 7 Bamboo House

v. **Ferro cement Channel Construction-** Ferro-cement channel construction is a low-cost construction unit, done using wire meshes and cement mortar. These channels are done in pre-cast using basic mould and same techniques requires in construction of R.C.C slab. FC channels are longitudinal and semi-circular channels basically use for roofing purpose as it is long-lasting, light, water-resistant, and cost-effective. The channels are constructed on site and requires large open space for precasting and curing. This construction does not need the use of a vibrator, concrete mixer, scaffolding, or shuttering. If the channels are not constructed on site, appropriate conveyance must be organised to avoid damage. These channels are now being utilised in the building of low-cost homes under the Indira Awas Yojana Scheme, which aims to make housing accessible to everybody.

Figure 8 Example of Ferro cement Channel Construction

vi. **Traditional Mud House-** Clay is a gift from nature to mankind. Mud is a low-cost building material that is commonly available, widely accepted, sturdy, and lasting. It is often utilised by the rural poor to construct their homes. Its bonding qualities have been increased thanks to cost-effective technological advancements.

Mangalore tiles are used to cover the roof. This construction is both cost-effective and environmentally friendly, making it ideal for community use in rural locations.

Figure 9 Example of Traditional Mud House

vii. **Pre-fabricated steel house-** In this model, ferro cement panels and pre-fabricated steel frames are welded in a given site which are transported from the industry for the construction of houses. Pre-fabricated steel house did not require centring or shuttering works as the ferro cement panels are welded to the steel framework for roof and walls. This is an advanced housing technology that is particularly well suited to isolated locations where traditional building materials are unavailable.

Thermocol is used to create good thermal insulation between panels. The structure is both earthquake-resistant and long-lasting. The steel housing is also inexpensive.

Figure 10 example of pre-fabricated steel house

viii. **Stone Patti House-** Physical security, weather (hot or cold), and locally accessible stone, mud, and lime mortar materials are three aspects that influence the design and building of dwellings in rural Rajasthan. For stone jointing, roof waterproofing, and wall plastering, cement is being utilised in place of mud and lime mortar, and the difference is obvious today.

To suit the practical demands, the traditional design of this plan is to create a central courtyard with three walls on one side and a residential area on the other.

Figure 11 example of Stone Patti House

1.5 BUILDING MATERIALS AND CONSTRUCTION METHODS IN RURAL AREAS

Because rural housing must accommodate not only people but also livestock, it is more difficult to construct than urban housing. Covered area is usually necessary for a number of activities, such as weaving, basket building, rope manufacturing, nets and fishing, food drying and processing, and so on. The open space around the home is equally as important as the house itself, and it's utilised for a variety of purposes like cooking, storage, and raising animals and poultry, among others. Because the current situation does not permit all of these criteria, these plans concentrate on the fundamental essentials, with the option to grow as needed. In terms of planning, design, materials, and construction methods, whether in rural or urban locations, the fundamentals of appropriate housing for all strata of society in all geographic or climatic zones should be expressed explicitly. With the exception of steel, cement and some major manufactured products, most other building materials used in rural construction are obtained from areas around the villages.

Structural Component	Materials/ Forms of Structures	Mortar (if any)
Wall or Structural System	Sun dried adobe bricks Cob blocks Random rubble field stone Burnt bricks Timber beams and columns with masonry infills	Mud mortar Mud-lime mortar Lime mortar Sand-cement mortar Cement-lime-sand mortar
Roof or Floor System	Flat timber roofs Inclined wooden or steel trusses Adobe domes and vaults Jack arches resting on steel girders Hollow concrete blocks with prefabricated concrete joists	Gypsum and soil Mud mortar Sand-cement mortar
Foundation	Lime and soil Random rubble field stone Concrete	Mud mortar Sand-cement mortar
Plinth	Random rubble field stone Burnt bricks Concrete blocks	Mud mortar Sand-cement mortar Lime mortar Cement-lime-sand mortar
Lintel	Timber Concrete Steel	Mud mortar Mud-lime mortar Lime mortar Sand-cement mortar Cement-lime-sand mortar

Figure 12 The most common Building's materials used in rural buildings

Bricks, lime, gypsum, concrete blocks are usually obtained from small industrial units located in rural areas, while wood can be obtained from the nearby forests or farms, aggregates from local mines, and stones from the nearby mountains and rivers. Different types of the most common construction materials used in masonry rural buildings. Introducing a new approach into the market, no matter how good it is, is always a struggle. It's difficult to change people's attitudes about traditional construction processes, and new materials frequently fail to win trust. Furthermore, consumers do not want to invest their savings in new and unproven products.

	CI Sheet House	Brick House	Earth - Jute House
			
Cost (100taka = 1Euro)	200,000 – 300,000 taka	500,000 – 1,000,000 taka	150,000 – 200,000 taka
Materials	CI Sheet, Iron, Wood, Cement	Kiln fired brick, cement, iron rods, concrete, wood, etc.	Earth blocks, cement, Jute Composite Tin, bamboo
Insulation	Very minimal insulation	High insulation	High insulation
Construction time	4 to 6 weeks	6 to 12 weeks	2 to 4 weeks
Comfort level	Low	Low to medium	Medium to high

Figure 13 Comparative study of construction methods in rural area

1.6 CONCLUSION

Ferrocement is a great construction material because of its mechanical qualities and low cost, and it has strong cracking strengths. Cement mortar is a cement composite material made composed of Portland cement, sand, water, and sometimes admixtures that is used in the manufacture of ferrocement.

In compared to typical construction technologies, ferrocement has numerous advantages, which can be described as follows:

i. Controlled manufacturing, i.e., a high level of quality assurance.

ii. Prefabricated products and quick assembly

iii. Labour requirements are reduced, and workers can be quickly taught on-site. Cost reduction, 15-50% cheaper than conventional techniques.

iv. Less upkeep and increased safety.

v. Dead weight reduction of 50-75 percent compared to traditional procedures.

vi. There is less waste.

vii. The most basic raw ingredients are readily available.

viii. Lower energy use for heating and cooling.

ix. Ferrocement is exceptionally good at resisting impact because it has a higher ability to absorb impact energy than traditional reinforced concrete, and the damage is concentrated to the impact zone.

The ferrocement building components can sustain direct fire for 212 hours at temperatures of up to 756 degree C with no segregation in the surface of the elements confronting the fire.

The use of ferrocement in the rehabilitation and strengthening of reinforced concrete elements is particularly successful in enhancing cracking and ultimate loads as well as impact resistance.

Catenaries are utilized in the construction of bridges and arches to reduce bending moments in architecture and engineering. The catenary is also thought to be the best shape for a free-standing, uniform-thickness arch. Because the catenary is the best curve for supporting one's own weight, the roof covering should be light.

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