Opportunities for Affordable Construction in Uganda using Locally Available Materials

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Abstract

Uganda, like many other countries in the Global South, is in dire need of affordable housing. According to the 2017 Uganda National Household Survey, the number of poor Ugandans increased from 6.6 million in 2012/13 to 10 million in 2017 (Twinoburyo 2018). Uganda's population growth is also the fourth highest in the world (The World Bank Group 2018). With the cost of manufacturing and purchasing construction materials like cement increasing due to scarcity of raw materials (Kamukama 2018), many Ugandans are unable to afford to construct homes.

This thesis examines the possibilities of using bamboo and compressed stabilized earth blocks (CSEB) as a substitute for expensive and carbon-intensive cement-based construction materials. These low-cost building materials will allow more Ugandans to afford to construct houses and other larger buildings like schools. Low-cost indigenous materials are perceived as poor quality and inferior. Therefore, this study looks to change the perception of using these building materials in Uganda. This research proposes new techniques of construction by looking at relevant low-cost construction precedents in the Global South.

The integration of new building techniques using local materials should be a gradual process. An abrupt replacement of current construction materials like burned bricks could potentially deteriorate current construction conditions in Uganda (Hashemi et al. 2015). This research considers incorporating local materials like bamboo and CSEB with current construction materials like burned bricks and concrete as a potential solution. In this thesis, a comparative analysis is presented between structures designed with current versus the proposed local materials. The comparative analysis was designed and tested to fit within the constraints of affordability, reduced material usage, and embodied energy. Another crucial concern is to what degree the general public would welcome the new technique. This thesis proposes solutions to change the general public's opinion on local materials.

Keywords: Affordable, Bamboo, Compressed Stabilized Earth Blocks, Construction

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Lastly, I want to thank you, the reader. I hope my thesis inspires you and many other Ugandans to make affordable construction a reality in Uganda.

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Chapter 1: Introduction and Literature Review

1.1 Introduction

The construction industry plays a big role in Uganda's economy. According to the Uganda Bureau of Statistics, the construction industry's contribution to Uganda's economy increased from 12.3% in 2008 to 13.1% in 2011 (Uganda Bureau of Statistics 2012). This can be seen in Figure 1 below. Despite this increase, Ugandans aren't able to afford to live in standard housing. Over 60% of the Ugandans within urban areas live in slums with poor hygienic conditions (UN-HABITAT 2007). In addition to this, the average Ugandan earns only about $65 a month (Otim n.d.). Ugandans aren't able to afford to live in houses made from strong and durable reinforced concrete construction materials. These materials are associated with a high social status and are very expensive for the average Ugandan. A 50kg bag of cement costs about $8 in Uganda while in countries like Egypt and China it costs about $1 (Nantume 2017).

High construction costs have caused a huge housing shortage in Uganda. Housing shortages have been rising steadily in Uganda since 2005. In 2005, the housing shortage was estimated to be around 560,000 units (Kalema and Kayiira 2008). This increased to 612,000 units in 2010 (National Planning Authority 2010). The housing deficit is predicted to increase further to 885,000 units by 2020 and 8,000,000 units by 2040 (Kalema and Kayiira 2008).

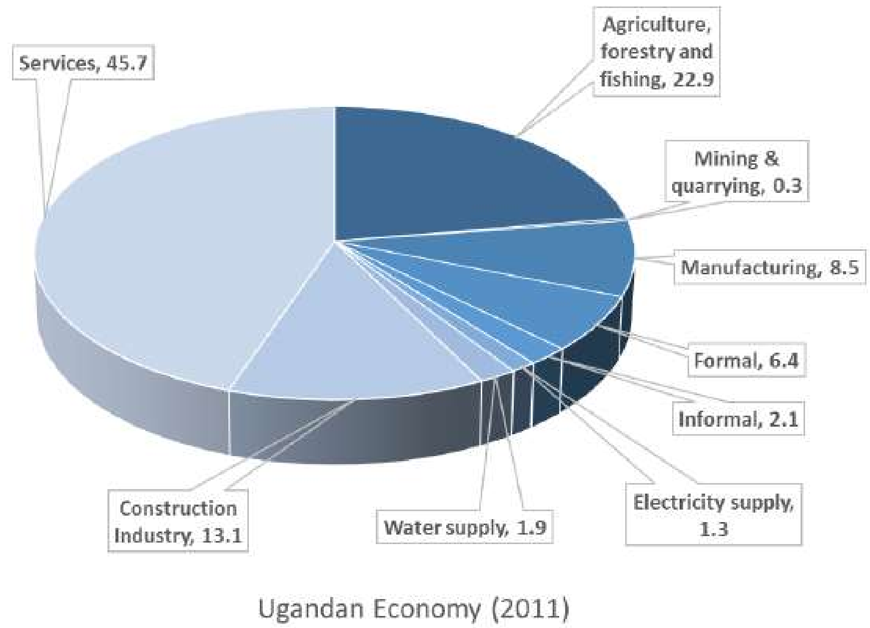

Figure 1: Ugandan Economy in 2011 in percentages. Credit: (Uganda Bureau of Statistics 2010)

One reason for the high construction costs is that the building code used in Uganda was inherited from the British during colonial times. Buildings in Uganda are over-engineered to meet the U.K. building code standards. For example, non-load bearing walls are often built with structural materials like CMU blocks, and therefore, have a compressive strength of 3.5 MPa, which is needlessly high. This utilizes more cementitious materials than necessary. Also, the British use standard shapes and sizes of structural materials. This allows them to save on fabrication time to cut down on labor costs. Since the cost of labor outweighs the cost of materials in the U.K., it makes sense to use this method (Anderson 2019; Ismail 2017). With the average monthly income being $65, the average Ugandan is earning an equivalent of $0.40 an hour. Thus, labor costs far less than construction materials in Uganda. Therefore, Uganda should focus on reducing the amount of reinforced concrete materials used to cut down on construction costs. Uganda needs to take advantage of her vast natural resources like bamboo and earth. Bamboo and Compressed Stabilized Earth Blocks (CSEB) can substitute for these high-cost construction materials and allow more Ugandans to afford to live in standard permanent houses. In this thesis, I examine alternative ways to construct affordable homes and other larger buildings like schools using natural and locally available materials, thus reducing construction costs in Uganda.

1.1.1 Conventional Construction in Uganda

Adobe, burnt and un-burnt bricks, cement, mud blocks, mud and wattle, sand, stones, and timber are materials commonly used for construction in Uganda. Figure 2 below shows the different types of materials that were used in Uganda between 2009 and 2010.

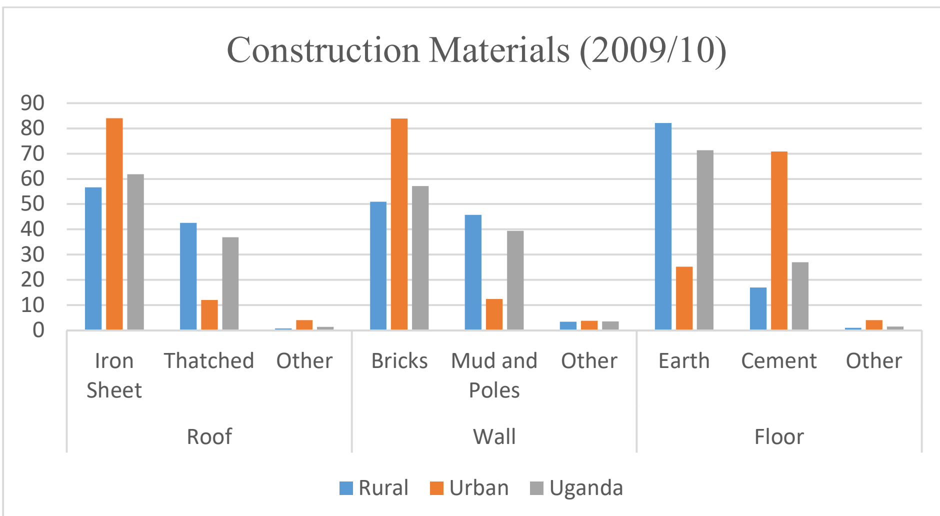

Figure 2: Construction materials in 2009/2010 in percentages. Credit: (Uganda Bureau of Statistics 2010)

From Figure 2, we can see that these materials are separated into three categories; roof, wall, and floor materials. For roofing construction materials, approximately 62% of all roofs in Uganda are covered with iron sheets while about 37% are thatched roofs. Iron sheets dominate the market in both urban and rural areas. Around 84% of roofs in urban areas are constructed with iron sheets compared to 57% in rural areas. 43% of households in rural areas have thatched roofs while 12% of households in urban areas are thatched. Iron sheets are affordable and require less maintenance than thatched roofs. This influences the trend seen in Figure 2 for roof construction materials in Uganda.

For flooring construction materials, the earth flooring technique dominates in rural areas. About 71% of all floors in Ugandan houses are made out of the earth. In rural areas, 82% of the houses use earth floors whereas around 25% of houses use this method in urban areas. Cement flooring is more common in urban areas in Uganda. About 30% of all floors in Ugandan households are made from cement. About 71% of floors in urban areas are made out of cement compared to about 17% in rural areas.

For wall construction, bricks are the most commonly used construction material in Uganda. About 55% percent of all walls are made from bricks. In urban areas, almost 85% of all walls are made from bricks. In rural areas, the figure comes down to about 50%. Mud and poles are the next construction material used for walls in Uganda. This material is used mostly in rural areas to construct wattle and daub huts. About 45% of all walls in rural areas use mud and poles whereas the figure in urban areas is 12%.

Reinforced concrete construction dominates the Ugandan construction industry in high-end homes and large-scale buildings like schools, hospitals, and commercial complexes. In Uganda, urban areas tend to use stronger and more durable material, concrete, since the average income is higher than in the rest of the country. In rural areas, fired/unfired bricks and mud construction dominate.

Conventional materials used in Uganda are costly and have a negative impact on the environment. The raw materials used to make cement and steel bars in Uganda are imported from neighboring countries like Kenya. Small-scale, medium-scale, and artisan manufacturers are the three major brick suppliers in Uganda (World Bank 1989). Burned brick production in Uganda consumes a lot of firewood to bake the bricks, resulting in large carbon emissions. Small scale brick suppliers tend to use the most firewood because their firing process is longer compared to artisan producers and medium-scale manufacturers. The production of burned bricks has increased the rate of deforestation in Uganda.

A study done by Hashemi et al. examined the embodied energy of brick and concrete walls in Uganda (Hashemi et al. 2015). Table 1 shows the results of their study. From their study, we can see that burned bricks have a large negative impact on the environment since they are widely used in Uganda for wall construction as seen in Figure 2.

Although concrete blocks have the lowest embodied energy, they are very costly. The cost of concrete blocks per m^2 is almost 36% more than burned bricks (Pérez-Peña 2009). The cost comparison between concrete blocks (concrete masonry units) and burned bricks is examined further in the literature review in Table 2.

Product	Brick/Block Size L x W x H (mm)	External Wall Thickness (mm)	EE of Material (MJ/kg)	Mass per item (kg)	EE of Wall (MJ/m^2)	EE of Wall (MJ/m^3)
Artisan Burned Brick/Block	300x150x130	150	4.76	7.6	810	5398
	20mm mortar		1.11	1.65		
	220x110x65	220	4.76	2	1067	4849
	20mm mortar		1.11	1.65		
Small Scale Brick	220x110x65	220	17.136	2	3542	16,100
	20mm mortar		1.11	1.65		
General Clay Brick	215x102.5x65	215	3	2	791	3677
	10mm mortar		1.11	1.65		
Cement Stabilized Soil Blocks	290x140x115	140	0.68	8	176	1257
	10mm mortar		1.11	1.65		
Hollow Concrete Blocks*	400x200x200	200	0.59	14	127	636
	20mm mortar		1.11	1.65		

* Assumptions: 50% Hollow; 8 MPa compressive strength.

Table 1: Embodied Energy (EE) of brick and concrete walls. (Credit: Hashemi et al.)

Ugandans have been examining alternative and locally available construction materials to save the environment and construct affordable homes. The literature review in the section below explores this research further.

1.2 Literature Review

Previous research has been done to tackle the challenge of affordable construction in Uganda. Construction in Uganda is affected by the policies governing construction and the building materials used. The cost of construction materials accounts for about 50% of the building cost (Naturinda and Kerali 2014). These materials, however, use cement because it’s a durable and strong building material. As this paper has shown so far, cement is expensive in Uganda. Researchers in Uganda have explored substituting cement with natural pozzolans and examined using locally available materials like bamboo and compressed stabilized earth blocks for construction. In this section, I present existing research on natural pozzolans, interlocking stabilized soil blocks, bamboo reinforced concrete, and tile vaulting.

1.2.1 Natural Pozzolans in Uganda

Pozzolans are materials that contain reactive silica or alumina. When pozzolans are ground into fine particles and mixed with lime in the presence of water, the pozzolans react to form a cement-like product (Naturinda and Kerali 2014). Natural pozzolans are located in the rift valley areas in Uganda. These pozzolans exist as a result of volcanic deposits. Extensive research in Uganda is being conducted to use pozzolans as a substitute for cement. This has been examined as an avenue for affordable construction in Uganda.

For example, Naturinda et al. (2014) have examined natural pozzolans in Uganda for low-strength construction applications. This paper established the physical and chemical properties of the natural pozzolans in Uganda. Based on their findings, the natural pozzolans in Uganda are suitable to be used in low-strength construction. They also found out that the quality of the pozzolans varies depending on where it's obtained from. This makes it challenging to set up a building standard using natural pozzolans. Despite this, the strength of the natural pozzolans can be increased by grinding them into finer particles. However, this would drive the cost of production up. The pozzolan-lime ratio can be varied to obtain the optimized grade that has enough strength for construction purposes. This research proposes that further examination of different strength grades of natural pozzolans is needed to determine the appropriate products for specific construction applications.

Balu-Tabaaro (2011) explored using pozzolans as a binder for affordable building materials in Uganda (Balu-Tabaaro 2011). This paper examines natural pozzolans based on volcanic ashes from the Kabale and Kisoro area in South Western Uganda. The tests that were carried out proved that the volcanic ashes reacted to form a cement-like product. This paper proved that natural can be used to substitute Ordinary Portland Cement providing a cheaper alternative.

The research presented in this section show that affordable houses in Uganda can be constructed using natural pozzolans. However, existing work does not yet investigate how these technologies can positively affect low-cost housing projects in Uganda or how practical it is to reproduce their research on natural pozzolans on a large scale.

1.2.2 Interlocking Stabilized Soil Blocks in Uganda

In Uganda, bricks are the most used material for wall construction. These bricks are either burned (fired) in a kiln or sun-dried adobe bricks (Hashemi et al. 2015). Almost 60% of houses in Uganda have brick walls that are either burned or adobe (Uganda Bureau of Statistics 2010). Burned bricks are a popular building material in both rural and urban areas in Uganda because they are very durable.

However, firewood is used to burn or bake these bricks in a kiln. A study was done by Oteng'I et al. (2007) to determine the impact of brick production in the Lake Victoria region found that a kiln that had produced 10,000 bricks required about 14 tons of wood. This translates to 3 mature trees with a basal diameter of 1.5ft (Oteng'I and Neyole 2007). With Uganda's very high population growth rate and increased demand in the construction sector, many trees have been cut down. This has increased the rate of deforestation in Uganda. This, in turn, has degraded the environment. Figure 3 shows a depiction of the firewood used in kilns.

Figure 3: Firewood used to burn the bricks in the kiln. (Credit: Hashemi et al)

Interlocking Stabilized Soil Blocks (ISSBs) provide a solution to this. Interlocking Stabilized Soil Blocks are a type of compressed earth stabilized blocks. The main difference is that the interlocking blocks have grooves that allow the blocks to be dry-stacked to form a wall. They do not require mortar like the regular compressed earth stabilized blocks. Interlocking Stabilized Soil Blocks are made by mixing soil and a stabilizing agent which is usually about 5-10% of cement. This mix is then compressed in a block press without the need of added heat. Extensive research in Uganda is being conducted to use interlocking stabilized soil blocks as a substitute for burned bricks. This has been examined as an avenue for affordable construction in Uganda.

Pérez-Peña (2009) demonstrated how the environmentally friendly and cost-effective Interlocking Stabilized Soil Blocks are. This publication serves to promote the use of earth as a building material to reduce carbon emissions and provide affordable housing in Uganda. Pérez-Peña explores the strength properties of Interlocking Stabilized Soil Blocks to prove that the blocks can meet the stringent building code requirements. The publication also makes a cost analysis between interlocking stabilized soil blocks and burned bricks proving that the interlocking stabilized soil block technology is affordable. Case studies of existing projects are also examined to learn from the challenges the projects faced and propose solutions for future projects.

Nambatya (2015) extends the work Pérez-Peña (2009) did by investigating the rationale to select interlocking stabilized soil blocks over burned bricks. Nambatya carried out interviews in Uganda with non-governmental organizations, local construction companies, real estate developers, and the National Housing and Construction Company that's partly owned by the government. The study found that acceptability, affordability, availability, and durability governed the choice of building materials in Uganda (Nambatya 2015).

The interviews demonstrated that most clients or building owners in urban areas viewed the soil blocks as inferior to concrete. In rural areas, the technology is also associated with NGOs, hence it's viewed as expensive. Nambatya proposes that more education needs to be done to show the cost and environmental benefits that interlocking stabilized soil blocks have. This would change the perception of interlocking stabilized soil blocks and allow the technology to become an avenue for affordable construction in Uganda.

The research done by Pérez-Peña (2009) and Nambatya (2015) point out the benefits of interlocking stabilized soil blocks. The compressed block is then air-cured. ISSBs are, therefore, environmentally sustainable since they don't need to be baked in a kiln like the regular burned bricks. In addition to the environmental benefits of ISSBs, they are also affordable. The unit price of the compressive block machine is between $1,640 and $1,800 for straight or curved block presses, respectively (Nambatya, 2015). This cost also comes with the training for the machine within Kampala. One bag of cement can make 100 to 150 blocks (Pérez-Peña 2009). Two to four workers in an eight-hour day can make 400 to 600 blocks (Pérez-Peña 2009).

ISSBs also have better technical performance than burned bricks (Nambatya 2015). According to Walker (2007), tests done at the Building Research Establishment (BRE) for innovative construction materials showed that ISSBs had over an 80% higher dry compressive strength than burned bricks (Walker 2007). ISSBs have a comparable thermal conductivity to burned bricks meaning they both have comparable insulating properties (Pérez-Peña, 2009). ISSBs with 5% cement stabilizer have a lower embodied energy and carbon according to the ICE database (Hammond and Jones 2008).

Interlocking stabilized soil blocks also consume one-fourth of the energy that burned clay bricks require during production according to studies done in India by Venkatarama et al. (Venkatarama and Jagadish 2001). Table 2 shows a comparative analysis between ISSB and other wall construction materials common in Uganda. We can see that ISSBs have numerous advantages. However, their quality depends on the soil selection, the stabilizer used with the soil, and how they are produced in the block press.

Properties	ISSB	Sun-dried Mud Block	Burned Clay Brick	Stabilized Soil Block	Concrete Masonry Unit
General Information					
Block Appearance					
Wall Appearance (not rendered)					
Dimension (L x W x H) (cm)	26.5 x 14 x 10	25 x 15 x 7 to 40 x 20 x 15	20 x 10 x 10	29 x 14 x 11.5	40 x 20 x 20
Weight (kg)	8 – 10	5 – 18	4 – 5	8 – 10	12 – 14
Texture	Smooth and flat	Rough and powdery	Rough and powdery	Smooth and flat	Coarse and flat
Blocks needed to make a m^2	35	10 to 30	30	21	10
Performance					
Wet Compressive Strength (MPa)	1 – 4	0 – 5	0.5 – 6	1 – 4	0.7 – 5
Thermal Insulation (W/m°C)	0.8 – 1.4	0.4 – 0.8	0.7 – 1.3	0.8 – 1.4	1 – 1.7
Density (kg/m^3)	1700 – 2200	1200 – 1700	1400 – 2400	1700 – 2200	1700 – 2200
Average Price (2009)					
Per Block (UGX)	350	50	150	400	3,000
Per m^2	35,000	10,000	55,000	45,000	75,000

$1 = 3,679.53/= (Ugandan Shilling / UGX)

Table 2: Comparative Analysis of ISSBs (Credit: Pérez-Peña 2009)

Although interlocking stabilized soil blocks are low-cost and more sustainable than burned bricks, they have not been fully integrated into the housing construction industry in the urban areas. Future research in Uganda should be done to examine how interlocking stabilized soil blocks can be integrated with reinforced concrete construction in urban areas. Interlocking stabilized soil blocks can be used to construct non-load bearing walls instead of using concrete masonry units in urban areas. This would reduce construction costs since the over reinforced non-load bearing walls would use interlocking stabilized. soil blocks instead of concrete masonry units. This could be a potential avenue to promote interlocking stabilized soil blocks in urban areas in Uganda

In addition to this, the local communities need to be sensitized on sustainable construction. As mentioned earlier, a lot of vegetation has been lost in Uganda since endangered forests and swamps have been cleared to make burned bricks. Members of the community must be advised to grow the firewood they need to make burned bricks and slowly integrate interlocking stabilized soil blocks. This will reduce the rate of deforestation and the demand for burned bricks in Uganda. Also, the construction standards used in Uganda need to be examined and updated to promote construction with interlocking stabilized soil blocks.

1.2.3 Bamboo Reinforced Concrete

A potential way of reducing construction costs in Uganda is by bamboo to reinforce concrete. Uganda's construction heavily depends on reinforced concrete for commercial construction. Cement is required to make concrete and there are only two producers of cement in Uganda. In the South West of Uganda, there is Hima Cement in Kasese district. In Eastern Uganda, there is Tororo Cement in Tororo District. As mentioned earlier, the cost of cement in Uganda is very high. Also, concrete is weak in tension; therefore, it requires reinforcement to carry tensile forces in a building. Concrete is usually reinforced with steel bars. Developing countries like Uganda have to import these steel bars, hence, the average Ugandan can't afford to build using concrete.

Using bamboo to reinforce the concrete instead of steel can greatly reduce the cost of construction in Uganda. Bamboo is a fast-growing, naturally occurring fibrous plant that is widely available in Uganda. Bamboo is a fast-growing, naturally occurring fibrous plant that is widely available in Uganda. Bamboo is grown in Uganda for its culms (stems) which are used to make furniture, fencing compounds, flooring material, roof trusses, temporary walls, and scaffolding ("How to grow BAMBOO in your Uganda Lawn" 2019). Also, the shoots from a species called Yushania Alpina bamboo are eaten as a delicacy along the slopes of Mount Elgon in Eastern Uganda. This dish is called "Malewa" ("How to grow BAMBOO in your Uganda Lawn" 2019).

Considerable research on using bamboo to reinforce concrete has been done in Africa. In Nigeria, Akeju and Falade (2001) examined how bamboo can be utilized as reinforcement in concrete for low-cost housing in Nigeria. This study investigated how concrete beams reinforced with bamboo would perform in flexure. The species of bamboo used was Bambusa Vulgaris, which accounts for 80% of the type of bamboo species present in Nigeria.

The variables in the experiment were the amount of bamboo reinforcement put in the mix, curing time, and the surface conditions of the bamboo used as reinforcement (i.e., whether it was coated with bitumen + sharp sand or not). Concrete beams containing mild steel as reinforcement were tested to compare the values. Mild steel is a type of steel with a low amount of carbon in it. The ultimate strength obtained for the bamboo reinforced concrete was 133.5 MPa (19.36 ksi) whereas for mild steel-reinforced concrete, 255 MPa (36.98 ksi) with yield strengths of 68.75 MPa (9.97 ksi) and 207.5 MPa (30.10 ksi) in compression respectively (Akeju and Falade 2001). Bamboo reinforced concrete's ultimate strength is about half of mild steel-reinforced concrete's ultimate strength. Its yield strength is about a third of mild steel-reinforced concrete's yield strength. This was a good result and demonstrates that bamboo reinforced concrete can be utilized to design low-cost housing projects walls that experience minimal loads.

The major drawback of using bamboo as reinforcement was that bamboo absorbs almost 35% of the water from the mix. This distorts the water-cement ratio, thus, reducing its strength. Coating with bitumen and sharp sand reduced this water absorption, allowing the initial strength to remain unchanged (Akeju and Falade 2001).

A major discovery was that concrete beams that had 2.7% volume fraction of bamboo for reinforcement had their strength increased by 135% compared with the control experiment that had unreinforced concrete beams (Akeju and Falade 2001). Although this percentage strength increase is insignificant compared to the increase steel-reinforced concrete provides, the bamboo can be used to substitute some steel reinforcement in low-cost housing projects where limited load-carrying capacity is required (Akeju and Falade 2001). Based on this research, it appears that bamboo-reinforced concrete would not be a good candidate to replace horizontal spanning systems such as floor and beams. Walls, foundations, and non-structural slabs, where tensile forces are lower, could be potential applications.

Future research in Uganda should be done to test the dominant species, Yushania Alpina, to see whether it will perform the same way as the Bambusa Vulgaris in Nigeria. In addition to this, the local communities need to be sensitized on sustainable bamboo construction. A lot of bamboo vegetation has been lost in Eastern Uganda since young bamboo shoots are cut down to prepare the Malewa dish. Since they cut down the young shoots, the rest of the plant can't regenerate. Members of the community must be advised to grow the bamboo they will use for construction. This will reduce the rate of deforestation and the loss of bamboo cover in Uganda. Also, the construction methods used in Uganda need to be examined to determine if bamboo is feasible to reduce construction costs.

1.2.4 Tile Vaulting

Guastavino Vaulting is a 600-year Mediterranean technique where burned clay bricks are used to make catenary vaults (Ochsendorf 2010). These vaults can be remarkably thin because their shape is very efficient and can resist pure axial tension or compression loads. Vaults that are in a catenary shape do not have bending moment forces acting on them. Bending moments require a lot of material to resist them. Therefore, vaults can be very thin since they don't have bending moments acting on them.

Block et al. examine the potential of tile-vaulted structural systems to provide environmentally friendly and affordable construction in Africa. The Guastavino Vaulting technique is combined with the compressed earth stabilized block technology used in Africa. Block et al. designed a prototype flooring system in Ethiopia using the tile vaulting technique. The vault was designed using thin compressed earth tiles that were made on site.

Low-cost in Ethiopia is defined to be less than $\$75/m^2$. The method proposed by Block et al. is still 30 – 40% higher than what is considered as low cost in Ethiopia. The use of fast-setting concrete to design the vaults raised the costs because this mortar is not yet available in Ethiopia. The tile vaulting technique solely relies on this fast-setting mortar since little to no formwork is used.

Unreinforced masonry buildings are very susceptible to earthquakes. Earthquakes induce bending loads which in turn lead to tensile stresses in the structure (Block et al. 2010). The singly curved and unreinforced tile vaults that were designed in this study perform poorly when loaded with bending and tensile forces. Therefore, the construction of unreinforced tile vaults in high seismic areas like Ethiopia should be avoided (Block et al. 2010).

Also, the tile vaulting technique requires highly skilled labor. Therefore, even though Ethiopia has an abundance of cheap labor, a lot of training and supervision is required to design a tile vault. This can potentially discourage local contractors in other countries like Uganda from adopting the technique.

Block et al. propose that if the tile vaulting technique is to be effectively executed in other countries in Africa, more research and prototyping is needed to verify whether this technique can safely be integrated into the construction sector.

1.2.5 Closing the Research Gap

The papers presented in this section show that affordable houses in Uganda can be constructed using locally available materials. However, the papers didn’t investigate how their research can positively affect low-cost housing projects in Uganda or how practical it is to reproduce their research on a large scale.

In this thesis, I explore the potential of using local materials in construction in Uganda. I examine materials like bamboo and compressed earth in Uganda. I also carry out interviews in Uganda with local architects, engineers, and professors to determine how feasible it is to incorporate them into the construction industry in Uganda.

I demonstrate how local materials reduce material usage, embodied energy, and work in a building system. I present a comparative analysis between conventional and local material construction that is tested to fit within the constraints of affordability, reduced material usage, and embodied energy.

1.3 Structure of the Thesis

The following chapters present the methodology and the results from the author's work to fill the research gap in Uganda and make. Chapters 2, 3, and 4 describe three diverse research methodologies. Chapter 2 focuses on case studies on local material construction precedents. Chapter 3 presents the fieldwork done in Uganda, including interviews and site visits, and the findings of the fieldwork focusing on conventional construction and the feasibility of local material construction in Uganda. Chapter 4 presents the comparative analysis between conventional and local material construction in Uganda to demonstrate how beneficial it is to reproduce local material construction on a large scale. Finally, Chapter 5 connects and discusses the findings of the above chapters, presents the overall conclusion, and areas for future work. All photos and graphics have been appropriately credited. Any image not credited was taken by the author.

Chapter 2: Local Material Construction Precedents

In this chapter, I present affordable construction projects in Africa that have used local materials. The first project, Gando Primary School, was constructed in Burkina Faso. This school was designed by Francis Kéré. Kéré used materials that were sourced locally and worked with the people in the community to design and build the school. The second project was done by Haileybury YouthTrust (HYT) in Uganda. They used interlocking stabilized soil blocks to construct the school. HYT was able to save on the cost of the overall project and reduce the embodied energy of the school.

The last two school projects were funded by the African Wildlife Foundation. The project done in the Democratic Republic of Congo was designed by MASS Design Group. The project done in Uganda was designed and built by LocalWorks. Both projects used materials sourced on-site and worked with the people in the community to build the school. All these projects demonstrate that it is feasible to design affordable large scale projects with local materials and present the socio-economic benefits offered.

2.1 Francis Kéré: Gando Primary School

I draw my inspiration to use soil blocks from Francis Kéré, a famous architect from Burkina Faso in Africa. He has won awards like the Aga Khan Award for Architecture and the Global Award for Sustainable Architecture. Kéré grew up in Gando, a small village in Burkina Faso. Despite all odds, he was able to study at the Berlin Institute of Technology on a full scholarship. In Berlin, he came up with the idea to build a school in his village using clay. After 2 years of fundraising, he amassed $50,000 to build the school. The walls were built using compressed clay blocks. The roof was constructed using cheap steel bars normally used to reinforce concrete. The ceiling was made from both clay and steel bars. An interesting fact to note is that there are two roofs on top of the school. The upper roof is a large overhanging corrugated metal roof. The one below is a barrel vault roof made from clay. Many houses in Burkina Faso have corrugated metal roofs that absorb a considerable amount of heat from the sun. This makes the interior of the house intolerably hot. To mitigate this, the two roofs were separated. The metallic roof was pulled away and the barrel vault was perforated. This allows natural ventilation to occur, keeping the interior of the classrooms cool. Using natural ventilation greatly reduces the carbon footprint of the school as it doesn't require the use of mechanical HVAC systems. Figure 4 below depicts how natural ventilation works.

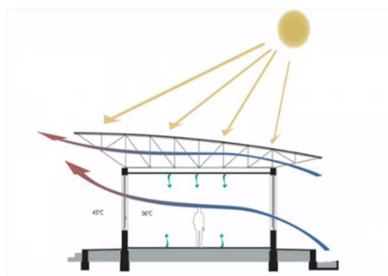

Figure 4: Passive design technique for natural ventilation.

The major challenge he faced was convincing the people of his community to build with clay. Clay is eroded during Burkina Faso's heavy rains, therefore, it's also seen as a material that's not durable. He was able to convince them by constructing a demonstration tile vault and physically jumping on it with his team. Once they were convinced, he worked with everyone in the community to build the school. This allowed him to pass on the skills to them so that they can continue to build with this technique and earn money. Not only did he build a school for them, but he empowered them with the skill to build affordable housing for themselves. Figure 5 below depicts the design process of the school.

Figure 5: The design process of Gando Primary School. (Credit: Kéré Architecture.)

2.2 Kawolo Church of Uganda Primary School

Haileybury YouthTrust (HYT), a non-governmental organization in Uganda, designed and built a demonstration project school at the Kawolo Church of Uganda Primary School. They embarked on this project to show how much potential the Interlocking Stabilized Soil Block (ISSB) technology has. They wanted to show the people of the Kawolo community as well as Uganda at large how affordable and environmentally friendly the ISSB technology is. They also wanted to show how beautiful ISSB structures are as a way to change the mindset that earthen structures are of poor quality and only used by low-income individuals. HYT partnered with the Richard Feilden Foundation, the charitable branch of the Feilden Clegg Bradley Studios. This project is situated very close to the Kampala-Jinja highway, making it visible to the public, who can thereby see how ISSBs are potentially the future of sustainable and affordable construction in Uganda.

Figure 6: Exterior of the ISSB School (Credit: Nuwagaba)

Figure 7: Interior of the ISSB School (Credit: HYT)

The two-classroom block, as well as the 20,000-liter water tank next to it, were both made from 5,875 ISSBs. Each classroom has a blackboard, railings to put up the student's work, and ISSB benches on the sides. Each classroom has six large windows to let in fresh air and light. The two classrooms are separated by a divider which can be folded to combine both classrooms to form one large learning space. The 20,000-liter water tank to the side of the school harvests rainwater runoff from the building's roof. It has enough capacity to supply the school.

This reduces the cost incurred by the school to obtain water, especially during the rainy season. Next to the water tank, there are small ISSB benches. The water tank also has a blackboard and it is situated under a tree that provides shade. During nice weather, the students can enjoy a lesson outside.

Figure 8: School blocks constructed with the conventional burned bricks (Credit: Nuwagaba)

Across from the ISSB classroom block, we can see the rest of the school blocks that were constructed with assistance from the government using the conventional burned bricks. Burned bricks required a lot of firewood to burn or bake them. Thus they are a danger to the environment. Table 3 below shows information about the ISSB classroom block project.

	ISSB Project
Compressive Strength	3.3 N/mm^2
Cost	$16,200
Employed	9 people
Energy Saved	34.6 MWh
Tons of firewood saved	5.6 tons

Table 3: ISSB Classroom Project Information (Credit: HYT)

The school blocks constructed with burned bricks had a total cost of $76,105. There are a total of 3 classroom blocks that were constructed with burned bricks. So on average about $25,368 was spent per classroom block. This is more expensive than the ISSB project which even came with a 20,000-liter water tank. This project proves that Interlocking Stabilized Soil Block technology has the potential to be the future of sustainable and affordable construction in Uganda.

2.3 Ilima Primary School – Ilima, Democratic Republic of Congo

MASS Design Group and the African Wildlife Foundation (AWF) worked together to start the Classroom Africa Initiative. This is a network of conservation schools all around Africa meant to alleviate conflicts between people and wildlife. It was also designed to promote environmental sustainability and encourage the locals to look after the environment. Ilima was the first school done by the collaboration between MASS Design Group and the African Wildlife Foundation. Table 4 below portrays information about the project.

Location	Ilima, Democratic Republic of Congo
Architect	MASS Design Group
Client	African Wildlife Foundation
Consultant	Arup Engineers
Size	800m^2 (building) 1,100m^2 (plot)
Year	2015

Table 4: Ilima Primary School Project Information (Credit: MASS Design Group)

Ilima is located deep within the jungle of the Democratic Republic of Congo about six hours away from the closest airstrip. The school is used as a community center for programs in the village that promote and sensitize the locals on sustainable farming and hunting practices. This is beneficial to both the people and wildlife. The school is the largest structure that the locals of Ilima have seen. The classrooms have a capacity of 350 and provide shelter to the students. It also attracts a lot of students due to its sheer size and beauty causing more students to attend classes and stay in school. Ilima Primary School has no embodied energy and was designed for extreme sustainability. This is really remarkable considering that Ilima is in a very remote location.

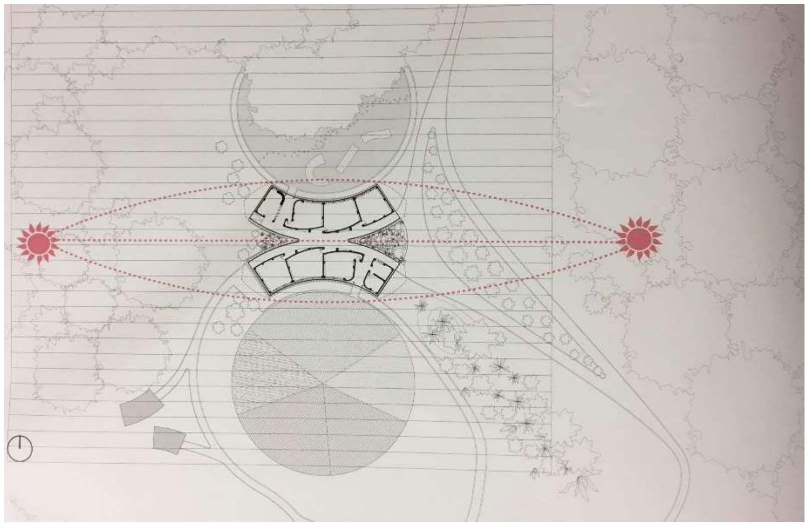

Figure 9: Ilima Primary School Layout (Credit: MASS Design Group)

For the design, MASS Design Group choose two large circles. One circle was to be used for the demonstration and conservation garden. The other was to be used as a playground. The school building is made is separated into two classroom blocks each shaped in the form of an arc. The two arcs lie in between the two circles. The southern arc has three classrooms and a library. The Northern arc also has 3 classrooms and administration offices. The school layout can be seen in Figure 9.

Figure 10: Ilima Primary School (Credit: MASS Design Group)

The Ilima Primary School project involved the people of the community in the design process. When you involve a member of the community in the design process, they appreciate the results achieved and are motivated to develop the idea further. This project was started by AWF. They agreed to build the school if the members of the community helped to protect 600,000 acres of the rainforest from illegal hunting, logging, and farming. The school was built by about 160 to 170 people from Ilima and the surrounding villages of Bolima and Lotulo. The construction was highly labor intensified to provide work for everyone and to inspire creativity and ownership of the primary school. There was also a lot of material research that was done to develop local techniques. This allowed the school to have a very low carbon footprint.

The Ilima Primary School project utilized sustainable materials in its construction. Due to the remoteness of the project, 99% of the materials were sourced within 10 km from the site. Mud bricks were utilized for the walls. Sun-dried adobe bricks made from soil from termite mounds. This soil is very cohesive thus making it good for the bricks. The plastered the bricks with two layers of a clayey sand mix, white clay rendering, and two coats of boiled palm oil. The oil made the bricks more resistant to water. The roof trusses, furniture, and roof frames were made from hardwood. The MASS Design team worked with local conservationists to identify appropriate trees within 6km of the school site. The MASS Design team also worked with the members of the community to design hardwood shingles. These were made from local trees and they are very durable and easily replaced. This innovation also created an income-generating opportunity for the people in the community.

Ilima Primary School, like many other schools in East Africa, doesn't have any operational energy requirements. It doesn't have any electric or mechanical equipment. This means that all the building's lifecycle emissions come from its embodied energy. 93% of the building materials were made from earthen materials which do not contribute to carbon emissions.

Ilima Primary School also incorporates some passive design techniques. The building is oriented in the east-west axis to make the most of solar shading. The school blocks were also made into two arcs so that it could mimic the variation of the sun's path over the course of the year. This means that the building corresponds directly to the local sun path. The school also has large overhangs that protect the building from heavy rainfall and sunlight. Ilima Primary school also incorporates passive ventilation since it doesn't have mechanical ventilation or electricity. The windows have perforated openings to allow air and light into the building.

This project provided a school and employment opportunities for the people of the Ilima community. It also helped to conserve the environment by motivating more people to conserve the rainforest. Future projects in Uganda and Africa at large should incorporate sustainability and community engagement in their design process. This greatly cuts down on costs and reduces carbon emissions.

2.4 African Wildlife Foundation Primary Schools – Karamoja, Uganda

These were two schools that were designed by Studio FH architects, an architectural firm in Uganda. The schools are located very close to the Kidepo Valley National Park in Karamoja and they are part of the African Wildlife Foundation's school initiative. The project incentivizes the locals to take care of the wildlife. Table 5 below depicts information about the project.

Location	Geremech and Sarachom, Karamoja, Uganda
Architect	Studio FH Architects
Client	African Wildlife Foundation
Consultants	The Landscape Studio (Landscape) Aquila Gallery (Structural Engineers) Equatorsun (Services & AT Engineers) Dudley Kadibante and Partners (QS)
Size	2000 m^2
Cost	\$380 / m^2 (excluding Value Added Tax)
Year	2018

Table 5: AWF Primary School Project Information (Credit: Studio FH Architects)

Like the Ilima Primary School Project, the AWF Primary Schools project sites in Karamoja were located in a remote area. Therefore, the building materials had to be carefully selected so that they could be obtained locally. This would cut down on the cost of transporting materials as well as the carbon emissions associated with the transportation of building materials. Luckily, the Kidepo area has beautiful local stones that are used to make foundations and plinth walls. A Plinth wall is a rectangular slab that forms the lowest part of the base column.

Compressed Stabilized Earth Blocks (CSEB) then formed the upper parts of the walls. The soil used to make the compressed earth blocks were obtained from the construction site.

Figure 11: AWF Primary School Foundation (Credit: Studio FH Architects)

The AWF Primary School's foundation was built on traditional rubble foundations. These don't require concrete. On top of the foundation, plinth walls that were constructed from hard granite rocks that were mined on site. The walls were made with 200mm non-interlocking compressed earth stabilized blocks. The blocks had a mix of cement, sand, and soil in the ratio of 1:4:8. The mortar was used to stack the bricks and provide the required lateral strength. Table 6 below shows a comparison of the properties of the Compressed Stabilized Earth Blocks (CSEB) with fired clay bricks and concrete blocks.

Property	CSEB	Fired Clay Bricks	Concrete Blocks
Wet Compressive Strength (MPa)	1 – 40	1 – 60	2 – 70
Moisture Movement (%)	0.02 – 0.2	0.00 – 0.02	0.02 – 0.10
Density (kg/m^3)	1700 – 2200	1600 – 2100	600 – 2200
Thermal Conductivity (W/m°C)	0.81 – 1.04	0.70 – 1.30	0.15 – 1.7
Durability against rain	Good to very poor	Excellent to very poor	Good to very poor

Table 6: AWF Primary School CSEB Properties Information (Credit: Studio FH Architects)

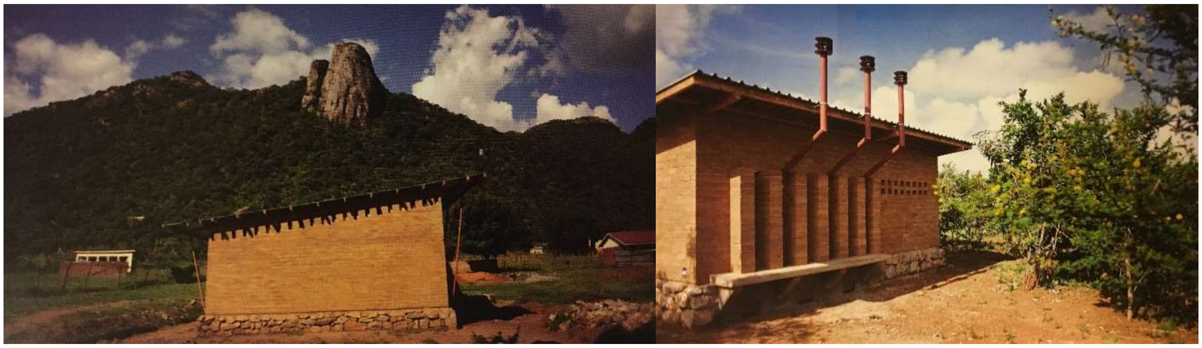

Figure 12: AWF Primary School (Credit: Studio FH Architects)

This project provided a school and employment opportunities for the people of the Karamoja community. It also helped to conserve the environment by motivating more people to conserve the rainforest. Future projects in Uganda should pick a leaf and incorporate sustainability and community engagement in their design process. This greatly cuts down on costs and reduces carbon emissions.

2.5 Final Remarks

It is interesting to note that all of these exemplary projects are schools, rather than housing. For various reasons, it appears that most built work using innovative local materials in Africa are at the larger scale of academic and healthcare facilities. There is a need to transfer these technological advances to housing, both at the single-family bungalow scale and in denser multi-family housing in urban areas. This chapter highlighted promising architectural possibilities of local and low-cost materials in these noteworthy buildings with the aim of identifying approaches that could be used more broadly in residential applications.

Chapter 3: Field Work in Uganda

In order to determine which materials were feasible in the Ugandan construction context, I traveled to Uganda in order to conduct interviews with local architects, engineers, Non-Governmental Organizations, and professors. I used the interviews and site visits to verify the findings of my literature review and decide which materials would be feasible to actually make construction affordable. In this chapter, I describe the methodology and the findings of my trip during IAP.

3.1 Methodology

To verify whether local materials like bamboo and compressed earth blocks are feasible for affordable construction in Uganda, I traveled to Uganda to conduct a series of interviews and visit construction sites. I interviewed two architects, two engineers, two Non-Governmental Organizations, and two professors. All parties that I met with had experience with constructing with local materials like compressed earth blocks and bamboo. They gave me insight into the benefits, challenges these materials come with, and the details about the projects they've worked on. I also visited two construction sites and visited a completed construction project in Kampala.

Before the interviews, I prepared a series of questions to obtain information needed from the interviews. The questions are displayed in Table 7. At each interview, these questions led to discussions of reasons why current construction methods are expensive, projects they've done with local materials, technical and cultural limitations the local materials have. In the next section, I present the major findings from these interviews and how they've impacted my research.

Question	Reason
What is the current state of construction in Uganda?	To learn whether there is an opportunity to incorporate low-cost materials in the construction sector.
What cost ($) per m^2 is considered as low-cost in Uganda?	To determine which local material based projects qualify as low-cost projects.
What types of projects has your company done using local materials?	To learn the firm's background with a focus on local materials.
Describe your experience with incorporating local materials in construction projects?	To understand the company's expertise in using local materials for construction.
How can the surplus of labor in Uganda be leveraged to embark on labor-intensive projects that use local materials?	To understand the required level of skill local materials require and see whether training people in the community can be done to increase local materials construction acceptance in Uganda.
How can we best market local materials to change people's perspective of them?	To learn how this perception could be changed.

Table 7: The Interview Questions asked and their Rationale

A couple of the interviews were scheduled ahead of time, however, most just happened organically. Through my connections at Makerere University and the interviewees', I was able to visit two active construction sites and three completed projects. The first active construction site was in Kampala near City Oil gas station on 6th Street Industrial area. The second active construction site was a secondary school, Mount Vernon School Maya, in Maya, Wakiso district. The three completed projects were Yamasen Japanese Restaurant and two Interlocking Stabilized Soil Block schools in Lugazi.

3.2 Construction Feasibility in Uganda

Through my interviews in Uganda, I investigated the potential of using local materials for construction. Local materials are a potential avenue for affordable and sustainable construction since they are sourced on-site like the Interlocking Stabilized Soil Blocks and act as carbon sinks like bamboo. Also, since they are sourced on-site, carbon emissions from transporting materials to the construction site are eliminated. In this section, I summarize each interview I conducted as well as the site visits. I also present a discussion of my findings. For the full notes from the interviews, please see Appendix A.

3.2.1 Summary of Interviews and Site Visits

I traveled to Uganda during the MIT Independent Activities Period in January. During this two week trip, I had interviews with two architects, two engineers, two Non-Governmental Organizations, and two professors. I met with:

- Dream Architects
- LocalWorks
- Engineer James Lucas Etot
- Engineer Joshua Mubangizi
- Haileybury Youth Trust
- Bamboo Village Uganda
- Dr. Apollo Buregyeya
- Dr. Moses Matovu

The underlined sections below give a summary of each of the different groups I interviewed during the MIT Independent Activities Period in January 2020.

Dream Architects

Dream Architects is a local architectural firm located in Kulambiro next to Ntinda View Nursery School. Their goal is to take architectural design to a new level in Uganda. I found out about their firm through a designboom article about a Japanese architectural firm (Terrain Architects) multipurpose building constructed with eucalyptus. Ikko Kobayashi from Terrain Architects in Japan designed Yamasen Restaurant located in Muyenga. Dream Architects were the local supervising architects on the project. I was able to get an interview with Dream Architect's Principal Architect, Patricia Khayongo Rutiba. During the interview, we talked about the Yamasen Restaurant project and potential approaches to affordable construction in Uganda. The Yamasen Restaurant project was special because it combined African cultural and Japanese modular construction. The project cut down on costs by using very simple details. It didn't require plastering, painting, and tiling. However, costs were incurred to import large eucalyptus wood for structural elements since the required size wasn't available in Uganda. The restaurant is also grass-thatched so that needs constant maintenance.

Figure 13: Yamasen Japanese Restaurant (Credit: Timothy Latim, Design Boom)

Architect Rutiba pointed out that timber construction could become a potential avenue for affordable construction. However, most of this wood is obtained illegally which increases the rate of deforestation. This has a negative impact on the environment. This fact is also true of bamboo. There is a lot of bamboo in Eastern Uganda along the slopes of Mount Elgon. However, young bamboo shoots are a delicacy in the region. The delicacy is called *Malewa.* The locals cut down the young bamboo shoots which prevent the rest of the bamboo from growing. This has caused a depletion of bamboo in Eastern Uganda.

Figure 14: Young bamboo shoot (Credit: https://www.wikiwand.com/en/Bamboo_shoot)

Figure 15: Malewa (Credit: David Mafabi, Daily Monitor Newspaper, Uganda)

Also, Architect Rutiba pointed out that Interlocking Stabilized Soil Blocks is another avenue for affordable construction. However, the soil that is used to make the blocks has to be easily compressible. For example, the slopes of Mt. Elgon have volcanic soils. This soil is very good for agriculture but bad for the ISSBs since it is very sticky and hard to compress. More cement has to be used to stabilize the blocks made from this soil. This drives up costs since cement is expensive. Architect Rutiba believes that Uganda needs to invest more in geological research. With a database on soil and rock types, it would be very easy to know which areas have good soils to make ISSBs. Also, areas like Karamoja in Northeastern Uganda that have large deposits of granite rocks could be mapped out to locate these areas. Foundations can be made from these rocks like in the African Wildlife Foundation Primary School discussed in the previous chapter and depicted in Figure 11.

In summary, to achieve affordable housing in Uganda, we need to plant bamboo forests that we want to use for construction and invest in geology research to identify areas with rock minerals that can be used in affordable construction projects.

LocalWorks

LocalWorks is a multi-disciplinary design and build firm in Uganda focused on designing sustainable architecture in Uganda. I found out about their firm through the African Wildlife Foundation Primary School project they designed. I was able to get an interview with the Director of LocalWorks, Felix Holland. Mr. Holland and I had a very in-depth conversation about the projects his firm has undertaken. The AWF Primary School project his firm did in Karamoja utilized local materials that were sourced on or near the site. However, it cost $380/m2 to complete the project. Mr. Holland pointed out that for low-cost construction in Uganda, it would have to be around $\$100/m^2$ or less of the building. His firm has incorporated passive design techniques for most of their projects. These techniques reduce the need to use air conditioning this saving on energy costs which is very crucial especially in remote areas in Uganda. For example, orienting buildings along the East-West direction to shield the windows from solar radiation. This can be seen in Figure 16.

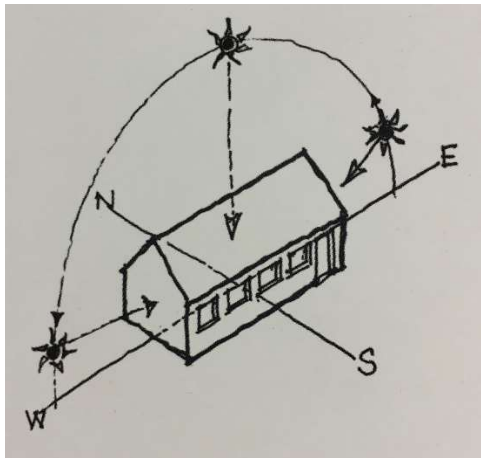

Figure 16: East-West building orientation (Credit: Felix Holland)

We then talked about different projects that have utilized local materials. The Renzo Piano Emergency Children's Surgery Center in Entebbe, Uganda is made from rammed earth. The rammed earth walls are constructed using formwork. The formwork is used to hold up the mixture of earth and cement stabilizer. This is then rammed with a hydraulic tamper to form the rammed earth walls. The two-story walls do not have any steel reinforcement. It is a pure gravity structure. However, Mr. Holland pointed out that the formwork used is very expensive plus the walls are also difficult to make. This wouldn't be an approach to affordable construction in Uganda.

Figure 17: Renzo Piano Emergency Children's Surgery Center (Credit: Lizzie Crook, Dezeen)

Mr. Holland and I then went on to other construction technologies like earthbag construction, earth floors, straw panels, and wattle and daub. Earthbag construction was very popular in the US in the ’70s. The walls are made from 50lb earthbags that are about 450mm (17.72in) deep. The bags contain a mix of soil and sand and the bag is compacted into a rectangular shape using a steel tamper. Barbed wire is placed between the bags to provide the lateral strength required.

Figure 18: Earthbag construction. (Credit: Cai Liangrui, EarthbagBuilding.com)

In, Rwanda, an NGO called EarthEnable is designing earthen floors. These floors are 75% cheaper than concrete floors. The traditional earth floors form puddles when they get wet. They also harbor parasites like termites, houseflies, etc. To make the floors, the backfill is first poured then compacted on the floor. Then laterite is brought in and put as the second layer of the floor. It is compacted on top of the backfill. Lastly, a screed layer is added and is the third layer of the floor. Varnish is then applied and this oil permeates the different earth layers and forms a waterproof layer at the top.

Figure 19: EarthEnable earthen floors in Rwanda. (Credit: EarthEnable)

Still in Rwanda, an NGO called StrawTec is designing straw panels made completely from compressed straw. The straw in Rwanda is obtained from wheat. It is heated to 200°C and then compressed. Cardboard is then attached on the sides. The panel is 60mm (2.36in) thick. These panels have a low embodied energy since the straw is an agricultural waste that farmers want to get rid of. StrawTec has also designed affordable home prototypes that cost 250/m^2. This could be a potential avenue for affordable construction.

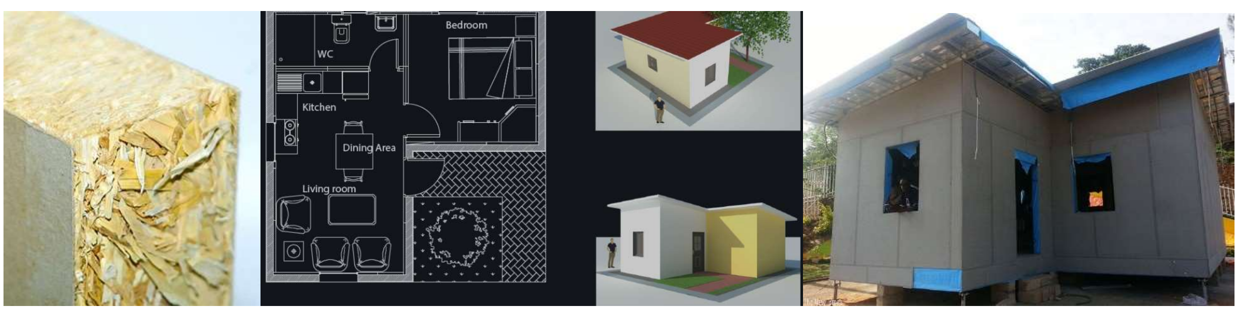

Figure 20: StrawTec affordable homes. (Credit: StrawTec)

Lastly, we talked about wattle and daub. Mr. Holland believes that this earth-related technology needs to be investigated or explored. The reinvention of wattle and daub to make it more durable would be the best approach to affordable construction in Uganda. The primary structure is made out of gum poles or eucalyptus or a bamboo grid across and then earth plaster is used to fill in the gaps. The structure is very lightweight and it has a nice indoor temperature.

However, with time, the wood exposed to the ground rots. The wood has to be continuously replaced and this drives costs up. If wattle and daub could be reinvented such that the wooden poles are lifted off the ground at least 300mm up and a stone slab placed below it, this technology would make affordable construction a reality in Uganda.

Figure 21: Wattle and daub hut in Uganda. (Credit: Mike Herrell, Pinterest)

<u>Engineer James Lucas Etot Odong</u>

I met with Engineer James Odong from Pernix Group Ltd. in Uganda. James worked on the Isimba Dam in Kayunga, Uganda. This project utilized a lot of fly ash for cement reduction. James is also working on the American Embassy office annex With Pernix Group. The embassy is more concerned about safety so they are using high strength concrete. The weakest concrete that's being used is C30 concrete i.e. has Compressive strength of 30MPa in 28 days.

Mr. Odong believes future construction in Uganda will expand to underground and high rises. Uganda, therefore, needs to invest in more geotechnical research. There have been a couple of commercial buildings that have collapsed due to poor geotechnical data research done on the site. The soil wasn't suitable to carry the weight of the building and it collapsed. An example of this happened in Jinja, Uganda where a two-story building collapsed in January 2020. Poor workmanship also contributed to the collapse. The contractor was trying to save on costs by using less cement in his concrete mix. This can be seen in Figure 22.

Figure 22: Jinja building collapse. (Credit: Daily Monitor Newspaper)

Mr. Odong proposed looking into reinforcing concrete with bamboo, sensitizing people about the environmental dangers of burned bricks, and looking at vermiculite as a building material. Vermiculite is a rock mineral that is very light and fireproof. It is currently used as a fertilizer but it could potentially be made into blocks and used in affordable construction in Uganda.

Engineer Joshua Mubangizi and Bamboo Village Uganda

I met with, Engineer Joshua Mubangizi, the Chief Building Engineer from COEF Limited. He was the site engineer at a commercial building project located on 6th street industrial area in Kampala. Joshua showed me around his construction site and afterward, he introduced me to Bamboo Village Uganda.

Bamboo Village Uganda is a Non-Governmental Organization that specializes in building bamboo houses in Uganda. I met with the founder, Henri Potze, and his mission is to reduce carbon emissions in Uganda by growing the bamboo required to supply the materials to build bamboo houses in Uganda. Bamboo is advantageous because it grows very fast (121cm/day). It's very workable compared to eucalyptus since it's consistent. In addition to that, bamboo acts as a natural carbon sink and can be used to reinforce concrete.

He has currently constructed a demonstration house in Mbale, Uganda. It also serves as a house for a single mother and her family. He is looking to construct a bamboo village in Uganda that'll attract tourists and later on spread awareness. He hopes to have more people using bamboo to construct.

Figure 23: Bamboo demonstration house in Mbale, Uganda. (Credit: Henri Potze)

<u>Haileybury Youth Trust</u>

I met with Haileybury Youth Trust (HYT). They are a Non-Governmental Organization that specializes in designing Interlocking Stabilized Soil Blocks in Uganda. I found out about them through the school project they did in Kawolo in Lugazi, Uganda. This can be seen in Figure 6 in the case study section. I met with one of their project managers, John Nsubuga, who was involved in the construction of the demonstration project at the Kawolo Church of Uganda Primary School. John showed me two different sites in which they used ISSBs to design the schools.

The first site utilized the dry-stacked interlocking stabilized bricks technique. Mortar was only used on the corners. It was a 2 classroom block and reflective iron sheets were used to keep classroom learning space cool. All the building materials were except the cement and iron sheets were obtained on-site. They also constructed a 20,000L tank with ISSB. However, they needed to use mortar to seal that tank off to prevent any leakages. This project involved people in the community. 1 person was from HYT while 2 men and 2 women were from the community. The project cost about $10,800.

Figure 24: ISSB School site 1. (Credit: Nuwagaba)

The second site was the demonstration project school at the Kawolo Church of Uganda Primary School. This site is older than site 1. This site also has a 20,000L tank. But it is multipurpose. It has a chalkboard and ISSB benches that allow teachers to have lessons outside if the weather is nice. The school plus the water tank cost $16,860. John believes ISSB technology is an avenue for affordable construction in Uganda. The public needs to be sensitized about the environmental dangers of burned bricks and the many benefits of ISSBs.

Figure 25: ISSB School site 2. (Credit: Nuwagaba)

<u>Mount Vernon School – Maya</u>

I had a site visit to Mount Vernon School – Maya in Waksio district. Mount Vernon School – Maya is a local secondary school that serves the community around it. The school is currently expanding as the number of students is increasing. They are currently adding a third floor to the school. The school is a reinforced concrete frame with a burned brick infill between the concrete columns. Figure 26 below depicts the school.

Figure 26: Mount Vernon School – Maya. (Credit: Nuwagaba)

Dr. Apollo Buregyeya and Dr. Moses Matovu

I met with Dr. Apollo Buregyeya and Dr. Moses Matovu from Makerere University. They are both professors in the department of civil engineering at Makerere. Dr. Buregyeya also owns EcoConcrete Ltd. His company specializes in manufacturing cement-based precast concrete materials in Uganda. He is currently working on a 22-floor residential building in Kampala. It will be the tallest residential building in Uganda. The foundations have 138 piles which are 8-12m in diameter and have a depth of 25m. The project will utilize 2760m^3 of concrete and 150 tons of steel.

Dr. Buregyeya believes that the affordable construction problem can be tackled by looking at the building standards that are used in Uganda. Uganda, being a British colony, inherited her building code from the United Kingdom. The Eurocode is used in Uganda today to design buildings. However, these codes were designed to be used in the U.K., not in Uganda. Dr. Buregyeya was explaining to me that if for example, the building standards say that for a loading bearing wall, it must have blocks with a compressive strength of 7MPa. But then, “I have a loading bearing wall where I used blocks with 1MPa compressive strength and it’s still performing the required tasks.” “Would the block I used have failed or it’s the standard that is requiring a higher strength than necessary?” This discrepancy causes non-load bearing walls to be over reinforced when it’s not necessary. This, in turn, drives costs up.

Dr. Matovu agrees because the quality of materials here in Uganda is poor but we use the same calibration devices and standards as the UK. Dr. Matovu also believes that getting a low-cost material say paper, for example, wouldn’t work. He believes that it would become a competing material and then the cost would eventually go up. Dr. Matovu’s approach to the problem is by looking into structural health monitoring of infrastructure. This would ensure that infrastructure and buildings are long-lasting and can be maintained reducing the cost of regular maintenance and repairs.

3.2.2 Discussion of Findings

Several major findings with impacts on this research emerged from the interviews and site visits that I did in Uganda during the MIT IAP period in January. First and foremost, concrete construction will most likely continue to dominate the construction of large scale buildings and infrastructure in Uganda for many years to come. Concrete is the most trusted building material in Uganda. From my interactions, I deduced that most Ugandans aspire to have a house constructed with concrete or burned bricks. These materials give a sense of safety. Thus, the goal of this research is to incorporate local materials with the current concrete construction. For example, have non-load bearing walls made from local materials like interlocking stabilized soil blocks or bamboo.

I also gathered that the building standards in Uganda need to be updated. This deduction came from my interaction with the professors from Makerere University. Uganda inherited the European building code. However, this code was designed to construct buildings in Europe that has a very different climate from Uganda. Extensive research needs to be done to address areas in the building code that can be updated to cut down on costs.

Uganda also has a surplus of cheap labor. However, the labor is unskilled, thus, innovative but high-skilled techniques like tile vaulting which presented enormous cost and environmental savings in Ethiopia and South Africa (Block et al. 2010) can't be implemented right away. With a large amount of unskilled labor, there are a lot of errors and low-quality construction. Such errors with techniques like tile vaulting are fatal. Therefore, the alternative techniques introduced must be simple and easily adapted into the current construction methods.

Henri Potze from Bamboo Village Uganda pointed out that he grows the bamboo he uses to construct his bamboo houses. Ugandans need to be sensitized on sustainable building. The timber, bamboo, etc. that we use in construction should be grown for that purpose. Or, the trees cut down for construction should be replaced. Practicing sustainable methods like afforestation, reforestation, and agroforestry can help provide the timber needed for construction without having a negative impact on the environment.

Lastly, at each interview, I asked about the feasibility of using local materials in construction projects in Uganda. All of the interviewees pointed out that people are reluctant to use local materials because they are viewed as poor quality materials used in low income earning areas. The rich in Uganda have houses that use concrete, burned bricks, and clay tile roofs. People in Uganda aspire to build using concrete because it gives them a sense of having succeeded in life. They would be very reluctant to have their houses built entirely from local materials despite their evident benefits. Also, local artisans whose entire livelihood comes from making burned bricks would be very reluctant to drastically switch to using local materials instead. The people I interviewed identified that sensitizing local artisans about the detrimental effect of making burned bricks on the environment could help alleviate the rate of deforestation their work causes. While this is a step forward towards saving the environment, the local artisans need to be provided with an alternative and innovative method and material to construct with. However, a study done by Hashemi et al. mentions that innovations need to be gradual and an abrupt change in current construction techniques would cause harm to the existing methods (Hashemi et al. 2015). The most effective way to address this is by making the current construction methods like the burned brick manufacturing process more efficient while gradually introducing local materials into the construction industry.

In summary:

- Concrete construction will continue to lead the construction industry in Uganda.
- Extensive research needs to be done to address areas in the Ugandan building code that can be updated to cut down on costs.
- Making the current construction methods more efficient while gradually introducing local materials into the construction industry will help convince more people to adopt this alternative building technique.
- The alternative building techniques must be simple and easy to incorporate with the current construction methods.
- Practicing sustainable methods like afforestation, reforestation, and agroforestry can help provide the timber needed for construction without having a negative impact on the environment.

Chapter 4: Results

In this chapter, I present the results for the comparative analysis between conventional and local building materials in Uganda. The analysis was designed and tested to fit within the constraints of affordability, reduced material usage, and embodied energy. A typical Ugandan house plan was designed in AutoCAD and based on the area of the walls, the embodied energy of various materials used in Uganda was obtained and compared.

This chapter is broken down into three sections. First, the methodology for setting up the comparative analysis is described. Next, I outline the process by which I calculated the embodied energy of the house using conventional and local building materials in Uganda. Finally, I present the results of the comparative analysis.

4.1 Methodology: The Comparative Analysis Setup

I designed a typical Ugandan house plan using AutoCAD software. Niwamara et al. performed a study on the embodied energy of low-income rural housing in Uganda. They collected data from 64 housing units in Mpigi district. The size of houses ranged from a single-roomed 6m^2 house to a 90m^2 six-roomed detached house (Niwamara et al. 2016). The sizes of houses increase in urban areas. I designed an 89m^2 house and this can be seen in Figure 27.

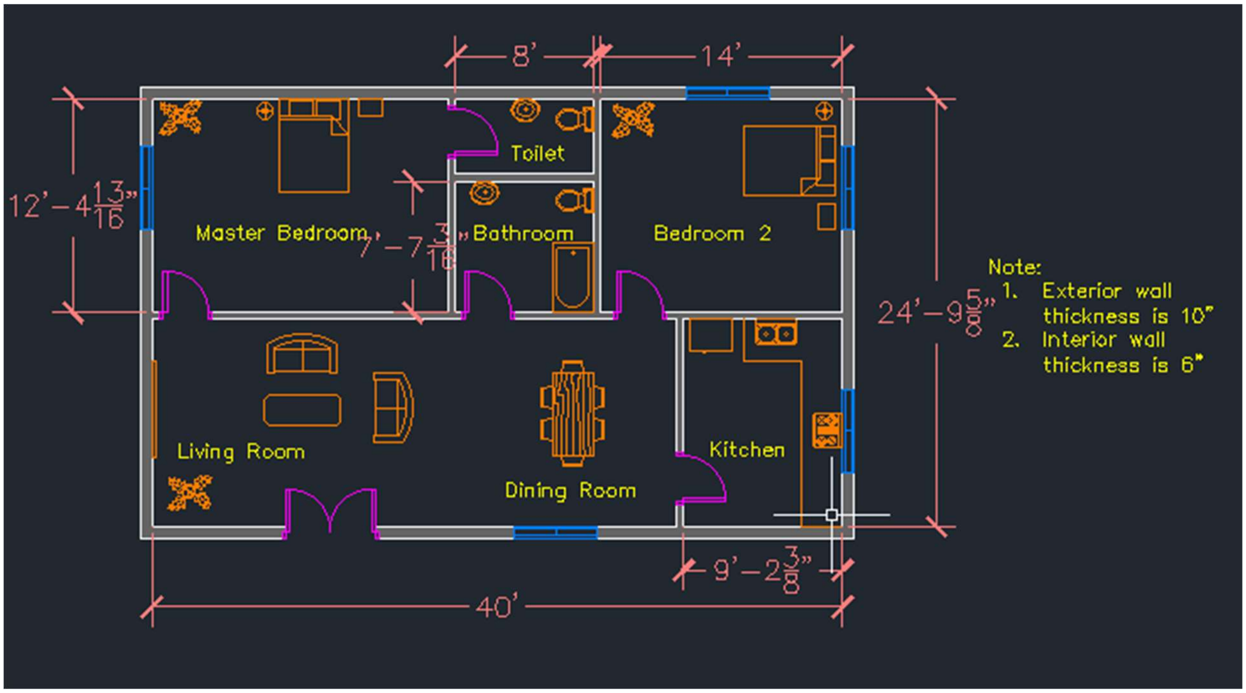

Figure 27: Typical Ugandan house plan (Credit: Nuwagaba)

Using the area function of AutoCAD, the area of each space in square meters was obtained. This is seen in Table 8.

Space	**Area (ft^2)**	**Area (m^2)**
Toilet	35.20	3.27
Bathroom	60.80	5.65
Kitchen	110.40	10.26
Bedroom	173.60	16.13
Master Bedroom	213.28	19.81
Livingroom + Dining	364.80	33.89
Total	**958.08**	**89.01**

Table 8: Area in square meters of each room

The area of the walls of the house plan was calculated and shown in Table 9. The total area comes to 141m^2. This area was used to calculate the embodied energy of the walls using different building materials in Uganda. This is explored more in the next section.

	Length (ft)	**Height (ft)**	**Area (ft^2)**	**Area (m^2)**
Outer Walls	105.4	9.0	948.6	88.1
Inner Walls	63.2	9.0	568.8	52.8
Total				**141.0**

Table 9: Area of the house's walls in square meters.

4.2 Methodology: The Embodied Energy Calculation Setup

To determine the embodied energy of the different construction materials used in Uganda, I utilized Table 1 from the introduction chapter. Table 1 details the embodied energy (EE) of brick and concrete walls (Hashemi et al. 2015).

The concrete blocks are 50% hollow so to represent a solid concrete block, I multiplied its embodied energy by two to get a value of 1.18 MJ/kg. While hollow blocks are commonly used, the hollow cores are typically filled with grout in at least parts of the structure, so assuming a fully solid block represents an upper bound. This value is then used to update the embodied energy values for concrete blocks. This is shown in Table 10.

Product	Brick/Block Size L x W x H (mm)	External Wall Thickness (mm)	EE of Material (MJ/kg)	Mass per item (kg)	EE of Wall (MJ/m^2)	EE of Wall (MJ/m^3)
Artisan Burned Brick/Block	300x150x130	150	4.76	7.6	810	5398
	20mm mortar		1.11	1.65		
	220x110x65	220	4.76	2	1067	4849
	20mm mortar		1.11	1.65		
Small Scale Brick	220x110x65	220	17.136	2	3542	16,100
	20mm mortar		1.11	1.65		
General Clay Brick	215x102.5x65	215	3	2	791	3677
	10mm mortar		1.11	1.65		
Cement Stabilized Soil Blocks	290x140x115	140	0.68	8	176	1257
	10mm mortar		1.11	1.65		
Hollow Concrete Blocks	400x200x200	200	0.59	14	127	636
	20mm mortar		1.11	1.65		
Concrete Blocks	400x200x200	200	1.18	28	254	1272
	20mm mortar		1.11	1.65		

Table 10: Updated Embodied energy (EE) of brick and concrete walls.

To get the embodied energy of bamboo, the values were obtained from a study done on future bamboo-structure residential building prototype in China: Life cycle assessment of energy use and carbon emission by Yu et al. (Yu et al. 2011). The values are shown in Table 11. These values from Table 10 and Table 11 are used in the comparative analysis in the next section to calculate the embodied energy of construction materials in Uganda.

Material	Extraction MJ/kg	Processing MJ/kg	Transportation km	Energy Use MJ/kg	Carbon Emission $kgCO_2/kg$
Bamboo	0.044	1.71	300	2.58	0.13
Wood	0.047	7.01	800	7.22	0.41
Laminated Bamboo Board	0.52	9.32	200	9.98	0.53
Laminated Wood Board	0.2	12.76	200	13.22	0.74
Steel (10% recycled content)	1.4	27.15	1000	28.65	2.21
Cement	0.03	4.62	500	5.27	1.05
Concrete (C40)	1.27	2 kWh/m^3	10	1.12	0.2
Cement Mortar (1:2.5)	2.7	2 kWh/m^3	10	1.64	0.31
Expanded Pearlite Concrete	0.044	2 kWh/m^3	10	9.39	0.61
Brick	4.66	1.57	50	1.75	0.14

Table 11: Energy Use and Carbon Emission of Building Materials. (Credit: Yu et al.)

The values for bamboo and laminated bamboo boards are in MJ/kg. However, from my AutoCAD house plan model, I obtained the total area of all the walls within the house. I assumed that the outer walls had a thickness of 10 inches (0.254 m) while the inner walls had a thickness of 6 inches (0.1524 m). I obtained the density of bamboo from a study done by Paul Laroque on the design of a low-cost bamboo footbridge (Laroque 2007). Laroque assumed the density of bamboo was 650 kg/m^3 and used this value for his calculations. I then obtained the density of laminated bamboo from a study done by Sharma et al. on engineered bamboo for structural applications (Sharma et al. 2015). The laminated bamboo has an average density of 686 kg/m^3 with a moisture content of 6% (Sharma et al. 2015).

Using the thickness of the walls from AutoCAD and the density of bamboo from Sharma et al. and Laroque's study, I found the embodied energy of bamboo and laminated bamboo board in MJ/m^2. This can be seen in Table 12.

Material	Energy Use MJ/kg	Density kg/m^3	Energy Use MJ/m^3	Wall Thickness (m)	Energy Use MJ/m^2
Bamboo	2.58	650	1677	0.1524	682
				0.254	
Laminated Bamboo Board	9.98	686	6846	0.1524	2782
				0.254	

Table 12: Embodied Energy of Bamboo and Laminated Bamboo Board in MJ/m^2

These values will be utilized in the next section to perform the comparative analysis of construction materials used in Uganda.

4.3 Comparative Analysis

The values from the previous section were used to calculate the embodied energy of construction materials used in Uganda. The house plan designed in AutoCAD was used to determine an estimate of the area of walls in a typical household in Uganda. This was then used in Table 13 to calculate the embodied energy in GJ.

Material	Embodied Energy MJ/m^2	Area of Walls (m^2)	Embodied Energy (MJ)	Embodied Energy (GJ)
Hollow Concrete Blocks	127	141	17907	17.9
Cement Stabilized Soil Blocks	176	141	24816	24.8
Concrete Blocks	254	141	35814	35.8
Bamboo	682	141	96162	96.1
General Clay Brick	791	141	111531	111.5
Artisan Burned Brick/Block	810	141	114210	114.2
Artisan Burned Brick/Block	1067	141	150447	150.4
Laminated Bamboo Board	2782	141	392262	392.3
Small Scale Brick	3542	141	499422	499.4

Table 13: The Embodied Energy of the Walls in a Typical Ugandan House

Material	Brick/Block Size L x W x H (mm)	Volume (m^3)	Mass (kg)	Density (kg/m^3)
Bamboo	-	-	-	650
Laminated Bamboo Board	-	-	-	686
Hollow Concrete Blocks	400x200x200	0.016	14	875
Artisan Burned Brick/Block	220x110x65	0.00157	2	1271
Small Scale Brick	220x110x65	0.00157	2	1271
Artisan Burned Brick/Block	300x150x130	0.00585	7.6	1299
General Clay Brick	215x102.5x65	0.00143	2	1396
Cement Stabilized Soil Blocks	290x140x115	0.00467	8	1713
Concrete Blocks	400x200x200	0.016	28	1750

Table 14: Density Comparison of Construction Materials used in Uganda

From Table 13, we can see that cement stabilized soil blocks and bamboo have one of the least embodied energies in Table 13. These materials have the potential to substitute current construction materials like burned bricks. Burned bricks are harmful to the environment, therefore, they need to be substituted with less carbon-intensive materials like bamboo and cement stabilized soil blocks.

It should be noted that although hollow concrete blocks have the lowest embodied energy, they are very costly. The cost of concrete blocks per m^2 is almost 36% more than burned bricks (Pérez-Peña 2009). It is paramount that we reduce the overall cost of construction while using an environmentally friendly construction material. Cement stabilized soil blocks are around 18% cheaper (Pérez-Peña 2009) than burned bricks and have a considerably lower embodied energy than burned bricks. Cement stabilized soil blocks are, therefore, a suitable environmentally friendly choice for low-income housing in Uganda.

In addition to the cost, the weight of the construction materials must be put into consideration. When the construction materials are light, the foundation needs less reinforcement to support the same size of a building. This, in turn, results in lower costs associated with the building. In my interview with Mr. Felix Holland from LocalWorks, he said that in some of their school they build, they spend 20-25% of the money to construct the foundations yet we put no one sees it. Mr. Holland said that "If you want to reduce costs, you must think about weight."

Table 14 compares the densities of the different construction materials available in Uganda. From this table, we can see that bamboo and laminated bamboo board construction materials have the lowest densities. On top of this, bamboo has a low embodied energy. Therefore, bamboo would be an affordable and environmentally friendly construction material to use in Uganda. However, the laminated bamboo board wouldn't be suitable because it has a high embodied energy. The embodied energy of the laminated bamboo board is high because the bamboo used to make it is manufactured to have definite dimensions similar to commercial wood products. This makes laminated bamboo board costly, therefore, not applicable for low-cost housing in Uganda.

The comparative analysis in this chapter has shown that cement stabilized soil blocks and bamboo are local materials that can substitute the current construction materials used in Uganda. They are both environmentally friendly and cost-effective thus applicable to be used in affordable housing in Uganda. In the next chapter, I summarize all the conclusions of this thesis and provide various avenues for future work.

Chapter 5: Conclusion

5.1 Summary of Contributions

This thesis has examined the potential of using locally available materials to lower the cost of construction in Uganda. Chapter 2 presented the exemplary architectural possibilities of local and low-cost materials in large scale academic and healthcare facilities. This chapter also exposed the need to transfer these techniques to the housing industry in both rural and urban areas in Uganda. Chapter 3 described the interview and site visits I did to verify the findings of my literature review and decide which local materials in Uganda would make construction affordable. Chapter 4 outlined the process and results of the comparative analysis and confirmed that local materials like bamboo and compressed earth blocks can be used to substitute the current construction materials utilized in Uganda.

I discover that bamboo has almost half the density of the burned bricks made by local artisans in Uganda. This means that burned bricks require additional reinforcement in the foundation, therefore, raising costs. Also, these same burned bricks have an embodied energy that is six times higher than compressed earth blocks. Burned bricks are very detrimental to the environment and action needs to be taken to gradually replace this technique of making bricks.

5.2 Potential Impact

As the population of Uganda continues to increase, the need to construct small and large scale structures like houses, hospitals, schools, etc. in Uganda will also increase. In this thesis, I have shown that local materials have the potential to substitute conventional construction materials while lowering costs and impact on the environment. Both bamboo and compressed earth blocks are environmentally friendly. They have the potential to reduce the rate of deforestation in Uganda. This will, in turn, keep the environment habitable for future generations of Uganda.

Local materials can gradually be integrated with conventional materials. They can be used in non-load bearing areas of the building or parts of the structure that don't experience heavy loads. This would reduce the construction costs as less burned bricks and concrete will be required. Also, material transportation costs will be lower since bamboo and compressed earth blocks can be obtained on the construction site.

5.3 Limitations and Future Work

The comparative analysis presented in chapter 4 was limited to the data obtained from the work done by Hashemi et al. 2015, Laroque 2007, Sharma et al. 2015, and Yu et al. 2011. This was due to time constraints and the COVID-19 pandemic that prevented me from obtaining samples of bamboo species and soil from Uganda to test their properties. The next steps of this research should be to obtain local material specimens from Uganda to test how their structural behavior when loaded and how they would interact when integrated with conventional building materials.

It was expressed by several interviewees that local construction materials are seen as inferior to concrete. They are associated with houses built in the village, therefore, looked at as less modern and used in low income earning areas in Uganda. In this thesis, I focused on presenting the potential local materials have and how they can be used to substitute the current construction materials used in Uganda. Future work should look at how to convince Ugandans to start using local materials to construct. This can be done by sensitizing the public on the benefits of using local materials and how detrimental materials like burned bricks are to the environment. Another avenue could be through designing demonstration projects that display the architectural beauty and strength of these materials. For example, a bamboo pavilion can be designed, tested, and constructed in Kampala. This pavilion can then be used during the various music festivals held in the city to display to the public how local materials can be used in modern settings. This would address the cultural resistance to local materials and help these materials to get integrated into the construction industry in Uganda.

5.4 Final Remarks

There is a potential to make construction affordable in Uganda. This thesis has shown that locally available building materials can be used to substitute the conventional building materials used in Uganda. Local materials have various benefits ranging from being environmentally friendly to saving on construction costs. With further research and testing, local materials can be gradually incorporated into the construction industry in Uganda. This would transform the construction industry thus allowing more people to afford to build enabling the standard of living to improve Uganda.

Appendix A: Interview Notes

Dream Architects. January 22, 2020
Principal Architect: Patricia Khayongo Rutiba
Connection provided by: Design Boom Article on Yamasen Japanese Restaurant. I reached out to the when I got to Uganda to set up a meeting.

Notes:

- Doing something new and different. Combined African cultural construction with the Japanese modular construction.
- The Japanese also like using/constructing with wood. This made the project special/unique and worth it at the end of the day
- Saved on costs by using steel window frames instead of Aluminum which is now common in Uganda though expensive
- Also, we looked to cut down on costs by using very simple details. We looked for places where we could take out unnecessary details that eat up the budget, for example, painting, tiling, and plastering
- The only place that has plaster was the kitchen for fire safety as that would be a fire hazard. The kitchen was mostly made with Gypsum since its fireproof
- To protect the timber from termites, dampness, and dry rot we opted to have a concrete base up to the window sill height (3 ft.) instead of treating the wood with anti-termite chemicals
- Maintenance for the grass thatched roof
- Low cost was achieved by getting rid of tiles, paint, and plastering since we can do without it
- Timber construction could become a potential low-cost solution, however, most of the wood for construction is obtained illegally from protected forests in Uganda
- Bamboo can also be a solution if they plant the bamboo forests
- There is a lot of bamboo in Eastern Uganda along the slopes of Mount Elgon. The natives there eat the young bamboo shoots ("*Malewa*").
- They chopped down very many bamboo forests to access the Malewa. This exposed the land on the Mount Elgon slopes which in the end led to mudslides.
- Structurally, bamboo is great and extremely workable. The stems or culms are consistent, unlike eucalyptus.
- Bamboo also grows fast. When you cut down one culm, several others grow back in its place. Growing bamboo for construction like they do in South East Asia would be a potential solution.
- Hydro-foam blocks or ISSB. We didn't use it in the Yamasen Japanese Restaurant but we've used it on other projects.
- There are two issues with these blocks.

    - The soil isn't easily compressible. Thus you have to use a higher amount of cement stabilizer. The soil matters a lot. If the onsite soil isn't good, you may have to buy good murram soil. This drives costs up
- Uganda needs to have a geological database for good construction materials because we have very many rocky places in Uganda with rocks that could be used for construction.
- However, the number of geologists in Uganda are few and most of them are focused on the oil discovery in Lake Albert.
- Nairobi stone is a low-cost construction unit. I'm not sure when it was discovered but most of the buildings in Nairobi had these rock quarries (10:02) where they would cut the stone into blocks.
- Once you cut it into a block, it has a very high compressive strength. It's very easy to cut because it forms in slices or layers like sedimentary rocks.
- They use the blocks to construct storied buildings, homes, fireplaces, and once you do it neatly, it looks very beautiful. You don't need to use plaster.
- The only material you may need to put on it is saddle binder, a type of varnish to protect it from harsh weather elements though it's not necessary.
- If our geologists could discover such rock material in Uganda, we could save so much money.
- There's a time where foreign road developers were working on a road in the Eastern Uganda and there was a huge plot of land where the road was supposed to pass.
- This plot had a huge rock which was giving the locals a hard time since they couldn't farm or till or grow anything on the land.
- The developers asked them if they could take the rock off their hands so they could farm to which they accepted. That same night they took that rock.
- No one knows what type of rock or how valuable it was. The villagers were just happy that they could now use the land to farm.
- If we had geologists studying rocks in Uganda, we would've known how valuable those rocks were and probably would've sold it to the developers and this money would in turn help the people in the village.
- We also would have a database where we would know which exact area has good soils for ISSB/Hydrofoam
- With this database, architects and engineers would be able to recommend ISSB as a low-cost construction in areas with good murram soil
- Also, we would be able to identify areas with good finishing rocks like the Karamoja Marble that is good for finishes and is very beautiful.
- Sandstone from Mombasa is also beautiful
- There isn't enough funding for research in construction. Even the Uganda Society of Architects (USA) doesn't have support from the ministries.
- The ministry of works sends the USA to the ministry of housing. Then the ministry of Housing and Urban Development sends the back to the ministry of works.

- We need a ministry that can fund research on rocks that can be used in construction. Determine its reaction with cement or resistance to weather effects. All these require a lot of funds
- Our material labs here in Uganda just focus on cement, which is very expensive
- Pumice volcanic rock found in Kabale in South Western Uganda is a potential building material but no one is using it
- Low-cost housing seems like a mystery because we don't currently know what construction materials we have in our country
- My family wanted to plant a bamboo forest on about 40 acres of land in Eastern Uganda where it grows best
- However, we found it challenging due to issues from neighbors, squatters and the local government.
- Such small issues make it hard to plant bamboo forests
- Uganda has a lot of quartz and granite but we've been importing the polished and finished granite from Kenya and India
- Bulambuli and Maluku are low-cost projects being constructed in the East
- Maluku was constructed to deal with the local population in Mbale who were living in slums.
- They used compressed earth blocks. However, Mbale has volcanic soils that are very good for farming, but terrible for ISSB.
- Volcanic rock is sticky which is hard to compress. They had to import murram from Soroti
- Bulambuli to resettle the locals that were displaced by the mudslides along the slopes of Mount Elgon
- Each housing unit cost between 28 – 34 million Uganda Shillings ($7,608.47 - $9,238.85) and was about 50 m2
- These houses were still inadequate. They didn't have a kitchen. It just had 2 bedrooms and a sitting room.
- They had to construct toilets off-site. They then had to add extensions for kitchens because cooking in open-ground was challenging with rains
- This caused the cost to increase from 28 million to 34 million which is very expensive for low-cost housing.
- 5,000 families were displaced by the mudslides. The government could only construct 100 of these homes during the first phase.
- They constructed a permanent settlement yet it was supposed to be temporary as the locals waited to see whether they could move back to their homes.
- In summary, to attain low-cost housing in Uganda, we need to plant bamboo forests (grow trees for construction) and invest in research

Perspective

- Low cost in rural areas is a mud hut with thatch. However, it's seen as backward. They aspire to have houses made with burned bricks and iron sheets for roofs

- Iron sheet roofs are good but they are very uncomfortable at night. It gets really hot in them. The local mud and thatch are very cool and nice inside.
- However, it's plastered with cow dung which makes them feel backward.
- To change this, we need to have projects that make huts look good. And have local celebrities stay in them.
- Changing the perspective of the locals by having aesthetically pleasing and beautiful houses or structures made from local materials.
- The rich in Uganda build their mansions using concrete so the average Ugandan aspires to have something like that one day.
- So using local materials would look make them feel like they aren't successful even though it's low cost and environmentally friendly
- In Urban areas, the population is very high is a small area.
- We could have many mixed development units at several levels
- Having 3 - 4 floored apartments as everyone is building bungalows but the space isn't available
- For the Bulambuli project, the government should've invested in building huts. All they would have to do is provide the material like the poles. The people in the community would work together to build their settlement.
- Also since the volcanic soil is sticky, it's perfect for plastering the mud huts.
- For example, we met a gentleman living in one of these Bulambuli houses. He had 3 wives each with children. So one family stayed in the living room while the other 2 in the other bedrooms.
- In a traditional setting, each wife would stay in their hut while the husband lives in a central hut. This new settlement has caused issues like this to arise
- Therefore, the government should've looked to traditional solutions. The money should've been spent to buy poles to construct huts which are cheaper and easier to build

Better huts

- Modern Yurt (https://www.youtube.com/watch?v=f05NYU3kmFs)
- Spruced up our huts to make it more attractive
- Current huts are so dark and people find them uncomfortable
- Improve huts by adding more daylight
- Innovate and put plastic water bottles with water in them in the hut walls
- The top part of the thatched hut covered with translucent sheets to allow in more daylight
- So that it's not as dark as they traditional huts.
- This could potentially change the locals perspective to use low-cost materials

Haileybury Youth and Trust. January 23, 2020
HYT Representative: John
Connection provided by: Kawolo Church of Uganda Primary School demonstration project. I found the project then reached out to HYT about scheduling an interview before I left for Uganda.

Notes:

Site 1

- No mortar used. Dry stacking
- Plaster the corners to create a good bond
- The only concrete used was on the ring beam
- There's a trick to making the ring beam with ISSB. We didn't use as many nails as usual
- For this project, we found that the school had already made some burnt bricks for the foundation
- When we took over the project, we used both the bricks but mostly our ISSB. We just had to put a waterproof compound
- "Dr. fix it" was the waterproofing used. We first constructed the water tank using this compound and ISSBs, then constructed the school
- For durability, care needs to be taken when making the bricks.
- Murram with light sand particles is very good for ISSBs
- The first building and water tank we did with HYT are now 11 years each and I participated in this construction
- We want to push for ISSB because it reduces the rate of deforestation as a lot of firewood is used to bake burned bricks
- ISSB can be used for storied buildings since the building sits on the columns. The ISSBs can be used to partition the building
- Usually, we find that when we compare the cost we incur to make this classroom block vs what the government uses to construct a 2 classroom block, the government school is double the cost
- This project cost about 40 million Ugandan shillings ($10,872.16) in total. This included labor etc.
- The school block has two classrooms but you can open up the partition to have one large hall for national examinations for P7 students
- We worked with people in the community. We make it a point to train at least 2 people from the community so that the knowledge stays with them and they can continue to build
- When HYT started, we used to leave the ISSB machine. However, the people in the community were so used to making burned bricks. It has been challenging to change their perspective
- Blocks and murram were obtained on-site apart from the cement and iron sheets
- The iron sheets we used are reflective so most of the sunlight is reflected to keep the interior cool

- The tank is a 20,000L water tank. We used mortar, cement, and waterproofing to seal the tank so that water doesn't escape
- We were only 5 men and women in total who constructed this school classroom block

Site 2

- This site is older than site 1
- The water tank is also 20,000L
- The tank is multipurpose. It has a chalkboard and benches. When the weather is nice, students can learn from outside
- The iron sheets had to match the color of the other classroom blocks. So it's not reflective like site 1
- We welcome researchers to critique our designs so that we can improve
- I was the first person in HYT to construct a building without mortar
- Within 2 days someone can learn how to make ISSB
- People in Uganda don't think about the environment so it's hard to convince the youth to use ISSB
- The two blocks over there were constructed by the government and it cost them 280 million Ugandan shillings ($76,105.12)
- Ours plus the water tank cost 62 million Ugandan shillings ($16,851.85)
- When comparing the 2 water tanks, ours made from ISSB vs the plastic one, ours is more durable, affordable and easy to repair.
- It is also environmentally friendly. The embodied energy of the ISSB tank is lower than the plastic one. The ISSB tank does use cement however, the plastic tank also uses cement to make the concrete slab on which it sits
- There's also the energy associated with making the plastic tank itself
- The plastic tank is also not functioning anymore. Students pierced it causing it to leak. However, with our ISSB tank, if you put a hole in it, we can easily seal it.
- Dr. Musaazi from Makerere University discovered the ISSB technology
- We also test the water in our water tanks to make sure it's safe to drink. And all the tests showed that the water is safe
- We tried not to cut down the trees. We used the tree next to the water tank as a shaded area to put up the benches for the chalkboard on the tank.
- We need to push for the sensitization of the general public. They need to know the dangers of burned bricks and how ISSBs can mitigate this.
- We need help from researchers like yourself to push for this to change people's perspective

Pernix Group Ltd. Jan 24, 2020
Director: James Lucas Etot
Connection provided by: James and I studied civil engineering at Makerere University together from August 2014 to August 2015.

Notes:

- I've worked on 2 projects in Uganda so far. The first was Simba Dam in Kayunga Uganda. The second is with the American Embassy which I'm currently working on
- Both are majorly cement-based but with Simba Dam, we used a lot of fly ash for cement reduction to reduce on the heat of hydration and to reduce on the cost
- But for the American Embassy, they are concerned with safety so it's mostly high strength concrete. The weakest concrete they're using is c30 cement.
- I've been doing some research on building materials.
- There's a rock called vermiculite. It's very light and fire-resistant. I've been looking at research where they made blocks from vermiculite
- A $1m^3$ block is very easy to carry by someone. It's also very hard. I've done some tests using a torch to burn it. It's very fire resistant.
- Uganda also has the biggest reserve of vermiculite in the world located in Eastern Uganda.
- It's unused and the only place I've seen it being used as fertilizers for crops
- It increases the germination rate of crops mainly in Kenya. Crops usually have about 60% germination rate but vermiculite increases this to 97%
- Vermiculite is being exported from Uganda to Kenya to be used as fertilizers
- I think vermiculite is a very good material that you should look into
- ISSB is good but they're still very heavy. It's good because it reduces the need for cement and we also have the soil that's needed to make the blocks
- Also, the speed of construction is high compared to burned bricks
- Majority Ugandans can't afford strong cement blocks, however, they'd prefer it to ISSB since it looks modern and is a symbol of success
- Designing a beautiful structure from ISSB may convince more Ugandans to use ISSB.
- I believe you can make housing affordable by
    - Looking into vermiculite
    - Cement reduction by adding ash to the mix. Ugandans use a lot of firewood for cooking so collecting their ash for free and using it to reduce on cement content can be another avenue
- Sensitize local brick artisans on the dangers of burning bricks and maybe giving them another option like ISSB. Involving the government to help subsidize the initial cost of the ISSB compression machine
- I like to think that the future of construction is in Africa
- Uganda has started to construct flyovers and pipelines

- I believe we will expand to underground and above ground construction like high rises not only in Uganda but elsewhere in Africa
- The Uganda government should also invest in research in geotechnical and geology
- Of recent, there has been a lot of building collapses. Everyone invests money in researching what they can see like bricks and concrete.
- However, they forget to carry out research to determine whether the soil can hold the building. The soil properties etc.
- We are very fortunate that Kampala is not in a high seismic area. If Uganda was to be hit by a serious earthquake, I highly doubt that many buildings would survive the impact
- Many people don't do geotechnical investigations in Uganda. Many companies just recycle old reports and use them for new projects which is very dangerous.
- I could say Uganda is surviving by luck or God's grace.
- Also, most Ugandan buildings are not high rises. The tallest building has about 20 floors. Maybe that's a reason why we haven't seen any issues yet
- Also, I think bamboo reinforced concrete can be another avenue
- As well as fiber reinforcement. The fibers could be obtained from recycled waste
- At the embassy, we've done tests on fiber-reinforced pavers and they are really strong. Imagine a paver going into 50 or 60 MPa
- You can also look into crushing bamboo and using the fibers to reinforce concrete. It reduces the chances of bamboo failing in a brittle way if you're to crush it.

Makerere University Jan 24, 2020
Professor: Dr. Apollo Buregyeya
Professor: Dr. Moses Matovu
Connection provided by: Nicholas Aijuka from Makerere University connected me with Dr. Apollo Buregyeya. Nicholas and I studied civil engineering at Makerere University together from August 2014 to August 2015.

Notes:

- Dr. Moses - Low cost is a challenge that everybody keeps thinking about. Is it at a material level
- Dr. Apollo – When I look at the blocks I make, cement productivity in blocks is about 25% compared to the strength you get in the concrete.
- That means that we are using a lot of cement for strength but that goes more into material science
- I think we can approach this from the angle of standards. The standards specify certain strengths
- If the standards say that for a loading bearing wall, it must have blocks of 7MPa but then I have a loading bearing wall where I used 1MPa and it's still performing the required tasks, is it the material that has failed or it's the standard?
- We should discuss this. Why are their standards expensive for us to use. I think it has to do with the labor structure

- Dr. Moses – I think it has to do with safety and the value of life. Here in Uganda, we abuse it. The ability of a structure to stand doesn't assure us of its continued performance in an event of strong winds.
- I think we may be able to take on more risks. Because I keep on asking myself as an individual when we keep on insisting on standards, are we truly helping the common man? We are not.
- Dr. Apollo – We are failing them. We are denying them. A standard is a commerce-driven product. The people who promote standards are not scientists but industrialists because they want to protect their markets.
- A pineapple that is not 1kg you can't sell it in Egypt. Because the standard is 1kg pineapple.
- As a researcher, I think you are free to question this. Where is the line
- Dr. Moses – But I'm also looking at when I integrate it as part of the system, I look at how does an ordinary person outside acquire a house. Here, I'm shifting towards the financing system, mortgages, etc.
- How many people build a house out of pocket and no credit? Can an ordinary man like me access this credit and what is the cost of this credit? It's a very big problem
- I'm not sure of the full scope you might be interested in because every time we talk about affordable housing I keep on shaking my head because many people have tried, National Housing has tried and either you come up with a magic bullet in terms of material where for example paper is the current catch and as soon as you start using paper it starts becoming a competing material and then the cost goes back up again
- But for me, one of the challenges that I've seen that people are probably blind to is the entirety of we carry out our assessments.
- I don't like it. Just dealing with the existing infrastructure and grappling with how do we deal with this. I tend to think that there's too much guesswork in whatever we're doing
- All the calibration devices that have been used on our infrastructure but for a certain quality but do they work with our quality?
- These tools could be good for the concrete in the west but are they good for the quality of concrete in Uganda?
- I am very happy that you're passionate about translating your research here in Uganda so we can brainstorm on the way forward
- Dr. Apollo – In many places where 1m3 is \$30 here the cheapest we have is \$135
- Dr. Moses – I'm passionate about any person who can come in with the assistance towards the actual assessment of existing, I'm talking about the condition of the existing infrastructure.
- I tend to think there are a bit of gaps because many of these tools, the smart tools, the non-destructive tools are based on an indirect parameter which requires a correlation
- Now even when they're performing the correlation, they are still dealing with quality products in their industry.
- Ours is very different and I don't know how you can use these tools in research when the quality is so varied.

- The way consultants in Uganda have addressed that problem is when you look at many of their reports, they are deceptive.
- One can write “the strength of the concrete is poor” It could be correct but with a wrong basis so sooner or later we may just end up in the courts of law all the time
- Another area I’m passionate about is the quantification of the defects in our infrastructure
- As a bare minimum, if we can get more tools in the quantification calibrated with our materials.
- And when I talk about materials, I’m talking about materials ranging from the 1980s, 1990s to present where the quality has gone a little bit berserk
- I don’t think it’s about the design, you need to look at the entire ecosystem when you’re thinking about something cheaper
- I would appreciate if you’d look at it holistically and outside of that kind of research where you look at several other disciplines and you bring it together. I think that would be great
- Because you have a bird's eye view and you can relate it to how other countries have solved. I think that might be more insightful
- In Uganda, we have bridges that are coming up, cable-stayed systems. The types of bridges we have in Uganda are more or less the same
- Pre-stressed is coming in but in the past people have been hesitant about it
- Dr. Apollo - The design narrative of a house/building for America/Europe. Should it be the same in Uganda?
- Dr. Moses – For me, it starts with is the environment the same, no. So could we make do with something less strong for our environment
- I’ll give an example of which wind speeds are we using here in Uganda in our code.
- When you purely from the structures point of view, and we are talking about the definition of our loads. We start with the codes from the UK, they will tell you that it is this wind speed, this is the basic wind speed that has this probability of non-exceedance of occurring at this height
- So sometimes in blindly making use of their codes, we come up with very expensive structures
- But that’s an issue of application. I’m yet to see what I saw in the US where the provide codes with design examples and they take you through the usage of the code.
- Now if this code wasn’t formulated for us, I think it’s high time that people in Uganda provided some design examples and explain it. Then we can appreciate that kind of input we need we don’t have it as yet in the format in which people need it
- So someone can start working with wind and start to develop the code to get the specific wind speed that’s applicable in Uganda.

Engineer Joshua Mubangizi and Bamboo Village Uganda January 27, 2020
Site Engineer: Joshua Mubangizi
Founder Bamboo Village Uganda: Henri Potze
Connection provided by: Eng. Joshua Mubangizi

Notes:

I met with Eng. Joshua, an old friend of mine with whom I studied at Makerere University. He was the engineer on-site for a construction project on 6th street industrial area. He told me about the construction he was supervising and I asked him a few questions. I later told him about my thesis and he introduced me to Bamboo Village Uganda. Before we went to Bamboo Village Uganda, I asked him about a recent mall that had collapsed in Jinja. Here was his response.

We Have 2 major problems in Uganda's construction projects;

1. **There's corruption**. Construction project inspectors from government who are supposed to ensure compliance with the approved designs are paid off about 500,000/= ($135.87) so that they do not come to inspect, and/or to keep quiet on some irregularities. This gives liberty to the contractor to do whatever they want to cut costs to make additional profits.

   Corruption also goes back to materials. For example, the drawings can specify using T25 Steel for an element on the project but the contractor may use T20 steel in an effort to cut costs and make more savings. This is especially done by contractors with less qualified personnel on site. Sometimes, they may use lower quality steel from a different manufacturer instead of using steel from a specified leading high-quality manufacturer, like Roofings Ltd.

2. **The second problem is the client**. Whereas there are some few clients who respect the work standards, some want good things but they do not have enough financial muscle. For example, to cut on costs, the client may instruct the engineer to use the concrete debris from demolition as backfill or hardcore. The Engineer may try to advise otherwise but the client will insist that it's their building and they can do whatever they want.

   Also, some contractors under-quote in order to get the contract. Once they get it, they have to cut costs to make a profit. Like where they specified 3 bars, the contractor may put two, or where they specify class 30 concrete, the contractor may use class 25.

Corruption and clients are the two main problems affecting construction in Uganda. The project I'm doing here is a design-build project. We designed it and now we're building it. So we have to do a good job to stay in business and avoid any problems.

After this, Joshua took me to his colleague's office where Bamboo Village is working from. Here, I met Henri Potze, the founder of Bamboo Village Uganda. He shared with me his mission to reduce carbon emissions by growing the necessary bamboo to supply the materials to build a bamboo village in Uganda. He has currently constructed a demonstration house in Mbale. It also serves as a house for a single mother and her family. He is looking to construct a bamboo village in Uganda that'll attract tourists and later on spread awareness. He hopes to have more people using bamboo to construct. One interesting thing to note was everything in the office/house was made from bamboo. From cups to chairs to beds. It was fascinating.

Local Works. Jan 28, 2020
Director: Felix Holland
Connection provided by: AWF Primary School project. I found the project then reached out to Felix Holland about scheduling an interview before I left for Uganda.
Notes:

<u>Karamoja Project</u>

- AWF Primary Schools in Karamoja. Used stone sourced on-site or around the site for foundations and plinth walls. For the rest of the walls, we used compressed earth blocks made on site.
- We did this with a general contractor, not a labor contractor. We spent $380 per square meter. This is little but to qualify for a low cost you need at most $100 per square meter
- Our focus is more on eco rather than the cost
- Eco is a very wide concept. Our idea of it is very basic. Our concept of green is to try and use as little technology as possible.
- There are so many ways of achieving a sustainable building. You can use technology or you can use some very basic techniques
- For example, you can orient a building towards the sun. If you have a long building and you align the length of it with the equator and you manage to keep those short sides relatively enclosed, and you keep the long sides relatively open, you will achieve a very comfortable building.
- You'll end up spending $1 on air conditioning as the sun doesn't enter or heat your building.
- Also, in many sites, the wind in Uganda tends to come from the South East. So ideally the cross ventilation is a very shallow long building
- These are very basic considerations of climate and orientation that cost nothing
- No maintenance, machinery, just considering the sun and wind can help you save a lot
- Not every site can allow this, however, it's extremely important to have this in mind
- Another interesting idea is planting trees and shrubs East and West and try to keep the level intense to prevent solar heating in the morning and evening
- Also, material consideration is super important. We are trying to minimize the use of imported materials both for cost and carbon footprint reasons.
- Although for some reason you can find out that products from China are cheaper than one found here which is very terrible.
- Sometimes you may find that an aluminum window from China is cheaper than a steel window from Uganda
- Our focus is more on the carbon footprint than the money so sometimes we may choose more expensive materials since we are looking at the local aspect of where the materials come from to reduce our carbon footprint

- I find it extremely important to do this site by site. In other words, there isn't one correct answer for Uganda. Every site and every region has its materials and we like to express that, play with that and to be inspired by that
- Like the project in Karamoja, Kidepo has this fabulous stone, it's a granite type of rock. The locals don't even see it.
- When we got there we were amazed by it and said that we must use this stone.
- Everybody told us that stone is very expensive, needs a lot of labor, and is hard to work with.
- But it ended up being a good solution for the foundation and the exposed part of the structure
- Also, Karamoja being so far away meant that any bag of cement we could avoid would be very cost-effective
- So with compressed earth blocks, only about 7% is cement. 93% is soil excavated on-site and sand. Sand from a riverbed close by in this case it was about 3km away
- We've used stabilized soil blocks that are made on-site with a hand press. It has challenges because you have to design the soil mix
- Each site has a different soil composition either more silty or clayey. You need to get the moisture content right and the compaction right.
- It's not a technology you can use without having a good site engineer and having good supervision.
- The workers on-site can manipulate the machine by loosening a screw to make it less work to compress the soil. But this ultimately affects the quality of the blocks
- You also need a good team that's dedicated to making quality bricks. They also need to cure for 4 weeks and store them undercover
- But once you overcome this, it's an amazing technology
- There are 2 types
    - The non-interlocking bricks which we've used. You need mortar for these blocks
    - The ISSB doesn't require mortar
- We haven't use the ISSB and we don't believe in it. It's usually called hydrafoam
- Hydrafoam is a company in South Africa that started making these blocks
- It has advantages in that the speed of construction is fast
- The reason why we don't use it is that
    - Our structural engineer isn't convinced that it has enough lateral strength when it comes to wind load or earthquake loads. It only has these little groves that they sit-in
    - I have architectural concerns. The corner solution and window solutions are terrible. At the corner, the grooves kind of protrude outwards. Most people plaster the corners.
    - In our projects, we rarely use plaster because we like to express the material we are using if it's brick or compressed earth, etc.
    - We do protect it from the rain using roofs and plinths but we like to show the material

- The 3rd reason I'm not convinced is that it is a bit of a high tech answer. It's inappropriate because mortar is a corrective medium that you use coarse by coarse until you hit the ring beam
- Hopefully, when you hit the ring beam, you're still horizontal
- In dry stack, there isn't any room for correction. In Uganda, we don't have laser tools to ensure that the blocks are straight over a long span like say 60m
- With an overall slightly bending coarse, this could lead to an offset of like 30mm at the door
- With mortar, this would've been corrected by adding more mortar where needed and less elsewhere to keep the blocks straight
- You'd always constantly come back
- The 4th problem is that there are sometimes gaps in ISSB and you can see the sun shining through the blocks
- So we've restricted ourselves to the non-interlocking 14:10 bricks

<u>Renzo Piano</u>

- Other Earth construction we've worked with is a project in Entebbe. This is a building by Renzo Piano. We were the local architects and the executive guys on the ground.
- This project is based on rammed earth. That is shuttering and then layer by layer, earth mixed with some stabilizer and then the soil is rammed with hydraulic tampers
- There's no steel in the wall. It's a pure gravity structure. There's a massive concrete raft under this entire building and in the long direction of the building, all three of the blocks have only these earth walls and they are 2 stories high.
- They support the slab. In the middle of the building, it is a composite slab steel and concrete. But there isn't another structure on the outer ends apart from that earth.
- For Renzo Piano, that's quite experimental because that's not quite what he usually does. And it's very exciting in that sense.
- What is beautiful about rammed earth is that you can read the layers of earth in which it is constructed
- It is by far the most expensive type of construction. It is very expensive. The formwork to design the rammed earth walls is expensive. Renzo also said that
- It also takes ages to build and is wildly difficult to make. You don't have any finishes and your formwork has to be perfect
- We want to do a project where we can do this ourselves but for your research purposes I wouldn't consider it

<u>Earth Bag Construction</u>

- It used to be very popular in the US in the '70s.
- We have a project ongoing in the construction phase called Mustard seed which is a little school which we are building ourselves. So we
- All the walls are made out of earthbags. These are woven plastic bags that they normally sell posho in. They are 50lb bags that we fill soil and sand inside them

- We then compact it and make it face on its side. We then tamper it by hand with a steel tamper.
- Each bag as you tamper it you make it rectangular about 450mm deep. You keep doing the next bag and then next till you make one coarse
- Between the courses, you place barbed wires. The same barbed wires used in fences
- The barbed wire pokes into the bags and gives them the required lateral strength
- We will finish it with stone and use earth lime plaster to finish it
- It is cheap but we have just started constructing it. We are interested to see how fast it will take. This will show us how cheap or expensive the technology is
- Material wise it's very cheap.

Wattle and daub

- Lastly, another earth-related technology that needs to be investigated or explored is a reinvention of wattle and daub
- The primary structure is out of gum poles or eucalyptus or bamboo grid across and then earth plaster to fill in the gaps
- This technology is amazing. It's entirely local. It's a wonderful invention. It's movable, lightweight, it has a very good indoor climate since it's all based on earth.
- It's also very easy to repair. You just need to take the same soil from the site and mix it with a little water and then re-plaster
- It has one very big disadvantage which one needs to resolve. Over time, that gum pole that provides the primary structure rots from below because it's directly sticking in the earth
- You can treat it but you won't be able to resolve the issue. You'd rather not use it in the first place
- What we are looking at is trying to get that primary timber structure out of the ground.
- Using stone is a good solution. It is a wonderful material when it comes to moisture and underground situations
- There must be a way of bringing the stone out a little bit and then having a horizontal member that is somehow tied into the foundation
- And then now you can fix vertical gum pole members on top and fill them in with plaster such that you have a meter above ground or at least 300mm above ground
- This is something that we are exploring because I believe that is the cheapest way to build
- There's a reason why wattle and daub has been used for many centuries. It is easy and cheap
- If you want to go into the low cost and green, I guess that you should look into wattle and daub

Changing the building code

- I wouldn't necessarily worry about the building code that we adopted for two reasons

    - One, you're doing research. Research is done to change mindsets and prove that things can be done otherwise
    - Two, Renzo Piano's hospital in Entebbe is using earth as a primary structural material. It's also a government project so 20% of it is paid by the government (the ministry of health)
    - At first, the government didn't know what material Renzo was using. So they got the ministry of works involved
    - The Ministry of Works wanted to ensure safety. So they proposed to do some tests and get the Bureau of Standards involved.
    - The system in Uganda is that where we don't have our standards, we use standards from elsewhere. That is the standard government policy.
    - If Uganda doesn't have standards on fire, we can just use the English ones or European or the US. You can use whatever you want.
    - We looked around and New Zealand and saw that they had well-developed standards for rammed earth. And that was the end of the story with standards for the project
- I think the reason why local materials aren't used is that there isn't any knowledge about them
- The local developer prefers steel, aluminum or glass because they believe it's long-lasting, beautiful, and modern.
- When you come with those techniques like wattle and daub, techniques used by their grandmothers, it just won't convince them
- I feel that's the real reason and not regulations
- One instance where you'd have problems is if you used grass-thatched roofing in the city. KCCA (Kampala City Council Authority) wouldn't allow it unless you get special permission.
- They are very scared of fire hazards

<u>Compacted Earth Floors</u>

- One very important aspect you need to look at if you're looking at costs is what floor you're using
- A lot of money generally goes into the substructure and the floor that you are using
- We are struggling with it. We haven't got the answer but there is a lot of knowledge of compacted earth floors
- For schools, hospitals, commercial buildings, I have my doubts that it could work. It won't last
- So we end up using concrete blocks which are expensive and not very green, however, they are long-lasting
- But for residential buildings, it could be explored
- There's this NGO you can look at, Earth Enable (https://www.earthenable.org/)
- They started in Rwanda and are now in Uganda
- You should look into it. You should also consider how low in cost you'll go

- When you go very low cost you can also accept a certain amount of temporary nature or that it won't last forever
- For roofs, you can't get away with iron sheet roofs. They are very cheap. Grass roofs are not cheap
- Metal roofs are hot and loud but you can't have it both ways
- It's cheap and lightweight
- If you want to reduce costs, you must think about weight. The heavier the material is, the more foundations you're going to put
- In some of our schools we build, we spend 20-25% of the money we put underground and no one sees it
- If you put these heavy brick walls or earth walls you just need a lot of material to distribute the load
- Whereas this wattle and daub where you just use a timber frame and plaster infill is a far lighter way of working so the foundations would be lighter

Tile vaulting

- We have done some vaulting but not the beautiful kind of vaulting as Peter Rich did in South Africa at the Mapungubwe National Park or the cricket stadium in Kigali which is made of earth tiles
- The tiles are the same technology as our stabilized soil blocks but they are ultra-thin about 30mm and they use 3 layers of it
- The amazing thing about these walls is that because the use the catenary arch shape, it's the most ideal shape you can have
- They don't need any shuttering
- Is it a technology for mass production and roll-out, I'm not sure.
- I've also heard that the original one that Peter Rich did has cracks all over it. This was the one at the Mapungubwe National Park
- It has cracks because it's not fully a catenary arch
- The buildings themselves have the perfect catenary shape but then the openings are semicircles.
- The opening at the edges is a semi-circular, not a catenary shape so this induced bending moments and thus cracks
- In Kigali, they learned from this so everything is a catenary
- We are currently a vaulted building out of brick. But we are using reinforced brickwork.
- So there's steel in the brick and a bit of concrete to fill the gaps so it's not as good as the ones Peter Rich did

Roof

- The roof is also very much dependent on where you are and the climate. The decision comes down to the sun and the rain
- In Uganda, we deal with enormous amounts of rain. The Mapungubwe National Park is located in a semi-arid or desert area that receives very little rain

- They put some stone finish on top with some waterproofing
- In Uganda, it's about big roofs, overhang and protects the walls from rain. We want to get that rain of the building as fast as possible
- This is more of a desert architecture so I'm not convinced that what was done in The Mapungubwe National Park can work in Uganda
- The one in Rwanda is a roof over a terrace. You can do that. But for a building, the walls set in. The whole fun about a dome shape is that the roof and the walls are the same
- We had a project, the Nile Safari Lodge, where we played with the roof and the walls being the same thing.
- But it's not a low cost. The cost per square meter was $1,135 excluding value-added tax and it has a total area of 2,230m^2 Vaults are complicated but interesting

Shaped Slabs

- It could work but what is not developed here in Uganda is the whole concept of prefabrication
- But that's a bit high tech. To do this you need a fabrication yard, cranes to set in place.
- But it is something to look into as you look at mass production of low-cost housing units or large commercial buildings. There must be an element of prefabrication
- In fact, in the '60s there was a very high standard of prefabrication in Uganda.
- There were many Italians who specialized in that. Pre-stressed concrete, lightweight waffle slabs
- Some residential houses in the Kisugu area towards Muyenga, I've seen amazing houses made from curved or vaulted prefab elements that are sort of spanning 15m
- They did this in the 60s so I don't know why we can't do this today
- Maybe there's not enough innovation or demand for it
- Void filler slabs are done in Kajjansi in Uganda. A void filler made out of clay and you can run your steel through it and cast concrete. But that's not prefab, you still need to do a complete shuttering
- For prefab, you don't need shuttering which uses a lot of timber and costs a lot
- I think there's some room for that
- It would be interesting if you could do some prefab with the earth. There's a lot of research going on in other countries where people try that
- Lightweight earth panels both for internal and external walls

Straw Panels

- There's an interesting company here in Rwanda and I think Uganda where a German guy uses straw. They started in Rwanda.
- It's called StrawTec. The panels are 60mm thick and
- They essential use rice straw in Uganda which is a free material and heat it to 200 degrees and then they press it. They put cardboard one either side
- In Rwanda, they use wheat straw which isn't very common in Uganda

- We have a sample and we are very excited to test it out. The ones made in Uganda are not strong enough yet. But the company just started here so it's still developing
- You can use it for inside partitioning, so it can replace gypsum or plasterboard for office partitions
- It has good acoustic properties because of its lightweight and porous
- But you can even use it in double layers structurally load-bearing. He claims you could use it to make the ground floor and even one above it without anything so that's interesting
- We haven't used it yet though
- But it's interesting. You can prefab the panels then bring them on-site and screw them together
- It's lightweight so you don't need any foundations. You can just use a slab a thickened edge slab

Appendix B: Site Visit Photo Gallery

This section presents several photos from each interview site visited, as well as miscellaneous photos of construction in and around Kampala, Uganda.

Site 1:- Makerere University

The first site I visited, the Makerere Guest House restaurant constructed with bamboo. *Photo: Herbert Nuwagaba*

These photos show the interior of the bamboo restaurant. The structure is supported by bamboo columns. The restaurant has burned bricks as infill for the walls and clay tiling for the roof.
Photo: Herbert Nuwagaba

These photos show the famous bamboo demonstration located at the Makerere University College of Engineering Design Art and Technology. The demo project was to convince the public that bamboo is a good and durable material. The material was donated by International Network for Bamboo and Rattan. The project cost about $20,000 to construct. *Photo: Herbert Nuwagaba*

Site 2:- Yamasen Japanese Restaurant

These photos show Yamasen Japanese Restaurant located in Muyenga. This restaurant was designed by Ikko Kobayashi from Terrain Architects in Japan. It is a multipurpose building constructed with eucalyptus. Dream Architects were the local supervising architects on the project. *Photo: Herbert Nuwagaba*

Site 3:- Haileybury Youth Trust Project 1

These photos show one of the projects done by the Haileybury Youth Trust. It is a 2 classroom block building made by dry stacking interlocking stabilized bricks. This building was built by one person from HYT and two men and two women from the community to pass on the skills to them. It cost about $10,800 to construct this structure. *Photo: Herbert Nuwagaba*

Mortar was only used on the corners as seen above. A 20,000L tank was also constructed using ISSBs near the school. Mortar was used in the tank’s construction to seal it off. To prevent leakage. *Photo: Herbert Nuwagaba*

Site 4:- Haileybury Youth Trust Project 2 (Kawolo Church of Uganda Primary School)

These photos show one of the projects done by the Haileybury Youth Trust. This site is older than the first one I visited. The total cost of the project was $16,860. More details about this project can be found in the case study section of the thesis. *Photo: Herbert Nuwagaba*

Site 5:- A Commercial Building Project

This construction site was being supervised by Engineer Joshua Mubangizi, the Chief Building Engineer from COEF Limited. It is located on 6th street industrial area in Kampala. Due to the size of the project, they are utilizing reinforced concrete construction for this project. *Photo: Herbert Nuwagaba*

Site 6:- Bamboo Village Uganda

Engineer Joshua Mubangizi introduced me to, Henri Potze, the founder of Bamboo Village Uganda. Everything in their office is made of bamboo. *Photo: Herbert Nuwagaba*

Henri Potze shared with me the pictures of the demonstration bamboo house that he constructed in Mbale, Uganda. The house also serves as a home for a family in Mbale. He hopes that this project will convince more people to build with bamboo. Henri also plans to design and build a bamboo village resort to attract tourists. *Photo: Henri Potze, Bamboo Village Uganda.*

Site 7:- Mount Vernon School, Maya

Mount Vernon School – Maya is a local secondary school that serves the community around it. The school is currently expanding as the number of students is increasing. They are currently adding a third floor to the school. *Photo: Herbert Nuwagaba*

The school is a reinforced concrete frame with a burned brick infill between the concrete columns. *Photo: Herbert Nuwagaba*

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