Tampere University of Applied Sciences

# Designing a vacation home in Same, Tanzania

Monica Mjema

BACHELOR'S THESIS

November 2020

Degree Programme in Construction Architecture

**TIIVISTELMÄ**

Tampereen ammattikorkeakoulu
Rakennusarkkitehdin tutkinto-ohjelma

MONICA MJEMA:
Designing a vacation home in Same, Tanzania

Opinnäytetyö 74 sivua, liitteet 5 sivua
Marraskuu 2020

---

Opinnäytetyön tarkoituksena oli suunnitella loma-asunto Sameen,Tansaniaan. Kirjallisuustutkimus keskittyi Sameen ja Tansanian rakennuslainsäädäntöön. Havainnointi paikan päällä suoritettiin joulukuussa 2018. Piirustukset ja visualisoinnit tehtiin Archicad-22 ohjelman avulla.

Satunnaisten vesi- ja sähkökatkojen vuoksi, talon piti olla toimiva ilman kunnallista vettä ja sähköä, jonka lisäksi talon piti suojata asukkaita lämmöltä, tuulelta ja maaperän eroosiosta johtuvasta pölystä. Kokonaisuuden suunnittelussa oli tärkeää, että talo sopi Samen maisemakuvaan. Passiivinen jäähdytys oli tärkeä osa suunnitteluprosessissa, jota käytettiin rakennuksen suunnan, rakennusmateriaalien ja rakennetyyppien valinnassa. Rakennusmateriaalien valinnassa suosittiin paikallisia, ympäristöystävällisiä ja kehittyneitä perinteisiä materiaaleja. Suunnitelman bruttoala on 202 $m^2$ ja rakennus täyttäisi 11% tontin pinta-alasta. Se koostui kahdesta siivestä, joiden välissä oli patio. Tällainen ratkaisu paransi ilmanvaihtoa ja lisäsi päivänvaloa rakennukseen. Hulevesi- ja jätehuoltosuunnitelmat lisäsivät talon riippumattomuutta kunnallisesta vesijohtoverkostosta.

Opinnäytetyö on vasta talon alustava suunnitelma. Ennen rakentamisen aloittamista on tutkittava tarkemmin maaperää ja pohjaveden syvyyttä. Asukkaiden elintavoilla ja talon säännöllisellä huollolla on merkittävä vaikutus talon kestävyyteen ja ympäristökuormituksen vähentämiseen.

---



Asiasanat: loma-asunto, kestävä kehitys, maa-ainekset

**ABSTRACT**

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Degree Programme in Construction Architecture

MONICA MJEMA:
Designing a vacation home in Same, Tanzania

Bachelor's thesis 74 pages, appendices 5 pages
November 2020

---

The purpose of this thesis was to design a vacation house in Same, Tanzania. The house had to be able to function off-grid when needed, and tackle heat, dust, wind and soil erosion while simultaneously fitting into the arid landscape of Same. Literature research was done to obtain information on Same and on the building legislation of Tanzania. On-site observation was made in December 2018, and drawings and visualisations were made using Archicad version 22.

Passive cooling was an important factor in the design process and it was applied in choosing the building orientation, construction materials and structure types. The embodied energy as well as ease of access were considered in the suggested building materials. The use of improved traditional materials and techniques was encouraged. The final design had a total area of 202m$^2$, which was 11% of the 1800m$^2$ plot. The design was made of two wings with a patio in the centre, a shape that promoted better cross ventilation and daylight throughout the building. Adequate rainwater and waste management further aided in making the building off-grid.

This thesis functions as a preliminary plan for the house, and tests to determine soil type and groundwater depth should be done before construction. Sustainable user behaviour and regular maintenance is essential for the building to function off-grid for a long time. Proper maintenance will make it possible to examine long-erm sustainability of the building in the future.

---

Keywords: green architecture, sustainability, compressed earth blocks, earthen materials

**CONTENTS**

# 1 INTRODUCTION

The challenges in constructing a building in Tanzania are like the challenges many developing countries face. There is limited infrastructure when it comes to providing amenities such as water, sewage, electricity and waste disposal, and in many cases the ability to obtain said amenities are largely dependable on one's socio-economic status. There is also limited access to different building materials and builders' skills vary drastically. The construction of family homes is also not strictly monitored by city councils.

Traditionally building with earthen materials, such as mud and soil, has been popular in Tanzania, but over past few decades its popularity has been diminishing. Buildings made from earthen materials have a lot of benefits, such as being environmentally friendly, recyclable and having better indoor thermal comfort. A disadvantage of earthen construction materials is the materials' inevitable degradation from environmental elements and their need to be regularly repaired. (Adegun & Adedeji 2017) Improved earthen materials which incorporate new technology with earthen materials exist, but the government should increase the promotion and the research and the use of these materials. little is done by the government to promote the use of improved earthen materials.

The purpose of this thesis is to design a semi off-grid vacation house in the small town of Same, located in the Kilimanjaro region of north-eastern Tanzania. The building should shelter its occupants from the environmental elements that of Same – heat, dust, wind and soil erosion - as well as fit in to the genius loci of the town. Even though the plot will be connected to municipal water supply and electricity, it should be able to function off-grid when needed. To support self-reliance, building materials, energy sources, building orientation and the type of rainwater management should be chosen with consideration to their sustainability.

## 2 AIM OF THE THESIS

The aim of this thesis is to design a vacation house in the small town of Same, located in the Kilimanjaro region of north-eastern Tanzania. The house should be able to function off-grid when needed. The clients are a couple from Tanzania who have lived in Finland for 29 years. The aim is to construct a house in the newly developed Sterling neighbourhood of Same. The owners of the plot have requested that the plot have an area for car storage, gardening, socialising and living. 3-4 bedrooms is preferred.

The most important task of the building is to keep its occupants protected from the elements. Locally, this means keeping the occupants cool and dry, as well as protected from winds and dust, and the occasional rain.

The house to be as energy efficient and self-reliant as feasibly possible. To support this, the types of building materials, building methods, orientation and energy sources should be chosen with consideration to their sustainability. Efficient rainwater management, efficient land usage and natural ventilation also support self-reliance.

The building should fit in the natural and built environments of Same. Local materials and local plants will be favoured in the house and the rest of the plot. The building should not only fit in with the surrounding built environment, but also, as much as possible, incorporate traditional local building culture.

Due to a lack of access to education, the know-how of construction and building is limited in smaller towns of Tanzania. Municipal councils are responsible for registering building permits, but the responsibility of ensuring safe building practices lies mostly on the owner of the plot. Due to this, when designing and constructing a house, lay people tend to not experiment on new building techniques or materials, but rather stick to tried and tested methods that local civil engineers and builders are used to. This is why throughout Tanzania, homes tend to be very similar – a typical family home is a one story, load bearing masonry house built from concrete bricks, with a hip and valley roof. Designing a house very different from this type of house, especially structurally different, could prove to be difficult to find the know-how in building it. Hence the structure has to remain relatively simple and it cannot be too expensive to construct. The materials should also be easily accessible, and the distance they are brought from should not be too long.

### 2.1. Methods

Literature research was done to obtain background information on the geography, geology, building customs and building history of Tanzania, as well as the microclimate of the plot. The JJPRO EPIK Drone was used to take aerial photographs of the plot on December 22nd and 23rd of 2018 (picture 1). On-site observation was made on the microclimate of the plot, as well as on the local built environment. Archicad version 22 was used for drawings and visualisations.


PICTURE 1. JJPRO EPIK drone. (Mjema 2018)

# 3 CONSTRUCTION IN TANZANIA

## 3.1. Building legislation

The housing sector in Tanzania falls under the Ministry of Lands, Housing and Human Settlements. Public sector activities are largely undertaken by the National Housing Corporation (NHC), Watumishi Housing Company (WHC) and the Tanzania Building Agency (TBA). They develop housing for mostly civil servants and realize large scale public building projects such as schools, universities and ministry buildings. (Makenya 2018)

Most family houses in both rural and urban areas are built privately by individuals. They either build the houses on their own or contract the services of private construction companies for e.g. erection of walls or roofing. Rural homes constitute the vast majority of buildings constructed in Tanzania. (Makenya 2018)

A building permit is required to construct a building in Tanzania. Building permits are handed out by city councils overseen by the Ministry of Lands. In order to obtain a building permit, all necessary drawings must be submitted along with the required fees.

According to the World Bank's Doing Business report (2020) where the process of building a warehouse was researched, it could take contractors and developers in Dar es Salaam up to 184 days to go through all the 24 procedures required, which is higher than the average of 145 days in sub-Saharan African countries (appendix 1). The report claims that extensive bureaucratic processes in obtaining building permits makes the process of building new non-residential and residential buildings difficult, which makes it difficult to meet growing housing demands. This is particularly true in larger cities and it is not uncommon for locals to begin construction before acquiring a permit. Due to bureaucracy, necessity and poverty, illegal construction on government owned or unclassified land is common in large cities. (Sanga 2017; World Bank 2018)

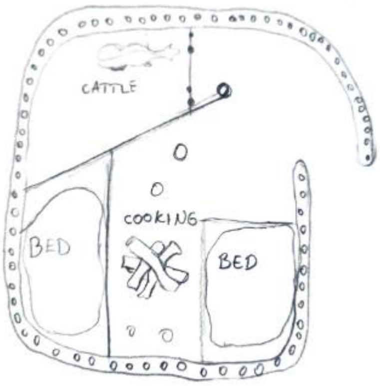
Public or private buildings higher than two storeys must be realized by contractors listed with the Contractors Registration Board (NRB). Contractors are classed from class I to VII, according to their skills and capabilities. The NRB monitors the contractors´ capacities, offers capacity building and other support with the aim to ensure quality in the construction sector and compliance with Tanzanian construction guidelines. (Makenya 2018)

### 3.2. Building heritage

Since the population of Tanzania has historically been an assembly of different tribes and peoples, there has not been a uniform Tanzanian house type, but rather different tribes have had different solutions for shelter. The layout of the house and the materials it was made from depended greatly on the culture and values of the people inhabiting it, as well as the surrounding environment. Land for building and farming was generally communally owned but given to extended family members by consensus or by elders. Building materials were locally sourced, and often house construction was a communal endeavour. Agriculture and animal husbandry were and still are an important factor in people's everyday livess, and often traditional houses reflected this, with spaces dedicated for animal keeping and the storing of tools. Houses were also constructed in the vicinity of family fields. (Elleh 1997)

A lot of everyday activities, such as cooking, laundry and socialising, took place outdoors and the need to retreat indoors was occasional. This outdoor way of life can be observed in many layouts of traditional homes. For example, the Gogo people of central Tanzania have an open pen in the middle of a family home for keeping their animals and cooking. (picture 4) (Elleh 1997)

The pastoral Maasai tribe, which lives in the highlands bordering Kenya and Tanzania, have a separate area in their home or compound to keep small animals such as goats or a few cows (picture 2). Maasai houses are made from mud, stick, grass and cow dung. The Maasai live in enclosed communities known as kraals with high acacia fences for protection from the wildlife (picture 3). Since animals are such a crucial part of the Maasai culture, animals are brought into the central kraal at night.



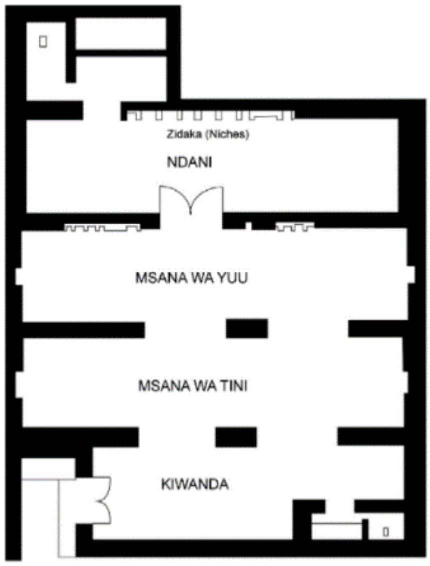


PICTURE 2. Plan of a typical Maasai house
PICTURE 3. Layout of a Maasai community.

PICTURE 4. Traditional Gogo house (Elleh 1997)

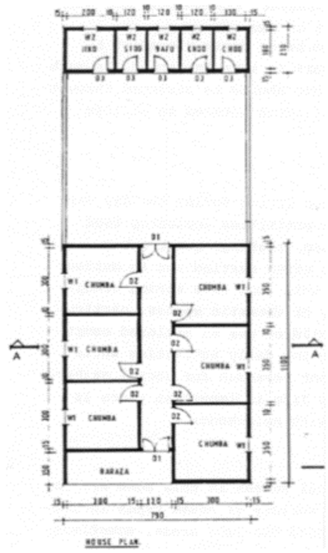
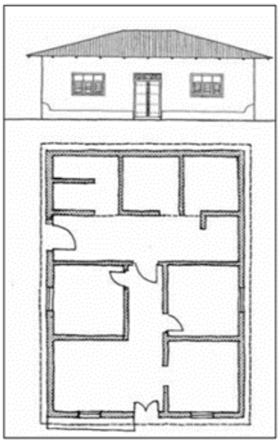
### 3.2.1 The Swahili house

As Swahili culture bloomed in the East African coast in the 14$^{th}$ century, so did the traditional Swahili house (picture 5). Swahili houses in the coast were traditionally built by stone. There was no corridor, but each interior space had to be accessed through the last as one travelled deeper into the house. The back room, or *ndani*, was the most private space and was mostly associated with women and female seclusion. (Sanga 2017)




PICTURE 5. Idealised layout of the 14th century Swahili stone house from Lamu. (Wynne-Jones 2013)

By the end of the nineteenth century, Swahili houses had made their way further into the mainland, and with time, modifications were added (picture 7). Swahili houses in rural areas were generally made from sticks and mud and had thatched roofs. Households with higher incomes built the houses with cement walls and corrugated iron roofs. The traditional Swahili house came to feature a central corridor from where rooms are accessed. The corridor leads to the courtyard, where the shared kitchen, showers and toilets are (picture 6). One enters the house from a front veranda. Variations of the Swahili house exist, but the common feature is the central corridor and increasing privacy as one travels through it. Because of their functionality, Swahili houses' facades tend to be symmetrical and unornamental, and they often have simple, gable roofs. Swahili houses are common especially in cities, although they are found in rural areas as well. Because the kitchen and latrine are situated in an outdoor courtyard, these houses tend to be off-grid. This is especially true when cooking is done using stoves fuelled by wood or charcoal. Less than half of Tanzanian households are connected to a sewerage network, so often the latrines in Swahili houses are pit latrines. The simple plan of the Swahili house and the fact that it can be self-reliant make it a popular type of house in low income households and in government run low-cost housing projects. It is also not uncommon for owners to rent out one or all the rooms for income. (Sanga 2017)

PICTURE 6. Plan of a traditional Swahili house.(Sanga 2017)
PICTURE 7. A modified version of the traditional Swahili house. (Scholz 2006)

### 3.2.2 **Dar es Salaam colonial architecture**

Situated by an estuary next to the Indian Ocean, Dar es Salaam was once called Mzizima and was the traditional home of the Zaramo people. In 1862 Sultan Majid of Zanzibar established a town close to Mzizima, in hopes of making it his capital in Tanganyika, and called it Dar es Salaam, Arabic for “House of Peace”. By the late 19th century Germany had colonised a significantly large part of East Africa and moved its administrative and commercial centre from Bagamoyo to Dar es Salaam in 1891, after a couple of decades of the Sultan’s death. (Elleh 1997)

By 1902, the government had constructed government offices, a post office, harbour buildings, hospitals and residential buildings near the waterfront (picture 8). Some of the most famous German buildings in Dar es Salaam include the Azania Front Lutheran Cathedral (picture 9) and the Catholic St Joseph’s Cathedral. The old German street plan stills defines the basic urban framework of Dar es Salaam. After World War I, the German East Africa Company became Tanganyika under British rule, who added their signature in the city’s architectural heritage until Tanganyika’s independence in 1961. According to Elleh (1997) central Dar es Salaam reflects the nation’s history architecturally, with both Anglo-German and

Afro-Arabian influenced buildings, stating that "it is not uncommon to find Victorian buildings crowned with German pagoda roofs, while the white surfaces are articulated with decorations derived from Islamic calligraphy".

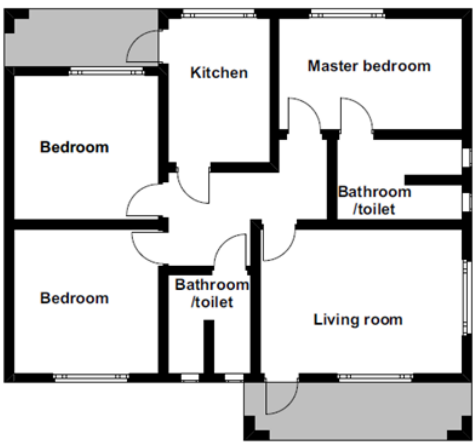
PICTURE 8. A German government building, originally the High Court. (Great Mirror 2020)

PICTURE 9. Azania Front Lutheran Cathedral, built in 1902. (Azania Front Lutheran cathedral)

By the time of independence in the 1960s, Dar es Salaam had come to be seen by many as a city of colonial oppression. Urban inequalities had begun to emerge during the time of German colonialization, with an underprivileged, servant lower class and highly favoured middle and upper classes. The city's master plan and infrastructure served the city's upper classes only, and there started to be areas associated with European wealth and African poverty. This negative division of the city led the socialist government of Nyerere to move the capital city from Dar es Salaam to the central city of Dodoma in 1971. Similar measures were carried out by other African governments like Nigeria and Cote d'Ivoire around the same time. The idea behind Dodoma was to offer locals an equal city, where everyone had the opportunity for subsistence farming and self-reliance. Today Dodoma is the de facto capital with the Tanzania's parliament and the office of the President residing there, but most governmental activities are still conducted from Dar es Salaam. (Elleh 1997)

### 3.3. Tanzanian middle-income houses

Today, the majority of urban populations live in single or two-storey buildings. According to Held, Jacovelli, Techel, Nutto, Wathum and Wittmann (2017), only 5 % of urban residential buildings are higher than two storeys. The rise of middle-income households after independence saw a shift of preference from the traditional Swahili house to, what Sanga (2017) calls, the "modern European [style] house". This type of house is generally built from bricks or concrete blocks, and it has generally one floor, although some opt for two floors. The average house does not feature a middle corridor, but rather bedrooms are situated around the most important room in the house, the living room (picture 10). The middle-income house tends to be more complex in design and more angular, as opposed to the rectangular Swahili house. The hipped roof is the predominant type of roof in a middle-income house (picture 11). The kitchen and bathrooms are generally inside the house instead of outside. Middle-income houses tend to be more comfortable for the user because they are often connected to grid electricity, municipal water supply, and often have air conditioning.



PICTURE 10. A layout of a typical Tanzanian middle-income house. (Durabric 2018)

PICTURE 11. Modern concrete block houses being built in Dar es Salaam. Hipped roofs are the preferred type of roof.

The average household size in Tanzania is 4.9 people. The households are usually larger than the core family and it is not unusual to have grandparents as well as other relatives living under one roof. Middle-income families also tend to have one or more domestic worker, also known as a “housegirl” or “houseboy”. Because of the large household sizes, family homes tend to have many bedrooms, usually three or more, which are commonly shared by two or more people.

There are generally two terraces in a modern European style house, one through which one enters the house (the formal one) and one directly next to the kitchen. The kitchen terrace functions purely as a room extension and is rarely enjoyed by visitors. It is a connection to the outdoors, a source of ventilation and at times used as a secondary kitchen, when wood or charcoal burning stoves are used in the cases of electricity or gas interruptions. Back terraces and backyards are not common. Often, the back areas of the house are private and entry and exit take place solely from the front and side doors.

A similarity between the European style house and the traditional Swahili house is that privacy increases as one goes deeper into the house. The living room is the first room one walks into and is commonly the room most invested in when it comes to furnishing and sometimes interior finishing. In some houses kitchens remain purely functional while in some more modern houses the kitchen will be incorporated into the living room.

Modern houses also tend to come with the increased need for security. This can be seen in high walls or fences throughout the plot (picture 12). Urban residential areas are usually always lined with walled blocks and streets. Although some use metal fences, concrete blocks are the norm. Concrete walls around the plot have the potential to reduce comfort within the plot and house due to the heat island effect.

PICTURE 12. A wall around a plot. (Real Estate Tanzania 2018)

While traditional Swahili houses are common within low income households, the lack of traditional Swahili houses in urban middle-income areas shows that the more income a household has, the less traditional elements they incorporate into their built houses.

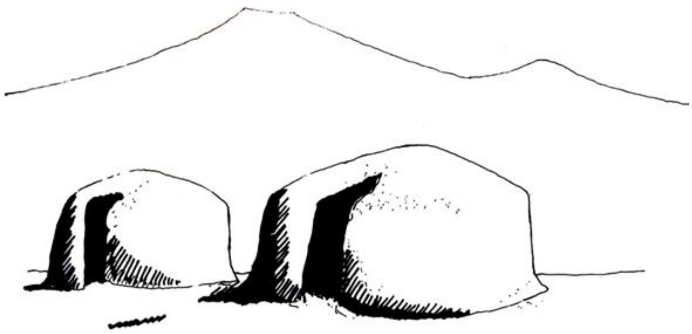
### 3.4. Building materials

Building materials in Tanzania include both industrialised construction materials (metals and concretes), as well as natural construction materials such as stone, wood and earthen materials. The presence of different cultures and the fact that resources are unequally distributed throughout the population leads to extremely different ways of construction and living. It is not uncommon, particularly in rural areas, to find buildings constructed of both traditional and industrial building materials. Which building materials a household chooses depend on the amount of resources the household has, the availability of certain materials and the local know-how of how to build with them.

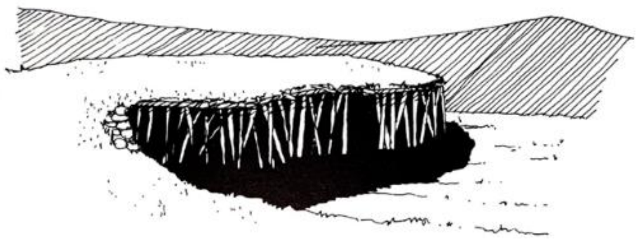
### 3.4.1 **Earthen materials**

Building with earthen materials, particularly mud and soil, has a long history in Tanzania, and different techniques have been used in different areas and by different peoples. Traditional techniques in using earth as construction material include using rammed earth, the wattle-and-daub technique, cob construction and the use of sundried clay bricks, also known as adobe. (Adegun & Adedeji 2017) Sometimes multiple techniques using earthen materials are used in a single building.

Typically, earthen materials have been used on walls, but some tribes have used earthen materials for roofing purposes as well, such as some Masai peoples of the steppe-land in northern Tanzania, who opt build their houses out of rammed earth (picture 13) instead of the more widely used poles and cloth. The Mbulu people of southern Tanzania take roofing a step further and build their houses partly underground (picture 14). (Cook & Spence 1983)



PICTURE 13. Masai mud houses. Cook & Spence (1983)



PICTURE 14. Partially underground Mbulu house with a flat mud roof. (Cook & Spence 1983)

Flat mud roofs provide good means of coping with daily temperature fluctuations, but they require frequent maintenance and they do not offer adequate protection against heavy rain. For this reason, mud roofs are generally built in drier areas with less rainfall.

Cob construction involves building with soil, water and fibrous organic material, such as straw or grass. Sometimes also lime is added. Walls are built with damp lumps of cob mixture and are sculpted into smooth forms. This type of construction technique makes it possible for cob constructions to have plenty of arches (Craven 2019). In Tanzania, cob is used primarily in wattle and daub type of constructions.

Wattle and daub is a construction technique where wet soil, clay and straw is plastered inside and outside of a frame work of vertical poles, tied together with horizontal branches, called a wattle, to make a wall (picture 15). This is a popular type of construction technique in rural Tanzania.

PICTURE 15. An extended wall made by both fired bricks and wattle-and-daub. Mwembe, Tanzania (Mjema 2018)

In many areas in Tanzania, people use hand moulded, unfired earth bricks (also known as adobe bricks) for the structural material of buildings (picture 16). Bricks are made from local soil, moulded and left to dry out in the sun. Once dry, the bricks can be used as load-bearing walls with mud or cement as a mortar. These types of adobe bricks are cheap, but can vary in shape, strength and durability. (Adegun & Adedeji 2017; Banobi 2018)

PICTURE 16. Sundried clay bricks. (Banobi 2018)

Adobe structures have high thermal energy, which means they store heat during the day and release it slowly during the night. A disadvantage of adobe bricks is that they shrink and swell with the weather, can break easily and are not as hard as burnt bricks. Because of this, adobe bricks fair best in dry and arid parts of Tanzania.

Because adobe bricks require a certain type of microclimate to function properly, many people opt for the more durable fired bricks, which are fired in kilns after being dried in the sun. Some brick makers use actual kilns, while others use makeshift kilns from the bricks themselves, which can lead to un-uniform bricks. Though firing bricks produces stronger bricks, the process requires large amounts of firewood, which adds to the embodied energy of the bricks and building costs. (Banobi 2018)

PICTURE 17. A makeshift kiln out of unfired bricks. Firewood is inserted and burnt in the holes. (Banobi 2018)

Studies have shown that earthen construction materials tend to increase thermal indoor comfort. A study done by Adegun & Adedeji (2017) showed that a house made by mud bricks had an indoor maximum temperature of 29°C compared to an indoor maximum temperature of 34°C in a same size house made by cement bricks in Sudan. Sanya (2012), found that certain houses made by traditional techniques in Uganda had cleaner air than even certain stabilised earth blocks, due to the absence of cement. (Adegun & Adedeji 2017)

Disadvantages of using earthen materials for construction is that they are in the mercy of climatic and environmental factors. The strength and durability of an earthen wall reduces if water infiltrates into or through it. Other factors like wind and solar radiation affect and determine the speed of degradation of earthen materials. Adding natural materials such as straw, wood pulp, coconut fibre, rubber and jute aid in stabilising earthen materials. Chemical additives and binders such as cement, bitumen, and gypsum similarly stabilise earthen materials, though these are less available in rural parts of Tanzania. (Adegun & Adedeji 2017)

Earthen construction materials also often tend to be cheaper than their industrialised counterparts due to their reduced embodied energy. For example, producing gypsum-stabilised earth blocks involves calcinations at 125 °C, while concrete block production involves sintering at 1100°C. Rammed earth walls were found to be up to 60% cheaper than conventional cement-based sandcrete walls in Zimbabwe. (Adegun & Adedeji 2017)

Earthen construction materials are environmentally friendly, recyclable, and often the most convenient construction material for rural Tanzanians with limited resources. Research has shown, however, that the use of traditional techniques with earthen materials in Tanzania is decreasing. According to Adegun & Adedeji (2017) "walls made from un-burnt mud bricks reduced from 25.4% in 1991 to 23.3% in 2000 while houses built with mud and poles also reduced from 43% in1971 to 19.4% in 2001." The decrease in using traditional construction techniques is most likely due to associating them with poverty and primitiveness, as well as difficulty of accessing government financial support (bank loans, subsidies and grants) when using said techniques, as these are unregulated. (Adegun & Adedeji 2017)

### 3.4.2 **Thatch**

In Tanzania people have traditionally built pitched roofs of thatch in areas with high rainfall. Different types of dry vegetation can be used for thatching, including straws, banana leaves and dry palm branches. Thatched roofs are characteristically built on top of a round hut, with walls of wattle-and daub, but sometimes the whole building is made of thatch, like the traditional Chagga house (picture 18). The thatch roof is usually supported by a framework of poles. (Elleh 1997)

PICTURE 18. Chagga traditional architecture. (Elleh 1997)

There are many positives to thatched roofs. Firstly, a wide range of natural materials can be used for thatching, meaning that thatched roofs can be constructed in different areas of rural Tanzania and it is a very cheap building material. When well built and maintained, thatched roofs fair better in places with heavy rainfall compared to mud roofs and are generally a quieter roof structure than metal sheets during heavy rains. Thatch roofing is also a poor heat conductor, which helps keep indoor air cool. (Moriarty 1980; Bokalders & Block 2004)

Disadvantages to thatched roofs are that they are flammable, they need a lot of maintenance and adequate thatching skills are diminishing. Thatch can be made more fire resistant by using an aluminium barrier foil under the thatch or by spraying it with fire retardant spray. However, these methods are not always available for rural populations nor are they necessarily the most environmentally friendly solutions. Certain thatching materials are less flammable as well; for example, reeds are less flammable than straw. (Moriarty 1980; Bokalders & Block 2004)

Thatched roofs need to be maintained quite regularly. Bokalders & Block (2004) argue that that, if well built, thatched roofs can be fairly durable and last up to 30 years with maintenance. Increasing the roof slope and increasing the compaction and thickness of the thatch can also greatly affect impermeability and durability. (Moriarty 1980).

As it is with many traditional building techniques, the know-how of building good quality thatched roofs is diminishing in rural Tanzania, as more people are opting for metal sheets as a roofing material. Moriarty (1980) argues that metal sheet roofing requires less skill than constructing a good quality thatched roof. (Adegun & Adedeji 2017)

### 3.4.3 **Concrete**

Most urban middle-income households build their homes using sand cement blocks, also known as sandcrete blocks (picture 19). These blocks are made from sand, cement and water. According to Makenya (2018), about 70% of Tanzanian building material products consist of sandcrete blocks.

PICTURE 19. A house made out of sandcrete blocks under construction in Bagamoyo, Tanzania. (Mjema 2018)

Concrete block production is common in nearly all regions of Tanzania and is increasing at the same rate as cement production within the country. The most common type of cement used is the Ordinary Portland Cement (OPC) because of its reliability, availability and affordability. The most common product is the 6-inch sandcrete solid block. (Makenya 2018)

In many cases sandcrete blocks are made and cured onsite by workers of varying skills. Research done on the characteristics of sandcrete blocks in Dar es Salaam show that a large percentage (up to 40%) of the blocks made for family homes do not meet Tanzania's blocks standard's (TZS 283:2002) requirement for compressive strength of 3.0 MPa for individual blocks. (Isaksson, Kinabo, Maganga, Minja & Sabai 2016; Makenya 2018; Isaksson & Mrema 2016) This is most likely due to poor quality control onsite, as few private house builders send their blocks for proper testing but are rather tested using different methods onsite. Professional users and larger projects that need to comply with national standards and specifications do send their blocks for testing. (Isaksson et al. 2016)

### 3.4.4 **Stone**

Stone as a building material is used in areas where it occurs naturally in large quantities. Stone was used historically as a main building material mostly in the Swahili coast, in cities such as Kilwa, Zanzibar and Bagamoyo (picture 20). The type of stone used in the coast was coral limestone. (Wynne-Jones 2013) In the mountains of the northern Pare region, local stones are used predominantly for the foundations of buildings (picture 21), although complete stone houses exist as well. Stone is not a common building material outside of areas where it occurs abundantly.

PICTURE 20. A colonial stone building in Bagamoyo (Mjema 2018)
PICTURE 21. A stone foundation under wattle and daub construction in Mwembe, Kilimanjaro (Mjema 2018)

### 3.4.5 **Wood**

Tanzania does not naturally have a lot of hardwood trees for construction and it is not favoured as a main building material due to its high cost of harvesting, transportation and treatment. Termites are a constant risk for the integrity of the wood if it is not properly treated. The risk of damage from termites is especially high in humid regions. For these reasons, wood is generally used solely in secondary building materials, such as roof trusses, doors, shuttering (i.e. formwork used in concrete construction) and construction poles. (Held, et al. 2017)

The best material for constructing quality roof trusses is pressure treated timber, but its availability in Tanzania is limited and according to Held et al. (2017), the market is flooded with inadequately treated timber. Pine wood (mainly *Pinus Patula*) is used mostly for wood trusses, while eucalyptus (generally *Eucalyptus grandis*) is used for other construction purposes.

Wood for construction purposes is obtained either illegally from government-owned or private forests or bought from from timber plantations. The Tanzanian government owns about 100,000 ha of timber plantations, of which over half is in the Southern Highlands. The private sector (both large industrial investors and small-scale tree growers) have a plantation area of around 51,000 ha (picture 22). (Held et al. 2017)

PICTURE 22. A pine tree forest plantation in Tanzania. (The New Forests Company n.d.)

The volume of wood products consumed in the year 2013 in the Tanzanian construction sector was estimated at more than 1 million m³. In the same year, most of the wood products produced were spent on either constructing new roof trusses or modernising old ones. The rest were used in aiding construction. (Held et al. 2017)

### 3.4.6 **Metal**

Corrugated galvanised iron sheets are the most common roofing material in Tanzania at the moment. Advantages of corrugated galvanised iron sheets are that they are lightweight, making them easy to transport, they only require a simple supporting structure, and they are more durable than thatch. Disadvantages include the possibility of rusting (especially in humid areas), noise during rainfall, and bad thermal performance without a ceiling and adequate roof insulation. The use of insulation is not common in roof structures in Tanzania.

Rusting of iron sheets can be slowed down by painting the metal. Painting with certain paints, for example light coloured paints or spectrally selective paints, can also improve thermal comfort by decreasing the metal's heat conduction. The metal would, however, have to be repainted often. Noise from the metal could be reduced by adding proper insulation and a ceiling. (Cook & Spence 1983; Moriarty 1980)

Corrugated aluminium sheets are more durable than corrugated galvanised iron sheets. They erode at a much slower rate and they reflect more solar radiation back into the atmosphere than their iron counterparts. Otherwise their other properties are similar. (Svard 1980)

### 3.5. Household energy

The average electricity consumption per capita in Tanzania is 108kWh per year, which is significantly less compared to Sub-Saharan Africa's average consumption of 550kWh per year, and 2,500kWh average world consumption per year. Though electricity consumption is low, the demand for electricity in Tanzania is estimated to be growing at 10–15% per year. (Tanzania Invest n.d.)

A large portion of Tanzanians rely on different sources of energy. These sources are kerosene, firewood, charcoal, grid electricity, solar electricity, natural gas, crop residues, diesel and petrol (Lusambo 2016). In his research (2016), Lusambo found that kerosene was used by 83% of the respondents, firewood by 81%, charcoal by 58% and grid-electricity by 14.6%. Firewood and charcoal are used as the main cooking fuels throughout Tanzania. 36 % of Tanzanians live in abject poverty and more than 90 % have low purchasing power, a situation which encourages the population's dependency on wood fuel. Alternative sources of energy other than biomass fuel have poor availability and have high prices. (Lusambo 2016)

Lusambo (2016) found that households prefer to use hardwood obtained from natural forests instead of plantations because they are denser and burn for longer than fast growing softwood species. However, this practice is quickly depleting the country's forest reserves.

Grid electricity is mostly used in urban areas, but electricity interruptions are nearly a daily inconvenience. To deal with electrical interruptions, many households have fuel-run generators installed. There are large areas of rural Tanzania which are not electrified, and high connection costs make it difficult to obtain grid electricity for those living in electrified areas. According to Tanzania Invest, only

24 percent of Tanzanians have access to electricity. Most of the grid electricity available is sourced from hydropower and natural gas.

Electricity from solar energy is not yet widely used in Tanzania, though there is potential for growth. (Lusambo 2016) The country's sunshine hours per year range between 2,800 and 3,500 with global horizontal radiation of 4–7kWh per m$^2$ per day. The central region has the most solar resources, and by 2016 up to 5.3MWp of Photovoltaic (PV) solar energy had been installed. The government has supported the use of solar by removing VAT and import taxes on main solar components such as panels, batteries, inverters and regulators. (Lusambo 2016)

### 3.6. Water

Access to water is poor in Tanzania. Even though the country boasts Africa's largest lakes, two-thirds of the country is arid or semi-arid. Poor water accessibility plagues people both in rural and urban areas. Nkonya (2010), correlates the lack of access to safe drinking water directly with the strain on the healthcare system and the increase of poverty. (Nkonya. 2010)

Accessibility to safe water in Tanzania depends greatly on one's location (water is less accessible in rural areas) and socioeconomic status (wealthier people have more means in obtaining safe water). (Nkonya 2010; Lufingo 2019.) Some parts of the country receive up to 3,000 mm of rain per year, while others (for example the Dodoma area or Rift Valley) only 600 mm. According to the World Health Organisation (WHO) (2017), basic access to water is defined as the "availability of a source of water that is at most 1,000 metres or 20 minutes away and has the possibility of obtaining at least 20 litres per day per person." Basic water access meets the water needs for consumption and basic hygiene, but not necessarily laundry or bathing. WHO also states that impact of water quantity on health is low when a person has intermediate access to water, in other words, a person has access to 50 litres per day at a distance of less than 100 metres or 5 minutes. Since more than half of rural households, of which more than 70 percent of the Tanzanian population is, have to travel more than a kilometre and forty minutes on foot to access water (Nkonya 2010), one can argue that more than half of the Tanzanian population does not have basic access to water. To make things worse, young women and girls are generally responsible for fetching water, an extra chore which reduces their time for education and hence increases the risk of rural households falling into deeper poverty. (Lufingo 2019)

A person needs 20 to 40 litres of fresh water a day to meet drinking and sanitation needs. This amount does not necessarily include water for bathing, cooking and laundry. When the latter are included, the minimum amount of water needed is between 27 and 200 litres per person per day. (Nkonya 2010; WHO 2017). The average Tanzanian uses an average of 10.1 litres of water a day, approximately half of the required minimum. For context, the average person in Finland uses 150 L of water a day for all their daily needs. (WWF Finland 2012)

Water is considered safe to drink when it is free from pathogens, odour and other pollutants. In Tanzania, water is obtained from surface water sources, wells, drilled boreholes and piping from municipal water supply and sanitation authorities, or WSSAs for short. Unfortunately, all these methods carry the risk of being contaminated. In rural areas both surface and underground water can be polluted by different contaminants such as silt, sediment, and contaminants from soil loss and surface runoff. In urban areas surface and ground waters have the risk of being polluted by chemicals from factories, as well as from human waste leaching into the waters from latrine pits and cesspits. Piped water can be contaminated by chemicals from old and untreated pipes, as municipalities (especially rural ones) at times lack maintenance funding. (Nkonya 2010; Lufingo 2019.)

Piped water is convenient for its users because theoretically there is no limit of how much water one can obtain, as the users pay the WSSAs for the amount of water they consume. Piped water also adds comfort to the user, since water can be obtained from home by opening the tap. Unfortunately, water supply interruptions are common in Tanzania, since public water supply in the country is highly deficient due to occurrences such as faulty valves, broken piping, insufficient water pressure and water rationing. Because of this, households have to rely on alternative sources of water, such as water tanks and privately drilled boreholes. Buying water from vendors is also a common occurrence. (Nkonya. 2010) It is important to note that tap water in Tanzania is not recommended for drinking without treatment, as it could have pollutants from not only the piping but also have varying amounts of pathogens such as *E. coli* and *Giardia* from different pollutants. Those that have access to water treatment use methods such boiling, filtration, ultraviolet (UV) light and chemical disinfection such as chlorination. (Lufingo 2019)

### 3.7. Sanitation

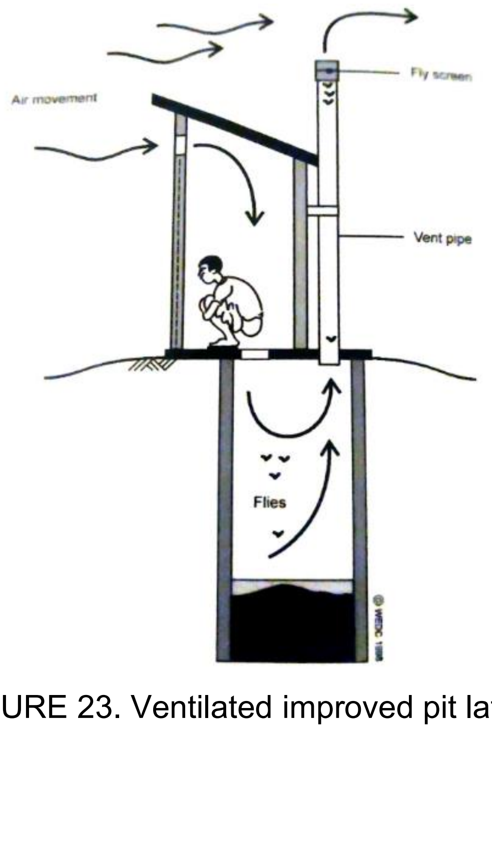
Sanitation plays a major role in the lack of development in Tanzania. According to UNICEF (2017), It is estimated that Tanzania spends 70 per cent of its health budget on preventable diseases related to inadequate water, sanitation and hygiene services (WASH). Such diseases as diarrhoea, typhoid fever and leptospirosis are all associated with poor WASH. (Huuhtanen & Laukkanen 2009) Inadequate water quality and sanitation have a direct correlation to malnutrition, which is critical, as approximately one third of children under the age of 5 in Tanzania are physically stunted. The Tanzanian's governments public service capacity is weak and urban sanitation and solid waste services are inadequate to serve the tens of millions of people living in cities. Because of this, citizens rely on themselves for designing and constructing sanitation solutions in their homes. (Thomas, J., Holbro, N. & Young D 2013)

In a survey conducted in 2007 (The National Household Budget Survey), it was found that 97.3 % of households had a basic latrine in urban areas, but many of them were not hygienic and were at risk of negatively impacting the health of their users. According to UNICEF (2017), Only 4.8% of the Dar es Salaam population had sewerage coverage in 2012. In 2002, 80 % of the Dar es Salaam population used pit latrines, 2 % ventilated improved pit latrines, 2.5 % used septic tanks, and 1 % of the population were without any sanitation options (Chaggu et al. 2002; Thomas et al. 2013)

### 3.7.1 Pit latrines and ventilated improved pit latrines

The most common sanitation solution in Tanzania is the pit latrine. Pit latrines are latrines under which a pit is dug, commonly between 2.5m to 5m. They do not utilise water for flushing, but in many households the latrine is also used for bathing. In these cases the pit gets excess liquid and it runs a higher risk of getting fly and odour problems, as well as nutrient and pathogen runoffs to the ground and groundwater. A study showed that on 30% of households who have pit latrines de-sludged their pits, with the rest preferring to dig a new pit to save on costs. There are different ways to de-sludge pits. There are de-sludging pumping services, which are the priciest option. Another option is the “vomiting method”, where the sludge is redirected to a second pit. Some households sink the sludge into the ground by using a coagulant. (Thomas et al. 2013; Huuhtanen & Laukkanen 2009)

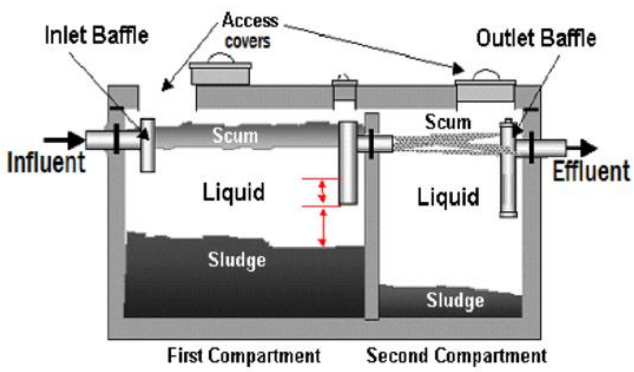
Ventilated improved pit latrines (picture 23) help decrease fly and odour problems, making them a more hygienic and comfortable solution for their users, compared to the traditional pit latrine. A downside for the ventilated improved pit latrine is that due to the pit’s need for ventilation, its location has to be selected more carefully. (Huuhtanen & Laukkanen 2009)




PICTURE 23. Ventilated improved pit latrine. (Huussi ry 2010)

### 3.7.2 **Septic tanks**

A septic tank is a sanitation solution which involves, typically, a two-chambered tank dug into the ground to which the latrine is connected to and where the wastewater undergoes basic purification before it is drained and transported for further purification (picture 24). In septic tanks, solids and inorganic material are broken down through anaerobic reactions, and those that do not accumulate at the bottom as sludge. The second chamber ends up having less organic material and more purified wastewater. Septic tanks require regular sludge removal and treatment for them to remain safe and healthy for their users and their environment. Toilets that are connected to septic tanks generally tend to be flush toilets. The sludge in septic tanks is normally emptied by de-sludging companies, or then left to decompose to the bottom. A positive of the septic tank is that, when well maintained and emptied regularly, they are easy to use and have little fly or odour problem. A negative is that a septic tank is an expensive sanitation solution compared to the pit latrine when it comes to construction and maintenance. Septic tanks also have a high risk of causing nutrient and pathogen runoffs to the ground and groundwater. (Huuhtanen & Laukkanen 2009)




PICTURE 24. A cross section of a two-chambered septic tank. (Alnahhal 2017)

### 3.7.3 **Ecological sanitation**

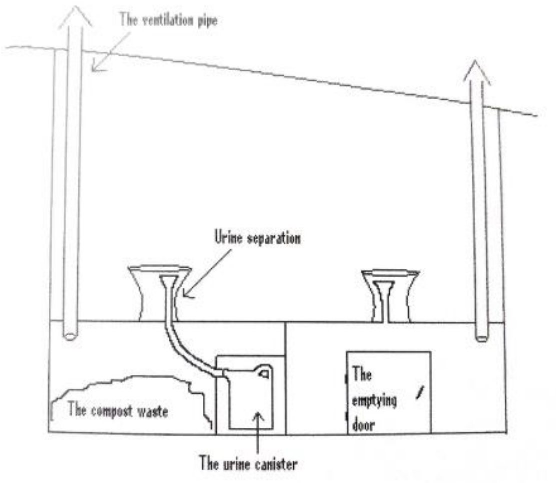
Ecological sanitation, or ecosan, is a form of sanitation in which nutrients from human waste are collected and returned safely into the environment. There are different forms of ecosan solutions, but some of the most basic ones are composting latrines; latrines which do not require water for flushing but instead rely on the composting process to change the sanitation waste into reusable organic matter. In the composting process the organic matter, in this case sanitation waste, undergoes chemical processes and is turned into humus, a nutrient-rich, pathogen-free fertiliser from which plants obtain nutrients, particularly nitrogen (N), phosphorus (P) and potassium (K), as well as smaller amounts of other elements. Nitrogen, phosphorus and potassium are essential elements in soil, as they are easily deplenished through agriculture. During the composting process heat and water vapour is also released into the environment. (Mjema, 2018)

#### 3.7.3.1. Composting pit latrine

The simplest type of composting latrine is the composting pit latrine. The composting pit latrine is like the pit latrine, but once filled, it is covered with about 30 cm of earth and left to decompose for about a year. A new place is then chosen for the next composting pit latrine. The year-old waste, which is now fertiliser, can either be dug up and used, or fruit trees can be planted in them. (Huuhtanen & Laukkanen 2009)

#### 3.7.3.2. Dry toilets

Dry toilets do not necessarily require pits. Instead, the sanitation waste is collected in a container and left to compost. There are different types of dry toilets; some separate urine from faeces (picture 25), some have two chambers while others can be portable and made for public use. The type of users and the environment are the determining factors of what a dry toilet could be. (Huuhtanen & Laukkanen 2009; Mjema 2018).




PICTURE 25. A urine diversion dry toilet (UDDT) with two chambers. (Huuhtanen & Laukkanen 2009)

#### 3.7.3.3. Ecosan application in Tanzania

Whilst ecosan is not so widespread yet in Tanzania, there is potential for growth, particularly in rural areas and in areas where water is scarce. While composting food waste is practised to a certain degree, the handling and reuse of human waste is seen as a taboo and prejudice about dry toilets need to be tackled. Ecosan projects in Dar es Salaam and Arusha (e.g.the Rosa project), where pilot toilets were built in schools and the obtained fertiliser used in the school gardens, have left positive results in their respective communities (picture 26 and 27). The toilets proved to be suitable for their respective climates, had positive effects in changing negative assumptions about handling human waste and showed potential for upscaling. (Senzia 2011)

PICTURE 26. Urine diversion dry toilets in a school compound, built by the ROSA project in Arusha. (Senzia 2011)
PICTURE 27. A garden fertilised by compost gained through the ROSA project in Arusha. (Senzia 2011)

## 3.8. Challenges in construction

Nearly all challenges the construction sector in Tanzania face boil down to inadequate resources allocated to infrastructure and housing by the government and low GDP per capita.

### 3.8.1 **Housing deficit**

In 2015, there was a housing deficit of 3 million units in Tanzania, with the annual demand growing between 200,000 and 300,000 units (Makenya 2018) This housing deficit is exasperated by rapid urbanisation. Materials constituted over 76% in housing construction in 1998. Adegun & Adedeji (2017) argue that escalating cost of building materials is one of the major factors responsible for the widening gap between demand and supply of affordable and adequate housing. By 2018, there was no large scale national social housing program in place to address housing deficit. (Makenya 2018)

### 3.8.2 **Poor housing quality**

According to Sanga (2017) most of the Tanzanian population live in poor conditions which lack "adequate basic social infrastructure services such as water supply, sewerage, access road, storm water drainage and solid waste management systems." Significant housing differences are few except for high-income households in large cities. For many households, obtaining all of the beforementioned amenities at once are either impossible due to the lack of access or finance.

A lot of housing investment happens through incremental building (gradually building or improving a home) rather than at once and it is not uncommon for people to move into a house while it is still being built. Renovation is also not always possible due to the lack of funding, and because of this, many private houses tend to deteriorate quickly.

### 3.8.3 **Informal housing**

Mortgage programs have been put in place to enable citizens to acquire property, but about 80% of the population in Tanzania cannot afford to buy or build a decent house because of “economic hardships due to high cost of materials, labour and technical know-how”. (Makenya 2018). Low income households therefore, have to resort to private rental housing as the only legal means to access housing, or live in an informal settlement.

A survey conducted in 2010 found that 74-80% of Dar es Salaam settlements were unplanned and un-serviced, i.e. informal, a trend seen in other Tanzanian cities as well. Only 57% of the informal settlement population had access to on-site sanitation, the remainder reporting to use public or shared toilet facilities. Most informal settlements cannot receive municipal water, so many have to resort to drinking unsafe water from unclean sources or pay high prices for water - up to 200 times the price for piped water - from vendors. (Lufingo 2019)

### 3.8.4 **Challenges in the concrete industry**

Most urban middle-income households build their homes using sand cement blocks, also known as sandcrete blocks. These blocks are commonly made and cured onsite by workers of varying skills. In a researches done on the quality of sandcrete blocks made onsite in Dar es Salaam, it was found that up to 40% of the blocks did not meet Tanzania’s blocks standard’s (TZS 283:2002) requirements for minimum compressive strengths: 3N/mm$^2$ for non-load bearing blocks and 7N/mm$^2$ for load bearing blocks.(Isaksson et al. 2016; Makenya 2018; Isaksson & Mrema 2016) Two thirds of the blocks also absorbed more than 15% of moisture, higher than the maximum limit set by the Tanzanian Bureau of Standards. Failure to meet these standards is mostly due to poor and un-uniform production processes on site; for example, not testing sand on site and un-uniform cement: water ratios, as well as inadequate quality control testing of finished products. (Makenya 2018)

Makenya (2016) argues that the blocks with lower strength than the minimum of 3.5 N/mm2 could still suit the building structures of low rise single-storey buildings, since the most common blocks used are 6 inch wide solid blocks with a relatively large load carrying surface. Isaksson et al. (2016) points out that it is very rare to find a one-family house that has collapsed in Dar es Salaam, instead, it is more common to hear about multi-storey buildings collapsing. In 2013, a 14-storey building collapsed, and one reason reported were iron bars with inadequate quality which were imported from Asia. It was not clearly reported if and how the block quality contributed to the building failure. (Isaksson et al 2016)

Isaksson and Mrema (2016) argue that cement price probably forms a larger part of the building investment in Africa, compared to the industrialized world. Hence it is the government's challenge of finding ways of improving cement use in order to improve quality and efficiency of concrete blocks' production and provide affordable buildings in the future. Resources could also be allocated in improving education of labourers on construction sites to improve skills and ensure uniform sandcrete block quality. Also contractors should be supervised to make sure their work on family homes meet requirements.

### 3.8.5 **Loss of vernacular architecture**

In Tanzania, vernacular architecture is slowly vanishing along with building know-how. Walls made from un-burnt mud bricks reduced from 25.4% in 1992 to 23.3% in 2001, while houses built with mud and poles also reduced from 43% in1971 to 19.4% in 2001. More buildings are being built with expensive industrialised materials which do not work well thermally compared to traditional materials. When looking at construction trends, it is evident that a lot of people do not value traditional or even alternative ways of living.

Earthen materials are environmentally friendly since they have low embodied energy and they are recyclable. Improved earthen materials, such as compressed earth blocks, tend to have less embodied energy compared to their industrial counterparts. For example, up to 30% less quantity of water is consumed in the production of simple or stabilized blocks compared to other conventional walling materials. (Adegun & Adedeji 2017)

Building with improved traditional materials increases indoor thermal comfort and in many cases, building traditionally is cheaper than building with industrialised materials. Sanya (2012) found that construction of a house was up to 42.9% cheaper when compressed stabilised earth blocks (CSSB) were used for construction instead of industrially fired, concrete blocks. In a case study in Uganda, savings from using wattle-and-daub technology instead of brick walls was significant enough that it could fund high quality galvanized iron-sheet roofing (Sanya, 2012).

Despite the benefits, earthen structures are associated with poverty and primitiveness. There are no national standards for building with earthen materials, which makes accessing financial support (bank loans, government subsidies, grants etc.) difficult. There is a lack of government support when it comes to improving awareness of the benefits of earthen construction and supporting the use of improved earthen materials and technologies, particularly for low-income households and in rural areas. At the moment earthen materials are mainly used for wall construction and more research is needed to determine the possibility of using it for roofing, flooring and finishing - for more cost and environmental benefits. (Adegun & Adedeji 2017)

# 4 KILIMANJARO REGION

The Kilimanjaro region is one of twenty administrative regions of mainland Tanzania and covers an area of 13 209 km$^2$ (picture 28). (Kusare. 1984) The region, along with neighbouring regions Arusha and Manyara, hold some of Tanzania's most valued tourist attractions, such as the Serengeti and Lake Manyara National parks and mountain Kilimanjaro (picture 29). Other tourist attractions in the area include the Mkomazi national park and Lake Challa. Because of these attractions the region receives a plethora of tourists, and infrastructure in the area is well maintained compared to the Southern regions of Tanzania. The Usambara railroad, which connects Tanga to Arusha, passes through the region, as well as the B1 road, which runs from Dar es Salaam all the way to Arusha. The Kilimanjaro International Airport (KIA), is located approximately 100 kilometres north east from Same.

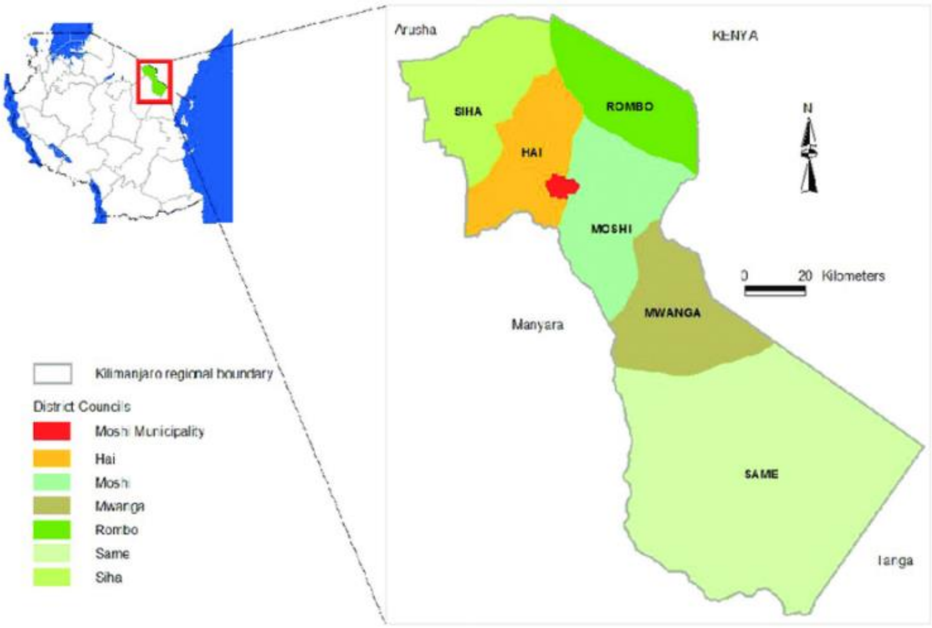
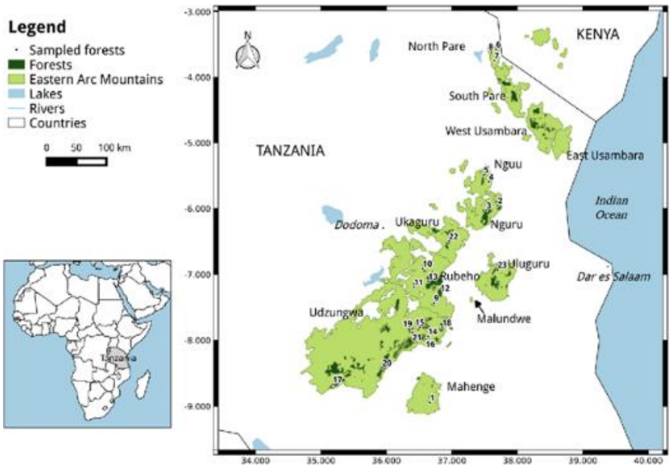



FIGURE 28. Location of Kilimanjaro region within Tanzania and its districts. (Mkanda et al. 2014)

The Kilimanjaro region is made of six districts: Moshi, Rombo, Mwanga, Hai, Same and Siha districts. The municipality of Moshi, 107 km north west of Same, is the regional capital. According to the Kilimanjaro investment guide (2018), the population of the region was estimated to be at 1,8 million in 2017.

PICTURE 29. The Kilimanjaro national park with the Kilimanjaro mountain in the background. (Kilimanjaro investment guide 2018)

The dominant features of the Kilimanjaro region are its mountains and highlands. Apart from the freestanding Mountain Kilimanjaro, the Eastern arc mountain chain dominate the region’s landscape. The Eastern arc mountains start from southern Kenya all the way into central Tanzania and are at least 100 million years old. All the Eastern Arc mountains share a similar ecology, and act as tropical forest “islands”, with many endemic plants (picture 30). (Niemelä. 2011) Trees typically found in the mountain forests include the *Acacia* specie of tree as well as the Combretum species, commonly known as the bushwillow. The red soil found in Kilimanjaro is common in the tropics and subtropics. This type of soil has no humus layer, instead, the iron oxides in the soil give it its red appearance (picture 31).




PICTURE 30. The Eastern Arc mountain chain. (Canteri et al. 2016)

PICTURE 31. Pare mountains in Same, Kilimanjaro. (Mjema 2018)

According to the Kilimanjaro investment guide (2018), only about 2.3% of the region is covered by water and 49% of the land is arable. The Kilimanjaro region has three agro-ecological zones; the lowlands (1500 m and below), the highlands (1500 to 3000 m) and the forests (above 3000 m). Most of the land under 3000 m can be used for agricultural purposes. Agriculture is the main source of economic activity in Kilimanjaro, contributing to 60% to the region's GDP and over 75% of its employment. The most fertile zones of the region are in the highlands, since they receive reliable rains and have moderate temperatures. Coffee is grown in the highlands and it is the most important crop economically for the region, as Kilimanjaro is one of the major coffee producers in Tanzania. Other crops grown in Kilimanjaro include wheat, barley, cardamom, sisal, cotton, sunflower, millet and groundnuts. Lower altitude areas grow crops such as maize, cotton, rice, onions and tomatoes. Minerals which can be found in Kilimanjaro and are currently extracted include gypsum, limestone, bauxite, copper, aquamarine, red garnet and pozzolana. (Kilimanjaro investment guide 2018)

The lowlands of the Kilimanjaro region have a biome closely resembling a semi-arid zone or a savannah with dry and rainy seasons.  (Niemelä. 2011) The warmest season in the region is between December and March, with the highest temperature reaching just above 30°C in Moshi, approximately 100 km north-west from Same (table 1). Temperatures drop from May to August, with lowest temperatures falling up to to 12°C at night. Moshi's average yearly temperature is 22.9°C (Kusare 1984) The region also receives less rainfall than the tropical east (approximately 970 mm a year compared to Zanzibar's 1 360 mm a year). Though rain amounts differ, rain patterns are similar throughout the country, with the rainiest month being April and the driest month being July (table 1). It is rare for it to rain the whole day during the rainiest months, instead, rains are occasional and spread out throughout the day. (Niemelä. 2011)

| MOSHI | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max (°C) | 36 | 35 | 34 | 30 | 29 | 29 | 28 | 30 | 31 | 32 | 34 | 34 |
| Min (°C) | 15 | 15 | 15 | 16 | 14 | 13 | 12 | 12 | 13 | 14 | 14 | 15 |
| Rain (mm) | 50 | 60 | 120 | 300 | 180 | 50 | 20 | 20 | 20 | 40 | 60 | 50 |

| ZANZIBAR TOWN | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max (°C) | 32 | 32 | 33 | 30 | 29 | 28 | 27 | 28 | 29 | 30 | 31 | 31 |
| Min (°C) | 25 | 25 | 26 | 26 | 25 | 24 | 23 | 23 | 23 | 25 | 25 | 26 |
| Rain (mm) | 50 | 65 | 140 | 310 | 290 | 45 | 25 | 25 | 35 | 60 | 180 | 135 |

TABLE 1. Climate table for Moshi and Zanzibar. (Fitzpatrick 2015).

### 4.1. Same

Same is both the name of the district as well as the district’s central town, which lies beneath the South Pare mountains on the south-eastern end of the Kilimanjaro region. The town is only 10 km from the Mkomazi national park and 37 km south-west from the Kenyan border (picture). In 2012, the town of Same had the population of approximately 25 800, while the district as a whole had the population of 269,800. (Tanzania National Census 2012)


PICTURE 32. Location of Same within the Same district. (Google Earth 2019)

Same is easily accessible from major Tanzanian cities, as a result of the the B1 road, which passes through the town (picture 33). The B1 road, via other roads, travels all the way to Arusha and Nairobi in the north and all the way to Mtwara via Dar es Salaam in the south. Hence the road is an important link between northern and southern Tanzania both logistically and economically, and numerous trucks and cars cross the town daily.


PICTURE 33. Aerial view of Same. (Google Earth 2019)

Same is important for the local Pare people. As the district capital, it draws people living in the villages on the slopes and valleys of the Pare mountains for its services and trade opportunities. Some of the services found in Same include private and public healthcare facilities, a post office, banks, as well as Christian and Muslim religious buildings.

Same has a savannah biome and the type of trees which grow in Same are short and wide branched, with small and thin leaves. (Niemelä, 2011). The most prominent species of tree is the Acacia tree (picture 34), which has many different types of subspecies. Many Acacia trees grow as bushes, and some grow as vines. Another prominent tree in Same is the drought-resistant bushwillow tree. Cacti and aloe vera also grow well in the area (picture 35).

PICTURE 34. A tree belonging to the Acacia species in Same. (Mjema 2018)
PICTURE 35. A cactus plant in Same. (Mjema 2018)

There is little research on the exact soil type of Same. Soil maps of Tanzania show that the soil type of Same is most likely ferrisol, which is a soil similar to Ferralitic soils. Ferrisol soils are abundant with iron and aluminium oxides, which gives the soil its characteristic red colour. (Niemelä, 2011) There are a lot of grasshoppers and termites in Same. Termites devour all dead plant remains, and they are part of the reason why there is essentially no humus layer Same. Another reason for low humus content is high temperature and relatively low rainfall, which encourages rapid rates of oxidation. (Niemelä. 2011)

### 4.2. Culture

The main ethnic group of the Pare region is the Pare people.The language spoken in the area is the Pare language, which, like Swahili, is part of the Bantu language group. Because the Pare mountains have remained less developed for tourism than nearby areas in the region, the traditions and folklore associated with the Pare people have been rather well preserved.

Shepherding and farming are how many people get their livelihoods in Same. Unused land can often be taken into use for agriculture if the community elders agree on it. Farms are often owned by families, which are passed down to descendants. In many areas, when the soil stops being fertile, new fields are taken from natural grasslands. According to Niemelä (2011), little responsibility is taken for sustainable farming in the area as farming is seen as a basic human right. Hence it is difficult to protect certain areas from deforestation. People also use unused or unowned land for cattle grazing and natural resources. (Niemelä. 2011)

The Pare people had a long history of iron smelting and smithing, and many Early Iron Age sites associated with iron smelting have been found in the Pare region. The industry played an important role socio-economically, as iron products were often traded in nearby markets. Researchers have attributed the iron industry in the Pare region to have contributed to early deforestation and erosion, since wood was used as fuel in iron working technologies, and erosion remains a major environmental issue in the Pare region. (Hakansson. 1998)

# 5 THE PLAN

## 5.1. The plot

The plot is situated in the Sterling neighbourhood, a newly developed area south-east of Same (picture 36). The plot is number 194 and is approximately 3 kilometres south-east from the centre of the town and 500 metres from the B1 road. The South Pare mountains lie on the East side of the neighbourhood. A masterplan of the area exists (picture 37), and the area is planned to become completely residential. At the time of writing, only a few houses have been built in the area. There is municipal water supply throughout the neighbourhood but no sewerage system. Builders are expected to manage their human and solid waste as well as rainwater runoff on their own.


PICTURE 36. Location and elevation of the Sterling neighbourhood.. (Google Earth 2019)


PICTURE 37. Part of the sterling neighbourhood master plan. (Same town council, simplified by Mjema 2020)

The coordinates of the centre of the plot are 4°05’21”S 37°45’38”E. The plot has dimensions of 30 m x 60 m, with an area of 1800 m$^2$, and has the elevations of +876 to +879 (picture 38). The plot runs vertically from north-east to south-west. The pare mountains are located in the north east direction of the plot, on its narrower side. The plot slopes down south-west with an elevation difference of 3 m. There is a road on both the north-east and south-east sides of the plot. By December of 2018 eastern and southern neighbours had started building on their plots. Maize is grown at the plot at the moment (picture 39).


PICTURE 38. Aerial view of the plot. (Google Earth 2019)
PICTURE 39. Aerial view of the plot. (Mjema 2018)

### 5.2. Microclimate

A visit to the plot was done on the 22nd of December 2018 at 11.20 am. The South Pare mountains lie to the east of the plot. Striking features of the plot were the mountains, the red soil and green vegetation (picture 40). The weather was warm and pleasant, with a light breeze coming from the east, and humidity levels were low. Since there were only a few houses built the area was open and breezy. There were not many trees around except for the occasional acacia tree and bushes. The eastern neighbour had a fence made of small trees and bushes around their plot (picture 41). The east of the plot had views to the mountains but there was virtually no significant view from the west, only a road and distant neighbours’ houses. The roads were unpaved dirt-roads and signs of soil erosion throughout the neighbourhood was visible (picture 42).

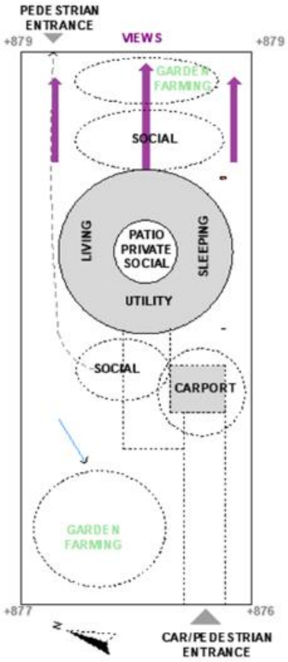

PICTURE 40. Eastern view from the plot. (Mjema 2018)

PICTURE 41. The eastern neighbour’s house under construction. (Mjema 2018)

PICTURE 42. Soil degradation at the road leading to the plot. (Mjema 2018)

### 5.3. Plot functions

One of the first steps when designing the house at Same was laying out wanted functions of the plot and finding their ideal placement. Important functions chosen were sleeping, living, utility (which includes sanitation, laundry, storage), farming and socialising (picture 43). According to research done by Wong and Li (2007), walls facing east and west receive more solar radiation compared to north and south facing walls. Hence sleeping and living areas were allocated to the south façade and north façade respectively. Utility could be placed in the west, since a lot of time is not spent in utility areas.




PICTURE 43. The functions of the plot. (Mjema 2018)

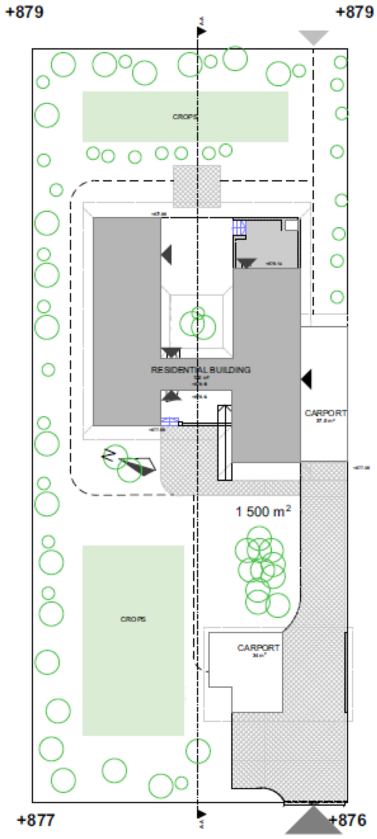
Since early in the design process there was an idea of having a patio in order to increase ventilation and act as a private socialising area. A semi-private socialising area would be ideal on the eastern side of the plot, since it offers the best views to the mountains.

The building will be located on the eastern side of the plot. There are two designated areas for farming, a smaller area on the east and larger area on the western side. Situating the building higher up on the plot means the building will be less vulnerable from rainwater runoff and there will be less manipulation of land needed for crop irrigation on the western farmland. Car traffic to and from the plot happens on the south-western corner of the plot, where the main entrance is located. Pedestrian entries can be placed in both the western and eastern sides

### 5.4. Masterplan of the plot

The masterplan of the plot can be seen in picture 44. The residential building has an area of 130m$^2$. When adding the area of the carports, storage and dry toilets, the total area becomes 202m$^2$. 11% of the plot would be built according to this plan.

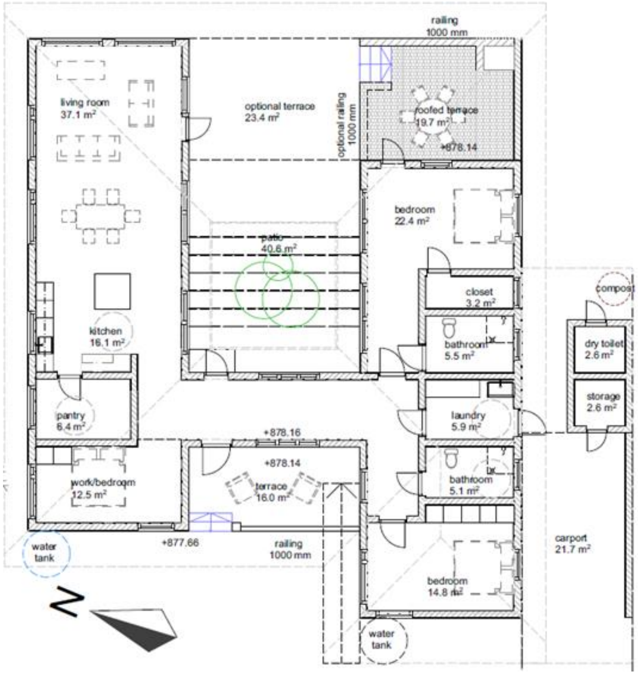
A carport is located at the entrance, at the south-western end. The carport is mainly for the use of guest. This carport also functions as a type of gate and provides some privacy from the road to the rest of the plot. A second carport, meant for the use of the owners, is connected to the house directly behind the guest carport. Having these carports relatively close to each other means that less paved space is needed, and less area is dedicated to car traffic. Pedestrians can enter the plot via the main western entrance or through the eastern entrance.




PICTURE 44. Masterplan of the plot. (Mjema 2020)

### 5.5. Floorplan

The floorplan can be seen in picture 45. The most defining feature of the building is that it has two wings, connected by a narrow corridor, with a patio between them. One wing is for sleeping and utility and the other one is for living. The main entrance is at the corridor, where there is also direct access to the patio. The entrance is connected to a front terrace. The entrance can be made accessible by building a 6 m ramp in its corner.




PICTURE 45. The floorplan of the house. (Mjema 2020)

The sleeping wing consists of a bedroom and an ensuite master bedroom. Between the bedrooms are the laundry room and common bathroom. The laundry room has direct access outside and this acts as an auxiliary entrance from the carport. The master bedroom has a roofed terrace attached to it on the east. The terrace adds a second layer to the room but also functions as a large overhang, minimising solar radiation to the room's eastern wall (picture 46).

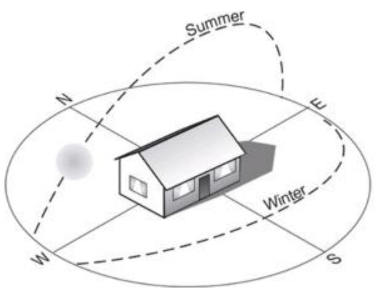
PICTURE 46. Eastern façade of the building. (Mjema 2020)

The living wing on the north side consists of an open kitchen and living space and a multifunctional room, divided by a pantry. Since the amount of people staying at the house can vary, it seemed logical to keep one room multifunctional. It can function as a work room, bedroom, or even a second living room. The owners can opt to add a wall in the room for privacy.

The kitchen, dining area and living room make up a spacious 53 $m^2$ area. Having these areas together promotes ventilation, more daylight and encourages socialising. It was a conscious decision to situate the living room at the end of the wing, which is different from the traditional Tanzanian way of the living room being the first room one enters. The living room situated at the end of the wing makes the area peaceful and it gets the best views to the Pare mountains. Having high windows and a longer roof overhang should minimise eastern solar radiation in the mornings.

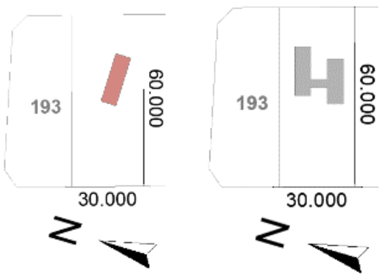
### 5.6. Building orientation

Same is located 4°40 south of the Equator, hence solar radiation plays a crucial role in indoor climates. Building orientation is an important factor for passive cooling. N.H Wong and S.Li (2007), found through research that eastern and western walls receive significantly more solar radiation than walls facing south and north due to the sun's path (picture 47). Up to 8.67% of cooling load was saved when a house's long side's orientation was changed from west to south in Singapore, which is 1°30 south of the Equator. The longest side of the building should hence face south or north. Wong and Li also found that using horizontal window shading devices 0,3 m to 0,9 m in length can save cooling load by 10.13%. (Wong & Li)




PICTURE 47. How the sun path affects a building's façade. (Buildcivil 2013)

The plot is rectangular in shape and is orientated 73.14 degrees to true north, with the narrower sides of the plot situated in the north-east and south-west. A building adhering to this rule would take on a long, “I” shape, however, it would run diagonally on the plot, making allocating areas for different functions challenging (picture 48). The challenge was thus to design a house which would both adhere to the east-west orientation, as well as be functional and practical.



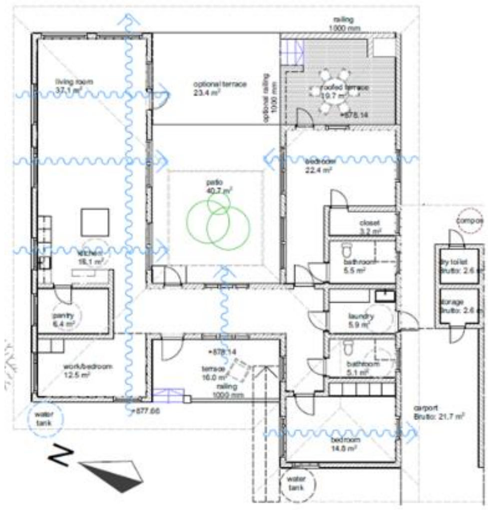

PICTURE 48. A building oriented to the east on the plot and the final, two-winged design. (Mjema 2020)

The final design is follows the orientation of the plot. Making the house have two long wings means that the area of the eastern and western façades can be kept to a minimum. The eastern and western façades also have longer roof overhangs (1,2 m and an additional 4-metre terrace in the master bedroom) and have higher windows to protect the inside from low sun rays. Larger windows were allocated to the living room’s northern façade, as well as towards the patio.

Placements of the rooms were also placed according to orientation. The living room and kitchen have a façade facing the north, which should keep them cool throughout the day. The second bedroom does have a western façade, however placing it on the west gives it the possibility to have ventilation from three directions as opposed to one. If the owners wish, it is possible to swap to the location of the second bedroom with the laundry and bathroom.

### 5.7. Ventilation

Ventilation was an important factor when designing the building. Every room has either a window or a door to the outside and every space meant for living has windows to at least two directions. Where possible, windows were placed opposite each other to ensure better air flow (picture 49) and the wings were kept narrow for this same reason.




PICTURE 49. Ventilation throughout the house. (Mjema 2020)

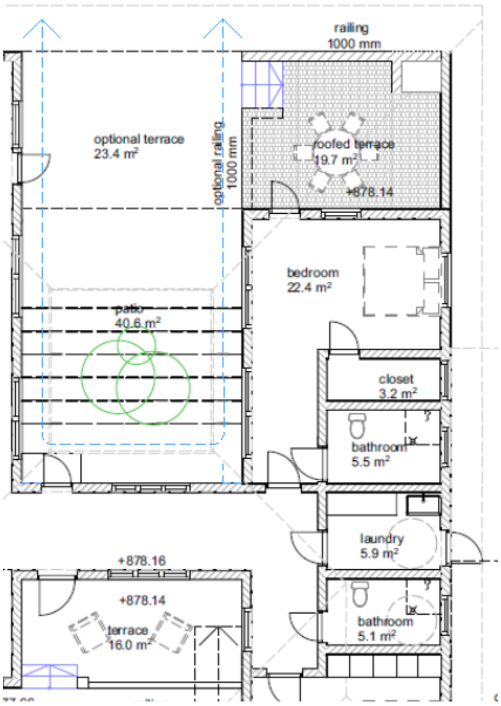
If glass windows are used, the windows should be double-glazed with a U-value of 3.0 W/m²K or less. This is optimal for hot and arid regions. The best type of window frame would be either vinyl or good quality, properly treated wooden frames. Aluminium-framed windows are not a good choice for hot climates, as the aluminium conducts heat more than wood or vinyl.

If glass windows are not an option, louvers made from good quality and treated wood could be used (picture 50). The main thing is that they should be able to open completely. Ideally the user should be able to adjust the amount of light coming from the louvers. Retractable mosquito screens should be inserted. A negative of using wooden louvers instead of glass windows is little or no noise insulation, and dust dispersion, which can be a problem in Same. Additional ventilation should be secured by adding ventilation openings on the walls; this is particularly important in the kitchen and in the bathrooms, to prevent built up moisture and mould growth. Ventilation openings should have insect screens installed in them.

PICTURE 50. A louver window. (Peakpx. N.d.)

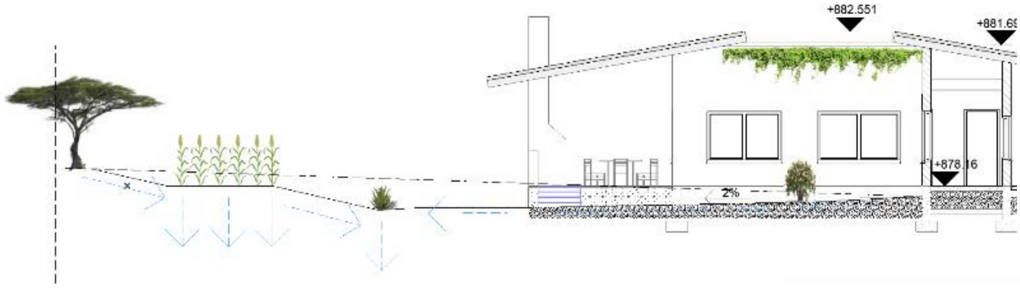
### 5.8. Patio and terraces

The 40.6 m$^2$ patio is located in the middle of the building It functions to separate the two wings, to increase cross ventilation and daylight throughout the building and to be utilised as a semi-private socialising space (picture 51). The patio is not roofed for the purpose of daylight. Beams can be added on the walls in order to hang shading and/or vegetation.




PICTURE 51. Detail showing the patio and terraces. (Mjema 2020)

The ground at the patio should be at least 300 mm lower than the building slab and it will have gutters on all sides from where rainwater will be directed east towards the absorption area (picture 52). The patio will be paved with natural local stones to prevent mud formation and promote rainwater absorption.




PICTURE 52. Detail of rainwater management at the patio. (Mjema 2020)

The terrace connected to the master bedroom can be made of concrete slab or from local stones, although local stones should be favoured for their lower embodied energy and locality. For accessibility, it should not be more than 20 mm lower than the building slab, meaning that the terrace is elevated from the ground. There is an outdoor grill with a chimney, which functions as a second kitchen.

If the owners wish, an extension of the terrace can be made so that the terrace reaches the living room. In this case, the extension should be made with plantation sourced treated timber, and be elevated in a similar fashion as the front terrace. The elevation ensures proper drainage of the patio.

The patio will be open towards the east and have views towards the mountain. If the owners wish, a tall, treated wooden gate can be placed at the eastern end of the patio to regulate breeze and privacy.

### 5.9. Building materials

The building materials used for constructing the building are materials which are found or can be made locally, there is know-how on how to build with them, and their use promote a healthy and comfortable indoor climate.

### 5.9.1 **Walls**

The walls will be made of stabilised soil blocks (SSBs), a modified version of the compressed earth block (CEB). Compressed earth blocks are a type of earth building techniques, the other ones being mud or adobe, and rammed earth. CEBs are created by compressing earth into steel, wood or aluminium forms by hand or mechanical compaction. They are versatile, as different substances can give them different qualities, and they can be made into several different types of shapes. Seismic reinforcement can be added by inserting rebar into hollow interlocking soil blocks. (Garg, Kamath, Yalawar & Vinay 2014)

#### 5.9.1.1. Compressed earth blocks, CEBs

Compressed earth blocks are made in a mechanical press, which forms a compressed block out of an appropriate mix of relatively dry inorganic soil, non-expansive clay and fine aggregates. (Garg et al. 2014) Soil, when compacted at an optimum moisture content, reaches maximum dry density, which is dependent on the energy input during compaction. (Gupta & Venkatarama. 2006) More pressure added increases the density and compressive strengths of the blocks (figure 1).

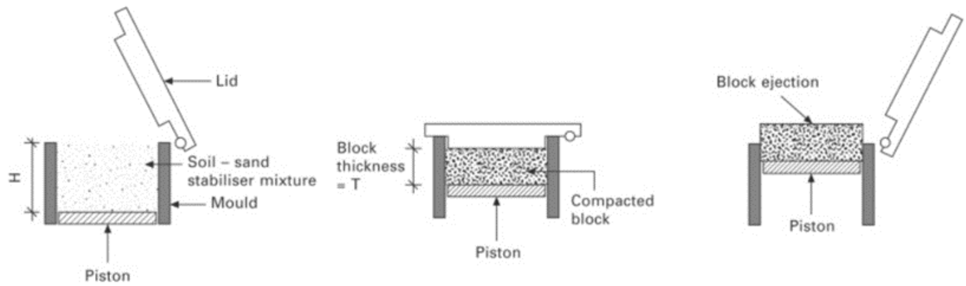



FIGURE 1. An illustration showing the various stages in the compaction process of a CEB (Khatib 2016)

CEBs as a wall material come with a lot of benefits. CEBs use less cement and up to 30% less quantity of water than the popular sandcrete blocks, which cuts back on carbon emission and the embodied energy of the house. In many cases CEBs are also cheaper than conventional building materials. In a study done in

Nigeria, CEB walls were found to be 33% cheaper than conventional cement-based walls. Adegun and Adedeji (2017) point out in their research that not enough life cycle cost analysis on CEB walls have been done to determine life cycle costs on such buildings. (Adegun & Adedeji 2017)

Compressed earth blocks have already been in use in Tanzania in private houses and in a few public projects, such as the Kibada project by the National Housing Company, and the completely off-grid Njoro children's library in Kilimanjaro (picture 53). Both projects used compressed earth blocks as the main construction material and utilised passive design in order to minimise heat gain. which produces affordable housing using interlocking bricks. According to Hydraform (2019), the Kibada project was completed for 30% less than the NHC's conventional brick and mortar building project. (Hydraform 2019; Design Indaba 2016)

PICTURE 53. The Njoro Children's library. (Design Indaba 2016)

#### 5.9.1.1.1. Stabilised soil blocks, SSBs

Stabilised soil blocks, or SSBs, are made similarly like CEBs, but stabilising agents are added to them. They are used in construction more than non-stabilised compressed earth blocks, as they have better construction properties. Stabilised soil blocks show greater resistance to extreme weather conditions and are more water resistant than non-stabilised blocks. Research done in Sudan showed that blocks with various quantities of lime as a stabiliser tested to be more durable than blocks which were not stabilised. (Adam 2001; Adegun & Adedeji 2017)

Possible stabilisers include Portland cement, lime, bitumen, gypsum, alkalis, sodium chloride, calcium chloride, aluminium compounds, silicates, resins, ammonium compounds, polymers, and agricultural and industrial wastes. According to Adam (2001), cement, lime and bitumen are commonly used as stabilisers in Third World Countries, due to their relative affordability and availability. Stabilisation of soils has shown to reduce the shrinkage and expansion of soils in various moisture conditions. (Adam 2001)

Cement is considered a good stabiliser for granular soils and can be used on a wide range of soil type. According to Adam (2001), The range of cement content needed for good stabilisation is between 3% and 18% by weight. According to Venkatarama Reddy & Gupta (2005), the best types of soils for producing soil-cement blocks are soils which have a sand content of over 65% and a clay fraction of 10%. It is uneconomical to use cement as a stabiliser for soils with high clay content because more cement would be required.

Lime combines with certain clay minerals to form cementitious compounds which bind the soil particles together. Lime has the property to reduce water absorption of clay, which improves its workability. Lime is a more suitable stabiliser for clay soils than cement. The National Building Research Agency (NBRA) of Tanzania suggests that soils which work best with lime are gravelly clay, sandy clay, silty clay, clayey gravel and clayey sand. Lime has low embodied energy and requires simple equipment to make, which makes its use as a stabiliser more appealing in low income areas. (Adam. 2001)

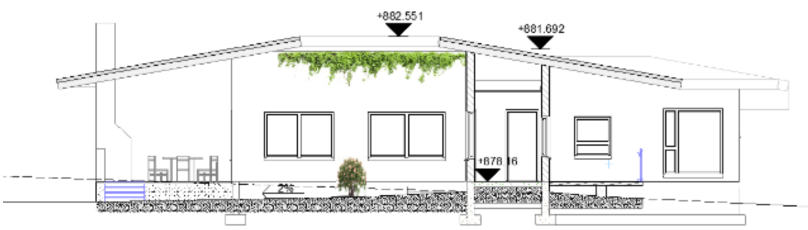
Bitumen can stabilise soil through a binding process, increasing strength in granular soils, or through acting as a water repellent. Small amounts of 2% to 6% of bitumen are enough to give soil cohesion. Too much bitumen can cause the bitumen to act as a lubricant and reduce strength. (Adam. 2001) Good soil types for bitumen stabilisation are sandy soils, whereas clays need large amounts of it for it to work as a stabilizer. Bitumen is not a traditionally used construction material in Africa as it is expensive to import, and heat can have an adverse effect on its binding properties.

#### 5.9.1.2. Application for Same

Field tests should be done in order to determine the soil type at Same, particularly at the Sterling neighbourhood. It was challenging pinpointing the exact soil type in Same, but through research, it can be assumed that the soil type is ferrisol. According to Niemelä (2011) ferrisols tend to have more siliconoxides, and hence more quartz, more kaoline and more clay material. They are usually also sandy with more than 60% sand and have topsoil organic matter of approximately 2-5 % (Young. 1976). Through what has been researched, one can suggest that lime be used as a stabilising agent because lime stabilisation works well on soils with high values of clay, and it is also manufactured in Tanzania. The silt and clay content as well as linear shrinkage all need to be properly verified in order to determine which stabilizer to use and how much.

### 5.9.2 The roof

The roof is shed-shaped and follows the outer walls as well as the terraces (picture 54). The roof shape thus mimics the popular hipped roof with a square cut out of it at the middle and hence blends well into the genius loci (picture 55). It is important that the roof is well ventilated for good thermal performance.




PICTURE 54. Cross section showing the roof structure. (Mjema 2020)

PICTURE 55. Aerial view of the plan. (Mjema 2020)

The most important requirement for the roof structure is that it provides adequate protection from the climate. In hot, dry climates, temperature differences require the roof to have high thermal mass. For example, if the roof is a lightweight metal roof, it is important that the ceiling is heavyweight in order to reduce heat radiation. Care should be taken that little solar heat passes through the roof structure into the living space below. Other requirements for a roof include strength to support its weight and external loads, it should be non-combustible, its supporting structure should have sufficient fire resistance, it should be durable, and it should be able to construct within the technical competence of the local building industry (Cook & Spence 1983).

To keep the roof cool, the following measures can be taken: have a reflective roof, add a radiant barrier, or add insulation into the roof structure (figure 2). (Parker 2003; Cook & Spence 1983). It is possible that all three measures can be used on the roof in Same, depending on the chosen roofing material.

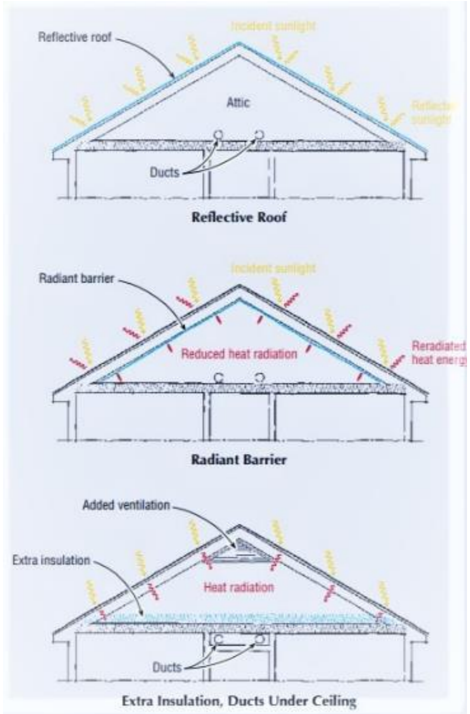



FIGURE 2. Ways which a roof can be kept cool. (Parker 2003)

According to Parker (2003), using a reflective material on the roof is the most simple and effective type of roof cooling. There are spectrally selective paints which reflect a significant amount of rays back into the atmosphere, but having a light coloured roof is more reliable in reflectiveness.

The basic radiant barrier is a layer of aluminium foil placed with its shiny side facing a clear air space (picture). The radiant barrier reradiates the heat back into the atmosphere and consequently the heat that would enter the attic space is reduced. (Parker 2003)

Having a ventilated attic space inside the roof decreases the heat load from the roof, especially if that space is insulated. Natural fibres such as hemp, sheep's wool, cotton, and straw could be used for roof insulation, however, considering Same's climate, sheep's wool would be the best insulator because of its relatively high fire resistance.

The best type of roof for minimal solar gain in Same would be a roof that has a reflective coating on the surface, a radiant barrier under it and a ventilated and insulated attic space. The simplest way to create a reflective roof coating is by painting the outer roof layer white. The roof coating, radiant barrier and overall roof structure should be checked and maintained regularly, in order to ensure the roof continues to function as a cool roof.

If the chosen roof material is thatch, it should be made more fire resistant by using an aluminium barrier foil under the thatch (a radiant barrier) or by spraying it with fire retardant spray. Care should be taken that the builders of the roof have a lot of know-how on building traditional thatch roofs.

Other possible roofing materials for Same are clay or concrete tiles. Clay tiles have less embodied energy than concrete tiles and technology for creating simpler and cheaper roof tiles has been created in Tanzania. A disadvantage of clay tiles is that they are a heavy roofing material and little know-how exists in building with them in rural Tanzania. (Cook and Spence 1983)

Corrugated and galvanised aluminium sheets should be the last material to be considered for roofing, as it has the most embodied energy. A reflective roof coating could still be painted on top, and other measures already discussed to keep the roof cool should be realised.

### 5.9.3 **Wall finishings**

The facades of the building are to blend in naturally to the surrounding nature, hence they should have a red tone to them. The red tone will not only help blend the building into its environment, but it will help reduce the appearance of red dust on the walls, something that white walls exasperate. Lime plaster can be used on both the exterior and interior of the building. Natural pigments can be added to the plaster to get the desired red tone (picture 56).

There are many advantages of using lime plaster on walls. Firstly, lime plaster is not affected by ultraviolet radiation from the sun, which affects synthetic paints. It also has high porosity, which means it “breathes” and prevents water entrapment in the wall structure. Lime plaster also does not have hazardous chemicals, which promotes healthy air quality. (Tadamun 2015)

PICTURE 56. The building’s western façade. (Mjema 2020)

## 5.10. Sanitation

The house will have septic tanks to support the two flushing bathrooms. To encourage self-reliance and sustainability, at least one composting dry latrine will be constructed outside in the storage building next to the carport and another composting latrine can be constructed next to the carport at the eastern plot entrance. It is recommended that the dry latrines be urine diversion dry toilets (UDDTs) with ventilated chambers.

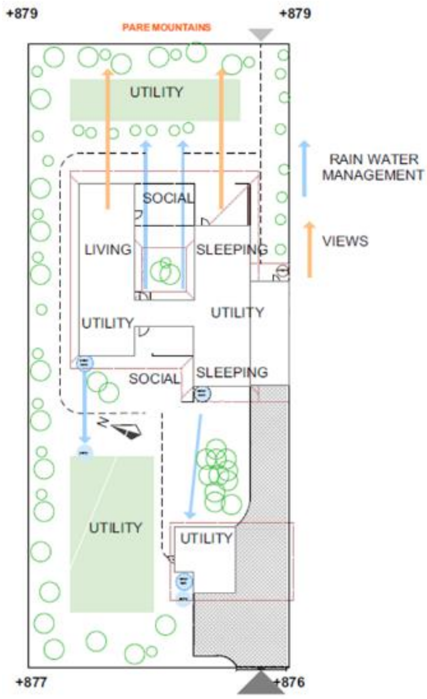
Separating urine from excrement brings many benefits. Firstly, urine can be used for the most part as is as a fertiliser. It can be spread undiluted to soil following the immediate watering of the plant with water, or it can be used diluted 3:1 or 10:1 with water. Any possible pathogens die more quickly in dry excrement, and runoff of pathogens and nutrients (e.g. nitrates) to the soil, ground water and surface waters reduces when urine and excrement are separated. (Huuhtanen & Laukkanen 2009)

Separating urine from excrement may also help reduce odour problems. Proper ventilation of both the chambers and toilet also aids in reducing odour. Painting the toilet blue inside and having insect screens in the openings will discourage fly presence. (Huuhtanen & Laukkanen 2009)

### 5.11. Rainwater management

The aim of rainwater management on the plot is to reduce flooding, mud formation and erosion, as well as protect the building from water damage. Rainwater runoff in the plot should be collected and used or drained into the ground. Roads on the plot should be paved by local natural stones so that the roads are water permeable and the water is drained to the ground. To promote self-reliance, rainwater runoff, when possible, should be used for indoor showers and toilets, and municipal water should be used as a secondary option. Grey water from showers and sinks can be stored in a surge tank, which can be then used to irrigate gardens and used for flushing the toilets. It is important that biodegradable soaps be used by habitants, in order to prevent waterways from being polluted by excess phosphates and harmful chemicals.

Rainwater runoff will be collected from the roofs and stored in tanks on the western side of the building (picture 57). The type of tanks chosen for rainwater storage can be surface tanks or subsurface cisterns, which are partly underground. Subsurface cisterns are generally cheaper than surface tanks and require little or no space above ground. The tanks will be connected to piping from which water will be able to flow to the western crops, which are at lower elevation. There will be a storage tank and a pump next to the farmland. Crops chosen for the western farmland should be crops which require more water than crops on the eastern farmland, as the western farmland will receive more rainwater runoff. Rainwater runoff is better for irrigation than piped water because of the lack of chlorination in rainwater. The possibility of using drip irrigation on the crops – subsurface irrigation where plants can obtain water slowly from the roots – should be considered, as drip irrigation has the possibility to save more water and nutrients. A dry toilet and an outdoor shower can be built adjacent to the western carport, which will both utilise water collected from the rain. The outdoor shower will not be connected to the municipal water supply, but rather, it will utilise solely rainwater. A water tank and a pump will be adjacent to the toilet for hygiene. Eco-friendly technologies, such as photovoltaic batteries or natural solar radiation, should be favoured in heating both indoor and outdoor showers.




PICTURE 57. Plot functions showing rainwater management. (Mjema 2020)

Nearly all roof surfaces are fine for rainwater harvesting. The gutters should have gutter protection screening in order to keep large debris from entering the gutters, and a tank screen, which helps keep mosquitoes and pests out, can be installed on the tank entry point. Copper and lead can be harmful in rainwater harvesting, so care should be taken that these metals do not appear in the harvesting system.

### 5.11.1 Rainwater harvesting calculations

If we take the amount of 27 litres a day, the minimum amount of water needed per person per day for bathing, cooking and laundry (WHO 2017), and set the number of occupants to 4, then the total amount of water needed for the house per year can be calculated with the following formula

$$\textit{Demand} = \textit{Water use} \times \textit{Household members} \times \textit{365 days} \qquad (1)$$

The yearly water demand can be calculated using formula (1)

$$27 \times 4 \times 365 = 39\,420 \text{ litres a year} = 39 \text{ m}^3$$

The demand for water of four people for one year is 39 $m^3$, which means that the demand per month is 39 420/12 = 3 285 l/month.

It is highly unlikely that the house will be in use the whole year. It is more likely that the house will be in use at most 8 months of the year. If the amount of 8 months is chosen, then the demand for water for 4 people for 8 months is

$$\text{Demand for 8 months} = 3\ 285\ \text{l/month} \times 8 = 26\ 280\ m^3$$

The water obtainable from rainwater harvesting can be
calculated through the following formula

$$\textit{Supply} = \textit{Rainfall} \times \textit{Catchment area} \times \textit{Runoff coefficient} \qquad (2)$$

The measured catchment area is 387 $m^2$. Metal runoff coefficient is 0.95 (Edström & Nyman 2017) and the yearly means of rainfall in Moshi (107 km from Same) is 970 mm/year (Fitzpatrick 2015)

The theoretical supply through rainwater harvesting thus is

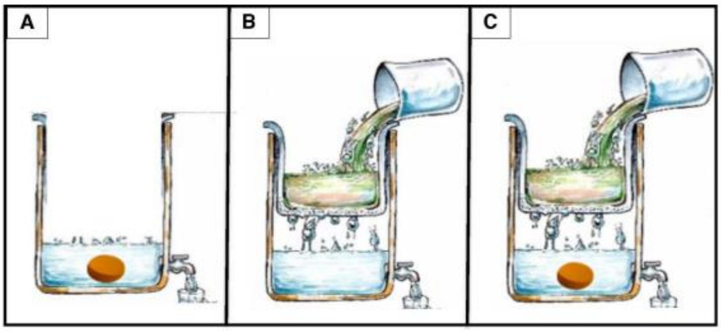
$$0.95 \times 387 \times 0.97 = 357\ m^3/\text{year}$$

357 $m^3$ of rainwater a year is what in theory can be harvested. This is 318 $m^3$ more than the estimated required value of 39 $m^3$. The excess water will be stored, used for irrigation and can be drained in catchment areas. Further calculations will have to be done to determine the total amount of water tanks that will be needed on the plot.

### 5.11.2 Water purification methods

Clean water technologies such as ceramic water filters and UV light treatment can be used to make harvested rainwater drinkable. Ceramic filters remove bacteria and parasites physically through their small pores. They can also effectively reduce bacteria through inactivation when combined with colloidal silver (in the form of silver-embedded ceramic tablets), which is an effective microbial disinfectant. Ceramic water filters are lightweight, convenient and effective, and can be made using locally available materials and labour. They also retain the natural taste and odour of water. (Morris et al. 2013)

According to Morris et al. (2013), the most effective purification method is the filter-tablet combination, where the water is passed through a ceramic filter, and then the water undergoes further purification through a silver-embedded ceramic tablet (picture 58). The use of ceramic water filters, and silver-embedded ceramic tablets by themselves are also good purification methods when only one method is available.




PICTURE 58. Different types of ceramic-based purification methods. A) Silver-embedded ceramic tablet. B) Ceramic water filter. C) Ceramic water filter with silver embedded ceramic tablet. (Morris et al. 2013)

## 5.12. Energy

To promote self-reliance, green energy should be used as much as possible. Solar panels will be placed on the roof, and lithium-ion batteries will store the energy. Suitable inclination for the solar panels to maximise the incident of radiation is 4°.

A modern induction stove will be situated in the kitchen. There is a grill with a chimney on the terrace, which acts as a secondary kitchen and can be used if there are electricity interruptions. If electricity is not available for cooking, then the use of improved cook stoves is encouraged. Improved cook stoves can use different types of biomass such as crop residue, animal waste, or small sticks. Many improved cooking stoves use solar powered batteries and due to their technology are virtually smokeless (picture 59). (AZO Cleantech 2020)

Instead of using charcoal and firewood, the use of alternative and more environmentally friendly fuels such as briquettes should be favoured. Briquettes are made by compacted biomass waste with a binder such as clay. They also burn longer than traditional wood fuels. (AZO Cleantech 2020)

PICTURE 59. A solar powered improved stove. (Africa Clean Energy 2020)

### 5.13. Vegetation

Different types of crops should be grown on the plot, in order to promote healthy soil and reduce erosion. A plethora of different crops can be grown in the Kilimanjaro region; fruit, spices as well as starch rich foods like potatoes and maize can be grown along legumes and peanuts. Fertiliser acquired from the dry toilets can be used on the crops, and growing legumes and peanuts improve the nitrogen content in soil. (Niemelä 2011)

Traditionally grown crops in Same, such as sorghum and millet, will be grown in the plot. These crops were traditionally grown in Kilimanjaro before being replaced with maize. Sorghum and millet are more economical than maize, as they need less water to grow, and hence should be favoured. (Spence & Cooke 1983). Fertile ground and a lot of sun exposure is needed for sorghum to grow. Sorghum is a practical crop to grow because it is self-fertile and does not need large plot for pollination, but care should be taken that the soil remains well fertilised. (My farmlife, 2019).

It is important that locally occurring trees and vegetation be planted on the plot to prevent soil erosion and reduce dust formation. Trees such as acacia and bush-willow should be planted particularly near the western and eastern facades to work as an auxiliary heat barrier. Green fences made from vegetation should be favoured instead of constructed ones in order to promote thermal comfort and to function as a rainwater catchment area.

## DISCUSSION

The objective of this thesis was to design a house in Same, Tanzania. The design had to tackle heat, dust, wind and soil erosion, and fit into the arid landscape of Same. The design is made of two wings with a patio in the middle. The building has an open concept kitchen and living room, two bedrooms, a laundry room, two bathrooms, and a room which can function as both a work room and bedroom. The master bedroom opens up to a terrace, which can be extended to the living room, creating a large outdoor space along with the patio. Additionally, two urine diversion dry toilets are recommended to be built next to the carports, and a rain-water utilising outdoor shower can be built at the lower side of the plot. The building has an area of $130m^2$ and a total area $202m^2$, with auxiliary structures.

Special attention was given to preventing solar radiation from entering the building by considering the sun's orientation when deciding the house's shape, allocating rooms, choosing right materials for the walls and roof, and paying attention to adequate ventilation. Having two wings increases functionality, light and ventilation of the building, but also helps lessen solar load on the walls by keeping eastern and western facades at a minimum. The allocation of the kitchen and living space to the north and the bedrooms to the south means that they will receive the least amount of solar radiation during the time they are mostly in use. The Pare mountains being on the east created a hurdle when allocating certain rooms; since the view must be seen from the living room, part of the living room's façade and openings had to be facing east. Solar radiation in the living room is minimised by having the eastern windows narrower and higher up on the wall and by having longer roof overhangs. The view can be seen from the master bedroom as well, but the terrace in front of it acts as a large roof overhang. The two other bedrooms were allocated to the west so that both rooms could have openings to at least two directions, even though their western locations increase the risk of higher evening temperatures. However, because of the openings, occupants can regulate ventilation according to their need.

The walls of the building can be made from lime stabilised soil blocks, which are compressed earth blocks with lime added for improved durability. A good quality compressed earth block is a durable, environmentally friendly, recyclable, and economical construction material which has less embodied energy than its industrial counterparts. Lime could be used as a stabilising agent for the blocks if the soil type in Same is the suspected ferrisol, however, field tests need to be done to verify this. Lime works as a good stabilising agent with soils with a high clay content like ferrisol. The facades of the building will be plastered with red toned pigmented lime plaster in order to help the building blend into the surrounding environment, and to reduce the appearance of red dust on the walls. Lime plaster also does not have hazardous chemicals and it promotes healthy air quality due to its high porosity.

The roof is shed-shaped and follows the outer walls and terraces. The patio is not roofed, giving the structure the appearance of the common hipped roof, which blends well into the genius loci of Same. The solar load on the roof can be reduced by having a reflective coating on the surface, a radiant barrier under it and a ventilated and insulated attic space. All three methods work together to reduce the amount of solar radiation entering the building. Sheep’s wool can be a good choice for insulation if industrial materials are not an option, due to its relatively high fire resistance.

Options for the roofing material are thatch, clay or concrete tiles and galvanised aluminium. Thatch is not necessarily the most environmentally friendly roof choice, since it would have to be made more fire resistant by using a radiant barrier under it or by spraying it with a fire retardant spray, both methods increasing the roof’s embodied energy. The benefits of a thatched roof are that it can be made from many different materials, it is a quiet roof structure and a poor heat conductor. Tiles are a heavy roofing material and little know-how exists in building with them in rural Tanzania, but if chosen, clay tiles have less embodied energy than concrete ones. Aluminium sheets should be the last material to be considered for roofing, as they have the most embodied energy out of all the other possible roofing materials, they perform poorly thermally, and they have the risk of rusting. Nonetheless, aluminium sheets are relatively economical and easily accessible in Same. Whichever roofing material is chosen, care should be taken that the roof structure is checked and maintained regularly, in order to ensure the roof continues to function as a cool roof.

The building will be connected to grid electricity, but green energy and technology should be used as much as possible. The collection, storage and use of solar energy is recommended. The kitchen will have an induction stove but an outdoor oven at the terrace can function as a secondary kitchen during electricity interruptions. If a cooking stove is used during said interruptions, it is recommended that it be an improved cooking stove, since they are virtually smokeless and can use different types of biowaste as fuel.

It is important that rainwater runoff at the plot be properly planned in order to reduce flooding, mud formation and erosion, and protect the building from water damage. The building’s floor slab and terraces should be adequately elevated off the ground to prevent water from damaging any building structures. Rainwater will be collected from the roofs, stored, and should be used for drinking, irrigation and showering before municipal water. When used for drinking, the collected water should be purified first by ceramic water filters or by other water purification methods. The grey water from showers and sinks can be stored and used for irrigation and for flushing the toilets. The roads and paths at the plot should be paved with local natural stones so that they are water permeable. Paving the roads will not only prevent mud formation, but also reduce dust on drier days.

Traditional crops grown in Kilimanjaro like sorghum and millet should be grown at the plot since they require less water to grow compared to other popular crops, but varying crops should be grown together in order to reduce soil erosion. Fertiliser acquired from the dry toilets can be used on crops as well as on non-food plants. It is important that locally occurring trees and vegetation such as Acacia and bushwillow be planted on the plot to prevent soil erosion and to reduce dust. A green fence should be favoured over a constructed one to promote thermal comfort and to reduce rainwater runoff.

The building and plot have been designed with simple green technologies in order to make the building function as off-grid as possible. The chosen technologies should be simple enough for builders of varying skill to implement. With the exception of compressed earth blocks, the green technologies suggested in this thesis have been in use in Same for quite some time and their long-term benefits are known. There are no national standards for building with earthen materials in Tanzania and building with compressed earth blocks is a relatively new phenomenon, hence not much research has been done on long-term cost savings of compressed earth block construction. However, the fact that earth blocks perform better thermally than concrete blocks make them a more desirable construction material for the building. It is important to mention that even if sandcrete blocks are chosen as a construction material, making other structures cool in the ways suggested in this thesis could still make the building thermally comfortable.

This thesis functions as a preliminary plan and civil engineers should be consulted for further planning before starting the building process. Tests should be done on the plot to determine certain factors such as soil type and groundwater depth before building. Calculations of obtainable rainwater at Same were made using Moshi’s rain chart and the value can change if an up to date rain chart for Same is obtained and used. It is important to keep in mind that sustainable user behaviour is essential for the building to function off-grid, along with proper and regular maintenance of all structures. Proper maintenance will make it possible to examine the long-term sustainability performance of the building.

## REFERENCES

Adam, E. A. 2001. Compressed Stabilised Earth Block Manufacture in Sudan. Graphoprint for the United Nations Educational, Scientific and Cultural Organization.

Adegun, O. B & Adedeji, Y. M. D. 2017. Review of economic and environmental benefits of earthen materials for housing in Africa. Frontiers of Architectural Research 6 (4), 519-528.

AZO Cleantech. 2020. African Clean Energy's Off-Grid Solar Power Technology Online article. 11.05.2020. Printed. 11.09.2020. https://www.azocleantech.com/article.aspx?ArticleID=1088

Block, M. & Bokalders, V. 2010. The whole building handbook: how to design healthy, efficient and sustainable buildings. Earthscan.

Craven, J. Updated on 30.05.2019. The Cob House — Sturdy Mud Architecture Simple Earth Architecture, Traditional Results. Online article. Printed on 17.08.2020. . https://www.thoughtco.com/what-is-a-cob-house-177944

Economic profile Tanzania: Doing business 2020. Report. World Bank Group. https://www.doingbusiness.org/content/dam/doingBusiness/country/t/tanzania/TZA.pdf

Edström, F. & Nyman, J. 2016. Proposal for a self-sufficient child care center. Master Programme in Architectural Engineering. Luleå University of Technology. Master thesis.

Elleh, N. 1997. African Architecture. New York: McGraw-Hill.

Fitzpatrick, M. 2015. Tanzania. Lonely Planet.

Held, C., Jacovelli, P., Techel, G., Nutto, L., Wathum, G. & Wittmann, N. 2017. Tanzanian Wood Product Market Study. Report. Forestry Development Trust.

Hydraform. 2019. Delivering En Masse Green Housing. Online article. Read on 01.08.2020. https://hydraform.com/portfolio/delivering-en-masse-green-housing/

Isaksson, R., Kinabo, L., Maganga, J., Minja, S. & Sabai, S. 2016. Relevance, consequences and change needs of the current Tanzania Concrete Bricks and Blocks standard TZS 283:2002. 2nd International Conference on Advances in Cement and Concrete Technology in Africa.

Isaksson, R. & Mrema, A. L. 2016. Cement Performance in Sand Cement Blocks – A Case Study from Dar es Salaam, Tanzania. Article. Advances in Cement and Concrete Technology in Africa (ACCTA) conference 27-29.01.2016. Dar es Salaam.

Jeanette Banobi. 2018. Building Blocks. Online article. Released on 20.10.2018. Read on 01.11.2020. https://coretanzania.org/building-blocks/

Kilimanjaro region investment guide. 2018. The United Republic of Tanzania president's office, regional administration and local government. Kilimanjaro region. http://www.kilimanjaro.go.tz/storage/app/media/uploaded-files/Kilimanjaro_Investement_Guide_2018.pdf

Lufingo, M. 2019. Public Water Supply and Sanitation Authorities for Strategic Sustainable Domestic Water Management. A Case of Iringa Region In Tanzania. Multidisciplinary Science Journal 2 (4), 449-466.

Lusambo, L. 2016. Household Energy Consumption Patterns in Tanzania. Journal of Ecosystem & Ecography 5 (7).

Makenya, A. R. 2018. Assessment of Production and Quality of Concrete Blocks in Dares Salaam, Tanzania. International Research Journal of Engineering and Technology 05 (03), 375.

Matroos, J. Design Indaba. 2016. Off-grid library encourages education in remote Tanzania. Online article. http://www.designindaba.com/articles/creative-work/grid-library-encourages-education-remote-tanzania

Moriarty, P. 1980. The Case for Traditional Housing in Tropical Africa. Habitat International 4 (3), 285-290.

Niemelä, T. 2011. Vihreä Afrikka: kasveja ja kasvillisuutta. Botanical Museum.

Nkonya, L. K. 2010. Realizing the Human Right to Water in Tanzania. Human Rights Brief 17 (3), 25-30.

Parker, D. 2003. Article. Cool roofs for hot climates. SOLEC Solar Energy Corporation. https://www.solec.org/wp-content/uploads/2015/05/Cool-Roofs-for-Hot-Climates.pdf

Sanga, S. 2017. The Impact of Traditional House-type on Rental Values in Kinondoni Municipality. Nordic Journal of Surveying and Real Estate Research 12 (1), 7–37.

Senzia, M. 2011. Case study of sustainable sanitation projects, UDDTs for teachers at a primary school Arusha, Tanzania. Sustainable Sanitation Alliance.

Tadamun. 2015. Practical Solutions, Lime as a Sustainable Alternative in Building. Online article. Released on 05.05.2015. Printed on 20.08.2020 http://www.tadamun.co/lime/?lang=en

Tanzania Invest. Tanzania energy. n.d. Read on 10.08.2020. https://www.tanzaniainvest.com/energy

Thomas, J., Holbro, N., Young D. 2013. A review of sanitation and hygiene in Tanzania. Report. MSABI NGO.

Wong, N.H., Li, S. A study of the effectiveness of passive climate control in naturally ventilated residential buildings in Singapore. Building and Environment 42 (3),1395-1405.

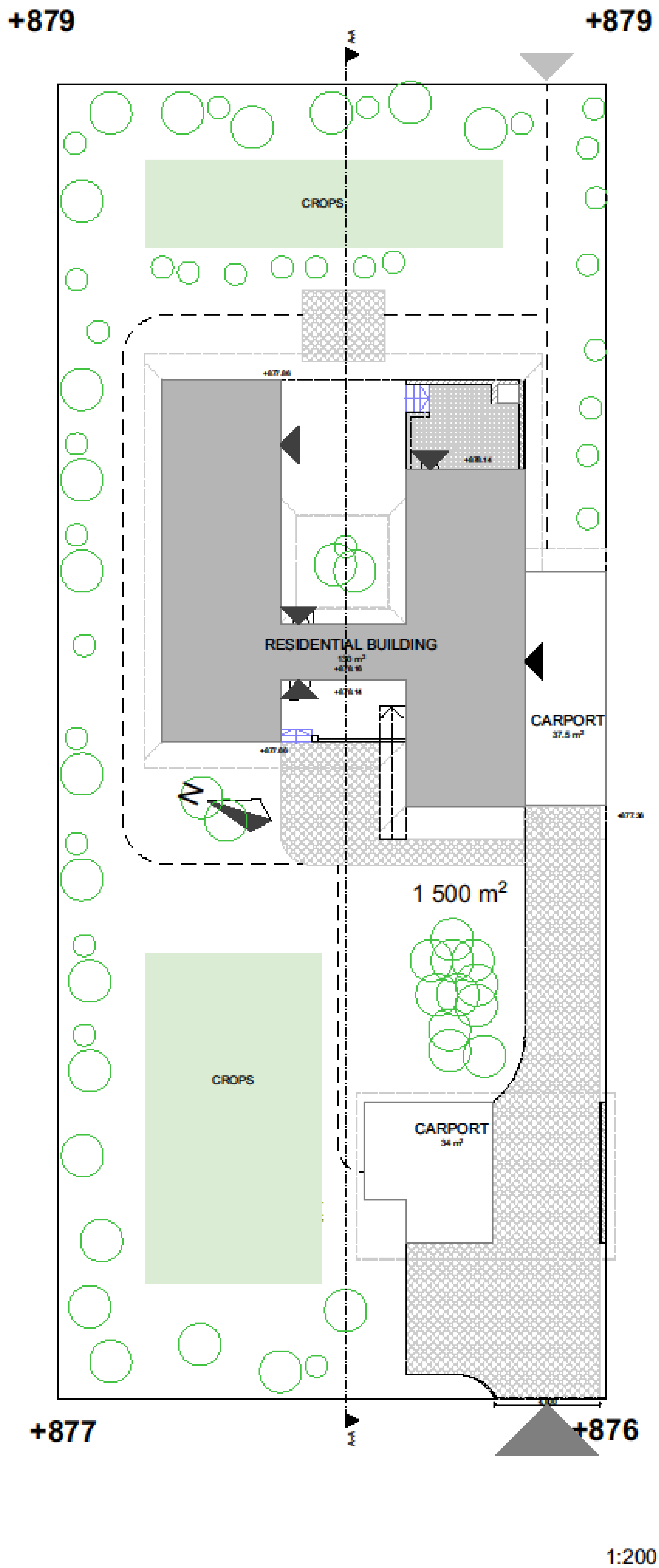
World Health Organisation. 2017. Guidelines for drinking-water quality. 4th edition.

WWF. 2012. Suomen vesijalanjälki, Globaali kuva suomalaisten vedenkulutuksesta. Report. Printed on 20.08.2020. https://wwf.fi/app/uploads/z/i/y/t2zi2zza3jpxr44qvrk5e2d/vesijalanjaelkiraportti_final.pdf

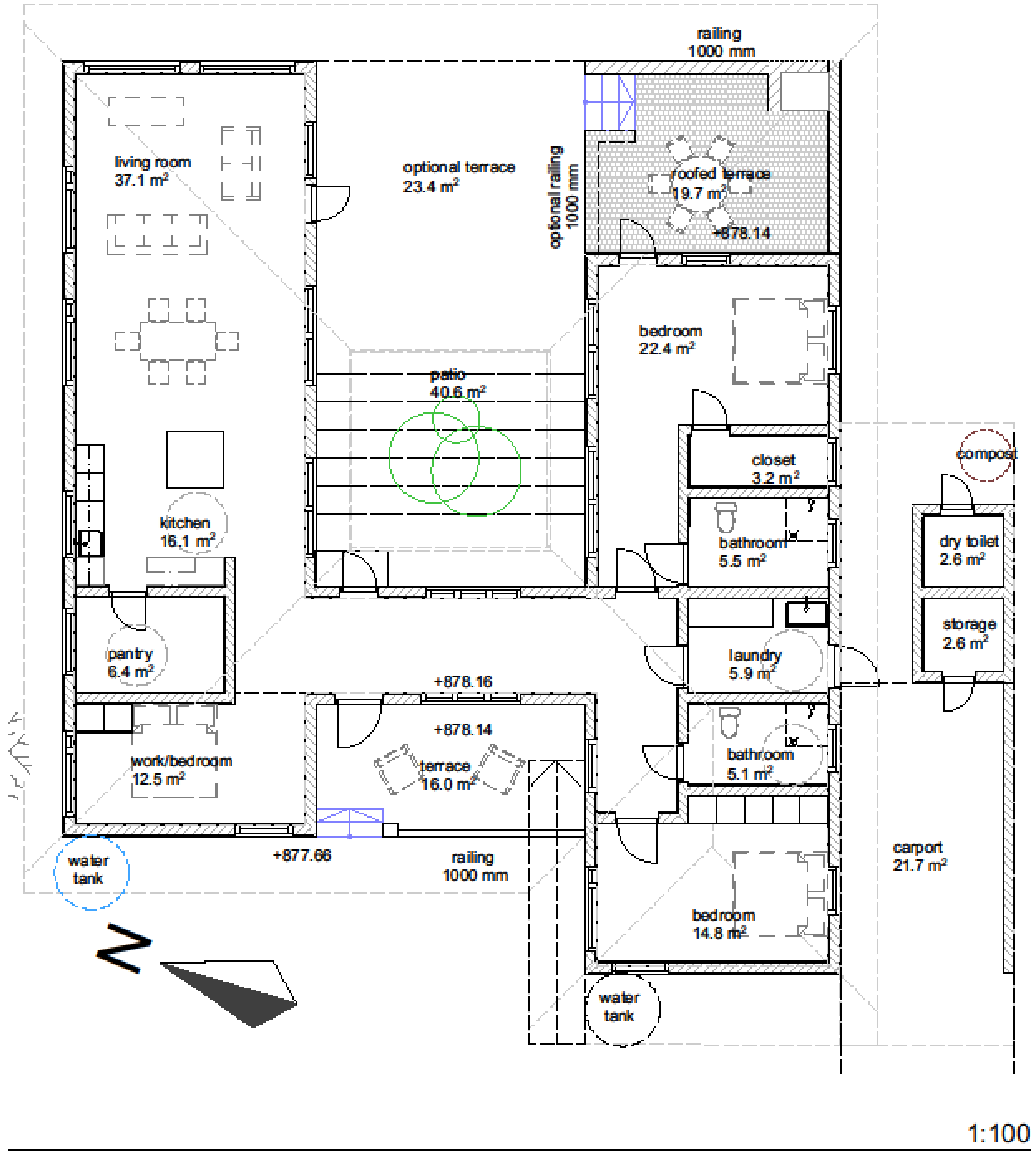
Wynne-Jones, S. 2013. The public life of the Swahili stonehouse, 14th–15th centuries AD. Journal of Anthropological Archaeology 32 (2013), 759-773.

**APPENDICES**

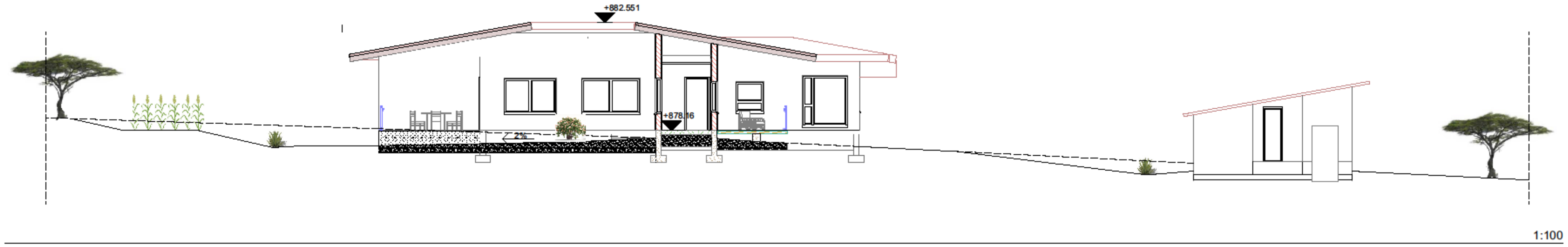
Appendix 1. Master plan



Appendix 2. Floor plan

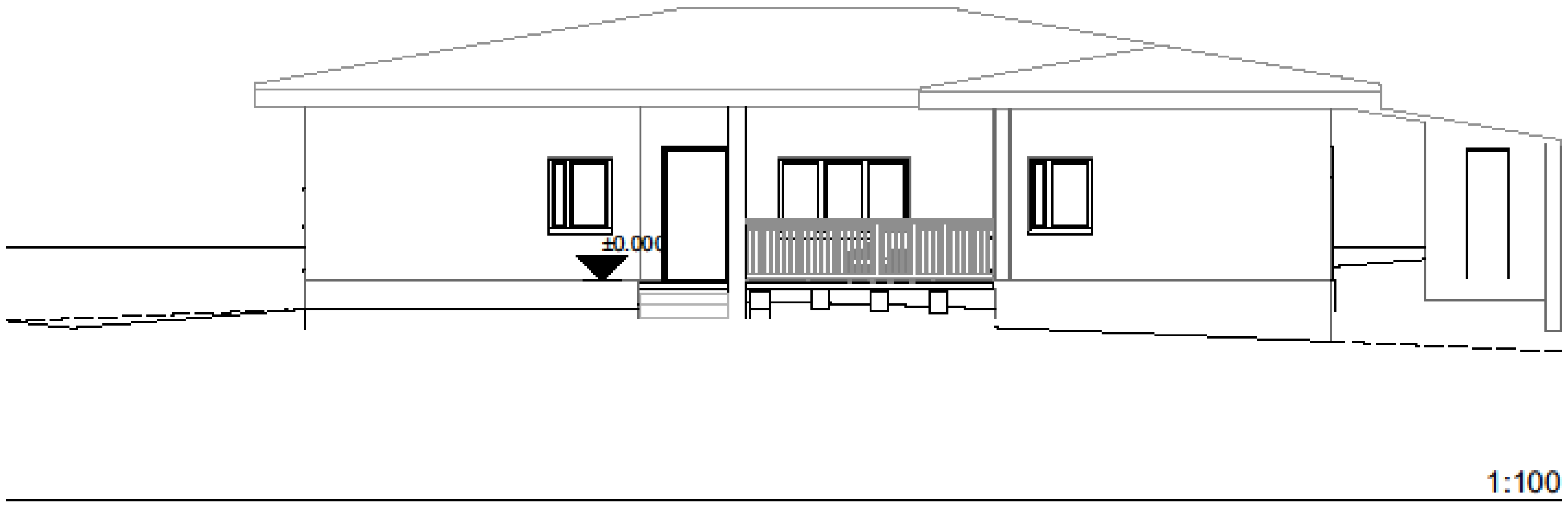


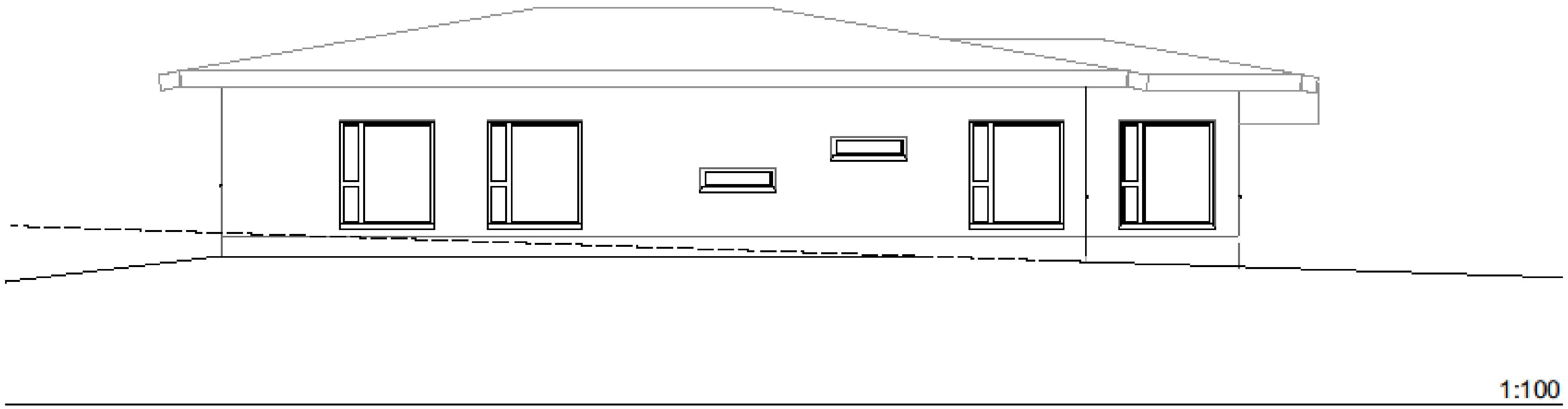
Appendix 3. Section A-A



Appendix 4. North and west facades

`



Appendix 5. East facade