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POPULAR BUILDING TECHNIQUES AND MATERIAL UTILISATION IN LOW INCOME TROPICAL HOUSING; A CONTEXTUAL REVIEW ON UGANDA

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Purpose

This paper is an investigation into commonly used materials, popular building techniques and material utilisation in the construction of low-income housing. This is achieved through a literature review, field studies and analysis of data collected.

The point of departure is a review of literature on the global discourse about low-income housing, specifically on what constitutes low-income housing. The various views are contextualised by comparing the worldview against existing studies on low income housing in Uganda.

The paper then looks at the nature of existing low income housing thereby grounding theoretical assumptions and providing an appropriate sample from which requisite studies on popular building techniques, and materials utilised in the construction of low income housing can be carried out.

While Kampala, Uganda's Capital will be the base, the study will extend to different climatic zones of Uganda (Savannah, Lake Basin and Highland Tropical). It will include Arua, Gulu, Jinja, Mbale, Mbarara and Kabale.

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1. Introduction

Worldwide, there is a growing concern on the need to better manage the world's available resources as observed by increasing mobilisation and literature on the subject of sustainability. Buildings and their use have been noted to be a major consumer of energy and materials. It is estimated that 40% of the world's energy is consumed by buildings, during construction and operation. (Dixit, et al., 2010; Menzies, 2012) Furthermore, the construction industry is reported to be the largest consumer of raw materials requiring 6 tonnes of material per person per year. (Menzies, 2012) It is clear therefore, that the conservation of materials and energy within this sector will go a long way in towards improving the management of the planets resources.

In this light, Energy and Low Income Tropical Housing (ELITH) as a research project with specific focus on low-income housing has the following objectives:

1. **To measure embodied energy in materials;**
2. **To measure operational energy in current low income housing;**
3. To improve rural building materials production in Africa;
4. To reduce housing- operational (use) energy and costs on building services and appliances;
5. To review and develop passive design strategies in tropical housing;
6. To reduce housing embodied energy and costs;

In order to fulfil these objectives, there is need to define low income housing in the context of Uganda and develop a data set on common housing typologies that fall within the working definition. This is to be done with a specific focus on popular building techniques and material utilisation that are in consonance with objectives 1 and 2. A follow up paper will look at the same data set among other studies in order to fulfil objectives 4 to 6.

The intended outcome will be to provide the basis for more efficient ways of building construction and material utilisation that reduce cost, energy consumption and environmental degradation.

The research is situated in a specific area of interest, that is, low-income housing. It is therefore necessary for the study to present an overview of the constitution of low-income housing. The discussion presented in the following section provides a global view of low-income housing. This presents a holistic background from which an ideology of low-income housing can be built. This is especially useful in the Ugandan context where research in the field of low-income housing is still in its infancy.

2. Global Discourse on Low Income Housing

The following section presents a discourse on the supply of housing with specific focus on the result that global trends have had on low-income housing provision. First, the ability of housing markets to provide housing for populations of varied incomes is discussed. This is done with the aim of highlighting factors that lead to the need, and the formation of low-income housing. This is followed by a discourse of terms that are often times associated with low-income housing, that is, poverty and housing affordability. In addition, different definitions for low-income housing as offered by various authors are examined and provide a notion of what constitutes low–income housing. This is done not only to set guidelines for the interpretation of low-income housing as used in this paper, but also provide background information for any reader to the meaning of these often arbitrarily used terms.

In a free market economy, as is the predominant case in the world today, housing is subject to the forces of demand and supply. Renaud (1984) while commenting on housing supply in developing countries – of which Uganda is a part, suggests that the housing market is comprised of a three-tiered structure attending to different market demands:

A. There is the small, well-financed upper class market which Renaud states is an exclusive domain of the private sector and draws its funds from institutional finance systems.

B. The second tier is the subsidized market catering primarily for middle class workers and civil servants who benefit from public housing.

C. Finally, there is the large, private and ever growing housing sub-market with no access to formal financing services and which produces housing that does not generally conform to official building codes and regulations.

According to these assertions, only the well-financed upper class is able to meet the full cost of their housing. The middle class and the "poor" are unable to readily afford housing. However, the middle class has access to subsides and formal financing services which enables them to access adequate housing. From these observations, it is clear that society's poor are precluded from accessing suitable housing by market forces of demand and supply. This notion is concretised by estimates, which show that in 2001, 924 million people, or 31.6% of the world's urban population, lived in slums. In developing regions, slum dwellers accounted for 43% of the urban population, with varying contributory proportions. The percentage of total urban population residing in slums was estimated at 72% for Sub-Saharan Africa and 60% for Asia (Habitat for Humanity, 2014.)

The poor have no access to formal housing financing services simply because they cannot afford conventional housing. Poverty is generally an all-encompassing term used to describe situations where, people lack many of the opportunities that are available to the average citizen within a political or economic region. While low-income is central to this notion, poverty also covers other factors relating to severe and chronic disadvantage. In order to emphasise the substantial complexities of the constituents of poverty, sometimes, the compound term "poverty and social exclusion" is utilised. (Palmer, 200?b) Low-income on the other hand refers to a situation where a household

may be in strained circumstances because it has to spend a greater proportion of its income on necessities than the average family of similar size. Specifically, the threshold for low income is defined as the income below which a family is likely to spend 20 percentage points more of its income on food, shelter and clothing than the average family. Palmer (200?a) giving an example reveals that 1992, an expenditure survey in the United Kingdom, showed that on average, families spent 43% of their after-tax income on necessities. Then, to calculate the low-income cut off, 20 percentage points are added, giving 63% of after-tax income. This is done on the grounds that a family spending more than this proportion of its income on necessities is significantly worse off than the average family.

Having rifled through the concepts of poverty, and low-income, it important to note that at the core of this paper is the need to examine the relationship between low-income and housing; in other words, what is low-income housing?

The idea of low-income housing is in many ways similar to that of low-income, in fact, it can be said that, the concept of low-income housing is an investigation into low-income, with particular emphasis on the impact of housing as a necessary burden on a household's income. According to the Washington State Labour Council (2009), Woo and Mangin (2009); the definition for low-income housing arises from the premise that a household's monthly cost of housing should not exceed 30% of its net income. This is because in a situation where housing costs are greater than 30% of the household's income, the fore mentioned household would find it difficult to meet other necessities such as food, clothing, transportation and medical care. Therefore, households that cannot be suitably housed at the 30% percent standard within an area are considered "low-income," meaning they earn below 80% of the area median income. This "standard" however is not fixed and various countries utilise a different income percentage. Canada for example changed from 20% to 25% in the 1950's and are currently utilising a 30% household income rule (Hulchanski, 1995) and India utilises a 40% rule.

Furthermore, studies carried out by the Urban Research Centre (2008) indicate that this idea that, a household's housing costs being more than 30% of its income poses financial strain, is a well-accepted phenomenon - as illustrated by financial institutions that have applied a rule of not allowing households to take out home loans requiring more than 30% of gross household income for their servicing. This indicates that the lending institutions recognise that a percentage beyond 30% of gross household income would place undue burden on the household, thereby increasing chances of absconding from repayment.

Affordable housing, that Milligan, et al. (2007) define as that which recognises the needs of households whose incomes are not sufficient to allow them to access appropriate housing in the market is often used interchangeably with low income housing. However, Milligan, et al. further extend the definition and recognise that affordable housing is not only for the poor; here taken to mean the most deprived of society, but also that, low-middle income earners require housing that is affordable. Ashkin (2013) agrees with the train of thought that affordable housing is not only for the poor. The author suggests that in many instances, national and regional administrative units determine "affordable housing" by utilising the 30% housing cost to income ratio in the provision of social housing; where a household's monthly housing costs should not exceed 30% of its

monthly net household income. However, social housing - which is defined as housing owned and provided by a Government authority for housing those with low-income or special needs; which is not run for a profit; through a Government subvention or subsidy; and is usually offered at below market rents - is erroneously known as low-cost public housing. The author argues that this is misleading because affordable housing can serve those other than low-income or special needs, that is, the lower middle-income group. Furthermore, it can be generally provided by the private marketplace and run for a profit, and financed fully by the purchaser or renter out of income without subsidy. It should therefore be noted that affordable housing is not the same as social housing.

The concept of housing affordability as described prior however has little real world significance; this is because different households have different levels at which housing expenditure becomes strenuous, that is, exceeds 30% of gross household income. Therefore, for practical application, other notions such as low-income cut offs and income limits are derived. Palmer (200?a) while discussing low-income limits notes that they vary greatly. The author suggests that there are separate cut-offs for seven sizes of family - from unattached individuals to families of seven or more persons - and for five community sizes - from rural areas to urban areas with a population of more than 500,000 inhabitants, underscoring the large difference between the levels at which housing expenditure becomes strenuous to a particular household.

Income limits as discussed by the Centre for Housing Pedagogy (2009) are derived from national statistics and are based on an area's Median Family Income (MFI). The government of the United States utilises MFI to create income categories and by extension income limits. These are commonly utilized in the formulation of various policies and implementation of different housing projects. In the United States, the population is categorised into six different groups; extremely low-income (0-30% of MFI); very low-income (30-50% of MFI); low-income (50-80% of MFI), moderate income (80-120% of MFI), middle income (120-250% of MFI), high income (>250% of MFI); and different levels of income as determined by the median family income attract different housing help.

Analysing the idea of median income in the determination of housing affordability, Smith (2006) suggests that since half of a given population exists below the median income, housing at market prices markets alone will never satisfactorily house a nation's poorest citizens. Therefore any study in low-income housing, is concerned with housing that can be comfortably accessed by those households considered to earn below an area's median income, that is, low-income earners.

It has to be noted that world over, there a number of housing affordability indices. Jewkes and Delgadillo (2010) identify 12 prominent housing affordability indices, but maintain that the housing cost to income ratio remains the most general measure of housing affordability

The housing cost to income ratio has a number of criticisms. One of its major perceived flaws relates to income and wealth distribution. Having defined 'affordable' as not being above a specified proportion of household income, when taken at a point in time, disregarding the persistent rise of incomes, 30% of a low income may be less 'affordable' than 40% of a high income. This is because 60% out of a high income still leaves this

household with an above-average disposable income (Paris, 2007.) This view is shared by Battellino (2008), who argues that households with high incomes can spend over 30% of their household income on housing and yet still have plenty of money to spend on other things. In an attempt to focus the challenge of housing affordability on low-income households, since evidence suggests that the groups most affected by the increase in housing costs are low-income households in the private rental market and moderate-income owner purchasers (Gabriel et al, 2005) the Australian government's 1991/92 National Housing Strategy, recommended that 30% of income be adopted as a measure for the maximum level of housing commitments for households in the bottom 40% of the income distribution (Battellino, 2008.)

From the proposed 30/40 definition of affordable housing as proposed by the Australian government, it is clear that different economic regions will have a different threshold for affordable housing and by extension low income housing depending on the area's median income. One can therefore conclude that low-income housing is that which is available at a cost that does not place financial burden on the household and more specifically targets households in the bottom 40% of the income distribution.

However, according to Randolph and Holloway (2002) there is need to assess housing affordability beyond the housing cost to income ratio, because, it is necessary to distinguish between the ways in which households experience affordability problems. The authors propose the use of the term 'housing stress' to encompass a range of financial circumstances. These include: A short-term or one-off issue of paying a mortgage deposit or rental bond; an on-going problem for households whose income is insufficient to meet housing costs (e.g. households who have over-extended themselves and pay too much in rental or mortgage costs); an episodic problem due to unforeseen circumstances such as redundancy or a rent rise; and lastly, it can also refer to factors such as over-crowding, insecurity of tenure, and inappropriate facilities within the home. Here, the authors are concerned with the ability of a household to comfortably live in a dwelling after it has been obtained. Tong (2004) introduces the concept of 'home ownership affordability' to differentiate the concerns of owner-occupiers from other groups. This is supported by Richards (Gabriel et al, 2005) who suggests that in the case of homebuyers, concerns about affordability are typically about the accessibility of home ownership, or the ability of younger households to gain access to home ownership for the first time as opposed to the ability to comfortably stay within a dwelling once it has been obtained.

From these arguments, housing affordability is then a complex construct and should be dealt with as being a more intricate phenomenon other than a result of household income. Gabriel et al (2005) asserts that the cost income ratio as a tool for assessing housing affordability is a simplification of a complex situation. The author suggests that question of housing affordability can be approached in a myriad of ways depending on how it has been understood. For example, housing affordability can be understood as; the continuing costs of a mortgage or rents relative to income, problems of accessing affordable housing (e.g., first home ownership), not being able to afford housing costs after meeting other expenditures, or a problem of too low an income or too high housing prices. In an even more detailed exploration, affordability and/or the lack of thereof can be experienced by households in different ways; that is, through employment, transport, health, and other consumption trade-offs that have to be made

by singles, sole parents and couples with children as they adapt their circumstances to high housing costs and/or low income. All this stems from the fact that housing not only constitutes of the physical dwelling, but also of the numerous factors for human wellbeing that contribute to feelings of housing satisfaction. These feelings play a major role in choice of housing and neighbourhood.

The arguments presented by Randolph and Holloway (2002) along with Gabriel et al (2005) instigate one to query housing choices made by low-income earners. Turner (1968) theorises about the nature of housing priorities and the needs of various levels of earners within the low-income bracket, all in an attempt to explicate drivers of housing choices. According to Turner, dwelling environments provide three basic functions, location, tenure and amenity. The level of importance of these in relation to each other is dependent on the level of social economic security achieved. Three social situations are identified: the lowest income is the 'bridge header' seeking a toehold in the urban system. The second is the 'consolidator' who has obtained a relatively firm hold but is in danger of losing it unless he can consolidate his newly achieved socioeconomic status. The third level is the higher income 'status seeker'. These three can be compared according to their priorities in terms of location, ownership, and amenity, rated according to the level of need (Ibid).

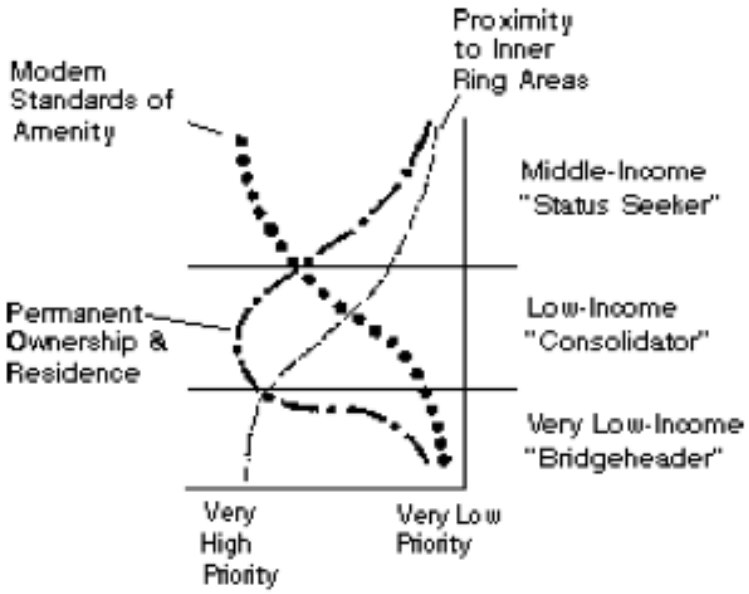

Image 1:Housing priorities based on income (Turner, 1968)

The diagram illustrates the idea that low-income earners have different priorities that affect the nature and location of their housing. Very low-income earners drawn to the employment opportunities offered by urban areas prefer to live as close to the inner ring of the urban area as possible. For these individuals, more so for recent city migrants, permanent ownership and modern standards of amenity are of low priority. This according to Matovu (2000) is because the location provides an advantage to residents who avoid high transport costs. He however points out that urban low-income settlements can be located anywhere depending on the availability of cheap unoccupied

land. In Latin America, this cheap unoccupied land is often found on hill slopes and in other cases such land is found along rivers, railway lines and swampy areas. An increase in income brings about a change in priorities. Improvement in tenure becomes the more important consideration as the individual seeks to create a foothold. The improvement in tenure can range from renting more permanent residence, or attaining ownership of land and housing. At the same time, proximity to the place of employment reduces in importance. In the final phase, what Turner (1968) calls the status seeker; modern standards of amenity take highest priority with proximity to area of employment having the least bearing on the choice of housing.

From these arguments, it is clear that low-income housing can take on a variety of forms, depending on the level at which the housing tenants are. According to Yeah (Matovu, 2000) low-income housing includes subsidised housing, emergency housing, temporary space rentals and, slums and squatter settlements. Subsidised housing is taken to mean housing that is available for use at a cost lower than market value. Emergency housing as the name suggests is that which is set up as a means of alleviating housing pressure as a result of an unexpected and often overwhelming event – for example, resettlement and aid camps.

The terms "urban low-income settlements", "squatter settlements" and "slums" have been used interchangeably and this led to a misconception of the actual meaning of each. It is important to distinguish these because the nature of response to these settlements; whether tolerant or aggressive has been determined by societies' perception towards them.

According to Yeh and Magatu (Matovu, 2000) the term "slum" is disapproving and evocative of conditions such as overcrowding, low income, disease and crime and social disorganisation. Furthermore, according to Obudho (Matovu, 2000); Morakinyo, et al. (2012) to this, can be added the definition that a slum is a collection of substandard housing constructed of recuperated waste material such as wood and corrugated iron sheets where there are no planned road networks, sewerage systems, and other basic amenities. In both contexts the term "slum" emphasise on the conditions and appearance of the housing units and their immediate physical environment.

Yeh (Matovu, 2000) however identifies a weakness of this qualitative definition by highlighting the fact that merely looking at the physical appearance of dwellings is an insufficient indicator of a slum since what may be good enough in one place is problematic or offensive in another. For example, a group of thatched huts becomes a slum only when transported to the city.

UN-Habitat (2011) offers an alternative insight into the definition of a slum that encompasses both the physical aspects of a dwelling and the environment within which it is found. A slum is an urban area in which more than half of the population live in inadequate housing and lack basic services. In particular, slums are made up of households that lack one or more of the following

> Durable Housing: A house is considered 'durable' if it is built on a non-hazardous location and has a structure permanent and adequate enough to protect its inhabitants from the extremes of climate conditions such as rain, heat, cold and humidity.

Sufficient living area: A house is considered to provide a sufficient living area for the household members if not more than two people share the same room.

Access to sanitation: A household is considered to have adequate access to sanitation, if an excreta disposal system, either in the form of a private toilet or a public toilet shared with a reasonable number of people, is available to household members.

Access to safe water: A household is considered to have access to improved water supply if it has sufficient amount of water for family use, at an affordable price, available to household members without being subject to extreme effort, especially to women and children.

Secure tenure: Secure tenure is the right of all individuals and groups to effective protection by the State against forced eviction. People have secure tenure when: There is evidence of documentation that can be used as proof of secure tenure status, and / or, there is either de facto or perceived protection from forced evictions.

By extension, housing can be considered inadequate if it lacks any of the 5 situations as highlighted by UN-Habitat.

Unlike "slums", "squatter settlements", refer to the illegal occupancy of land, which involves insecurity of tenure, irrespective of the quality of the buildings and the prevailing physical conditions Yeh (Matovu, 2000). Therefore in principle, "squatter settlements' are not necessarily "slums" because not all houses in a squatter settlement have to be sub-standard for it to be a classical "squatter settlement". A "squatter settlement" can only be a "slum" when the houses constructed are substandard and if there are no adequate sanitary facilities and sufficient amenities. However, this is mostly the case. Since most of the people in squatter settlements are "poor" they can hardly afford to purchase desirable and durable material to construct their houses, and consequently they resort to slum construction as a cheap alternative (Ibid; Willis, 2009). It is for this reason, squatter settlements are characterised by slum conditions and have always been referred to as slums.

On the other hand, urban low-income settlements refer to the communities where the urban poor usually reside. The dwellings constructed by the poor in low-income settlements usually resemble conditions of slums. The tenure system is not secure which is typical of squatter settlements. However, not all low-income urban dwellers are found in slum or squatter settlements.

Majale (1993) suggests that low-income settlements may also be known by other designations. These include spontaneous settlements; as they are built quickly and in the absence of government control and aid, marginal settlements; in reference to their location with respect to the urban setting, and the role residents are assumed to play in urban society. Also, some low-income settlements are known as transitional settlements; as an expression of the positive view that they can overtime become consolidated and permanent settlements.

The above list of designations must not be taken as being exhaustive; however, it is clear that, low-income among residents is the common variable found in slums, squatter settlements, spontaneous settlements, marginal settlements, transitional settlements and urban low-income settlements.

It is important to note that the global discourse reveals that the makeup of low-income housing is broad and tied to the context within which it is studied. Literature on low-income housing in the developed world is predominantly concerned with improvement of social housing schemes and methodologies to reduce mortgage burden on households. In the developing world, literature focuses more on how to cope with the growing challenge of informal housing - that which is built without formal planning permission and outside the formal construction sector. Studies on low-income housing are dominated by topics such as slum upgrading, improving access to housing finance, and strategies for improving community participation in low-income housing projects. The contrast highlights the stark differences between what makes up low-income housing in different economic regions across the word. It is therefore imperative to examine in detail the constitution of low income housing in the region of interest.

3. Low income housing – A contextual review

As mentioned in the previous section, the nature of low-income housing varies all over the world due to predominant social-economic circumstances. The ability to identify low income housing in the region of interest is important as this forms the basis for nearly every decision that the study undertakes. The following section presents general country information on Uganda, population and housing trends - in an attempt to have a framework through which low-income housing can be identified.

Uganda is a landlocked country situated in East Africa. It is bordered by Kenya to the east, Sudan to the north, the Democratic Republic of the Congo to the west, by Rwanda to the southwest, and by Tanzania and Lake Victoria to the south. The region is sometimes referred to as the great lakes region due to the presence of lakes; Victoria, Tanganyika, Malawi, Turkan, Albert, Rukwa, Mweru, Kivu and Edward. These lakes are important to note due to the fact that the lakes have a major influence on settlement patterns. This is most especially true for Uganda whose main urban centres lie within the lake basin region.

In terms of demographics, as of 2010 estimates, Uganda had population of 32.9 million and of this; the urban population was estimated to vary from 3.2 -7.5 million, with the generally accepted figure of 4.5 million. It has to be mentioned that this figure is set to rise to 7 million by 2020 (UN-Habitat, 2010).

With regards to housing, the increase in population has a not been met by a comparable increase in the stock of housing. According to the 2006 National Housing Survey, it is approximated that there is a housing deficit of 550,000 units and of these, 160,000 are in urban areas (Ibid.) It should however be mentioned that these figures may represent an overestimation of the problem; arising from unrealistic official norms of what is considered as satisfactory housing. Utilising an estimation of annual replacement of existing housing stock, a conclusion is reached by UN-Habitat (2010) that Uganda needs an addition of 79,200 units annually to adequately house its population and of these, 15,300 would be in urban areas. While opinions on the actual number of housing units required to adequately house Uganda's population may differ, one can comfortably conclude that there is a considerable housing deficit in Uganda. The relevance of housing demand versus supply to this study is tied to the fact that in any free market economy, such as Uganda, the wealthier of society are serviced first while other income classes are left to their own devices (Renaud, 1984.) Therefore, it can be assumed that the majority of people who lack adequate housing in Uganda mostly fall within the lower income brackets.

An appraisal of the housing situation in Kampala, Uganda's Capital helps to support the above assumption. In 2010, the city had a population estimated at 1,597,900 (Uganda Bureau of Statistics, 2010a) and a housing deficit of 100,000 units. Assuming a household size of 3.8 people per household (UN-Habitat, 2010), this deficit implies that at the time, 23% of Kampala's population lacked access to adequate housing. The housing deficit coupled with substantial poverty levels; approximately 31% of the national population is classified as living below the official Poverty line, defined as a per capita income of USD1 a day (UN-Habitat, 2010) - has had a telling impact on the housing situation with a large number of people living in substandard housing. The Uganda Human Settlements

Network (2014) estimates that up to 64.3% of the dwelling units in Kampala are tenements or "mizigo" – the typical housing structures in slum areas. Action Aid international puts the number of slum dwellers in Kampala at 1.5 million out of 1.8 million as of 2014.

From the global discourse presented earlier, in developed countries, there are clear-cut definitions for low-income housing. That is, in general terms, housing provided to households at a cost less than that which would be considered financially strenuous. The central administration utilising a number of tools intervenes in the process of housing supply to ensure that the housing needs of a cross section of low-income earners is met. However, in developing countries like Uganda factors such as wide spread poverty, a large informal sector and limited government resources limit the ability of low-income housing provision. It is important therefore, to examine the government policy on housing in order to understand how low-income earners access housing.

Housing policy in Uganda can be broken down into three phases, pre-colonial, colonial and post-colonial. Before colonialism, the area that currently makes up Uganda was made up of a rural based population of hunter-gatherers and farmers. With exception of the "Kibuga," there were no notable urban areas and housing was the responsibility of individual households. The family head, often helped by neighbours in the construction process, was responsible for housing provision (Sanya in Nnaggenda-Musana & Vestbro, 2013).

With the advent of colonialism in 1893, Uganda was declared a protectorate and Entebbe was declared the Capital of the new protectorate. In 1903 the Uganda ordinance was passed that gave the Governor the powers to define the boundary of Kampala. This was followed in 1912 by Kampala's first plan. The plan was intended to control and direct development, however it must be mentioned that it gave priority to upper and middle-class white and/or Asian populations and was therefore focused on Nakasero and old Kampala (UN-Habitat, 2007.) The indigenous population was largely ignored with the assumption that they would be migrant in nature, commuting from their rural based abodes to work in the urban areas.

Ernst May's plan in 1930 was the first comprehensive plan that included settlements for middle and low-income housing for Asian and African populations (Nnaggenda-Musana & Vestbro, 2013.) These settlements were located in Nakawa and Naguru, on the outskirts of the main industrial and commercial areas. The low-income dwellings were intended to provide accommodation for male labourers who it was still assumed would remain migrant in nature. This can be observed from the fact that the spatial nature of the dwellings did not afford living spaces able to house a family.

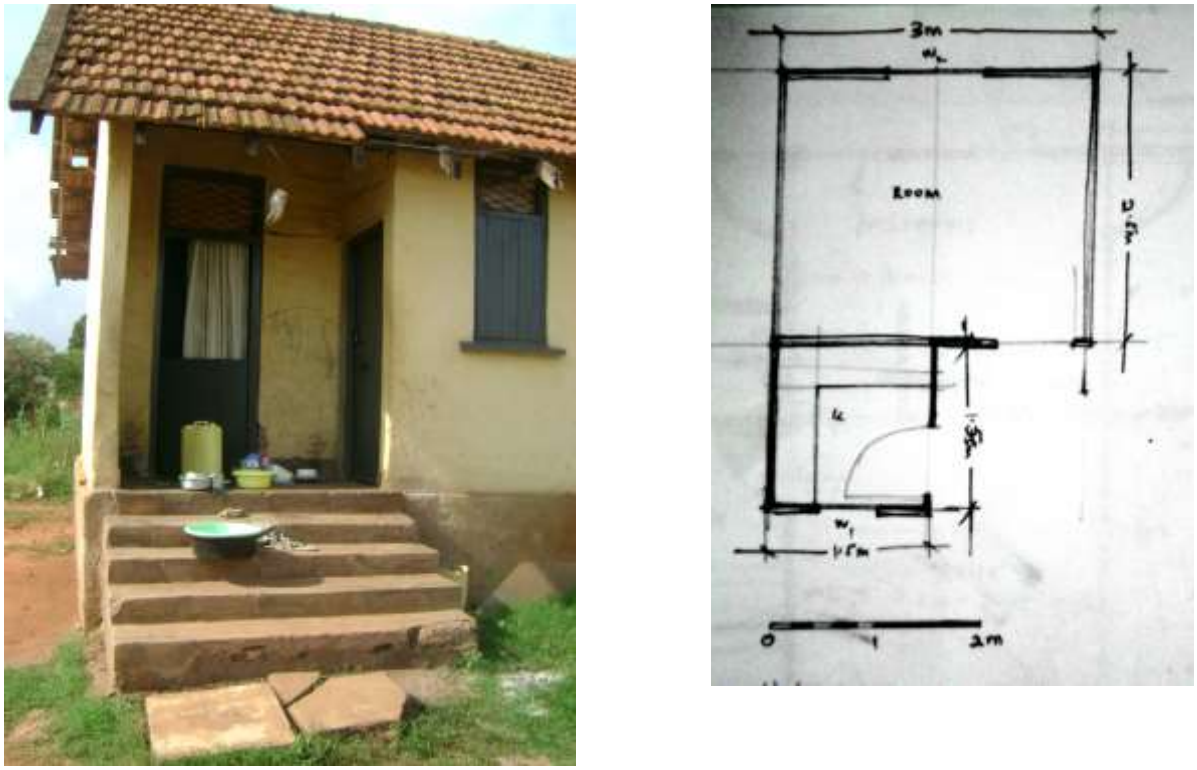

Image 2: Housing for indigenous low-income earners - Nakawa (Source: Author)

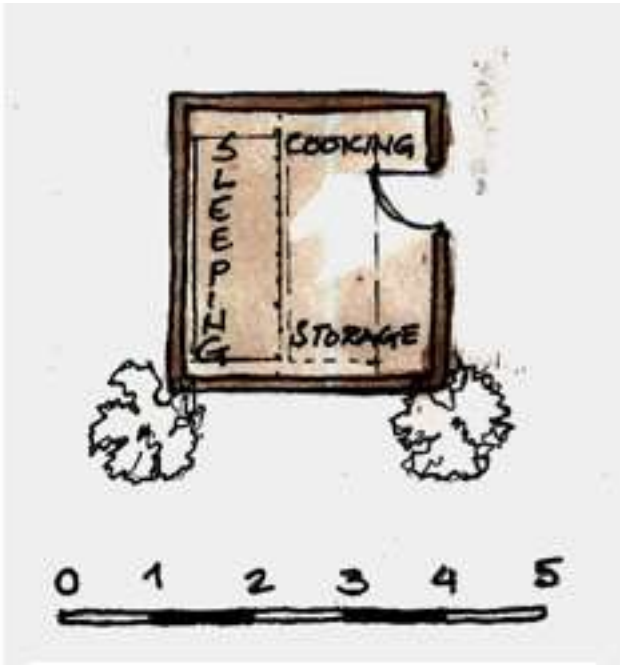

Image 3: One-roomed tenement (Nnagenda-Musana & Vestbro, 2013)

It can be theorised that housing developed at this time for the indigenous population gave rise to the modern day one roomed tenement commonly referred to as "Muzigo;" albeit with less permanent materials utilised to keep costs of construction low.

In 1951 a Planning Act was passed, it was aimed at stimulating orderly and progressive development of towns, and in 1972, the Kampala Development Plan was developed.

Envisaged as a guide for the development of a pleasant and healthy city for all bearing in mind the growing population of Kampala, the plan constituted proposals for the provision of housing for a cross section of Uganda's populations. The plan was never adequately enforced due to the political strife that engulfed the nation. It needs to be mentioned that the majority of urban development plans were centred on Kampala because various factors pushed it into becoming the primate urban area.

During the military rule (1971-79), there was significant collapse of the economy and social infrastructure. However, the construction of private homes continued, and it is during this period that informal settlements mushroomed in the various urban centres (Ibid).

Stability returned to Uganda in 1985 and in 1992, government adopted the National Shelter Strategy (NSS). The NSS was founded on the enabling approach where government as a facilitator would create an environment in which different players: households, private firms, NGOs, and both formal and informal community groups could operate to provide decent shelter. The enabling approach was favoured because it permitted the government to disassociate itself from the high cost of housing provision, while at the same time providing the regulatory framework and support infrastructure to ensure organised development. The NSS was boosted by the enactment of the 1998 land act, condominium act, and promotion of housing finance (Department of Human settlements, 2008). In 2005, the NSS was reviewed and a draft National Housing Policy was prepared. Its major attributes include slum upgrading, enforcement of standards to prevent overcrowding, and improvement of living conditions for the urban poor. This was done through varied partnerships: NGOs for example Habitat for Humanity that bring expertise and policy development; development partners - African Development Bank; and financing institutions like the African Housing Fund. The Government of Uganda and its partners approached low-income housing provision by implementing slum-upgrading projects with varying levels of success. While these have provided housing for up to 2000 households, it should be noted that they have faced a number of shortfalls. The slum upgrading projects are largely unsustainable and difficult to replicate on a substantial national level. Furthermore, they have faced a challenge of down raiding by higher income populations and outward migration of low-income populations (Department of Human Settlements, 2008.)

Complementary strategies have been attempted to increase housing supply for example: increasing the production and supply of building materials, especially to the low-income households at affordable costs; enforcement of housing construction according to building standards; and increasing the supply of land for housing as a way of minimising the development of substandard houses in urban areas. However, these have been relatively unsuccessful and out of the reach of many urban dwellers resulting in the construction of illegal structures (Sengendo in Nnaggenda-Musana & Vestbro, 2013). Physical planning and attempts at low-income housing provision in the other Ugandan urban centres have faced similar challenges as those highlighted in the Kampala narrative: limited scope, political instability leading to limited implementation and lack of finance.

It can be concluded therefore that, housing policy and associated attempts at housing provision for the general population in Uganda, have remained largely unsuccessful. Low-income earners face a multitude of challenges, leading to the construction of illegal

and often sub standard structures. It is plausible to deduce that in Uganda, low-income housing is synonymous with slums and more accurately, **informal housing**. The use of the term informal housing is preferred as it more exactly encapsulates the fact that the majority of low-income housing in Uganda; here including slums, squatter settlements, marginal settlements, spontaneous settlements and transitional settlements exist without proper planning permission and outside of the formal construction sector.

As presented, the review of literature reveals that the vast majority of Uganda's urban population lives in informal housing settlements (UN-Habitat, 2010; Uganda Human Settlements Network, 2014.) Considering the fact that the study has limitations in both time and resources and cannot thus cover all the urban areas countrywide, it becomes important to determine representative populations for the study. Selecting a representative population for the study is important as it ensures that: data collected is characteristic of overall national phenomena; it helps to determine the choice of sapling techniques; and ensures that the overall objectives of the study are met.
Selecting a representative population is achieved by utilising the make up of low-income housing having been prior discussed, and expounding upon the deliberation by theorising on how factors such as climate urban population size and geopolitical history may influence low-income housing typologies and material utilisation.

a) Climate and context

The importance of the framing this study within the tropics as a specific climatic zone cannot be overstated. This is because due to different average weather conditions existing in different climatic zones, different materials will be utilised either because of; the ease of acquiring them or their ability to provide protection form the elements.

A climatic zone is defined an area under the influence of a climate system usually determined by its latitude. Climate is defined as the average weather over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years. The quantities that are most often considered in the description of climate are temperature, precipitation and wind. (Inter Governmental Panel on Climate Change, 2007) It has to be mentioned that while average weather conditions overall climatic region may be similar, climatic conditions within particular locations differ due to altitude, terrain and proximity to water bodies. This in turn may bring about different methods of material utilisation and building techniques that are specific to a particular location.

Climatic regions for Uganda are determined based on available data, and extrapolation from archival sources. Through this data, it was determined that Uganda can be demarcated into three major climatic zones: The Lake Victoria Basin, The Lowland Savannah, and a relatively small Highland region. These are represented in the Diagram 1 below. The boundaries for the climatic zones have been mapped onto existing District boundaries in an approach used by the Building Code of Australia (BCA) to ease the administration of climate related policies. It should be noted that regardless of how climatic boundaries are indicated, they are indicative only as in reality, there are no sudden dramatic shifts in climate between climate zones, but only gradual transitions. Uganda can be said to have three climatic zones; hot and wet savannah, hot and humid

lakeside and cool and wet highlands. It must be mentioned that within this broad categorisation, there are more specific climatic variations.

Image 4: Climatic Zones, Uganda. FOBE (2013)

b) Urban population size

Urban areas with larger populations it is theorised have a larger diversity of people with varying incomes and different abilities to source for housing. The difference in ability to source for housing suggests a diversity of housing typologies. Diversity of housing typologies is an important consideration as the selected urban area is representative of the region. The study is therefore situated in different urban areas across the country that are considered to be regional centres, both in terms of population size and commerce.

c) Geopolitical location

Uganda and her neighbours have over the past half-century seen their share of political instability. In the case of Uganda specifically, the period from 1986 to 2010 saw a number of armed rebellions emerge in different parts of the country, however the most enduring and destructive was witnessed in northern Uganda. Armed rebellion and associated outcomes such as disruptions in trade and commerce, displacement of people and breakdown of social structures has impact on the choice of materials used in the construction of housing.

Further more, Uganda's neighbours have also faced civil strife in varying degrees and this too has had an impact on social economic activities within Uganda, not to mention the development of housing infrastructure and traditions. In order to capture a holistic regional picture of material use and selection data for the study is collected from areas located in different latitudes; north to south and longitudes; east to west in order to provide a holistic national picture.

Representing the hot and humid lakeside is the towns of Jinja and Mbarara. The towns of Gulu and Arua represent the hot and wet savannah while Mbale and Kabale towns represent the cool and wet highland climatic Zone.

d) Availability and ease of access to background data

The availability and ease of access to background data for the selected urban areas is an important consideration, because, the study cannot hope to satisfactorily collect baseline data such as population data and mapping data for low-income settlements. The study therefore relies on information gathered by organisations with inherent interest in low-income housings such as the Ministry of Lands Housing and Urban Development (MLHUD), Slum Dwellers Federation of Uganda and Acttogether Uganda who have

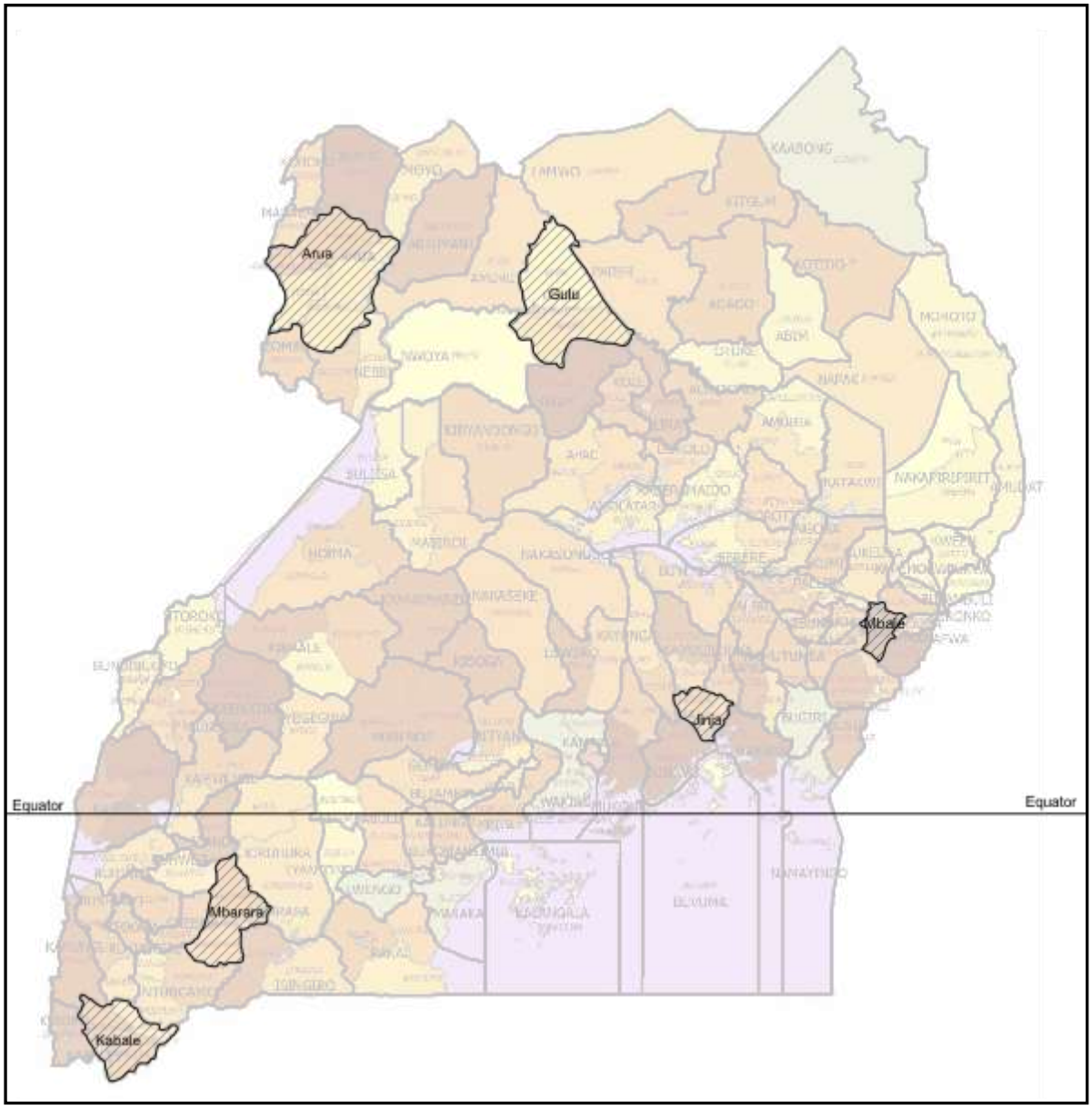

Image 5: Representative Districts

4. Overview of selected low-income housing settlements

The following section provides an overview of low income housing in the representative districts. The overview includes both formal and informal housing areas to generate a comprehensive characterisation of low-income settlements

4.1. Cool and wet highland

The districts of Mbale in eastern, and Kabale in western Uganda represent the cool and wet highland climatic zone. The districts' administrative centres, which share names with the district, are the main focus of the study.

4.1.1. Mbale

Mbale Town lies north of the equator at latitude 1°04'50. 0"N and longitude 34°10'30. 0"E; and an average elevation of 1125 m above sea level. The district is bordered by Tororo District in the south, Manafwa District in the southeast, Sironko District in the northeast, Kumi District in the north, Budaka District in the northwest and Butaleja District in the southwest.

Mbale district has a formal low-income housing project, Malukhu integrated poverty reduction project (MIPREP); however, according to Act Together Uganda and Uganda Slum Dwellers Federation (n.d) the majority of residents within Mbale town live in unplanned areas.

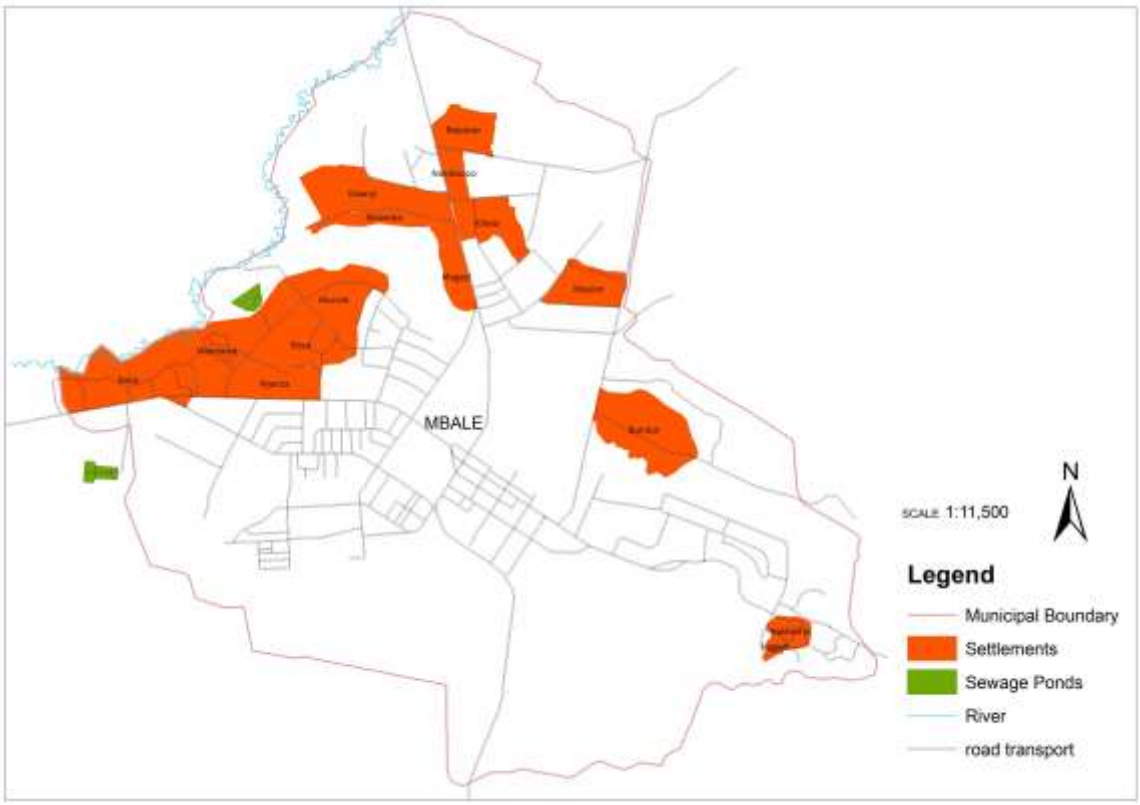

Image 6: Informal settlements Mbale (ACTogether & NSDFU, 2014)

A. Formal low-income housing: Malukhu integrated poverty reduction project (MIPREP)

MIPREP is located in Mbale district, Mbale municipal council in eastern Uganda. The project was implemented on a 25 hectare public piece of land that had been illegally settled by 860 households living in temporary structures. The main objectives of MIPREP were to

- Improve the living conditions of the residents through upgrading and construction of new structures; infrastructure and service provision
- Improve security of tenure
- Improve household incomes through training and provision of income generating loans

The project commenced by allocating plots based on criteria and guidelines agreed upon by the various stakeholders. With plots allocated, every beneficiary was tasked to build a pit latrine. The soil excavated was used to make stabilised earth soil bricks using hydra form brick pressing machines. After producing the bricks, beneficiaries were given building material loans ranging from 1.8 million and 2 million. The building material loans were to be utilised in the purchase manufactured materials such as cement, iron sheets, nails, sand lime and timber.

A group of nine women were also trained in brick making, carpentry and joinery as well as roofing. These mobilised the community into groups that produced bricks. However, there was concern about the quality of bricks produced. This was a result of the fact that many bricks were lost during firing. The problem was later found to be a result of the poor quality of soil that was used. Non the less, more than half of the bricks survived and these were used in the construction of Wambwa Primary School and office block (DCDM, 2013b).

B. Informal housing

Mbale has six informal settlements that fall under the administration of Winale, Northern and Industrial Divisions. The settlements are a result of migrations of people looking for employment opportunities in the urban centre, which has not been accompanied by equal increase in housing infrastructure.

According to Act Together Uganda (n.d) the majority of residents within Mbale town live in unplanned areas. Informal settlements within the town are Namatala in industrial Division; Nabuyonga, Namakwekwe, and Nkoma in Nothern Division; Busamaga and Mooni in Wanale Division.

A survey of the low-income housing within Mbale shows that the following materials are used in construction; mud and wattle, wood poles, sawn timber, sun dried bricks, compressed soil cement earth blocks, burnt bricks, cement sand mortar, concrete; grass thatch and iron sheets for roofing. (DCDM, 2013b; Actogether Uganda, n.d)

Division	Settlement	Cell	Area	No of buildings
Industrial	Namatala	Doko	617 acres	900
		Sisye	494 acres	1000
		Mvule	37 acres	1500
		Nyanza	170 acres	250

		Wandawa	30 acres	250
Northern	Namakwekwe	Nabigyo	296 acres	150
		Kiteso	617 acres	200
		Mission	370 acres	72
	Nabuyonga	Kisenyi	123 acres	100
		Kichafu	741 acres	300
	Nkoma	Nambozo	40 acres	100
		Bujoloto	150 acres	70
Wanale	Mooni	Zesui		
		Nagudi	12 acres	26
		Nashibisho	8 acres	90
	Busamaga	Bumboi		

Table 1: Informal settlement profile, Mbale Town (ACTogether & NSDFU, n,d)

4.1.2. Kabale

Kabale Town in South western Uganda lies on 01°15'00"South of the Equator at 2000m above sea level. Kabale Town has 9 informal settlements; Central division- Kigongi, Konyo, Nyabikoni; Northern division – Kijuguta (Katojo and Rwakaraba) settlement, upper Bugongi; Southern - Karubanda, Karigime and Kekubo (Actogether Uganda, 2010 d).

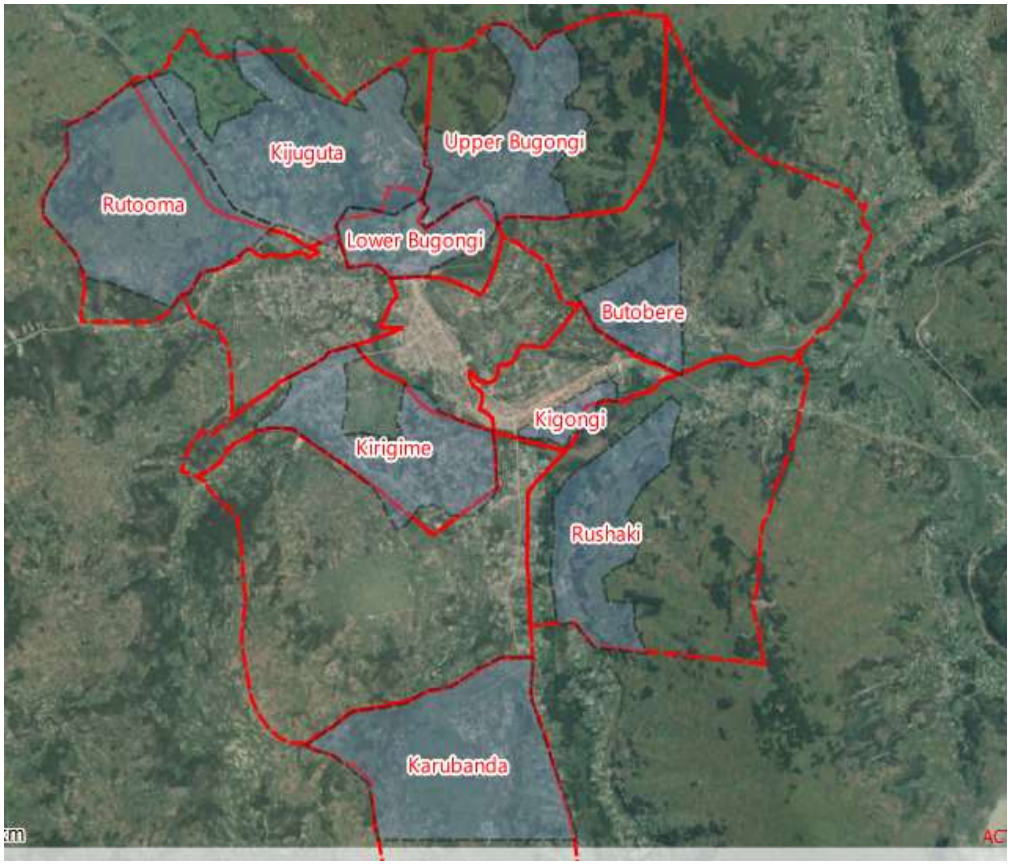

Image 7: Informal settlements (ACTogether & NSDFU, 2014)

The map shows the location and extent of informal settlements. It is visible that these have grown around the central business district of the town, the heavily developed area

at the centre of the map. Informal housing settlements have also developed along major transport arteries such as: Rutooma and Kaijuguta, flanking Kisoro Road; Karigime and Karubanda along Kabale – Kigali Road.

Documented surveys of low-income housing within Kabale shows that the following materials are used in construction; mud and wattle, wood poles, sawn timber, sun dried bricks, burnt bricks, cement sand mortar; grass thatch and iron sheets for roofing (Ibid).

Division	Settlement	Area	No of buildings
Central	Kigongi Focuses on Kigongi A – main informal settlement	200 acres	650
	Konyo	80 acres	28
	Nyabikoni	240 acres	232
Northern	Kijuguta settlement (Katojo and Rwakaraba B)	113 acres	212
	Upper Bugongi (Kakabano)	4 acres	80
Southern	Karubanda	30 acres	70
	Kirigime	50 acres	50
	Kekubo	5 acres	

Table 2:Informal settlement profile, Kabale Town (ACTogether & NSDFU, 2010d)

4.2. Hot and wet savannah

The districts of Gulu and Arua represent the savannah climatic zone. The districts lie north of the equator.

4.2.1. Arua

Arua is a town in Arua District in northwestern Uganda. It is located nearly 520km by road, northwest of Kampala, the capital city of Uganda. Arua town has both formal and informal low-income settlements.

A. Formal low-income housing: Oli Housing Project (OHP)

OHP was inaugurated in October 1994, but actual implementation commenced in 1996, targeting 886 households. The project was conceived to achieve the following: improve living conditions of residents through upgrading and construction of new structures; improve security of tenure; improve household income through training and provision of income generating loans.

In the conceptualisation of OHP, semi permanent structures were designed and proposed for the project. This was because according to the social economic study, it was found that the majority of households were low-income earners. The study showed that several beneficiaries operated survivalist businesses such as hawking clothes. Women beneficiaries were employed mostly as tea girls in the market earning about UGX

1,500 per day. Male beneficiaries were employed as labourers at construction sites, earning between UGX 30,000 and UGX 50,000 per month. The highest earning beneficiaries were teachers earning between UGX 150,000 and UGX 400,000 accrued from their full time job and several part time jobs. However, the idea to build semi permanent structures was later abandoned due to the fact that the area was close to the central business area of Arua municipal council. Therefore, it was decided that the new structures should be comparable in terms of durability to neighbouring structures.

In order to reduce project costs, members of the community were trained on how to implement self-help projects. Some of the topical training acquired included: clay work techniques and usage of various equipments in the production of low cost housing; brick making technology; financing/cost recovery; processes of setting up co-operatives; raising of animals and small scale fish production as income generating activities

Beneficiaries of the project were required to produce local materials such as bricks on their plots as part of their contribution to the project. Upon production of the bricks, the beneficiaries would access loans ranging from 1.2 to 3 million for purchasing non-local building materials such as cement, iron bars, roofing sheets, nails, doors, windows and timber.

Members of the community – using sand and sisal, made roofing tiles. The beneficiaries, mainly due to their poor quality, rejected the tiles. It was determined that the loss of quality was due to poor supervision during production (DCDM, 2013c).

B. Informal housing

Arua has six informal settlements found in two administrative divisions, that is, Arua Hill and River Oli; these are Mvara, Bazaar, Awindiri, Pangisha, Tanganyika and Kenya.

An inventory of materials used in the construction of low-income housing, both formal and are mud and wattle, wood poles, sawn timber, sun dried bricks, burnt bricks, cement sand mortar, concrete; grass thatch, cement sisal roofing tiles and iron sheets for roofing (Actogether Uganda, 2010c; DCDM, 2013c).

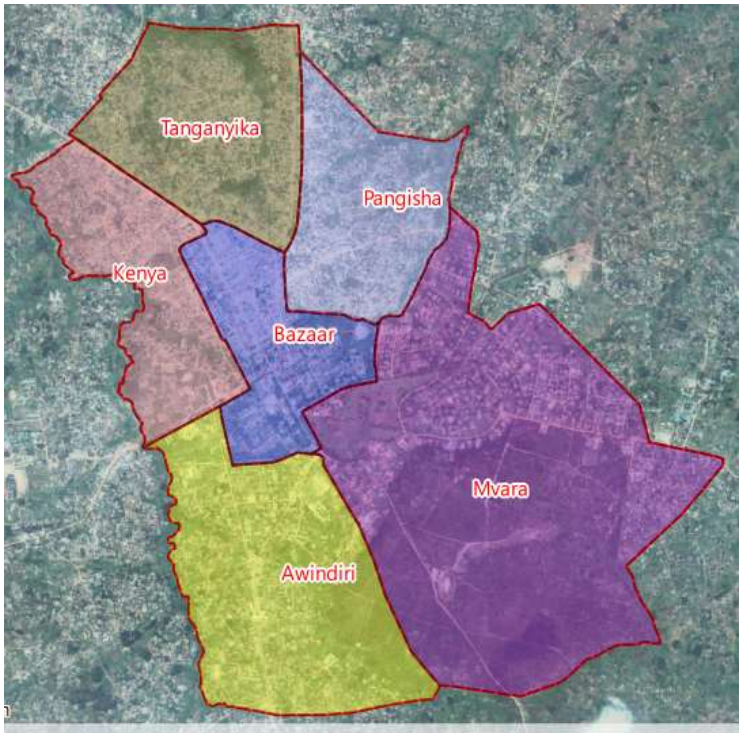

Image 8: Informal settlements - Arua (ACTogether & NSDFU, 2014)

Below is a breakdown of the settlement profile of informal settlements in Arua town.

Division	Settlement	Cell	Area	No of buildings
Arua Hill	Mvara	Congo cell	10 acres	105
		Zambia	9.5 acres	192
		Ewavio	8 acres	600
	Bazaar	Gurua	12.3 acres	194
	Awindiri	Nsambya	32 acres	580
		Academy	10 acres	50
River Oli	Pangisha	Orphanage	24 acres	450
		Oyooze	16 acres	150
		OJuluoa	14 acres	90
		Oluodri	13 acres	70
		Baruku	10 acres	170
		Muru	12 acres	130
		Upper Biabia	9 acres	250
		Osu cell	9 acres	120
		Azia	10 acres	150
		Abia	15 acres	170

	Kenya	Jacento	27.5 acres	220
		Odrokoroa	20 acres	85
		Club	35 acres	170
		Enyau	50 acres	150
		Ozua	20 acres	136
		Ombizevua	10 acres	100
	Tanganyika	Obolokofuku	16 acres	174
		Swalia	10 acres	75
		Oli	40 acres	2390

Table 3:Informal settlement profile, Arua Town (ACTogether & NSDFU, 2010c)

4.1. Hot and humid lakeside

The towns of Jinja and Mbarara represent the hot and humid lakeside climatic zone

4.1.1. Jinja

Jinja lies 87 km northeast of the capital, Kampala at latitude 0°25′28″ north of the equator. It is located on the shores of Lake Victoria, near to the source of the White Nile. The city is the chief town of Jinja District.

Jinja was the industrial heart of Uganda between 1954 and the late 1970s - supported by power from the hydro electric Nalubaale Power Station at the Owen Falls Dam, which was completed in 1954.

Jinja has a large population of inhabitants who are defined as "working urban poor". The average annual household income is estimated at USD. 100 (Actogether Uganda, 2010b)

Jinja's low-income settlements are mostly informal in nature. However, there are a number of housing estates that are formal in nature. These arise from government slum upgrading initiatives, dilapidated housing for low-income factory workers and non-governmental initiatives.

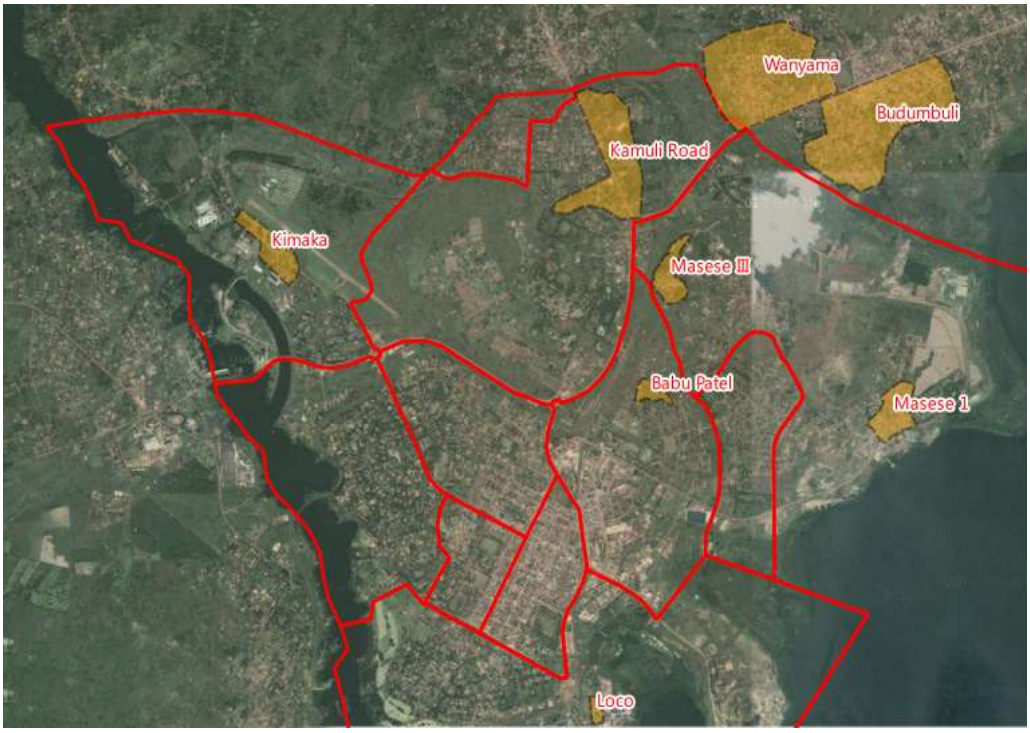

Image 9: Informal settlements, Jinja (ACTogether & NSDFU)

A. Formal low-income housing: Masese Women's Self Help Project (MWSHP)

MWSHP is located in Walukuba in Jinja municipality. The project commenced in 1989 targeting 700 households. The Ministry of Lands Housing and Urban Development (MLHUD) conceived the project with the following objectives: to improve the housing conditions, social and domestic infrastructure and services in Masese; to train women to acquire skills in building materials production and housing construction techniques; to promote and support trained women to become small scale entrepreneurs in building materials production and marketing.

Having carried out social economic, and cadastral surveys, plots were handed to project beneficiaries. A number of house designs were proposed by Ministry of Lands, Housing and Urban Development (MLHUD), and these were based on the size of the plot.

Block no	Plot size	Planned dwelling
Block M 153	14x10m 12x18m	2 roomed house, detached pit latrine (optional bathroom)
Block M105	14x10m 12x18m	2 roomed house detached pit and bathroom
Block M106	15x25m 15x24m 15x20m	3 roomed house with bathroom detached and pit latrine

Table 4: Plot size and proposed planned housing unit (Adapted from DCDM, 2013c)

The different housing units attracted different housing loans. It is reported that for he three bedroom house, 4.2 million was given and for the 2 roomed house, a loan of UGX 1.7 million was given. All loans disbursed to beneficiaries were given an interest of 4.1% per annum with a repayment period of 10 years.

The building materials loans were to be utilised for the purchase of building blocks, cement, nails, roofing tiles and floor tiles, doors, doorframes, windows and their frames. The majority of these materials were produced on site under the technical guidance of the trained volunteers. These included roofing tiles, floor tiles, wall blocks, toilet slabs and slab covers (DCDM, 2013d).

B. Informal housing

Informal housing settlements include in Central division, Loco Village; Central division, Rippon market landing site; Walukuba division Masese 1, Mpumudde market Zone A, Soweto, Walukuba - Zabef, Walukuba – Babu Patel settlement, Kimaka settlement, and Kikaramoja.

The materials utilised in the construction of low-income housing in both formal and informal settlements are mud and wattle, wood poles, sawn timber, sun dried bricks, burnt bricks, plastic sheeting, cement sand mortar, concrete; grass thatch, cement sisal roofing tiles, clay tiles, and iron sheets for roofing (Actogether Uganda, 2010b; DCDM, 2013d).

Name of settlement	Location	No of buildings
Kimaka	Budondo Road – near the airfield	473
Loco	Central Division, Loco village	20
Masese I	Lake Victoria shores, Walukuba division	210
Mpumudde market zone	Mpumudde division	50
Rippon Market	Old Boma Parish	80
Soweto	Walukuba division	150
Walukuba – Babu Patel	Masese Division	77
Walukuba – Zabef	Masese	80

Table 5: Informal settlement profile, Jinja Town (ACTogether & NSDFU, 2010c)

4.1.2. Mbarara

Mbarara town is located 270 kilometres southwest of Kampala, the capital city of Uganda along Kabale road. It is located at Latitude 00°36′48″ south of the equator and 30°39′30″ East of Greenwich.

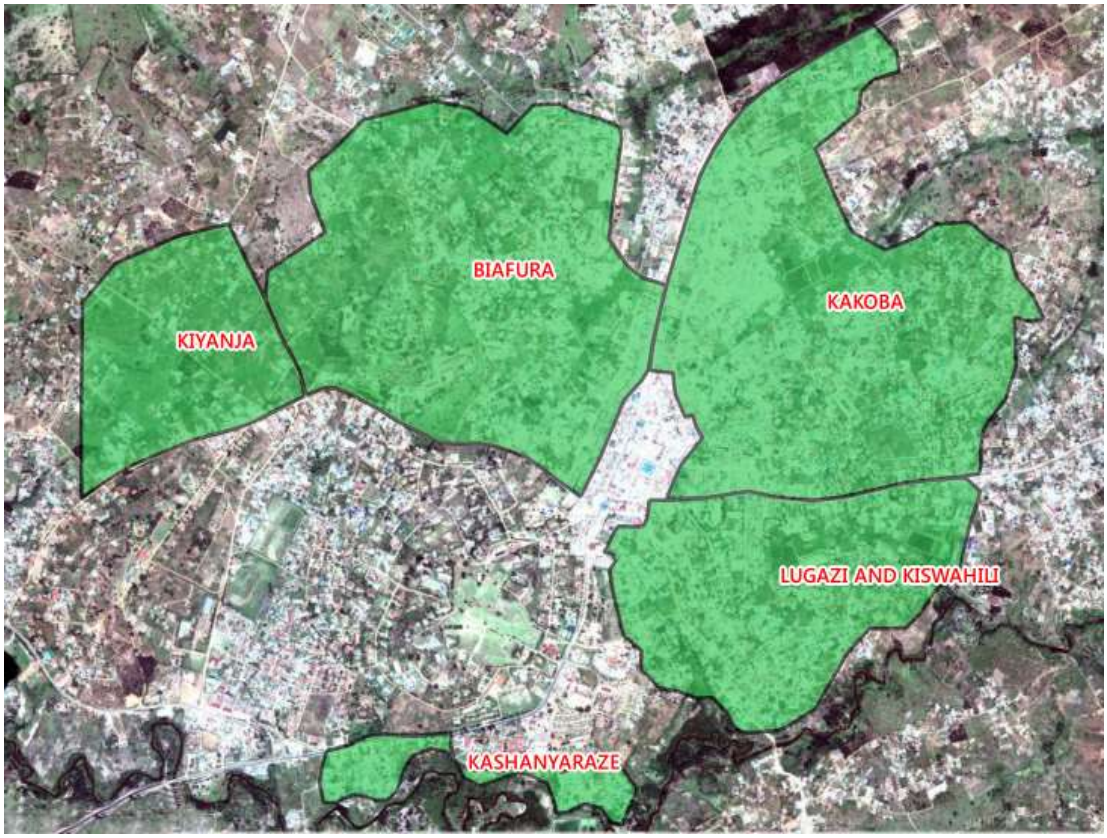

Image 6: Informal settlements, Mbarara (ACTogether & NSDFU, 2014)

Mbarara has got a total of 12 informal settlements with a population of over 80,000 people living within these areas the majority of whom are renters. The informal settlements are found in Nyamitanga division - Akachwampare, Kihangire, Tank hill Kirehe; Kakoba division - Kiswahili, Kizungu, Kisenyi and Kyamakuzi division – Kiyanja, Kashanyarazi, Butabika, Biafura-Kiyanja and Kajogo. (Actogether Uganda, 2010a)

Documented surveys of low-income housing within Mbarara shows that the following materials are used in construction; mud and wattle, wood poles, sawn timber, sun dried bricks, burnt bricks, cement sand mortar; grass thatch and iron sheets for roofing (Ibid).

An overview of low-income housing from the target towns indicates a materials palette that includes the following materials

Alternative building materials	**Conventional building materials**
Mud and wattle	Burnt clay bricks
Sun cured mud brick	Concrete block
Compressed soil cement blocks	Hollow concrete block
Untreated timber and poles	Steel sheet
Naturally occurring lime	Sand
Sisal-cement roofing tiles	Gravel

Grass thatch	Aggregates
Untreated timber and poles	Cement
Plastic sheeting	Processed lime

Table 7: Catalogue of construction materials used in low-income housing

In Uganda, the British standard is utilised for specifying construction materials. While this is not strictly adhered to in informal housing, it has provides a benchmark around which "conventional" materials are produced. However, materials traditionally not included in the British standard for example earth as used in earth construction (Little & Morton, 2001) pose a challenge as material and use primarily depends on the artisan and quality of workmanship greatly varies.

Construction materials are subdivided into conventional and non-conventional materials where conventional refers to those materials that are traditionally covered by British standards and are ordinarily used in the formal housing construction sector.

5. Methodology

The nature and scope of low-income housing in the context of Uganda having been presented, the following section presents a discourse of the discipline within which the paper is situated, with the aim of building a framework for data collection.

5.1. Life Cycle Analysis (LCA)

Embodied and operational energy studies are part of a larger comprehensive assessment of looking at the impact of a building on the environment over its lifespan. These studies are termed as Life Cycle Assessment (LCA). According to the ISO (1997) LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by

- Compiling an inventory of relevant inputs and outputs of a system
- Evaluating the potential impacts associated with those inputs and outputs
- Interpreting the results of the inventory analysis and impact assessment phases in relation of the objectives of the study

LCA is intended to determine the impact of inputs and outputs in a system on the environment. Environmental impacts include; climate change, water extraction, mineral resource extraction, human toxicity, eco toxicity to land, waste disposal, fossil fuel depletion, acidification, stratospheric ozone depletion, and eutrophication. (Anderson, et al. in Menzies, 2012)

The current study focuses on Life Cycle Energy Assessment (LCEA), a closely related concept to LCA. LCEA considers energy as the single criteria for analysis rather than a broad range of environmental impacts. This study utilises this approach because it provides the researcher with a manageable tool, suitable for identifying opportunities for change hence acting as one way of addressing sustainability in the building industry. (Mpakati-Gama, et al., 2011)

The definition of life cycle assessment forwarded by the ISO is expounded upon by Willmott Dixon (2010); Menzies (2012) and Haynes (2013), who define LCA as an examination of the entire life cycle of a product - and in the case of the study at hand, a building - encompassing extraction, processing of raw materials, manufacturing, transportation and distribution; use, maintenance, recycling and final disposal. This definition highlights the various stages in the lifecycle of a product giving an idea of the expansive nature of LCA.

The energy utilised over the lifespan of a product, and in this case, buildings, can be divided into embodied energy and operational (use) energy.

Operational energy refers to that which is associated with the use of the building; energy expended in maintaining the inside environment through processes such as heating and cooling, lighting and operating appliances. Reviewing power bills, or taking an inventory of appliances and multiplying their power rating with number of hours used are methods used to determine operational energy. The choice of method is determined by availability of data.

Embodied energy (EE) refers to the energy associated with the production of construction materials. This includes the energy sequestered for raw material extraction, processing, transport to site and construction. (Willmott Dixon, 2010; Institute of Civil Engineers, 2014)

Haynes (2013) suggests that the energy utilised in maintenance and replacement should be considered as recurring embodied energy. This energy applies to building components such as fittings that may, over the buildings lifetime, have a considerable contribution towards overall embodied energy. Recurring embodied energy is determined by multiplying the number of times an item is replaced (this is obtained through research and experience), and the material transport energy.

In order to perform an LCA, the different stages as derived from ISO 14040 (1997) are:

1. Defining the goal and scope of the study: Reason for carrying out the study, target audience and intended use; system boundaries, functional units, assumptions and limitations
2. LCA Inventory tables: Sources to quantify the environmental impacts
3. Data collection and impact calculation: data collection, calculation procedures, quantifying relevant inputs and outputs of the building and the transport
4. Impact assessment: Evaluation of potential impacts, comparison of results Interpretation: Evaluation of their significance

5.1.1. Goal of LCEA

In recent times, embodied energy has become an important consideration in the discussion of sustainability the construction sector. Earlier studies and discussions were pre-occupied with operational energy of buildings. However, with tighter building regulations, improvements in construction standards, ever improving energy efficient appliances, zero carbon energy supply on site; the total whole life carbon foot print is getting smaller while embodied energy and associated emissions are becoming more important in relative terms. (Lane, 2010) This line of thought is supported by Dixit, et al. (2010) who suggests that in new, well-insulated, energy-efficient buildings, embodied energy can account for 40 to 60% of the total energy footprint and can even exceed the operational energy use. This situation, it can be theorised, is true for low-income tropical housing in Uganda, since there is little or no heating or cooling energy load because of the relatively mild climatic conditions. Furthermore, the relative poverty of low-income households implies that the prevalence of heating, ventilation and air conditioning systems (HVAC) is low. It is therefore important to determine and compare embodied and operational energy in low-income housing to substantiate this theory. The first goal of this LCEA is therefore to determine the embodied energy (EE) of materials as used in the construction of low-income tropical housing.

The second objective of the study is to compare EE and operational energy in low-income housing. The information from the LCEA and subsequent energy comparisons will be utilised to further the overall research objectives that include the development of strategies to reduce housing embodied energy and costs; improve rural building

materials production in Africa; reduce housing-use energy and costs on building services and appliances; to review and develop passive design strategies in tropical housing.

During the process of determining EE materials, data gaps that exist in the material production process in Uganda will come to light. The importance of identifying information data gaps cannot be overstated as they inform new directions for research and building quality improvement. The third goal of the LCEA will therefore be to determine existing data gaps in the material production process in Uganda.

5.1.2. Scope of LCEA

It is important to note that for LCA studies, assessments are often carried out for parts of the "full" life cycle depending on the purpose of the study and the resources and the objective of the study (Dixit, et al., 2010) as shown in table 1.

Cradle to Gate	Describes the impacts associated with products, materials or processes up to the point at which they are packaged and ready for delivery to site.
Cradle to Site	Describes the impacts associated with suppliers (raw materials), transportation to manufacturing centre, manufacturing, packaging and transportation to site. In the case of construction impacts, this would also include any processing required on site to make use of the product or component.
Cradle to Grave	Describes all the processes which a product or component goes through from raw material extraction to obsolescence and final disposal. It assumes no end-of-life residual value.
Cradle to Cradle	Is similar to Cradle-to-Grave', but assumes that an obsolete building, product or component has a residual value at the end of its *first* life. It assumes that construction waste can be recycled and used to provide raw materials for the re-manufacture of the same product or the manufacture of new and different products.

Table 8: System Boundaries. Adapted from Menzies (2012)

The survey will collect data on EE of materials while considering the cradle to grave system boundaries. Cradle to grave boundaries for the materials are utilised because the process subsystems - material extraction, production and transportation and use can be satisfactorily documented.

The above mentioned process subsystems, have a number of primary and secondary energy flows. For the study to generate useful data sets and come to a logical conclusion, primary or zero-order energy flows that directly contribute to the process are examined. Secondary energy flows that contribute indirectly to material overall EE are not considered.

5.1.3. Embodied Energy Analysis (EEA) methods

With the realisation that numerous energy paths contribute to the EE of a material, methods have been developed to trace these. Traditionally, the Input- Output (I-O) and process analysis methods have been utilised.

a. Input-output analysis (I/O-LCA) method is based on national statistical tables, which represent monetary flows between sectors. These can be transformed to physical flows to capture environmental fluxes between economic sectors. I-O analysis provides a complete data within a system boundary. (Menzies, 2012) However, it must be mentioned that the I-O analysis method has a number of limitations. First, the method fails to distinguish the data inputs and outputs of different sectors in an economy therefore all sectors are treated as the same. Furthermore, updated I-O data may not be not available or all together missing. (Treloar, 1998; Menzies, 2012.)

b. Process analysis life cycle assessment (P-LCA) involves the evaluation of direct and indirect energy inputs to each product stage. It usually begins with the final product and works backwards to the point of raw material extraction. (Menzies, 2012; Dixit, et al., 2010)

Process analysis investigates direct and indirect energy flows, where direct energy is the energy utilised in the manufacture of a product. Indirect energy on the other hand, is any additional energy that may be utilised for primary processes to occur.

Process analysis involves three major steps. First, is the identification of both direct and indirect energy paths whose data is available, and also, identification of the functional units. The second step is the quantification of raw materials required in the manufacturing process and, finally, the evaluation of energy intensities (Ibid).

Process analysis while considered straight forward, suffers a number of limitations such as considerable time consumption and truncation errors. These arise due to the fact that there a numerous number of possible upstream energy paths.

In order to overcome the shortfalls of the traditional methodologies, hybrid methods based on either process or I-O life cycle analysis have evolved. These seek to diminish the disadvantages of either procedure and are discussed in depth by Menzies (2012) and Treloar (1998.)

Table 2 compares the various methods of LCA and highlights their strengths and weaknesses.

	Process analysis	Input-Output analysis	Hybrid methods
Composition	Based on energy data requirements from various processes	Based on national statistical I-O data tables converted into Leontief inverse I-O	Combination of process and I-O data sets. Can be either process or I-O based
Evaluation criteria	Energy per unit mass/volume/area	Equates energy input per monetary output	Combines the two methods but leaning on

	e.g. GJ/ Kg, M3	e.g. MJ/$	what each is based on
Advantages	Simple and systematic. Useful for analysing energy of individual items in a system	Captures entire energy flows in an economy	Minimise weakness of traditional methods
Disadvantages	Time consuming, truncation leads to incompleteness	Aggregation of data inputs Difficulty of acquiring up to date I-O data	Process-based: adopts the disadvantages of the traditional methods I-O based: use of old data

Table 9: Comparison amongst EEA methodologies. Adapted from Treloar (Mpakati-Gama, Wamuziri & Sloan, 2011)

The study will utilise a process analysis based approach. This is because despite its flaws, process analysis provides a basic starting point particularly where data problems prevail like most parts of Sub Saharan Africa. (Mpakati-Gama, Wamuziri, & Sloan, 2011)

The process analysis will involve a survey to document materials procurement, here taken to mean the process of building material extraction, processing and manufacture, and their use in the construction.

5.1.4. LCEA Inventory

There is a general deficiency in availability of recent economic data in the Uganda context thereby negating the use of I-O methodology of LCEA. The study will therefore utilise the Process analysis methodology to determine embodied energy of various materials.

Conducting an LCEA from scratch is a complex, laborious and time-consuming task. One would have to know, document and analyse all the processes involved in detail. However, a number of Inventory databases have been established for example BRE's Environmental Profiles building materials database, the US National Renewable Energy Laboratory's U.S. Life Cycle Inventory Database for commonly used materials, products and processes and the Canadian Athena Sustainable Materials Institute's Building Material Life Cycle Inventory Database. A major challenge faced by the current study in utilising these internationally renowned data sets stems from the contextual differences in material production technology; differences in energy sources and efficiency and material use. The study will therefore base itself in the EE inventories from Venkatarama Reddy & Jagadish's (2003) work on alternative building materials in India. India presents a suitable backdrop for the study because, levels of technology applied in material production and fuel sources as reported in the study are similar, to those in Uganda, to a great extent. However, the study will also utilise direct measurements and surveys to further improve the reliability of the proposed data sets within the context of Uganda.

The idea of utilising data from elsewhere in EEA is not new in literature, with researchers

indicating that data is not always available where needed and therefore, coefficients from elsewhere can be, and are utilised. (Mpakati-Gama, Wamuziri, & Sloan, 2011) The use of material coefficients from different parts of the world however remains controversial with authors such as Baird and Chan (Ibid) expressing concern that resultant EE values are not a true representation of the materials within the latter context. Baird and Chan's arguments are however countered by Hammond and Johns (Ibid) who communicate that while variations will always exist, the extent of these is what needs to be seriously considered.

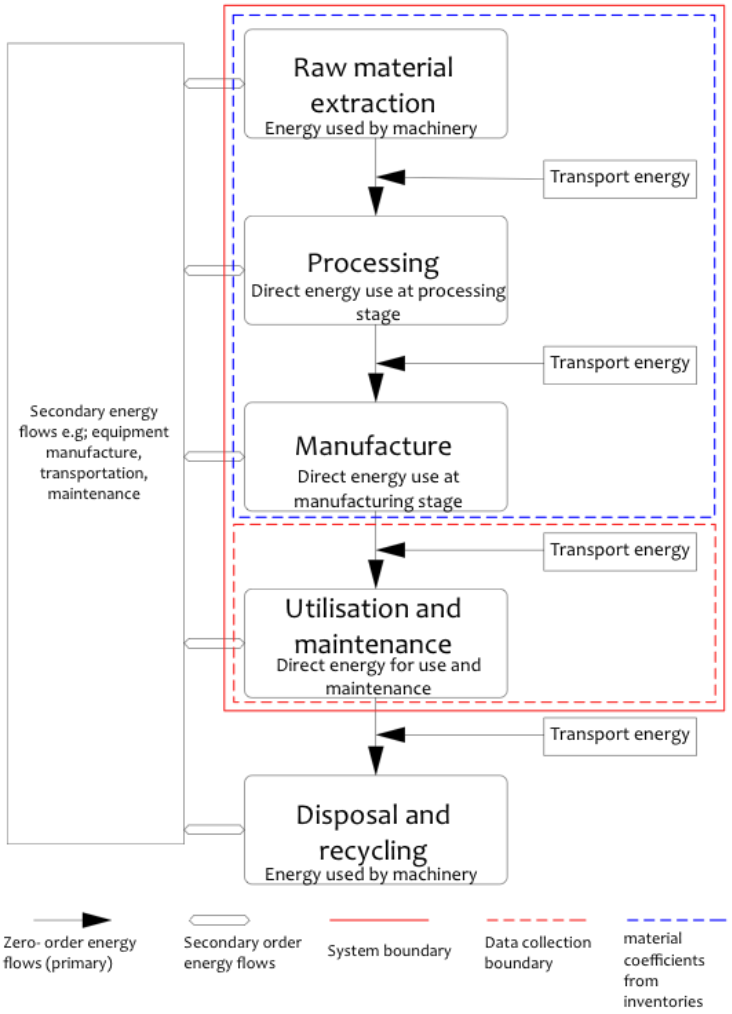

Diagram 3: System and energy flow boundaries

Having encapsulated the methodology of the study, it is important to discuss the main subject matter, that is, low-income housing. The following section discusses the concept of low-income housing, starting from a global perspective of low-income housing definitions and indicators, followed by contextualisation achieved by analysing the Ugandan situation.

5.2. Research Methods

The study in question is neither qualitative nor quantitative as usually dichotomised in literature. As Routio (2007) explains, when a research question is based in practice, it is found to have qualities of both. The research is normative in nature, that is, it is rooted in the notion that the object about which data is gathered can be improved. The study

therefore aims at getting knowledge; descriptions and explanations about material utilisation in low-income housing for the purpose of analysis, with the outcome being proposed improvements to the system. The study therefore has to collect both qualitative and quantitative data to understand not just the amount of material utilised but also reasons and processes behind construction decisions; it is from this combined data that meaningful suggestions for improvement can be made.

The study utilises a field survey undertaken by a research assistant conversant with the subject matter. This is because of the expansive nature of energy flow that may require the researcher to probe for additional information beyond the scope of the designed survey tool.

5.2.1. Survey considerations

The following section presents considerations made in the design of the field surveys. The considerations are a result of information gathered from literature review.

A. Sampling

The study will collect data to enable the calculation of EE and operational energy. It must be noted that for these calculations, there are observations that when carried out on a finished building are difficult to determine, such as materials utilised in the internal structure, foundation types and materials used in the building envelope. Comparably, surveys carried out on incomplete structure may not yield results on things such as, material finishes, and fittings. This is especially true for low-income housing in the context of Uganda, which is informal in nature; as discussed earlier, this form of housing has little or no construction documentation. Collection of relevant data will therefore be carried out on two buildings that are under construction and two that are occupied within the study area.

According to UN-Habitat (2010) material choice for construction is a complex phenomenon subject to a vast number of factors that include availability of resources, availability of materials, durability of materials and personal choice of the developer, peer pressure and public influence. However, in their urban housing sector profile, UN-Habitat was unable to conclusively determine factors that influence material choice.

Town	NA	Durable	Inadequate resources	I don't know	Cheaper	What I wanted
Kampala (%)	41.1	24.7	13.0	15.7	5.0	0.3
Gulu (%)	75.8	3.4	4.7	8.7	7.4	0.0

Table 10: Underlying considerations for material use in housing construction. Adapted from UN-Habitat (2010)

The underlying reasons for choosing a particular material for construction cannot be overstated. Subjective motives such as the developers' choice may override more grounded rational such as durability. Personal choices are considered undesirable by the study as they introduce data that deviates from the stated purpose, which is to determine norms in material utilisation in the construction of low-cost housing.

The uncertainty behind decisions that influence material choice is taken into account by the study; a pair of dwellings per scenario – under construction and occupied – are considered rather than a single sample. This serves to eliminate outstanding data that may be based on subjective choices.

The study acknowledges that a larger number of samples would further reduce the possibility of subjective data entering into analysis, however it must be pointed out that resource limitations have to be considered.

Nevertheless, the study is refined by incorporating the query of influences on material selection in the data collection tool. It elaborates on the discussion presented by UN-Habitat (2010) with regard to reasons behind material selection, by introducing peer pressure and public influence as additional parameters for consideration.

Within the test quartet, each pair and each unit within the pairs serves as a control. It is therefore of utmost importance that the buildings chosen are within close proximity, that is, no more than a km apart. This will ensure that the four buildings are under similar conditions.

B. Data sources

Sources of data for a research project play a large part in determining the level of accuracy of the analysed results. It is therefore important to select data sources that provide the most reliable data.

The research project seeks to gather information on housing that involves construction methodologies and finished product use. Part of the data requirement is quantitative in nature and can be obtained by the researcher's own devices. However, the research has qualitative that requires the contribution of a third party. In existing low-income housing as profiled, there are three possible sources of data, that is, the building owner; contractor/ construction trades men, and the final user. It should be noted that the building owner and end user are presented as separate entities because surveys done to determine the settlement profile of low-income reveals that the vast majority of low-income dwellers in informal areas are renters. (Actogether

Each of these groups has data they can provide as illustrated in table 11

Source	**Data requirement**	**Accuracy**
Building owner	Energy use data	Accurate*
	Justification for material selection	Fairly accurate
	Material sources, location and processes	Fairly accurate
Construction tradesmen	Energy use data	Accurate*
	Justification for material selection	Accurate
	Material sources, location and processes	Fairly accurate
End user (renter)	Energy use data	Accurate

	Justification for material selection	N/A
	Material sources, location and processes	N/A

Accurate* - Only accurate when the party in question resides in the neighbourhood of interest

Table 11: Comparative matrix of data sources

From the above matrix, overall, construction trades men are the most accurate sources of qualitative data, followed by building owners. Construction tradesmen will therefore be sought after as primary sources of data. The end users are a reliable source of operational energy data.

5.2.2. Survey instruments

A survey tool has been designed for the study and is structured from general to specific data. (See Appendix B) The requirement is to ensure that adequate data on the representative sample of buildings is achieved in the different climate zones.

5.2.2.1. General Data on location and context

This is the first classification that includes information on site description, location contextualization and the occupation profile. Other site-specific data such s building proximity to neighbouring buildings, orientation, and detailed building documentation are covered within this section.

5.2.2.2. Building description

Having covered the building and the context within which it lies, the section covers details of the building envelope. The tool starts off by collecting data on materials used on the façade, followed by windows, window frames, roof, floor construction and fixed shading devices. The section is rounded by a query about the factors that influence material choice.

Transport method must include details of mode conveyance, capacity in tones or kg, fuel utilised, and consumption per km.

5.2.2.3. Materials inventory

The section collects details of primary construction materials such as sand cement and aggregates. Furthermore, the section collects detailed data of composite masonry units, that is dimensions and constituent materials

5.2.2.4. Machine inventory

This section covers equipment utilised in construction such as earth moving machinery and diggers.

5.2.2.5. Operational energy audit

Primarily carried out as a walk through, this section will require the researcher to document various household appliances and equipment. Where the energy rating of the equipment is not available, the make and model should be recorded.

6. Findings

State of housing

On-going projects/experimentation

7. Discussion

Missing links

Suggestions

8. Conclusion

9. References

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Appendix A

Inventory for material coefficients –

Venkatarama Reddy & Jagadish (2003)

1. Factory manufactured materials

Portland cement represents one of the major materials consumed in bulk quantities for building construction. Energy of cement arises from the use of coal in the rotary kilns and energy needed for crushing and grinding the clinker. In cement is manufactured by employing both the wet (old cement plants) and dry (new plants) process. Wet process used in earlier cement plants leads to an energy consumption of 7.5 MJ/kg of cement, whereas modern plants employing pre-calcination and dry process consume 4.2 MJ/kg of cement. The value of 5.85 MJ/kg of cement given in Table 1 represents the average value of 7.5 and 4.2 MJ. The average value of 5.85 MJ/kg of cement has been used in the computation of energy in various components and systems.

Hydrated lime consumes 5.63 MJ of thermal energy/kg, which is about the same as that for cement. High-energy consumption for lime can be attributed to low thermal efficiency of small-scale kilns employed for lime burning in India.

Energy in basic building materials	
Type of material	Thermal Energy (MJ/Kg)
Cement	5.85
Lime	5.63
LP cements	2.33
Steel	42.0
Aluminium	236.8
Glass	25.8

2. Masonry materials

Masonry walls constitute one of the major energy consuming components of the building, especially in case of load bearing masonry structures. Varieties of materials are used for the construction of masonry walls. Five types of building blocks viz. stone, burnt clay brick, soil–cement block, hollow concrete block and steam cured mud block have been considered for the analysis.

2.1. Stone block

Splitting the hard natural stone into convenient sizes generally produce Stone blocks and slabs. Manual labour is employed in bulk of the sizing operations. Occasionally, very hard and big stones are reduced to smaller sizes (for the convenience of handling for further sizing by manual process) using detonators. They therefore carry no embodied energy

from the production process.

2.2. Burnt clay bricks

The common brick size is 230 mm x 110 mm x□60–75 mm. Bricks require a considerable amount of thermal energy during the burning process. Coal, coal cinder and firewood are the most commonly used fuels for brick burning in India. In general, each brick needs either 0.20 kg of coal or 0.25–0.30 kg of firewood for the burning process. This translates into a thermal energy of 3.75– 4.75 MJ per brick. An average value of 4.25 MJ per brick (size: 230 mm x 110 mm x 70 mm) has been considered for the comparison and computation of energy content of buildings and masonry.

2.3. Hollow concrete blocks

The basic composition of the blocks consists of cement, sand and coarse aggregates (□6 mm size). The energy content of the block will mainly depend upon the cement percentage. Energy spent for crushing of coarse aggregate will also contribute to the block energy. The cement percentage generally varies between 7 and 10% by weight. Quality of the block, particularly compressive strength is the deciding factor for cement percentage. Energy content of the hollow concrete block of size 400 mm x 200 mm x 200 mm will be in the range of 12.3–15.0 MJ.

2.4. Soil–cement blocks

These are produced by pressing a wetted soil–cement mixture into a solid block using a machine (manually operated or mechanised) and then cured. Energy content of the blocks is mainly dependent upon the cement content. Soil–cement blocks used for the load bearing masonry buildings will have cement content of about 6–8%. Such blocks will have energy content of 2.75–3.75MJ per block of size 230mm□x 190mm□x 100mm.

Energy in masonry materials			
Type of material	Size (mm)	Energy in one brick/block (MJ)	Energy per brick equivalent (MJ)
Stone block	180 x 180 x 180	0	0
Burnt clay brick	230 x 105 x 70	4.25	4.25
Soil-cement block	230 x 190 x 100	2.60 (6% cement)	1.00
	230 x 190 x 100	3.50 (8% cement)	1.35
Hollow concrete block	400 x 200 x 200	12.30 (7% cement)	1.32
	400 x 200 x 200	15.00 (10% cement)	1.62
Steam cured block	230 x 190 x 100	6.70 (10% lime)	2.58

Appendix B

Data collection tool