Proceedings of IOE Graduate Conference, 2017
Volume: 5 ISSN: 2350-8914 (Online), 2350-8906 (Print)

Earth as Building Material for Sustainable Development: Case from Jhong, Mustang

R.M. Pandey [a], Sudarshan Raj Tiwari [b], Sushil B. Bajracharya [c]

[a, b, c] *MSESSD Program, Department of Architecture and Urban Planning, Pulchowk Campus, IOE, TU, Nepal*
Corresponding Email: [a] rm_frizzid@hotmail.com, [b] srtiwari@ioe.edu.np, [c] sushil_bajracharya@hotmail.com

Abstract
Use of earth for building has sustained throughout generations. Mustang region also has building practice which makes use of mud. However, recent building trends make use of imported building materials and itinerant workers. Building industry contributes significantly in anthropogenic emission of GHG, also, economy and society. Environment and socio-economic life cycle assessment (LCA) of two house prototypes, modern and traditional was conducted. Field study consisted of surveying house prototypes and interaction with stakeholders. Material and energy inputs, GHG emission, water use for construction and man-power were calculated in E-LCA. Stakeholder identification, impact category and indicators with inventory data were compiled in S-LCA. Material use for Modern house prototype is 10.47 cu.ft./ sq.ft.built-up, and for Traditional is 12.97 cu.ft./ sq.ft. built-up. Similarly, total lifecycle energy expenditure is 54.72 MJ / sq.ft. year and 113.36 MJ / sq.ft. year, for modern and traditional house prototypes, respectively. GHG emission in material sourcing phase is 10.58 kgCO_2e/ sq.ft. and, 2.37 kgCO_2e/ sq.ft. for Modern and Traditional house prototypes, respectively. Building cost per sq.ft. area of modern house and traditional house prototypes are 4,707.20 NRs and 1,490.96 NRs, respectively. Manpower estimate for construction and demolition is 2.68 and 1.11 man-days/sq.ft. built-up of modern house prototype and traditional house prototype, respectively. Traditional prototype, mud house, has environmental, economical and man-power advantages over modern prototype house. Use of stone in mud mortar and CSEB in modern prototype makes use of local material and has aided local economy. Both models suggest uses of local material, earth, results in better environmental and social performance.

Keywords
Earth building material – Life Cycle Assessment – LCA – SLCA – Building Typologies

1. Introduction

1.1 Background

Earth as building material has been practiced since ten thousand years ago and is used for housing by 30 % of world's population [1]. Uses of earth for building purposes have gone through adaptation, modification and innovation in course of history. It has been adapted for sheltering commons and also for building prominent structures of various civilizations [2, 3]. Due to earth's abundance, accessibility, its simplicity to build and the characteristics it possesses, which entails its building performance, it has been widely used material for building. Earth construction has its vernacular roots in Asia, and also in Himalayan regions of Nepal. Use of rammed earth, placing mud in between two planks and ramming, has been one of the vernacular construction techniques, together with sun dried mud blocks. Centuries old buildings have survived until today. Kag Kag Chode Thupten Samphel Ling, a monastery established in 1429, was built in rammed earth wall, that leans inwards as it rises and consists of horizontally laid timber beams at intervals throughout the wall, visible from exterior, which might have been used to improve the seismic resistance of the structure[4]. Jaquin also pictures a modern rammed earth construction taking place at Kagbeni, done in "Bugey method"[5], which is dissimilar to traditional construction style, framework without the aid of putlog. Similarly, a case study of a private residence at Jharkot, a two stories house built in 1950, describes the walls made in sun dried mud blocks, and walls shared with the annex houses are built in stone foundation and rammed earth walls [6]. Changes in construction practices by use of new building materials has been a part of developmental trends in Mustang region. Mud has been used as walling and roof insulating material in local buildings. The shift in building culture from traditional to modern methods has impact on social aspects and bio-physical environment. Increased trends in use of modern building material and technology, results in influx of outsourced building materials. Lack of technical supervision during construction can result in poorly performing buildings; physically and socio-culturally. This presents need to study the impact of housing typologies in the environment and society.

1.2 Objectives

The research intends to identify factors and criteria that influence social sustainability of community in Mustang through use of mud as building material. The study will use life cycle impact assessment tools for socio-economic and environmental sustainability of using mud as building material.The specific objectives to carry out the study are as follows:

1. To use Environmental Life Cycle Assessment (ELCA) for assessing energy and environmental impacts of modern and traditional housing typologies of Jhong, Mustang.
2. To use Social, Socio-economic Life Cycle Assessment (SLCA) as a tool for assessing social impacts due to modern and traditional housing, in Jhong community.

2. Methodology

The study incorporates use of LCA and case study for developing basis for identification of issues, function, functional unit and reference flow. Social and socio-economic life cycle assessment (S-LCA) will produce insights on impact on social sustainability by use of mud in building. Similarly, impacts on environmental sustainability by use of mud for building will be assessed using environmental (E)LCA. Case study during field study will add to data collection of life cycle inventory processes through mixed methods. Life cycle assessment [7]tool evaluates a product or its processes involved throughout various phases of its life cycle, from sourcing of raw material, its manufacturing, transporting, operating and maintaining to disposal or reuse of the product, commonly referred to as from cradle to grave.

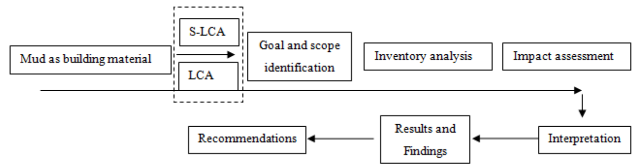

Figure 1: Research design

Goal and scope identification incorporates defining concept, illustration of product life cycle, scope of study, functional units, system boundaries, assumptions, limitation and cut-offs, inventory list, performance indicators, data sources and method of collection. Its objective is to identify purpose and target audience. The second part of study involves life cycle inventory analysis. Preparation of data collection, prioritization, site specific evaluation and impact assessment characterization is done in this phase. The third phase involves aggregation of inventory data are related to midpoints (impact categories) and endpoints (area of protection). The final life cycle interpretation phase serves to direct life cycle inventory model to meet the needs derived from study goals.

Use of framework of environment (E)LCA (ISO: 14040, 14044) and social, socio-economic (S)-LCA [8] intends to produce assessment model for sustainability, which incorporates triple bottom line of sustainability, also known as three pillars of sustainability; people, planet and prosperity.

ELCA framework:

The goal of ELCA is to identify and innumerate material and energy inputs, and waste output incurred during various phases of lifecycle. The functional units are taken as components in which mud are used such as wall, floor, roof and exterior rendering. System boundary of prototype house concerns with building components and building materials.

Total input fuel for transportation of materials is given as

$$\sum_{m=1}^{n} F_m = \sum_{m=1}^{n} (I_m * E_m)$$

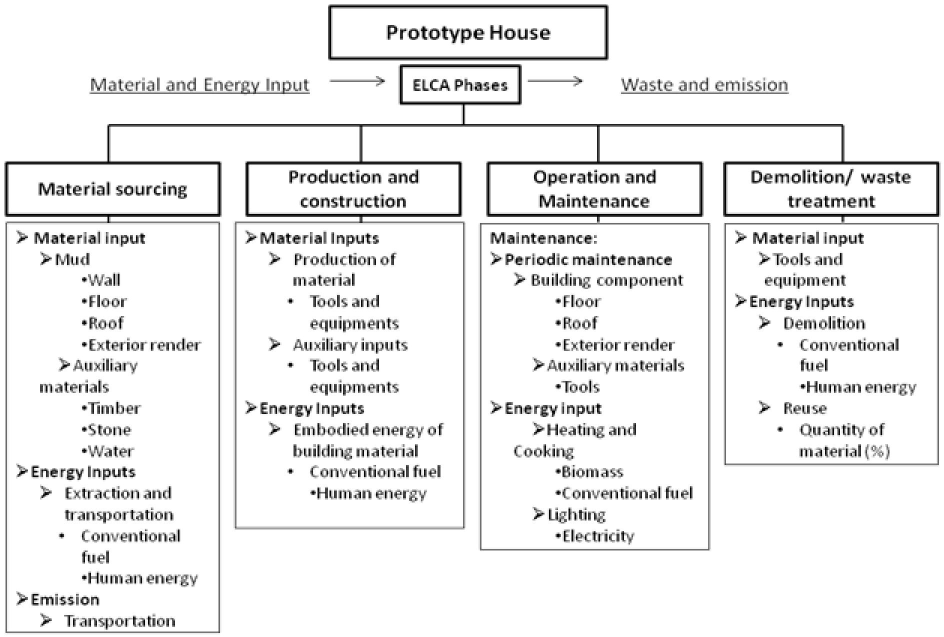

Figure 2: Framework for ELCA

where, F_m is fuel consumption for material
I_m is quantity of input material
E_m is fuel efficiency in terms of unit quantity of material

$$E_m = F_t/Q_t$$

where, F_t is fuel consumption per trip
Q_t is quantity of material per trip
Transportation of material uses fossil fuel which results in GHG emissions. Primary activity for extraction of raw materials, such as environmental degradation, has not been considered in the assessment. Total emission resulting from transportation is given as,

$$\sum_{m=1}^{n} G_m = \sum_{m=1}^{n} (F_m * F_f)$$

Where, G_m is GHG emission resulting from transport of material (in kgCO2e)
F_m is quantity of fuel consumption for transportation of material
F_f is emission factor of fuel, here, diesel fuel.
Processing of raw material for production of building material also consumes energy. This energy has been also referred to as initial embodied energy. Industrial material has been accounted for initial embodied energy, referring to secondary sources.

$$\sum_{m=1}^{n} IE_m = \sum_{m=1}^{n} (I_m * EE_m)$$

Where, IE_m is initial embodied energy of material (in MJ)
I_m is quantity of input material
EE_m is embodied energy (cradle-factory gate) per unit quantity of material.

The method used incorporates study of modern and traditional prototype houses. Physical measurements of houses provide data on input material. Site measurements also made use of volumetric and weight measurement of units of measurements, for density assertions. Similarly, check list was used to acquire relevant information from resident of the house, such as use of fuel for heating and cooking for operational energy. Transportation distance was developed using satellite imagery of google map, whereby the efficiency of vehicles were context specific. Since, construction involves no use of machine or fuel, human energy has been calculated as per guidelines by FAO. The construction process has been broken down into components of building, or broader phases of construction.

SLCA framework:

The goal of study intends to further sustainability assessment through stakeholder inclusion, and identification and evaluation of impact categories and sub-categories, with respective impact indicators to produce inventory data.

Semi-structured interviews with stakeholders were used to perform data collection. In particular, resident, worker, primary school teacher, lama from gumba, lodge operator, social mobilizer and local community resident were consulted. A check list was prepared in accordance with the impact category and subcategory, for relevant stakeholder. The issues to be discussed were introduced, talked upon and required information was gathered by recording. The type of data included qualitative, semi-quantitative and quantitative as well, such as satisfaction with work, number of man days and daily wages, respectively. Use of subjective judgments was also encouraged while gaining insights on aspects such as aesthetics and cultural heritage.

3. Life Cycle Inventory Assessment and Interpretation

Results from life cycle inventory analysis has been aggregated and expressed in terms of functional units for ELCA, whereas, for SLCA, significant issues gathered in accordance to the SLCA framework.

3.1 ELCA

Modern house prototype is recent construction taking place in Putak village, in Jhong VDC, Mustang. The house is RCC framed structure with external walls done in dressed stone and mud mortar, internal walls in locally manufactured CSEB, and RCC flooring. Modern building materials like cement, steel, glass are transported from Pokhara , 180 km away from the site.

Traditional house prototype, case studied, is located within the settlement, connected by narrow street, with water canal for overflows, and reminisces traditional setting. The house is supposed to have been built nearly 200 years back, which still continues to house its 6th generation. It is built in stone foundations, 2 feet wide, and upto a meter in superstructure. Stone, mud, timber hold largest share of building material, however, locally available grass, agricultural residue, woven splices mat, has also been used for holding mud in flooring. It is observable that socio-cultural and religious aspects have shaped this vernacular mud architecture.

3.1.1 Material use

It was found that modern prototype uses 10.47 cu.ft. of material per unit square foot of built up. The share of stone is highest, 47%, mud is 23% and 28% accounts for RCC. Similarly, traditional prototype house uses 12.97 cu.ft. of total building materials per sq.ft. of built-up area. Mud, stone and timber share 56%, 37% and 7% of total volume, respectively.

3.1.2 Man-power estimate

For production, construction and demolition phases of LCA, unit sq.ft. of buit-up are of modern and traditional house prototypes were found to require 3.68 and 1.11 man-days, respectively. Although material volume per unit built up was higher in traditional house prototype, it is found to require less number of man-power for construction and demolition phases.

3.1.3 Fuel for transportation

Transportation of RCC material and cement applications requires 96% of fuel,diesel, required for construction of modern house. Stone, although had largest share of materials by volume, it being in proximity, the total fuel consumption due to transport has only taken 2% of total fuel consumption. Similarly, in case of traditional house, since timber is sourced from distant, amongst the material sourcing locations, it has consumed,80% of fuel, although its share in total volume of building material is 7%.

3.1.4 Water for construction

Water use for construction of unit sq.ft. of built-up area of modern and traditional houses are 101.3 liters and 29 liters, respectively. Cement mixing accounts for 43% of water for construction, while 52% is used for curing of cement. Similarly, in case of traditional house, 84% is used for production of adobe, while 15% for rammed earth.

Stakeholder categories	Impact categories	Inventory indicator	Inventory data
Workers	Working conditions	Workers	Workers
Head mason Stone dresser	Health and safety	Working hours	Hrs/day
Young worker	Housing affordability	Workers' wage	NRs/day
Resident	Local economy	Occurrence of accident	In case of hazard
Karsyang Angmo Gurung	Environmental	Child labor	Age, condition
Nyima Gurung	considerations	Gender inclusion	Gender ratio, condition
Local community	Cultural heritage	Residents	Residents
Primary school teacher Lama from monastery		Indoor comfort	Thermal comfort, quality of
Lodge owner		Cost of building	space
		Traditional rituals	Estimation and costing
		Local community	Continuation of tradition
		Access to material	Local community
		resources	Source of material,
		Local employment	No. of employment,
		Cultural rituals	economy generated
		Aesthetic	Cultural heritage, identity
		Technology transfer	Visual appeal
		Waste generation	Alternative technology
			Reuse, Re-cycle

Figure 3: Framework for SLCA

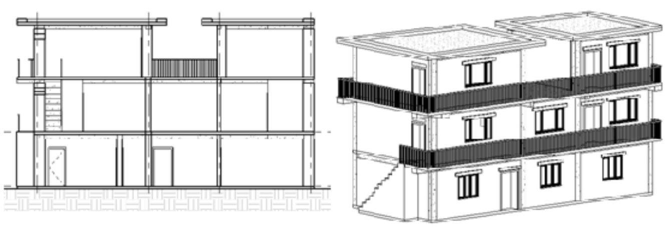

Figure 4: Sectional and 3-D view of Modern house prototype

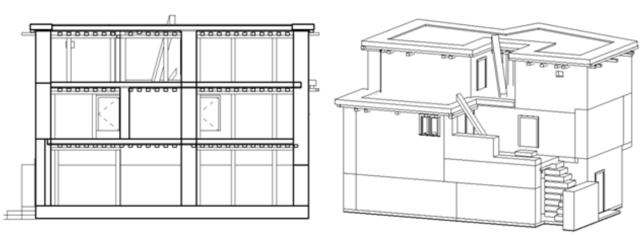

Figure 5: Sectional and 3-D view of Traditional house prototype

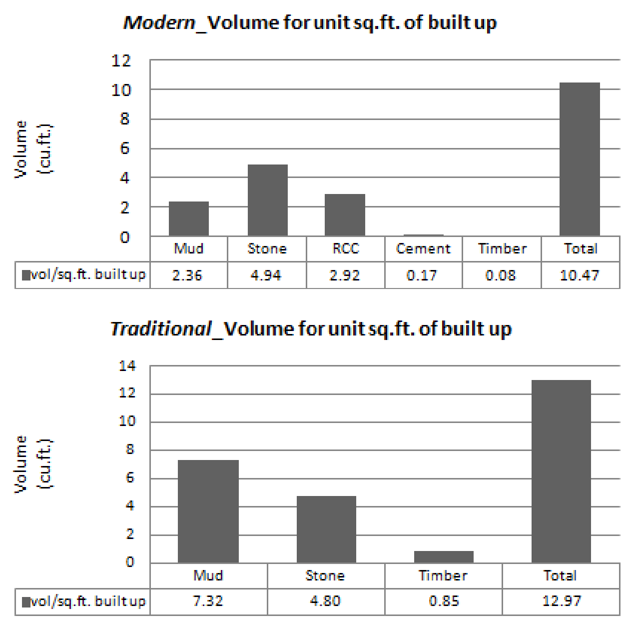

Figure 6: Material volume per sq.ft. built-up

3.1.5 Energy use in LCA phases

Total life cycle energy expenditure was found to be 54.72 MJ / sq.ft. year and 113.36 MJ / sq.ft. year, for modern house prototype and traditional house prototype, respectively. Operational energy contributes to 85% and 95% of TLEE of modern and traditional house prototypes, respectively. Direct energy uses in building, throughout lifecycle phases is represented in graph. Initial embodied energy in case of modern building prototype contributes in 65% of direct energy into building, represented in production phase of LCA.

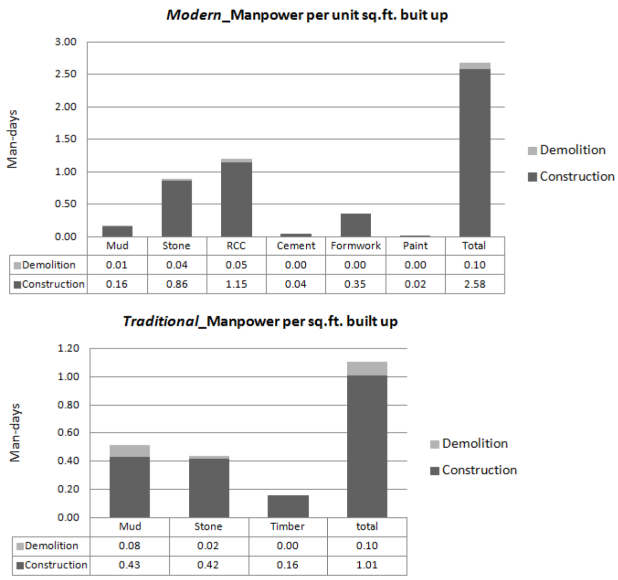

Figure 7: Man-power required per sq.ft. built-up

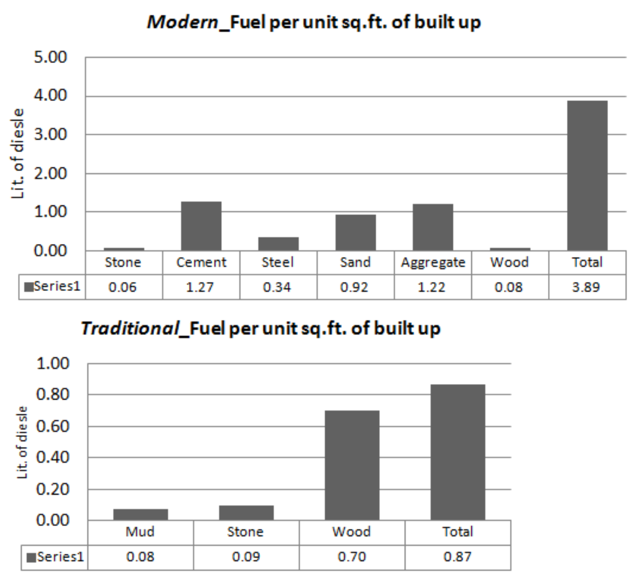

Figure 8: Fuel consumption in transportation of building materials per unit sq.ft.built-up

Similarly, 59% of share of direct man-power use in building is contributed by construction phase of LCA.Higher energy expenditure in traditional prototype is use of firewood for operation,which is less efficient.

Modern LCA phases comprises of energy from fuel technologies with human energy. Production phase of LCA represents initial embodied energy of building materials, and has 11% share of direct energy use in building, which is 65% of TLCEE.

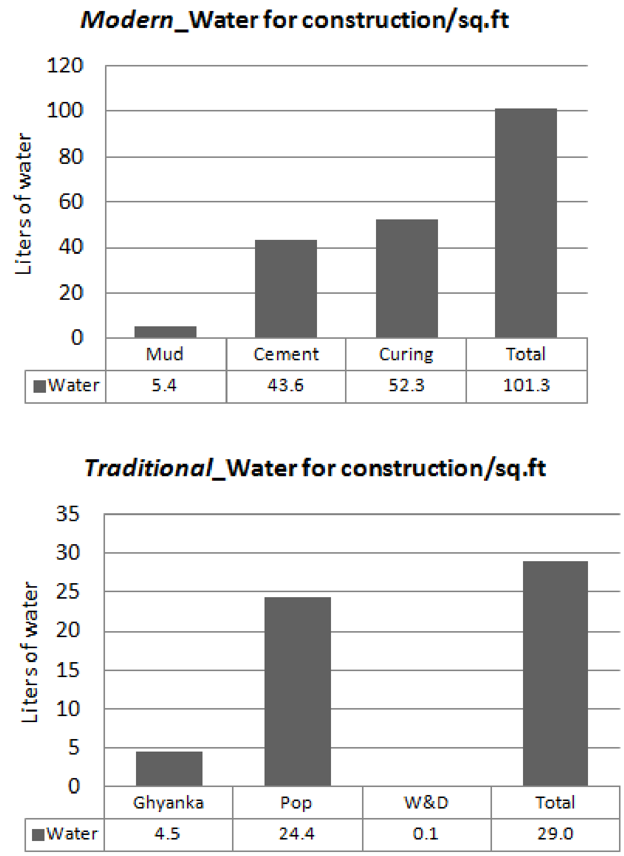

Figure 9: Water use for construction of unit sq.ft. built-up

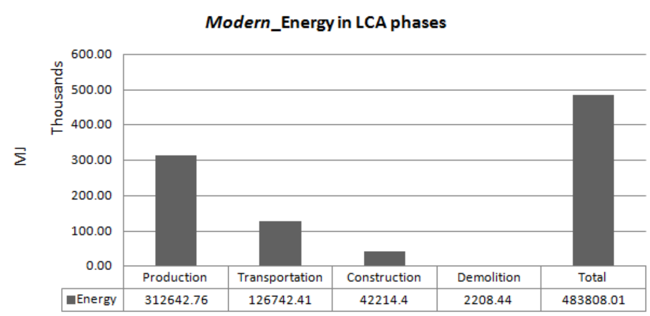

Figure 10: Direct energy use in Modern house prototype building in various phases of life cycle

3.2 SLCA

Stakeholders have been consulted with the impact categories, indicators as per SLCA framework to produce inventory data. Workers and resident are directly impacted by house construction activities, while local community stakeholders are indirectly affected by house construction activity. It was possible to get

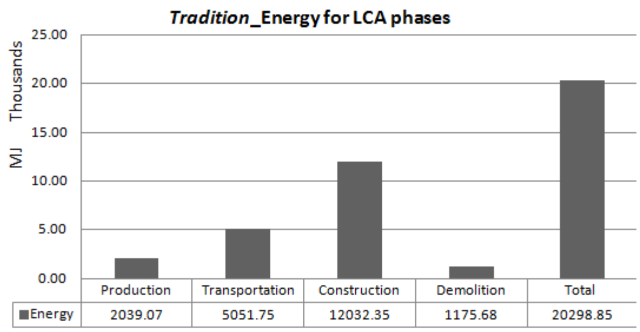

Figure 11: Direct energy use in Modern house prototype building in various phases of life cycle

insights from workers of modern house prototype, while for traditional house prototype, local community informants were consulted to assimilate working ideals and conditions. The following section consists of inventory data with respective stakeholder and its impact category, for both the house prototypes. Information presented has been collected from field interviews and observations.

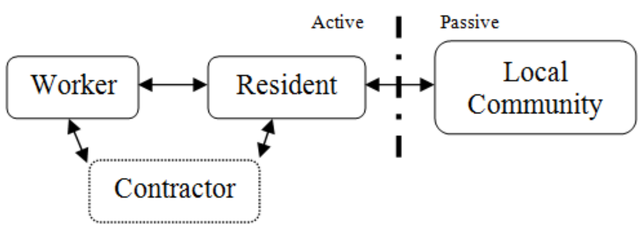

Figure 12: Stakeholder relationship

Significant issues found in the assessment were found are interpreted in accordance to stakeholder category, impact category and inventory indicator results. From impact assessment, significant issues and its end-point impact category has been inferred.

Modern house prototype total cost of building material is found to be 22,63,797 NRs, similarly, the cost of labor was found to be 19,30,320 NRs. Thus the total cost of building material and labor sums up to 41,94,117 NRs. This results in cost of unit square foot of built-up as 4,707.20 NRs.

Similarly, Traditional house prototype total building material cost is 4,18,676 NRs. The construction of house requires 655 man-days. Assuming the average labor wage is 840 NRs, the total labor cost is 5,50,454 NRs. Thus, the total cost of building material and labor

Stakeholders	Impact categories	Significant issues	End point impact
Worker	• Working conditions • Health and safety • Child labor • Gender Inclusion • Workers' wage	• Lack of contract agreement • Lack of health benefits and safety measures • Young workers aged 16 and 18 • 14:1 male to female ratio • Unfair wage of female employee	• Security • Work performance • Training and capacity building • Gender gap • Livelihood
Resident	• Indoor comfort • Relation with employee • Cost of building material • Cost of labor • Traditional rituals	• Poor thermal performance • Managing food for workers • High cost of imported building materials, expensive • 1/3rd of total construction cost • Adaptation to new house	• Health and operational energy • Working relation • Economy • Employment • Customs and practice
Local Community	• Access to material • Local economy • Visual appeal • Technology transfer	• Far-fetched, expensive • Itinerant workers; local CSEB • Distinct from surrounding houses • Pop similar to CSEB; provision of building services	• Environment, Economy • Income generation • Aesthetics • Alternative technology

Figure 13: SLCA Interpretation of Modern house prototype

Stakeholders	Impact categories	Significant issues	End point impact
Resident	• Indoor comfort • Traditional rituals • Cost of building material • Cost of labor	• Sound thermal performance • Agrarian provisions • Purchasing Timber • Change in labor practice	• Health and operational energy • Customs and tradition • Economy • Employment
Local Community	• Access to material • Waste generation • Local economy • Cultural rituals • Visual appeal • Technology transfer	• Locally available • Reusable, natural building material • Use of local material and social capital • Crisis of building heritage • Buildings require maintenance • Sound building technology	• Environment, Economy • Economic and eco-friendly • Value addition • Heritage • Aesthetics • Innovation

Figure 14: SLCA Interpretation of Traditional house prototype

sums to 9,69,130 NRs, which results in 1,490.96 NRs per square foot of built-up.

4. Conclusion and recommendations

Use of mud in both prototypes depict considerable share of mud for building application, 30% and 56% of volume of building materials used in modern and traditional house prototypes. Wall, as building component, has highest share of building materials by volume. Mud being locally available material, its use would lessen environmental impact resulting from transportation emission. Importing of building materials from distant lead to high cost and also additional cost for transportation of material, which is 16% of cost of building material. Mud based construction requires less water as opposed to cement based constriction, 29% of water for construction consumed by Modern house prototype. Modern house prototype uses less volume of material per unit built-up area to that of Traditional house prototype, however, requires higher number of manpower for construction. Also, cost per unit area of built up of traditional house is lower to that of modern house. This insists advantage of traditional house in terms of economy and manpower. Total lifecycle energy expenditure of Modern house prototype and Traditional house prototype were calculated to be, 54.72 MJ / sq.ft. year and 113.36 MJ / sq.ft. year, respectively. Use of industrial building material resulted in higher value of direct energy expenditure in building of Modern house prototype, whereas, high operational energy of traditional house makes it have higher TLEE.

From SLCA of housing prototypes, contractor was found to be not in compliance with regulatory framework. Lack of contract agreement, health and safety measures for workers has less to no employee benefits. Young workers aged 16 to 18 are also common in the region of study. Training and skill development programs for employee can aid in working performance. Female worker was found to be less with respect to male, and also getting lowest payment in the workers' group. Resident had to make provisions of necessary supplies for workers, which would be deduced at the end of construction from workers' fee. Visual aesthetics of settlement is in homogeneous appearance and repetition of houses, which is also in threat due to new built forms. Guidelines to facilitate exterior works of building can result in maintaining the visual appeal of the settlement. Traditional house typology is facing crisis with new buildings being preferred to built in modern house typology. This has also lead to loss of building heritage and local building practice. Mud construction being local construction technology, its continuation with technological innovations can provide alternatives to building trends. Maximizing use of local building material, in our case earth, provides for environmental and social sustainability.

References

[1] Hamed Niroumand, MFM Zain, Maslina Jamil, and Shahla Niroumand. Earth architecture from ancient until today. *Procedia-Social and Behavioral Sciences*, 89:222–225, 2013.

[2] Gernot Minke. *Building with earth: design and technology of a sustainable architecture*. Walter de Gruyter, 2012.

[3] Horst Schroeder. *Sustainable building with earth*. Springer, 2016.

[4] Paul Jaquin. A history of rammed earth in asia. *International Symposium on Innovation & Sustainability of Structures in Civil Engineering*, 2011.

[5] Patrice Doat, A Hays, H Houben, S Matuk, and F Vitoux. Building with earth. *The Mud Village Society, New Delhi*, 1991.

[6] Charles Harrison, John; Ramble. Houses and households in southern mustang. *Ancient Nepal 140*, 1998.

[7] International S. Organization. ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework. Technical report, International Organization for Standardization, 2006.

[8] UNEP/SETAC. Guidelines for social life cycle assessment of products. Technical report, UNEP/SETAC, 2009.