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Design of a Building to Address Informal Housing in Lusaka, Zambia

I. Introduction

Lusaka, the capital city of Zambia, is in a housing crisis. The Lusaka City Council Department approached us to design a building to resettle families currently living in Lusaka's informal settlements, which make up 90% of housing in Lusaka due to the fact that 80% of urban residents are below the poverty line (World Bank AFTU, 2002). Zambia, one of the most urbanized countries in Africa, has a population of 2.5 million and is rapidly growing by 3.6% yearly (Zambia Data Portal, 2015). As shown in Figure 1, by 2030, the total population is expected to surpass 5 million, exacerbating already poor living conditions.

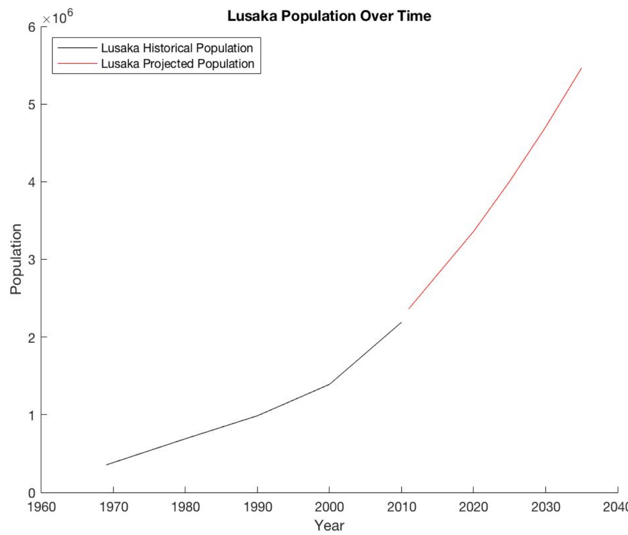


Figure 1. Lusaka population from 1960 to 2040. Black is collected data, red is predicted population growth.

Issues such as rampant malaria and cholera and unsafe, unsustainable building design indicate that these residents need more adequate housing (World Bank AFTU, 2002). Accounting for others affected, like farmers, small businesses, and foreign investors, as will be elaborated on later, this project alleviates some of the issues residents face by providing a model for a safe, affordable housing design for low-income residents that combats disease and improves quality of life with a minimal environmental footprint.

II. Challenges

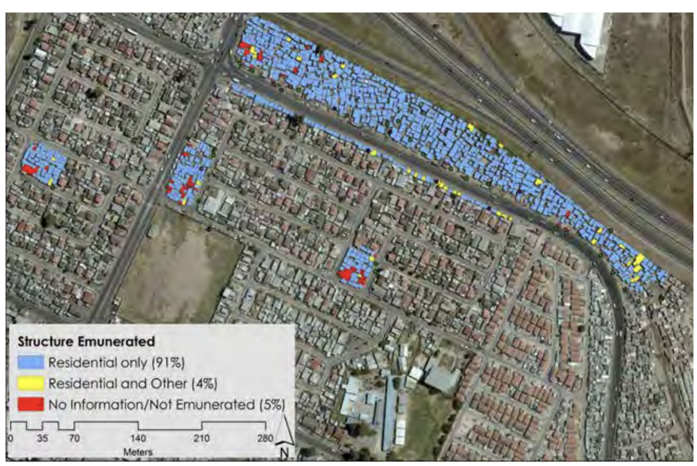


Figure 2. One of the largest informal settlements in Lusaka (CORC, 2016).

Most informal settlements are densely packed on the outskirts of Lusaka, as shown in Figure 2. A lack of on-site sanitation and protection from insect-borne disease, as well as unstable living conditions, are pressing issues for informal settlement residents (WSUP, 2018). Therefore, this building should prioritize health, comfort, and environmental design so that families move voluntarily, while also being realistic and sustainable for the city government to build. Inconsistent electricity and lack of access to formal plumbing constrain designs. Electricity in Lusaka is mostly derived from hydroelectric power, dependent on rainfall and water levels, and currently formal plumbing is mostly unavailable. A 2018 report shows that the Lusaka Water and Sewerage Company (LWSC) will connect only 33,000 more residents to formal plumbing (WSUP, 2018).

In these settlements, lack of running water and poor sanitation practices contribute to diseases like cholera and dysentery (World Bank AFTU, 2002). These diseases, caused by an exposure to bacteria-ridden fecal matter, impact children most significantly, and an outbreak in October 2017 saw 5,900 cases of cholera (CDC, 2018). Commonly used pit latrines are infrequently emptied and often close to overflowing, leading to contamination of the water table as waste seeps down. Only 10-20% of the city is currently connected to sewage services (WSUP, 2018), so to protect the vast majority of the population from disease and improve living conditions, the design must provide access to safe, healthful, on-site sanitation for each resident. Additionally, the proposed plan for sanitation must be affordable for tenants, especially since sanitation is often associated with high initial and maintenance costs.

Another large contributor to poor health in Lusaka is exposure to malaria and other insect-borne vectors. Because informal housing is typically made of cheap, readily available materials, this often does not include protection against mosquitoes and other dangerous insects. As a result, residents suffer from more exposure to malaria, sleeping sickness, schistosomiasis and other diseases. Over 16 million people in Zambia are at risk of contracting malaria (NMEC, 2019), so in efforts to drive down insect disease incidence, improved sanitation techniques and insect protocols are integral to the project.

Cooling of the home presents both a health and comfort challenge in informal settlements. Cooling is a problem as Lusaka is located close to the equator and as a result the city experiences warm and humid weather during the day year round. The average daily high temperature year round is 81.3°F coupled with an average humidity of 72.6% (NOAA, 2012). Furthermore, most of the small tenements are occupied by families of five, which increases interior temperatures (Central Statistical Office of Zambia, 2015). Untreated, the hot and humid temperature conditions put tenants at risk of dehydration, fatigue, and heat stress. In addition, the constant warm and humid environment inside the homes are the perfect breeding ground for insect-borne diseases.

The majority of formalized buildings in Lusaka are built using concrete blocks, which can be cost-prohibitive since cement, the key binding agent, must be imported (World Bank AFTU, 2002). For this reason, over 69% of the urban poor around Lusaka build their own residences using clay blocks, the method of vernacular architecture of the region (Mwango, 2005), thus creating a negative association of earth houses with poverty (Baiche, Osmani, Hadjri, & Chifunda, 2008). Moreover, due to the informal nature of these compressed earth blocks, their production is not standardized, so they are not authorized for official use by the city building codes. Therefore, most of the buildings in the informal communities are illegal under the current regulations but are also the only option to those who cannot afford standard, imported building materials. These are obstacles that can be dealt with through the formalization of earth construction by the government.

In addressing these challenges, because affordability is an important factor, residents' rent may not completely offset initial costs, though the design's simplicity enables some irregular maintenance to be covered by it. In terms of regular maintenance, investments have direct economic output due to the involvement of private water trusts and the LWSC. Construction and maintenance inevitably require government capital at first. But the investments' positive impacts on the population of Lusaka are immeasurable. Although the value of human capital is difficult to quantify, there are tremendous benefits of increasing the dependability and lifetime of a country's work-force, and a well-founded trajectory for success and development attracts local entrepreneurs and foreign investors alike. As the cost-effective elements discussed below promote residents' health and improve daily life, a positive feedback loop of a longer-lived, more productive work-force and increasing ability to pay rent justifies initial investment, which will help catapult Zambia on a path towards equitable and profitable development.

III. Our Proposal

Figure 3. Render of final building design.

This design is a 5-story, 18-family (90-person) housing complex. Figure 3 depicts the front face of the building, which is composed of compressed stabilized earth blocks (CSEBs), provides safe and healthy sanitation, and regulates temperature. While the building houses 90 tenants due to considerations of typical family size and cost, the design is intended as a model for safety and comfort that can be implemented throughout Lusaka, thereby reducing the sprawl of informal settlements by relocating people to a multistory structure. It provides a framework for building housing with off-grid sanitation for low-income residents; however, it also has preemptive plumbing lines for future housing built with access to the city's sewerage services. In creating such a building, farmers on the city's outskirts may be affected as land is reallocated, but the stability and healthful living conditions provided by the building support the overall health and quality of life of the work-force. Thus, local businesses, in addition to foreign investors, may be enticed by the opportunities that formal housing presents financially and for the work-force.

One of our solutions regarding health, insect deterrence, consists of a three-pronged approach. Screens will be installed in the windows, and wall paint will be light or neutral in color, as bright and dark colors attract tsetse flies (IAMAT, 2019). The third and major safeguard is providing 3 two-person, long-lasting insecticide treated nets (LLINs) as part of rent for each unit. Since LLINs can last for at least 3 years, they will be replaced every 3 years to ensure that residents are properly protected (CDC, 2019b). To reduce insect resistance, the LLINs will be retreated with alternating classes of pesticides (pyrroles and pyrethroids) at the end of each year, and will be wrapped around beds, as these insects are most active at night. LLINs were chosen over indoor residual spraying (IRS) since IRS does not target insects at night, and releases environmentally-damaging airborne toxins (CDC, 2019a). Traditional LLINs cost only $21 per unit and $378 total per building (Ntuku, 2017), and LLINs will be polypropylene or polyethylene until more sustainable materials, such as bioplastics, are cost-effective. Overall, LLINs are concentrated, environmentally-friendly sources of bug deterrence that effectively eliminate dangerous insects at night. By distributing these, especially in such high concentration in one complex, this cheap solution can provide extremely effective bug resistance.

To address sanitation issues, dry toilets will be implemented to avoid creating standing water, which promotes harmful insect populations. Nairobi-based MIT startup Sanergy was used as a model for the type of dry toilet installation and processing (Engineering for Change, 2019). The LWSC already has expanding programs that transport fecal sludge to external processing locations, including Kanyama, which is only 30 minutes away from Lusaka (WSUP, 2018). An important extension is to follow Sanergy's model of generating animal feedstock and crop fertilizer from the waste so that the Water Trusts in charge of this service can afford and even profit from waste transportation costs, in addition to providing jobs through the pickup service, processing, and promoting farmers' success. These dry toilets have a 3'x5' footprint and can be used 120 times before their cartridges need to be emptied; as illustrated by Equation 1, 4 toilets are necessary for the complex, which will only cost $1,200 total, as shown in Equation 2. To ensure that all toilets are evenly filled, 3 to 4 residential units will be assigned to each dry toilet.

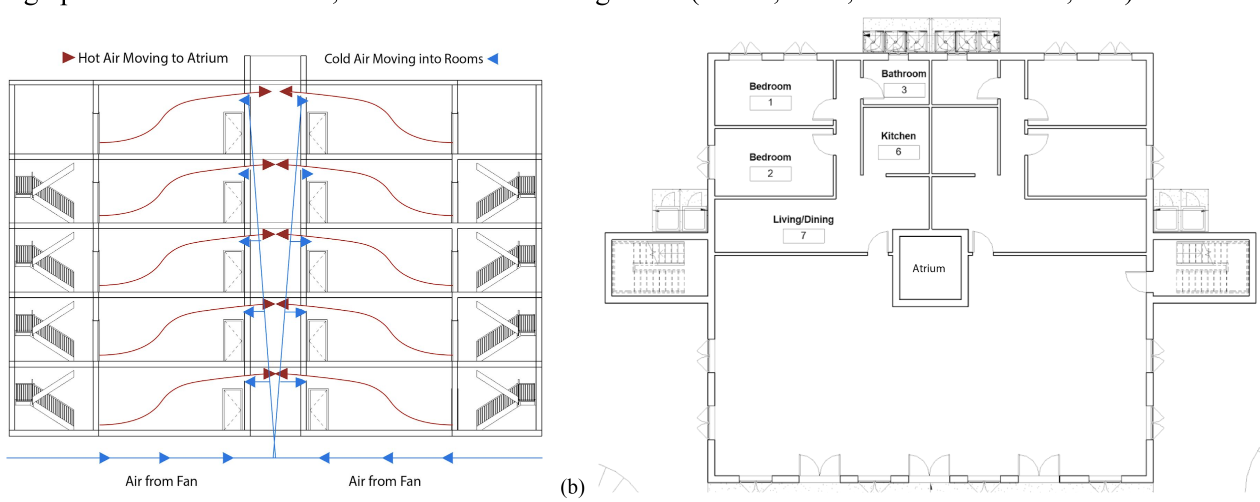
$$\text{Total number of toilets per building: } \frac{4\ total\ toilets}{building} \approx 90 \text{ residents} * \frac{5\ uses}{day} \text{ / 120 uses before emptying} \quad (1)$$

$$\text{Total cost per building: } \frac{\$1200}{building} = \left(\frac{\$250}{toilet} + \frac{\$50}{permanent\ membrane}\right) * 4\ (toilet + membranous\ cartridges) \quad (2)$$

Cartridges will be composed of a polymer membrane that promotes evaporation of clean water from the waste, allowing for waste pickup every three days instead of daily, reducing transportation, labor, and material costs. The removal could happen even less often based on Change: Waterless toilet's model (Engineering for Change, 2019b), but more regular removal would limit odors. 20-30L waste-filled cartridges are easily removed by trained personnel from the dry toilets. Sanergy's estimated lifetime for each dry toilet is 5-6 years, so these can be replaced every 6 years. Sanergy uses a $588 charge for installation and daily collection for a year per toilet (Engineering for Change, 2019a), so by increasing the scale of the pickup through many housing complexes and decreasing frequency of pickups, these toilets should be cost-effective and may even provide wide profit margins for the Water Trusts who can process waste into animal feedstock and fertilizer, thus stimulating the local and national economy through services and farming.

To enable residents to bathe without contaminating the environment, residents will carry water to bathing areas outside of the complex. These areas will be composed of a 4'x4' grated panel over a flat basin connected to a PVC drain pipe that can disperse water underground away from the complex. It will be lockable for safety and will have rooftop solar paneling, costing $250 (Solar Africa Shop, 2018), to power UV lights under the flooring to neutralize small amounts of urine. Magnesium sulfate (epsom salt) filters will remove detergents before the water is released into the ground and will be periodically refilled by the Water Trusts during sewage pickups. The 3 shower areas for the first year would cost $5130, and with an estimated 4L of water per shower every two days, epsom salt would cost about $4,380 yearly after that (an overestimate based on 10 oz/$1). Although this may seem costly, a $1.9 million investment in Michigan, U.S., for instance, would provide a year's operation of a waste treatment plant servicing roughly 25,000 people (Big Fish Environmental, 2019; National League of Cities, 2019). In contrast, that same investment in our shower/dry toilet solution would service about 32,000 people (with costs of about $5200/year for 90 people), demonstrating that our solution costs are comparable to or beat average water treatment costs in the U.S, without as much costly initial investment. Moreover, bathing access improves the quality of life and ensures that contaminated water is not released into the environment. As mentioned before, the LWSC will only connect a limited number of residents to plumbing lines in the near future, so the house was designed with the capabilities for indoor plumbing to enable connections to external sewerage systems at a later date.

Stacked cooling, a form of passive cooling, was selected to cool the building because it is cost effective, efficient, and can work with or without electricity since it cools through natural physics of hot air rising. This method of cooling meets the goal of keeping the temperatures safe in the building because it can cool the building to room temperature (70°F) year round (Boardman, 2005).The building has a large atrium, seen in that is opened all the way to the roof, as seen in Figures 3 and 5b. Vents will be placed in a zigzag going up the atrium to the roof, as shown below in Figure 4a (Ismail, 2012; Stack Ventilation, n.d.).



(a) (b)

Figure 4. Stack cooling utilizes heat's natural tendency to rise with (a) zigzagged vents and (b) an atrium and chimney.

This design and vent location strategy will promote the hot air in the building to rise up the atrium and out chimney on the roof of the building, while cool air will be let in through vents on the ground level and pushed up the atrium with industrial sized fans powered by the Lusaka city powergrid, as shown in Figure 4. Solar energy was considered as it is a renewable source of energy that could provide long-term, reliable electricity for the building. However, it was not feasible as the panels themselves, excluding shipping, installation, and maintenance, would cost $55,080/m^2 (Solar Africa Shop, 2018), over 250 times the Lusaka average household income of $219.90 (Central Statistical Office of Zambia, 2015).

There is no additional cost to incorporate the passive cooling, in regards to design, but there are two fans at the bottom that will cost around $7,800 each. Although the cost of the fans seems high, passive cooling can reduce building energy usage by as much as 90% compared to HVAC air conditioning. Thus the initial cost of the fans would be worth the long-term cost-savings (Collins, 2012). To further increase energy efficiency, the fans can be turned off during colder seasons, reducing the rate at which warm air escape the building, thus increasing the temperature in the building (Gupta, Neha, and Gopal, 2016).

Before picking a passive cooling system, multiple forms of cooling were discussed, the second most likely option being air conditioning (HVAC) system. An HVAC system was deemed unfeasible because of the constraints of price and power reliability in the country. HVAC systems can cost upwards of $20/ft^2, meaning cooling the proposed building with HVAC would cost well over $100,000, which isn't feasible for budget housing (Hullebusch, 2019). Furthermore, as mentioned earlier, the main source of power in Lusaka is hydroelectric, and at times it can be inconsistent; thus passive cooling was a better alternative because while AC does not work without power, the passive cooling without the fans would only increase the inside temperature to around 75°F, which is still safe (Boardman, 2005).

Compressed Stabilized Earth Blocks (CSEBs) will be used as the building material as they are more cost-effective and sustainable than concrete blocks, the predominant material for large-scale structures in Lusaka. Using CSEBs with 5% cement stabilization, the unreinforced masonry of the walls costs around $235,000, 35% less than it would using concrete blocks (Mwango, 2005). Additionally, CSEBs emit 5.5 times less CO_2 and require 10 times less energy than concrete. Since Zambian soil is high in sand, cement is the better stabilizer, allowing the CSEBs to have a wet crushing strength of over 2 MPa, the minimum necessary strength to build with (Auroville Earth Institute, n.d.). However, since unreinforced masonry cannot undergo bending, concrete slabs will be used for each floor. Overall, since CSEBs are made using local material, they are inexpensive and sustainable, and their fabrication can provide jobs for local unskilled laborers.

IV. Conclusion

Informal settlements are a major issue in Lusaka, but by designing a building that is environmentally, socially, and economically feasible, we hope to begin the path to a sustainable solution. Our design goes above and beyond the constraints provided by the Lusaka City Council by addressing not only the top two priorities of current residents of Lusaka's informal settlements — formal housing and toilets — but also others that we found to be important to the long-term success of the project and the development of Lusaka as a whole. We addressed health concerns with long-lasting insecticidal nets (LLINs), light wall colors, and dry toilets, comfort through stacked cooling and showers, and sustainability through Compressed Stabilized Earth Blocks (CSEBs). In the long term, our design provides a formalized, permanent residence for low-income inhabitants of Lusaka that improves their quality of living in regards to insect protection, waste removal, and air circulation. The construction and maintenance of the building fosters the local economy by providing jobs for unskilled workers to manufacture the CSEBs and collect waste. In addition, the waste can be processed as fertilizer to aid agriculture. Overall, we see this design as the ideal solution to informal housing in Lusaka.

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