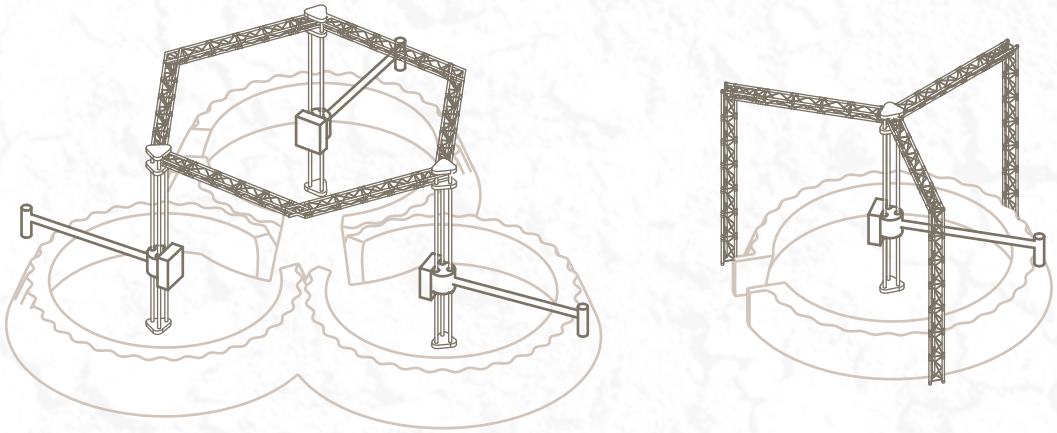
Exploring the Potential of 3D Printing Construction to Address Housing Issues for South Sudanese Refugees

Kyle O'Brien Quinn



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EXPLORING THE POTENTIAL OF 3D PRINTING CONSTRUCTION TO ADDRESS HOUSING ISSUES FOR SOUTH SUDANESE REFUGEES

KYLE O'BRIEN QUINN

ABSTRACT

South Sudan currently has the third largest refugee crisis around the globe, with over 3.7 million people being displaced from their homes due to ethnic and political civil war. Over 2 million of these refugees have been displaced from their home country, seeking asylum in refugee settlements that neighbor South Sudan.

One of the most important needs within these settlements is adequate housing. Through polling and census data, it has been found that more than half of the refugees are living in dilapidated housing conditions, without any resources to make repairs. The average amount of time spent within these settlements is over a decade and is increasingly getting worse as more refugees enter these settlements.

Due to the exponential technological advancements in 3D additive printing technology, using this form of construction could potentially address a situation within a refugee settlement. 3D additive technology could provide benefits due to its ability to produce housing units at a high rate, its ability to use clay aggregate soil as construction material, mimicking adobe brick housing found in Africa, and the ability to lower the need for labor within these settlements.

This thesis will explore the idea of employing this technology within a refugee settlement, to test if it can appropriately balance the implementation of a high tech 21st century technology with the historic and cultural vernacular architecture found regionally throughout Africa.

EXPLORING THE POTENTIAL OF 3D PRINTING CONSTRUCTION TO ADDRESS HOUSING ISSUES FOR SOUTH SUDANESE REFUGEES

KYLE O'BRIEN QUINN

GENERAL AUDIENCE ABSTRACT

The country of South Sudan currently is experiencing the third largest refugee crisis around the globe. Over 2.5 million refugees have fled their home country of South Sudan and are entering refugee settlements from neighboring countries. Due to the exponential increasing rate of refugees within these settlements, issues such as overcrowding and inadequate housing are afflicting the lives of everyone here.

Typical houses in South Sudan consist of mud and adobe brick material known as "tukul huts". While these huts have remained the leading housing type for the past 2,000 years, these houses where not intended for addressing the common refugee crisis we are experience today. These huts require the period of months to construct and extensive physical labor. Given that the refugees are entering these settlements at an exponential rate, it is ineffective to approach housing construction in a traditional manner due to the time and effort it requires to keep up with the high demand.

A possible way to address this concern, is by looking at other construction practices that could potentially supplement the traditional forms of erecting houses. Construction technology has advanced to the point where 3D printers can create life size structures that provide housing to individuals.

This thesis explores the idea of employing 3D printers into a refugee settlement, to see if it can adequately produce houses that provide shelter for the incoming refugees.

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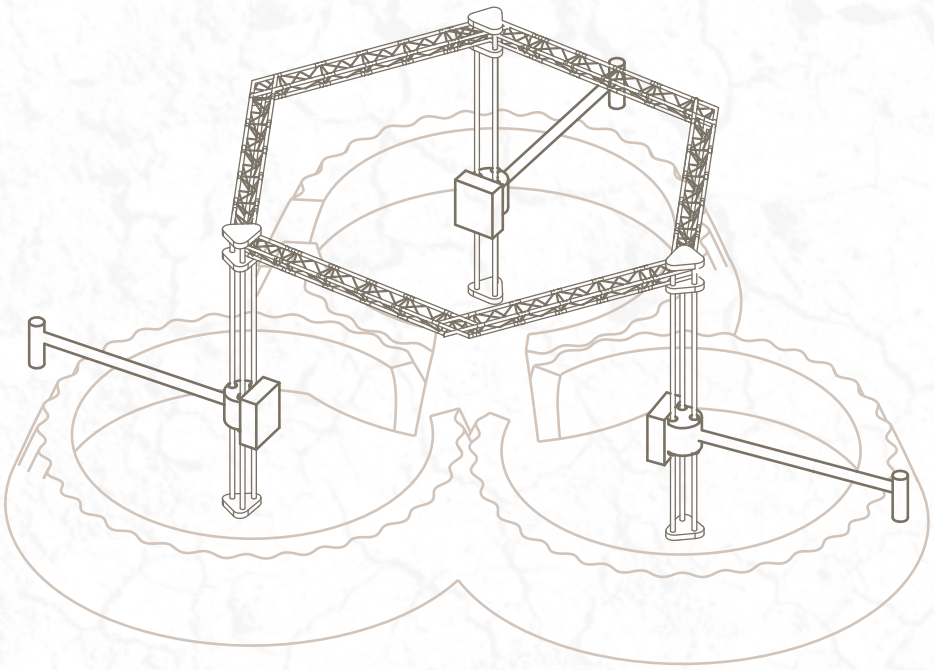

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Fig.1 Mackenzie Knowles, “Freedom, 3, stands on the chasis of an old United Nations vehicle in the Malakal PoC.”

Conceptualize a world where the necessity for adequate shelter could be obtainable to everyone in impoverished regions around the world, such as refugee settlements that experience common issues of overcrowding and material scarcity. Imagine a world where insufficient funds will not limit one's access to living in safety, and most importantly, where the most vulnerable can obtain the resources they need to live in safety without being a hindrance to others around them.

Unfortunately, due to the technological limitations within current construction practices, this vision has yet to become reality. For this to be changed, construction needs to technologically advance to a point where it can become more accessible and inexpensive to manufacture in challenging environments.

However, due to the recent exponential development within 3D printed construction, this conceptualized vision may become plausible in the foreseeable future.

This is Alana. He was once a successful farmer in his former life. He was forced to leave his home country, South Sudan, to preserve his own safety from Civil War. For more than a year, he has been living in a small leaky tent, and because his shoulder is dislocated, he lacks the energy to make repairs. He is constantly worried about his future and does not feel safe living in the conditions he is currently in [1].

Fig.2 Tommy Trenchard, “Alana John, 53, has lived in this tiny, leaking tent for over a year.”

Fig.3

Fig.4

Sadly, Alana's story is not isolated, but mirrors the life of many refugees escaping from their home country, South Sudan. The pictures above offer only a glimpse of what it is like to be a South Sudanese refugee within a resettlement camp. The magnitude of insufficient living conditions is appalling, as these people here struggle to find and use the resources to build what is needed to live safely. To make matters worse, hundreds of thousands of victims are continuously fleeing to these settlements ever year, making the housing crisis exponentially worse. These refugee settlements should provide a base line of security for the victims that seek refuge here but are unable to because of these prominent issues.

Fig.3 Sophie Casimes, "Impoverished Refugees."
Fig.4 Department for World Service, "South Sudanese seek refuge at the UNMISS IDP camp in Bentiu, 9 Jan. 2014."

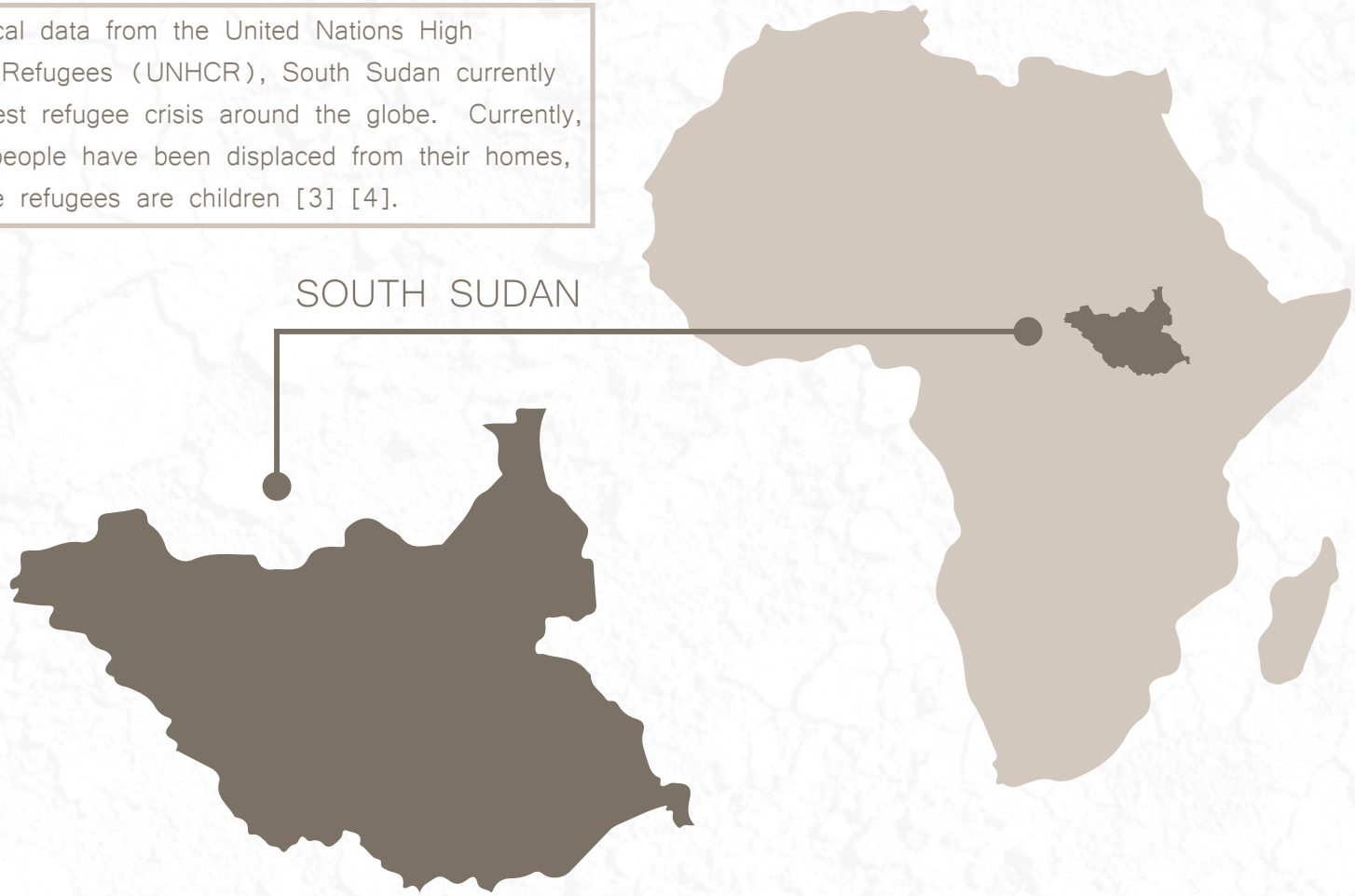
Fig.5

Fig.6

A survey cited from the REACH Initiative states that one of the three most important needs within common refugee settlements are for better access to acceptable housing conditions. Within these zones, substandard shelter stems from the lack of funds, access to construction resources, or shortages in refugees that are able to contribute to construction labor [2]. These problems continue to worsen as more immigrants establish themselves into these settlements.

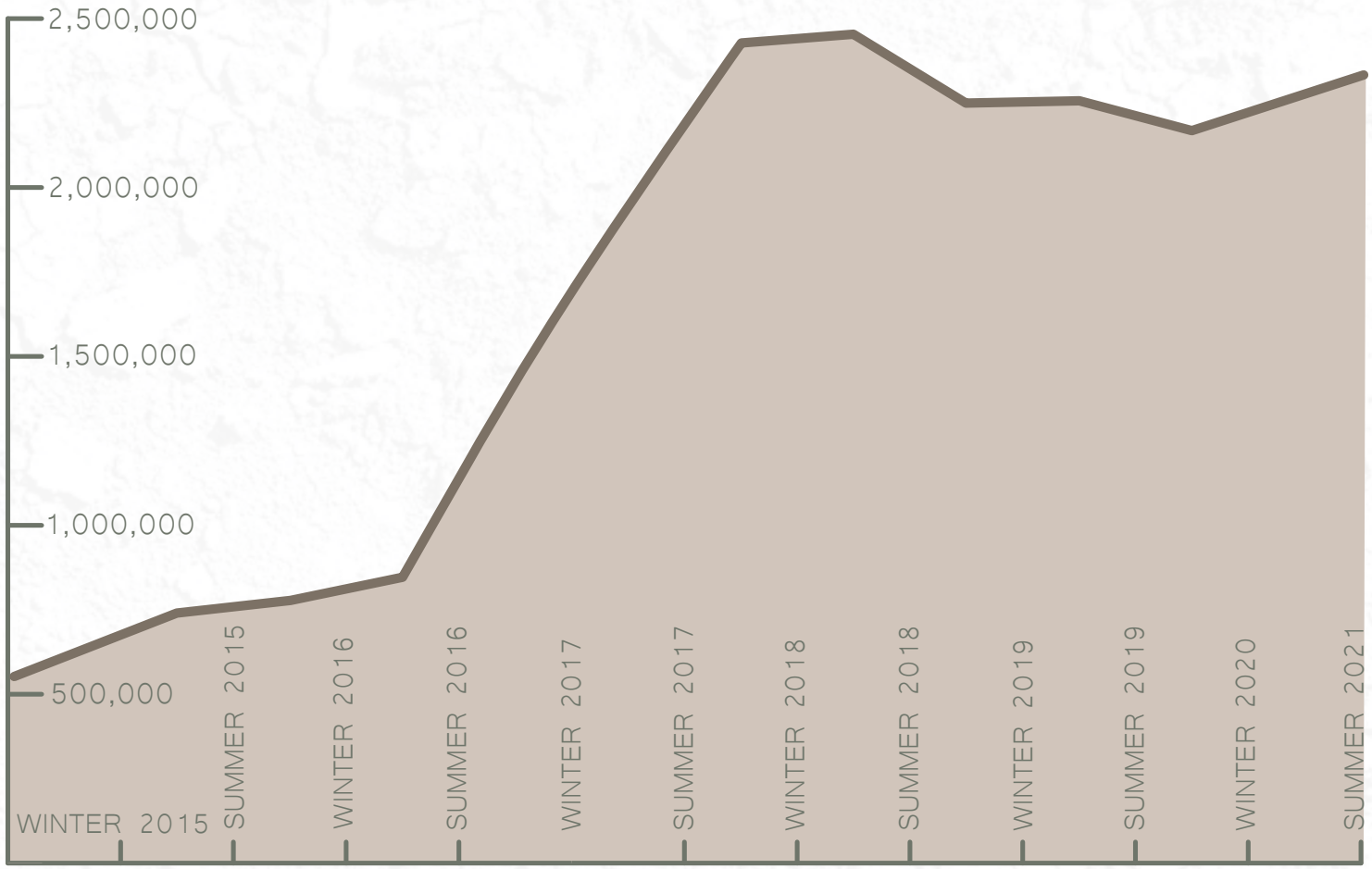
Fig.5 World Vision, “Poor housing conditions in the Bidi Bidi refugee settlement.”
Fig.6 Jack Taylor, “Kyangwali Refugee Settlement and Reception Centre in Uganda.”

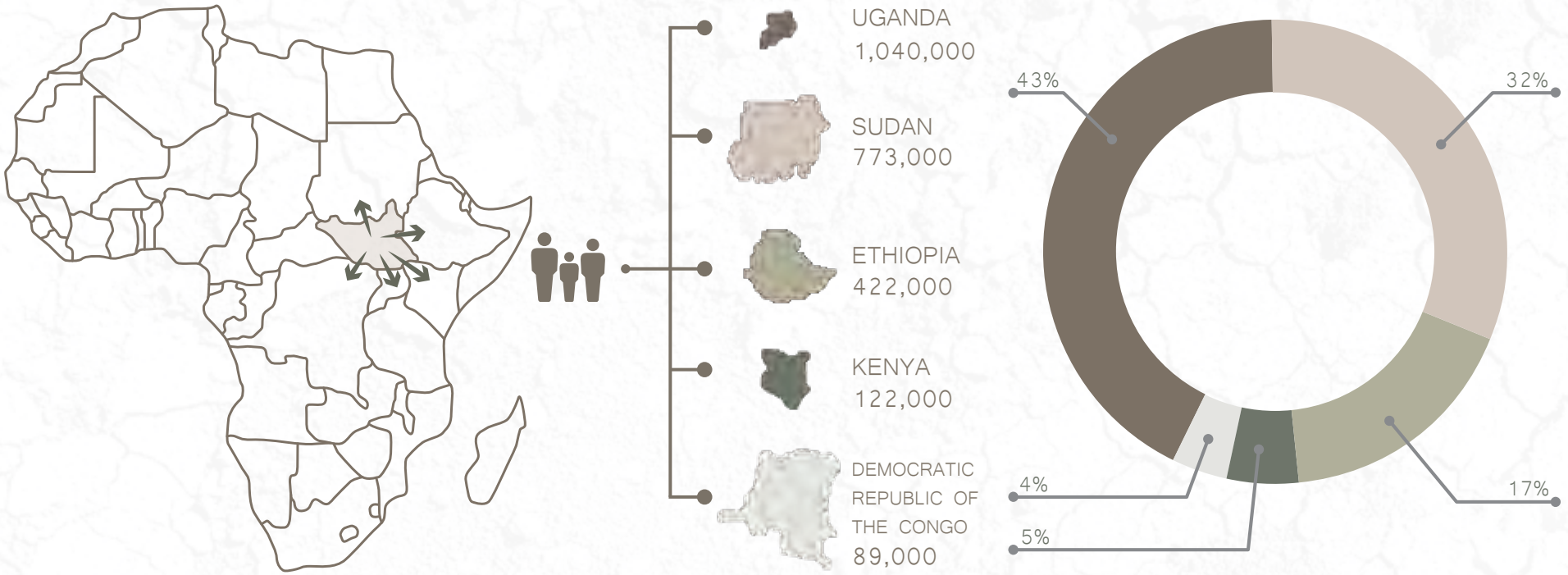
Looking at statistical data from the United Nations High Commissioner for Refugees (UNHCR), South Sudan currently has the third largest refugee crisis around the globe. Currently, over 2.5 million people have been displaced from their homes, and 60% of these refugees are children [3] [4].



The UNHCR has stated that approximately 2 million of these displaced refugees are seeking asylum in neighboring countries around South Sudan [3].

The majority of refugees from South Sudan have fled into Uganda because of its successful integrative refugee policies. Currently over 1 million refugees reside inside their country and numbers are expected to rise [5].




UGANDA
1,040,000
SUDAN
773,000
ETHIOPIA
422,000
KENYA
122,000
DEMOCRATIC REPUBLIC OF THE CONGO
89,000
43%
32%
17%
4%
5%

To address the housing crisis within these South Sudanese refugee settlements, this thesis will explore the potential of employing 3D printing construction technology, to see if this could be an optimal way to approach this challenge, in addition to testing its adaptability with the historic and culturally vernacular architecture found regionally throughout Africa.

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Fig.7 Paola Crociani, “Sudanese demonstrate their joy over the coup that ended the 16-year reign of Jaafar al-Nimeiri as their country’s president.”

01 First Sudanese Civil War

- Sudan receives independence in 1955
- First Sudanese Civil War starts in 1957

Fig.8

1956

02 First Peace Agreement

- Temporary peace made in 1972

Fig.9

1972

03 Second Sudanese Civil War

- Second Sudanese Civil War starts in 1983

Fig.10

1983

04 Lost Boys of Sudan

- 20,000 boys were displaced from their homes

Fig.11

1987

05 Second Peace Agreement

- Second Civil War ends through the 2005 Comprehensive Peace Agreement

Fig.12

2005

The amount of inner political and tribal conflict within the country of South Sudan is daunting. Even though South Sudan should be a country full of hope after gaining independence from Sudan, six decades of ongoing war, have only made problems worse, by contributing to some of the worst global crimes against humanity within this past decade. From 1956 – 2005, Sudan went through two civil wars, with an estimated four million people becoming displaced from their homes and approximately 2 million people having been killed [6].

Fig.8 "Child Soldiers, First Sudanese Civil War."
Fig.9 PaanLuel Wël, "Riek Machar and Pagan Amum signing the IGAD peace deal."
Fig.10 Anansh, "The Second Sudanese Civil War."
Fig.11 M. Amar, "The lost boys of Sudan."
Fig.12 BBC, "The peace accord brings new hope for Sudanese people."

06 Independence Referendum

- Calls for sucession from Southern Sudan in 2011
- Widespread political protests

Fig.13

07 South Sudan Made a State

- South Sudan gained independence with a 98.9% majority
- South Sudan Becomes the youngest country in the world to date

Fig.14

08 South Sudan Civil War

- South Sudan civil war starts in 2013

Fig.15

09 Refugee Crisis

- Over 2 million refugees are displaced from their homes

Fig.16

10 Current Refugee Crisis

- Currently there are over 3.7 million South Sudanese displaced refugees with no resolution in sight

Fig.17

2009 2011 2013 2017 2021 PRESENT

Due to the vast differences in northern and southern Sudan, a call for succession was proposed in the independence referendum deal, crafted in opposing governmental parties. In 2011, Southern Sudan gained independence from the country of Sudan with an overwhelming governmental majority of 98.9%. Unfortunately, Civil War erupted two years after South Sudan gain independence due to rumors of an incoming coup, causing ethnic genocide, destruction of villages, and the death of hundreds of thousands of Sudanese [7]. Now currently there are over 3.7 million South Sudanese refugees displaced and there is no resolution in sight [8].

Fig.13 Pete Muller, "Pro-separation activists hold signs and chant pro-independence slogans outside the Juba airport in southern Sudan, on Jan.4, where Sudanese President Omar al-Bashir arrived."

Fig.14 Tyler Hicks, "The Dawning of Africa's 54th State."

Fig.15 Charles Lomodong, "Sudan People's Liberation Army (SPLA) soldiers raise their rifles at a containment site outside of Juba on April 14, 2016."

Fig.16 Kieran Doherty, "South Sudanese refugees arriving in Imvepi settlement in northern Uganda, fleeing deadly war and hunger in their country, in 2017."

Fig.17 B. Gezahegne, "Refugees standing in line."

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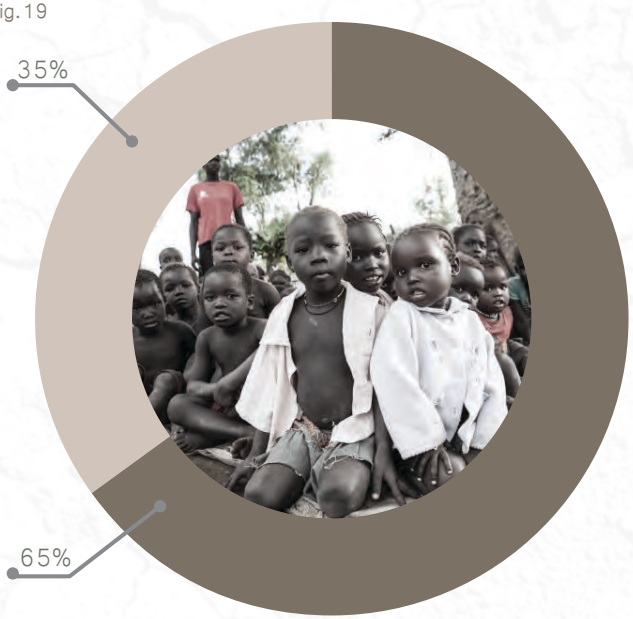
Fig.18 Philippa Russell, “Janina Poni from South Sudan walked to Uganda on her own.”

From a multitude of surveys completed by the REACH Initiative Refugee Program and UNHCR, found that the majority (65%) of refugees seeking asylum are women and children because the men are left behind to fight or have died in South Sudan's civil war [9].

Fig.19

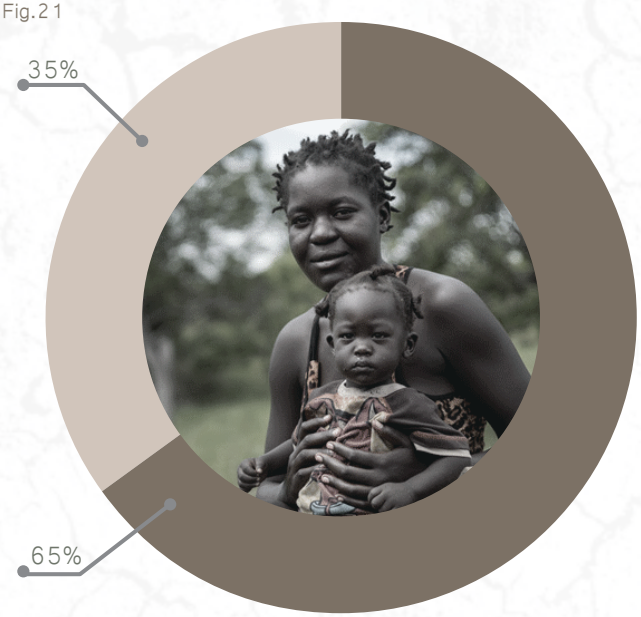


A statistical survey conducted in Uganda's Paloryina refugee settlement, found that 65% of the refugees are children under the age of seventeen [9].

Fig.20

Further, 67% of the overall population is female [9].

Fig.21



And 65% have at least one unaccompanied or separated child [9].

Fig.19 Colin Crowley, "Children at a child friendly space run by Save the Children in Doro refugee camp, Maban, South Sudan."
Fig.20 Tara Fischer, "The vast majority of those fleeing South Sudan are women and children."
Fig.21 Kieran Doherty, "Beatrice lives in Imvepi Refugee Settlement with her husband and young baby."

Beatrice, a nineteen-year-old woman, fled the war in South Sudan with her husband and young baby after her mother was raped and killed. Beatrice lives with her family in a refugee settlement, where she found some protection and access to limited food and water. She worries for her child and for her own future, and dreams of going back to school to become a tailor [10].

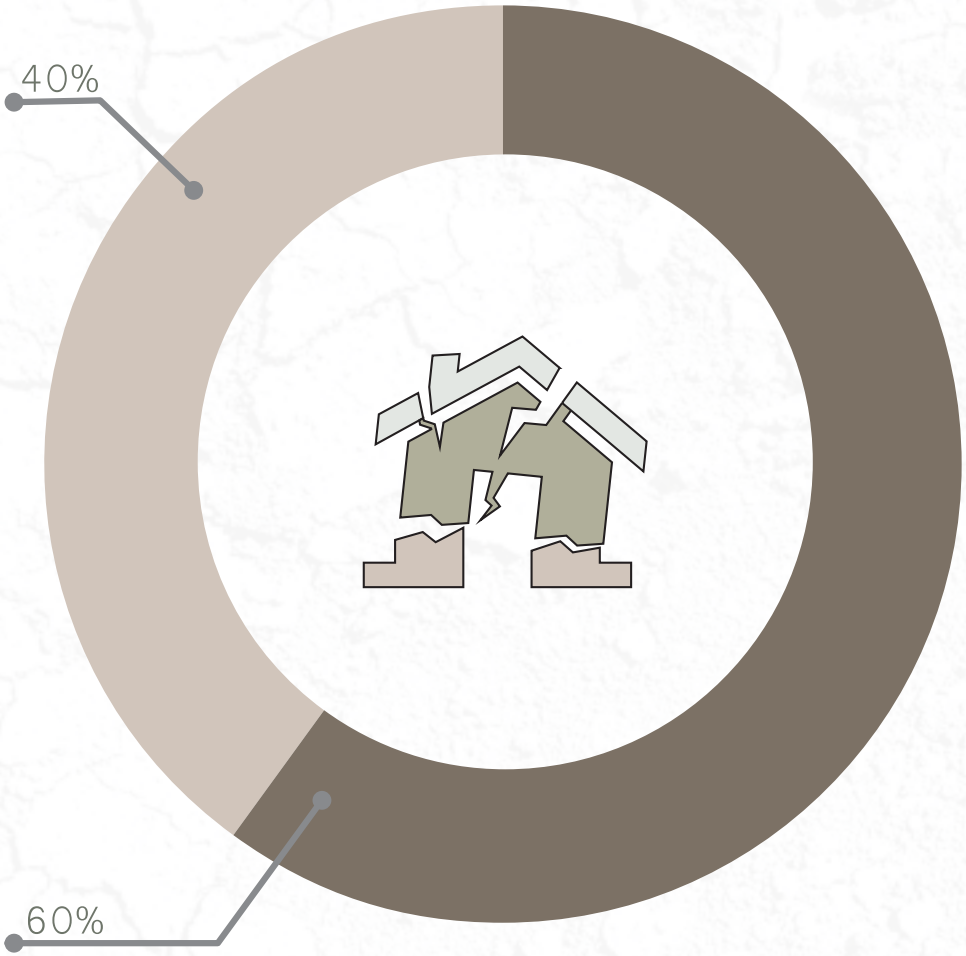
Fig.22 "Beatrice drying clothes."

Jackie, a twenty-four-year-old woman, fled to Uganda in 2019 for her own safety. Her husband was kidnapped by an armed group of soldiers, and she believes, forced to fight in South Sudan civil war. She lives with her father and two daughters, in a small hut within a resettlement camp. All she wants is to go back home and regain the life she once had [1].

Fig.23 "Jackie is learning tailoring skills."

Okongo lives in the Palorinya refugee camp located in Uganda. His tents leaks when it rains, and his belongings consist of two cooking pots and a pair of broken shoes that he wore on his long walk from South Sudan. He lives by himself and is terribly lonely. He dreams of seeing his children again after they were left behind in South Sudan [1].

Fig.24 "Malis Joseph and baby Flora."



The UNHCR and Reach Initiative states that one of the three most important needs within these refugee settlements is access to better housing [2].

In the Palorinya settlement, 60% of refugees have reported damage to their homes. The main reported issues involve roofing damage, wall damage, and/or structural damage [2].

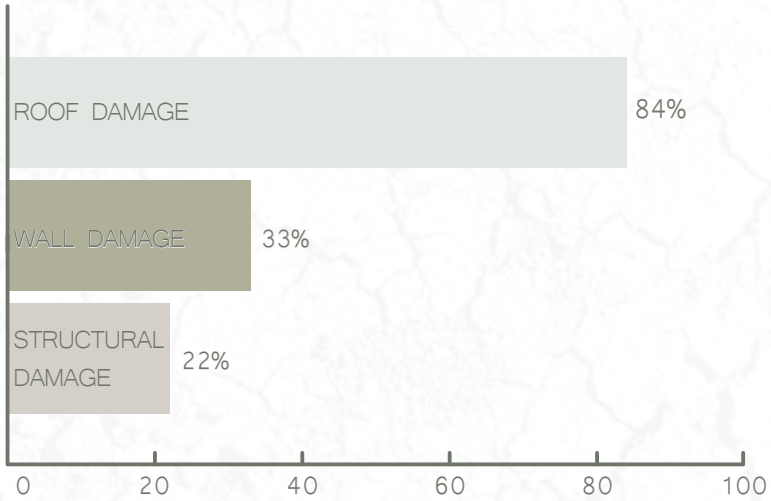


Fig.25

Fig.26

Most importantly, it was noted in this survey that 26% of men and 33% of women do not feel safe where they currently live because of their housing issues [2]. While this percentage is in the minority, it represents over 700,000 refugees that are negatively affected from their poor housing conditions.

Fig.25 Sara Hylton, “Obede Lutana, an orphan who found himself alone in a war zone after his father was killed. He says he is 15 years old, but looks younger.”
Fig.26 Tom Perry, “The conflict in South Sudan has forced more than a million people out of their homes.”

TECHNOLOGY

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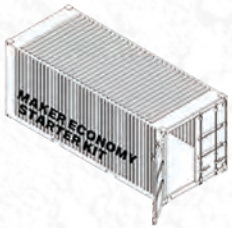


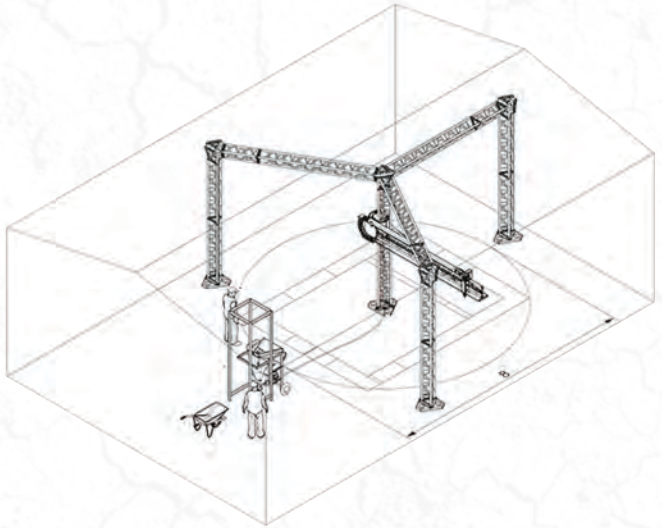
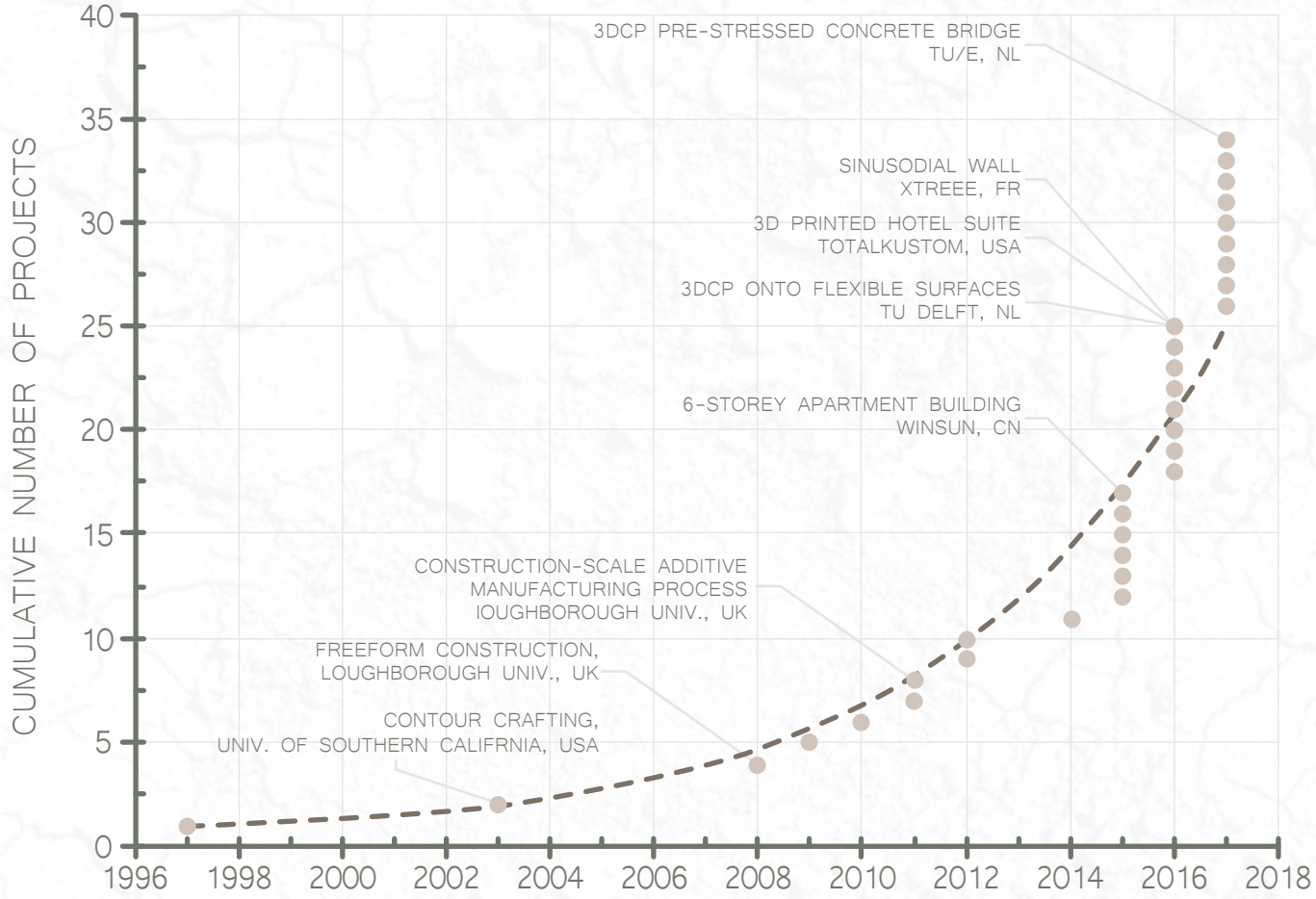
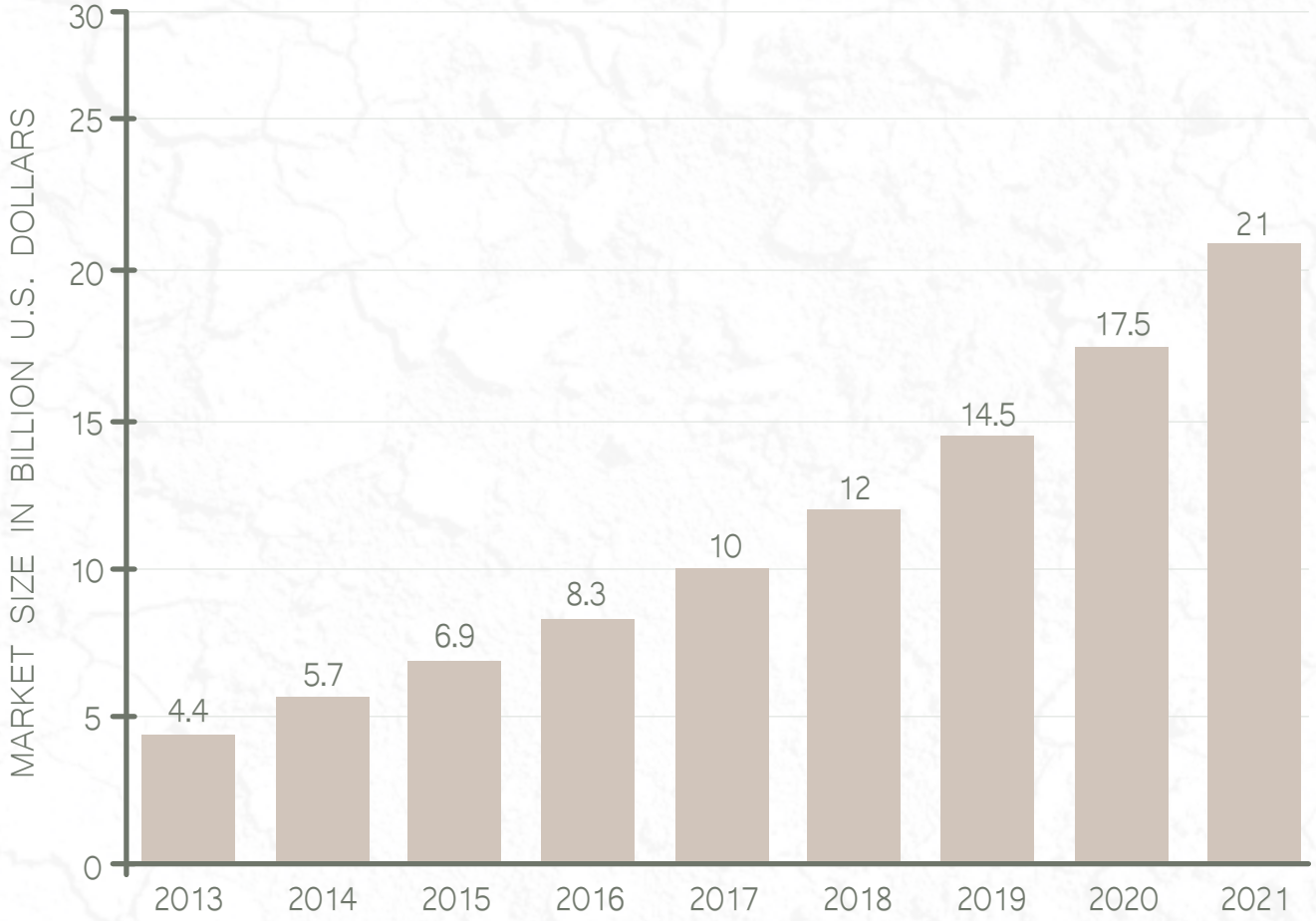


Fig.27 Alberto Chiusoli, “1 Crane WASP Unit.”

Fig.33



Citing a 2018 research paper from the Architecture School of Loughnorough University, it is claimed that the use of 3D printers in architecture has been on the exponential rise within the past two decades. As time has passed, more architectural research projects have explored the use of 3d printers to reach a desired outcome, and it is predicted that 3D printing technology will become more common within the near future [11].

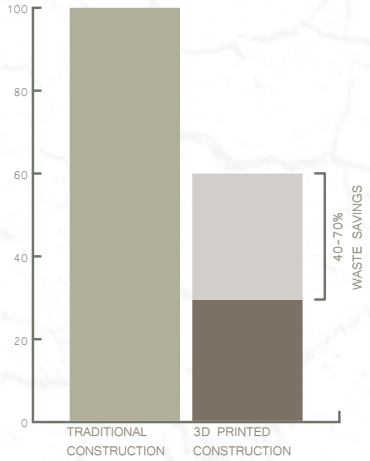


A regional survey from Statista predicts that 3d printing technology is expected to rise as well, as 21 billion dollars have been invested within this market worldwide within the year of 2021 [12]. Given this data, it is likely estimated that as time progresses, 3D printers are going to become more accessible and cheaper to produce, making them more accessible in harder to reach regions around the world.

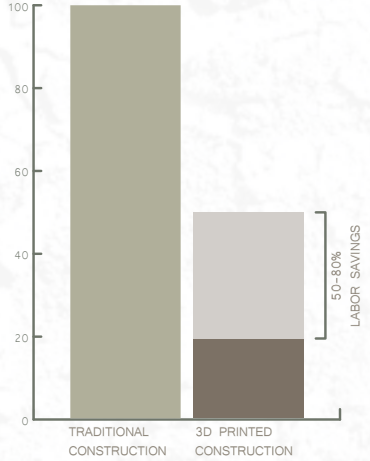
3D printing can potentially address serious construction issues within refugee settlements. Three of the main reasons refugees are unable to build or repair adequate housing is due to the lack of funds, access to construction resources, and shortages in refugees who are able to contribute to construction labor [2].

A research paper published in September 2020 from Nazarbayebv University (NU), makes the claims that 3D printers can reduce construction waste by 30–60%, the amount of labor by 50–80%, and cut construction time down by 50–70% [13]. While these claims still need to be thoroughly tested, for the purpose of this thesis project we will assume these tests are accurate.

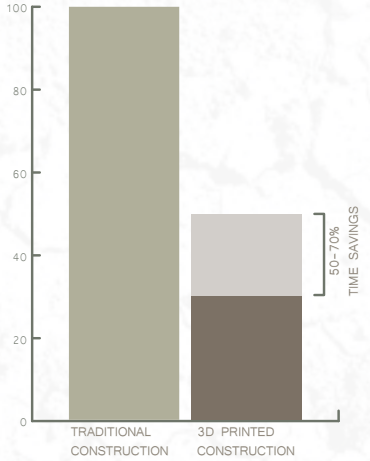
Fig.28 Hossain, Md. Aslam, et al. “A Review of 3D Printing in Construction and Its Impact on the Labor Market.”



The NU research paper, first claims that construction waste can be minimized by 30-60% due to the precision of 3D printing technology during its extrusion process. Builders can accurately estimate the exact amount of extrusion material needed for an individual build [13]. This can help address potential material shortage and can contribute to lowering the overall cost of materials needed to build a shelter [14].



Secondly, the research paper states that 3D printers reduce the amount of labor by 50-80% [13]. In other regions around the world where construction labor is considered an “essential job”, this could be problematic. However, within these settlements, there are frequent construction labor shortages due to the low number of qualified construction specialist within the camps [2]. In this setting, 3d printers could help meet this need due to the low number of workers needed when working on site.



Most importantly, this paper claims that 3d printers can reduce construction time by 50-70% [13]. While traditional construction methods require months to create a typical hut, 3d printing demonstrates the ability to continuously print new huts without stopping until completion [14]. The ability to print multiple structures simultaneously also contributes to the overall speed and efficiency of the housing needs, thereby increasing the capacity to meet the needs of fleeing refugees.

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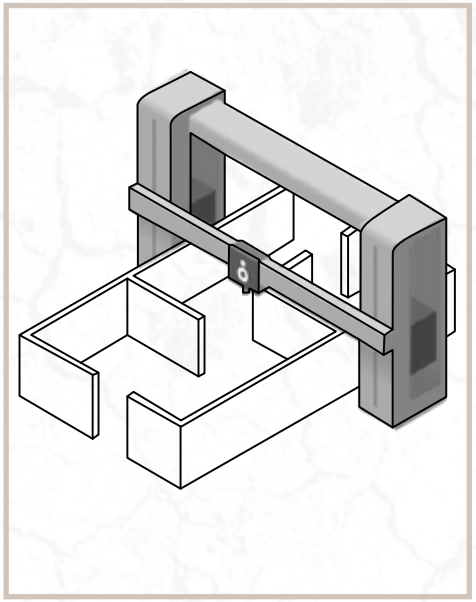
Fig.29 Iago Corazza, "Model unit of TECLA - the eco-sustainable house 3D printed from raw earth – in Massa Lombarda, near Ravenna (IT)."

Fig.30

Fig.31

Fig.32



ICON's Vulcan printer has been used to successfully complete two housing projects in Austin, Texas and Tabasco, Mexico. Both projects produced 400-500 square foot single story homes, that provide a living space, two bedrooms, and a single bathroom. Three houses can be printed at the same time roughly in the timespan of twenty-four hours. Because of the efficiency and low labor costs associated with these projects, they are being used to provide housing to the homeless and people making less than ten dollars per day [15] [16].

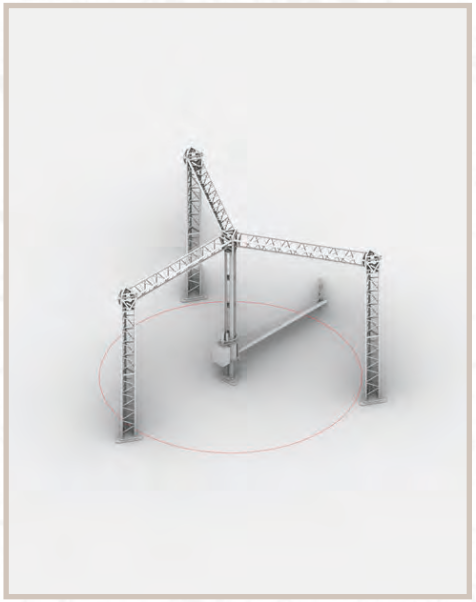
Fig.30 Tess Boissonneault, "ICON VULCAN 3D Printer Conceptual Render."
Fig.31 ICON Team, "ICON 3D Printed Homes."
Fig.32 ICON Team, "ICON 3D Printed Homes."

Fig.33

Fig.34

Fig.35

Fig.36



As of spring 2021, WASP produced the TECLA housing unit, being the first prototypical home entirely constructed with a clay based material. By blending vernacular history with parametric modeling, the TELCA unit can successfully print a 645 square foot unit in under 200 hours. This technology could be used in impoverished areas of the world where vernacular architecture is commonly used [17].

Fig.33 Mario Cucinella, “WASP and Mario Cucinella Architects present TECLA A 3D printed global habitat for sustainable living.”

Fig.34 Iago Corazza, “The TECLA house took 200 hours to print. It’s made from 60 cubic metres of natural materials, which became 150km of extrusion when fed through the nozzle of the specialised printing arms.”

Fig.35 Alberto Chiusoli, “The 3d printed house Gaia.”

Fig.36 Alberto Chiusoli, Francesca Moretti, Diego Villa. “Crane WASP.”

CULTURE AND TECHNOLOGY

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Fig.37 Jacob Lueth Achol, “Wedding Parade”

Fig.38

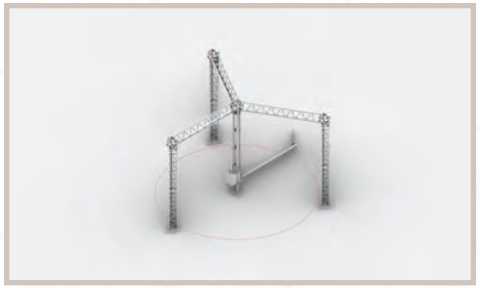


Fig.39

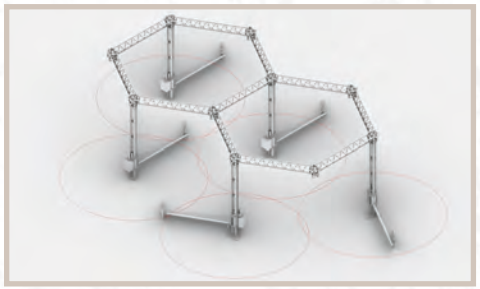
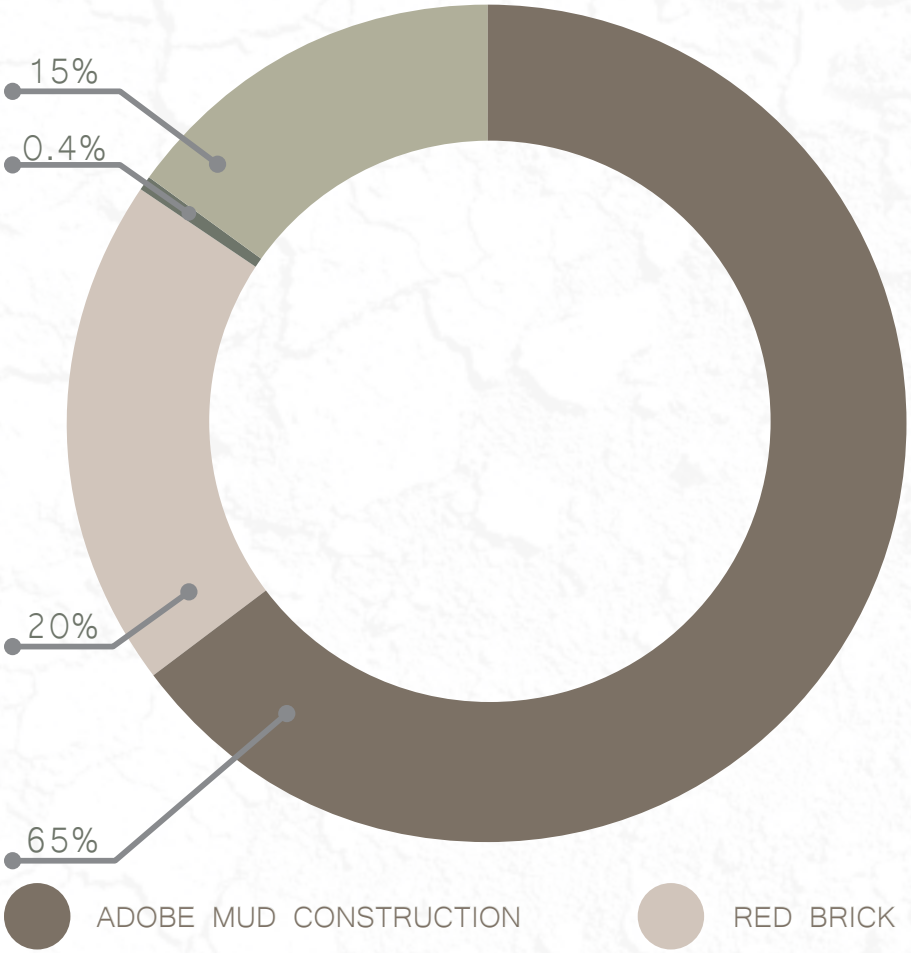


Fig.40

The printer that will be used in this design exploration will be the Crane Wasp Printer, because of its ability to print with vernacular material and its efficient modular set up. This technology is best suited to address this issue culturally, while simultaneously printing houses at an accelerated rate. Because Wasp has created a printer that can extrude a clay-based material, this system can culturally address the material typology in this region, while providing benefits through this novel medium of construction. Using a 3d printer has the potential of eliminating the adobe brick curing process because the clay is cured quickly when using a printer. All that is required to produce the extrusion is for wet clay aggregate to be made available on sight. Once the clay is fed though the printer, it cures while the rest of the printing process is taking place [17].

Fig.38 Chiusoli, Alberto,"CRANE WASP."
Fig.39 Chiusoli, Alberto,"CRANE WASP."
Fig.40 Alberto Chiusoli. "Tecla Concept."



Culture and tradition are two of the most important aspects to be considered when designing for the people of South Sudan because of how strongly their ethnic and tribal ties shape their lives. A household sample survey from 1968 shows that 65% of South Sudanese houses use mud and adobe brick as primary building materials [18].

Fig.46 BRICK MAKING PROCESS

Fig.47

Fig.48

Adobe and mud bricks for construction purposes are made in a process involving five phases. First sand, water, and soil must be mixed to the right consistency. Next, the mixture is poured into brick shaped molds, and then excess material is scraped off. Then the full mold is thrown on the ground to prevent cracking while curing. Finally, the bricks are placed in the sun to cure. This process can take weeks to complete and requires extensive labor to bring the bricks on sight to be used in construction [19].

Fig.41 Design Cause Inc., “Sun dried soil brick making process.”
Fig.42 Zurab Elzarov, “Adobe Brick Making”
Fig.43 Samaritan’s Purse, “Following a tragic fire, a local church helped abuk and her children in part by building them this home.”

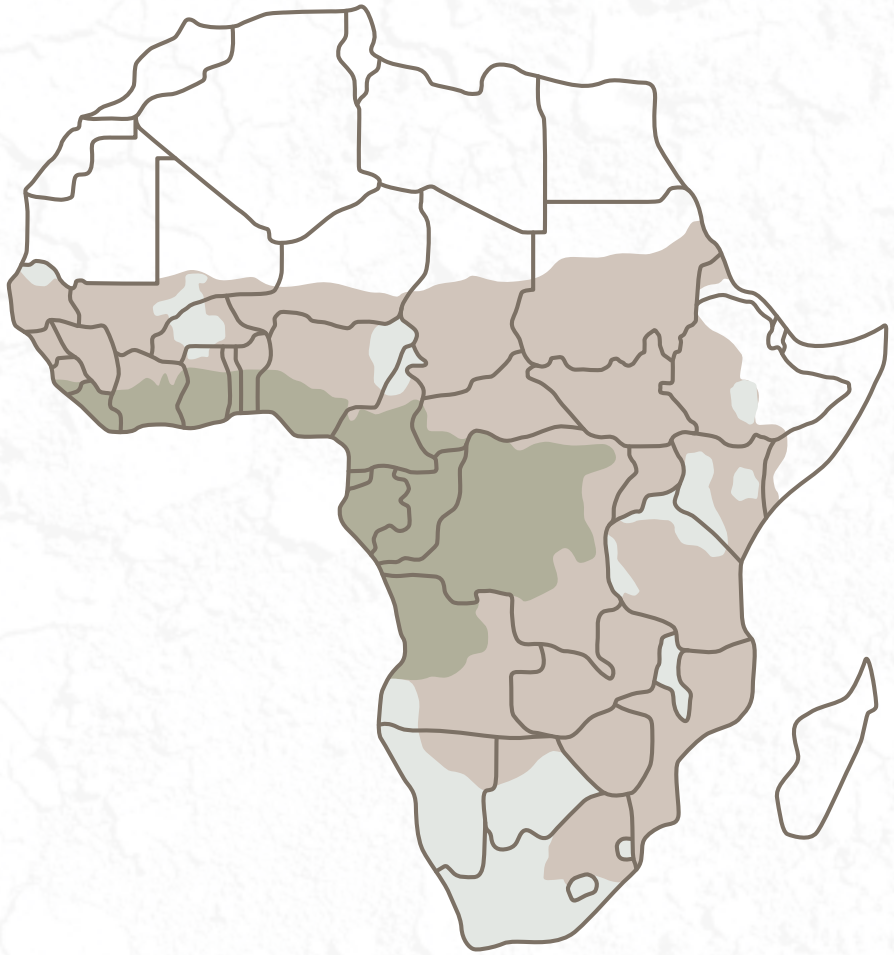


Fig.44

Fig.45

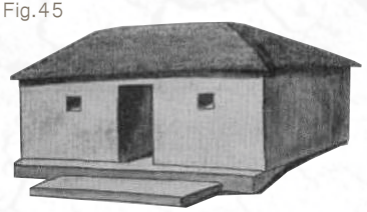
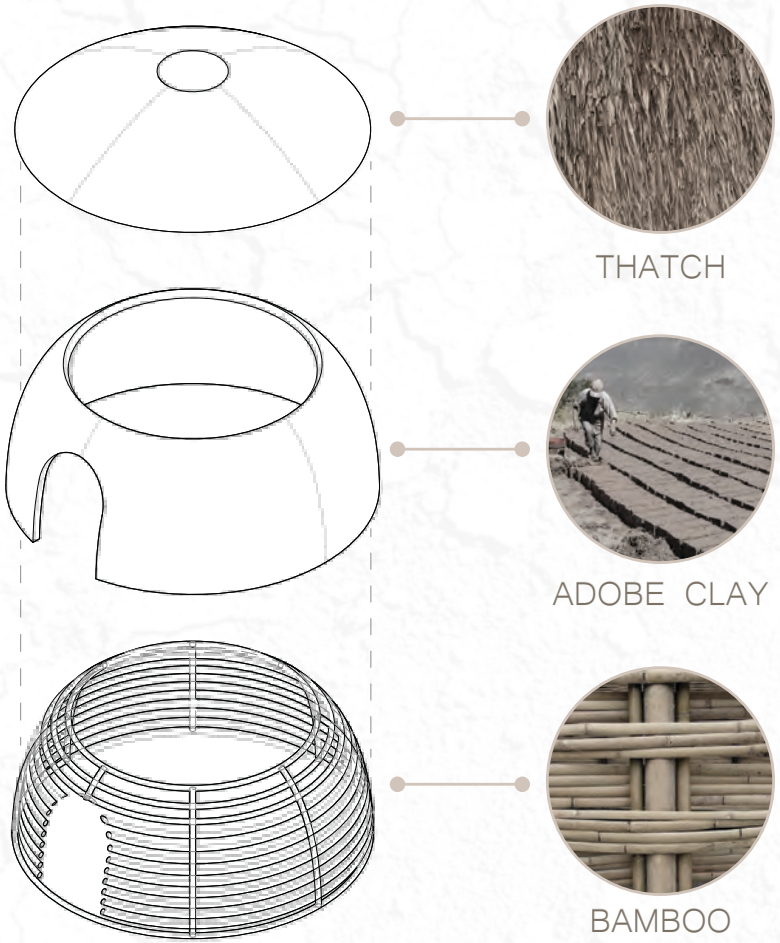


Fig.46

Fig.44 Naude, M. “A legacy of rondavels and rondavel houses in the northern interior of South Africa.”
Fig.45 James Walton, “Basutol and Folk Building Types.”
Fig.46 Lewis Waring, “Beehive Hut.”



Almost 100% of homes in the rural areas of South Sudan are the vernacular Tukul Huts [18].

A “Tukul” hut is a traditional mud and brick hut with thatched roofing. It is circular in design, with a conical roof. Bamboo is used for the wall construction and roof support. The wall is reinforced with maize, is usually plastered with a mud mortar, and sometimes mixed with ash and fresh cow dung as the second coating. The floor consists of packed dirt and grasses are used for thatching.

The overall area of the average Tukul hut is around 375 square feet, with a ten-foot radius and an eight-foot wall height. The average hut consists of one room and holds approximately five people [20].

The specifications for the Crane Wasp machine can accommodate the average requirements of a Tukul hut, by building to its typical height and radius. Because of this, the machine can adequately produce geometry that can closely mimic the original Tukul hut design [17].

Fig.47

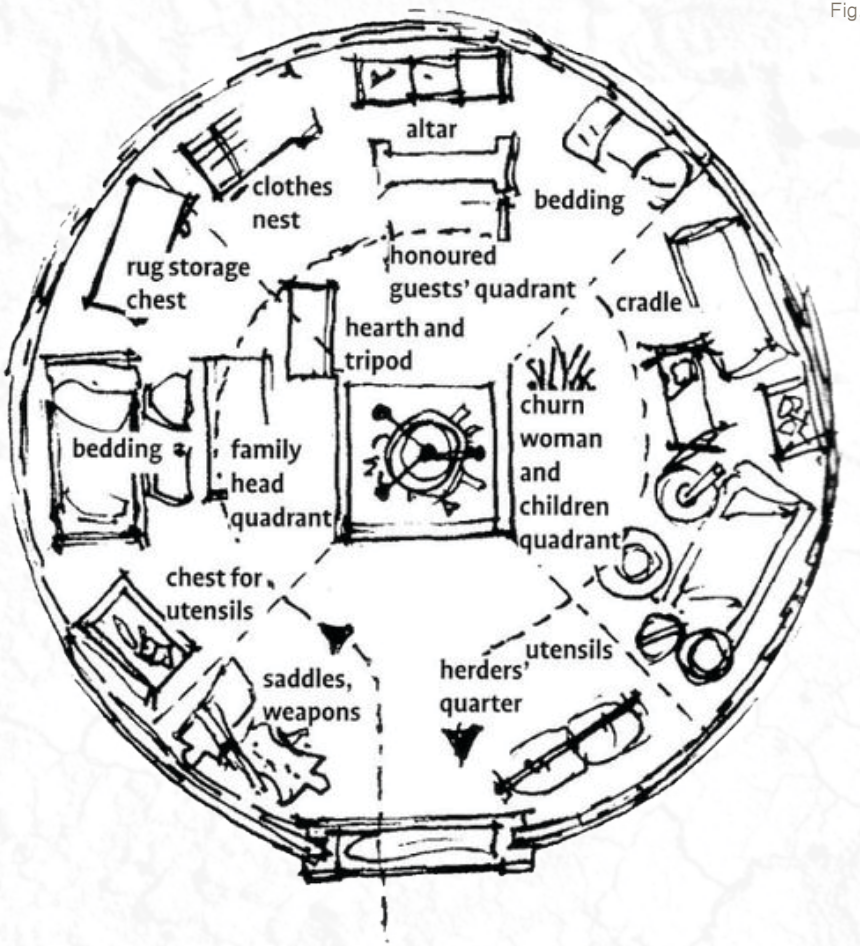


Fig.47 Gerald Steyn, "Distribution of hut types in sub-Saharan Africa."

SITE PLAN

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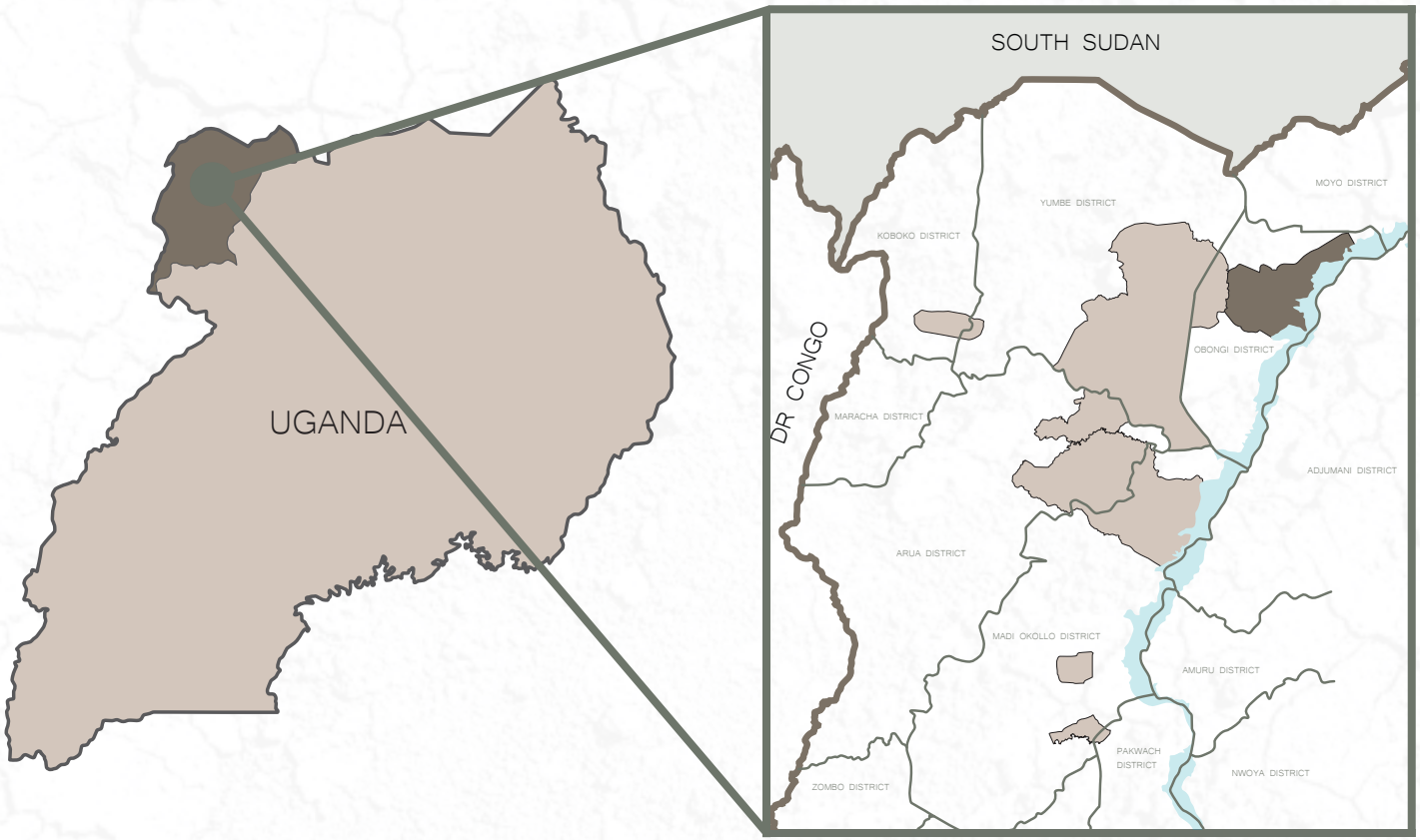
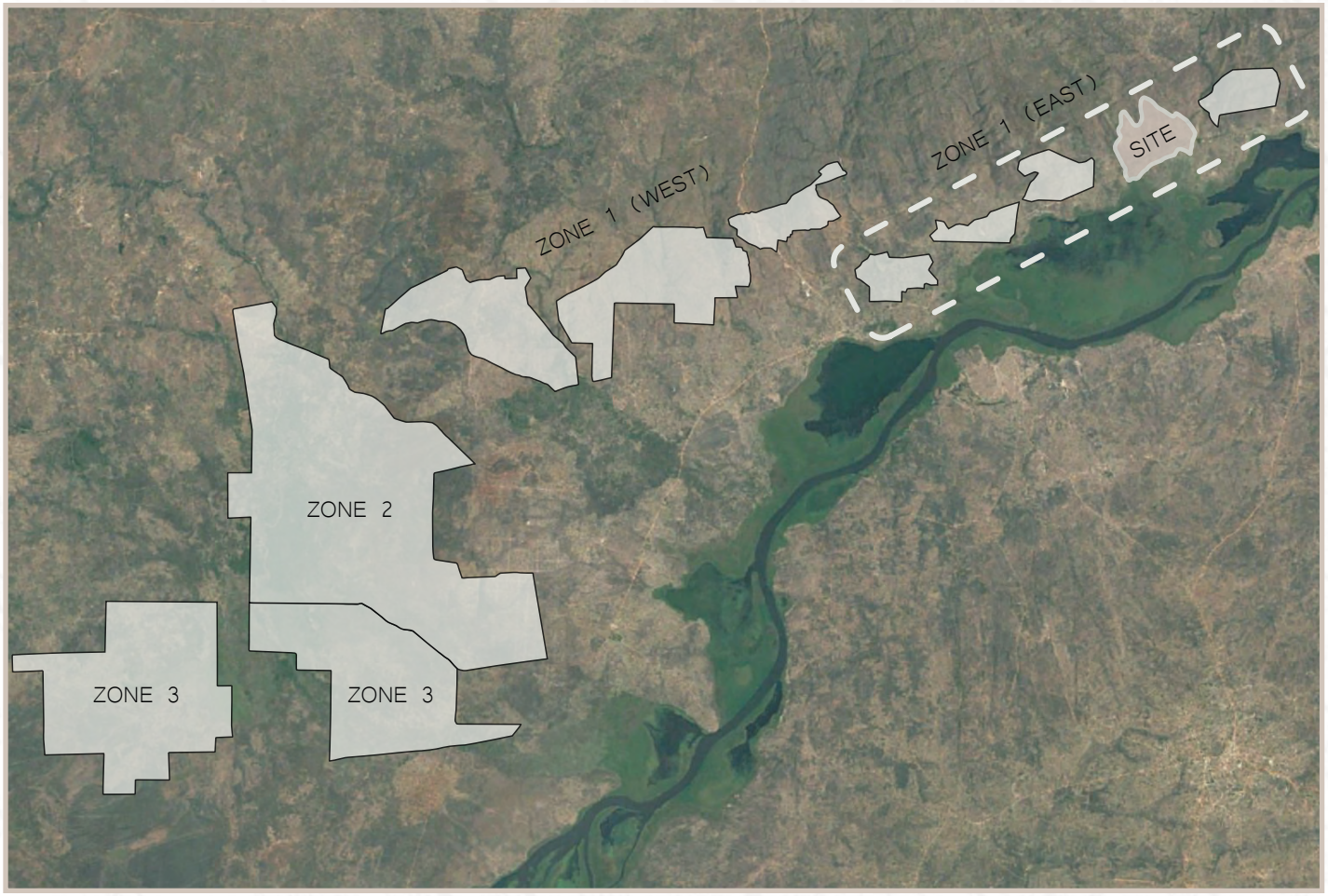
Fig.48 Bernard Dupont, “Albert lake (Albert Nyanza) in Uganda’s Murchison Falls National Park is Africa’s seventh-largest lake and one of the African Great Lakes.”

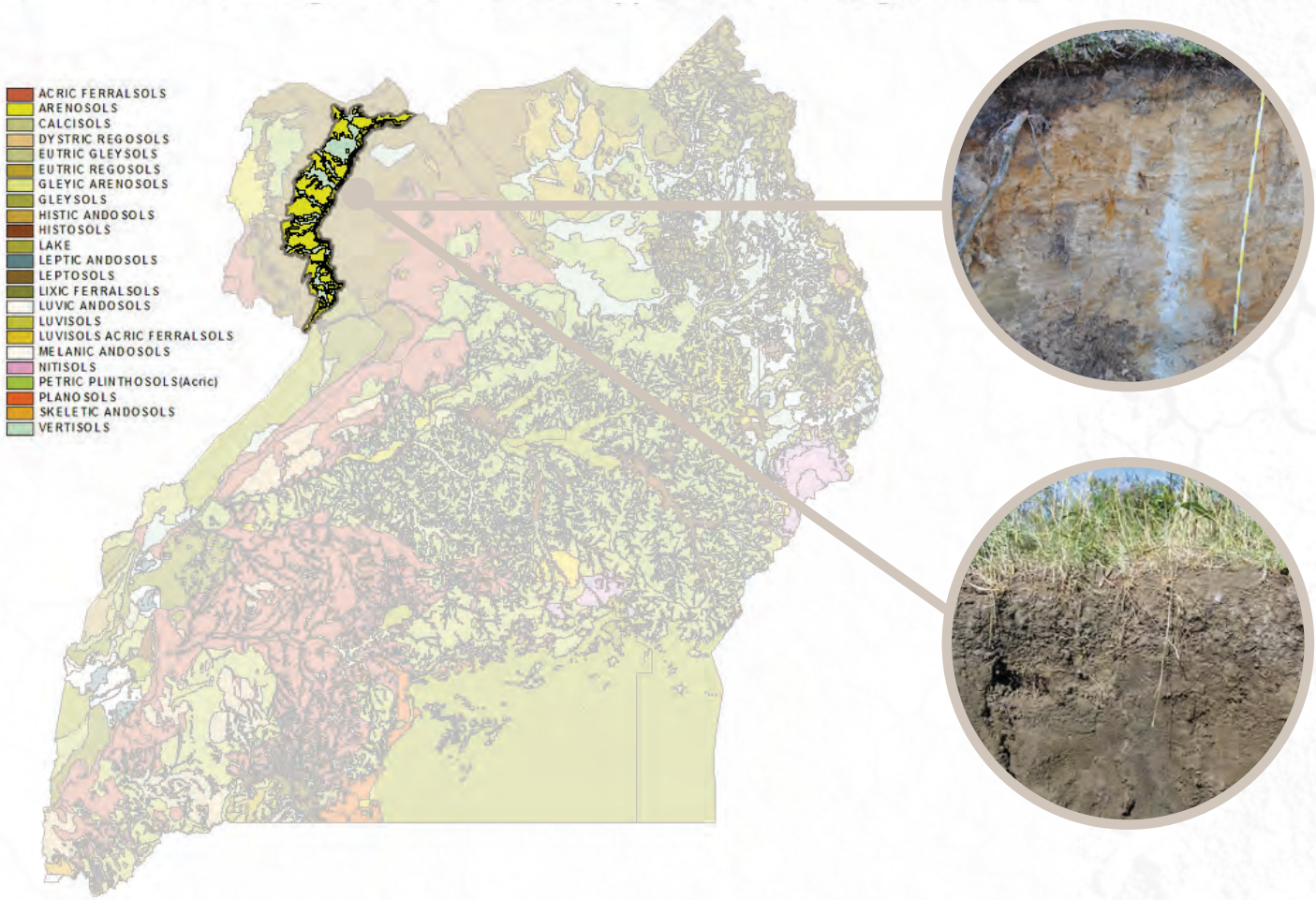


The majority of South Sudanese refugee settlements are located in the northern region of Uganda. The refugee settlement I will be focusing on is the Palorinya camp located in the Moyo District [21].



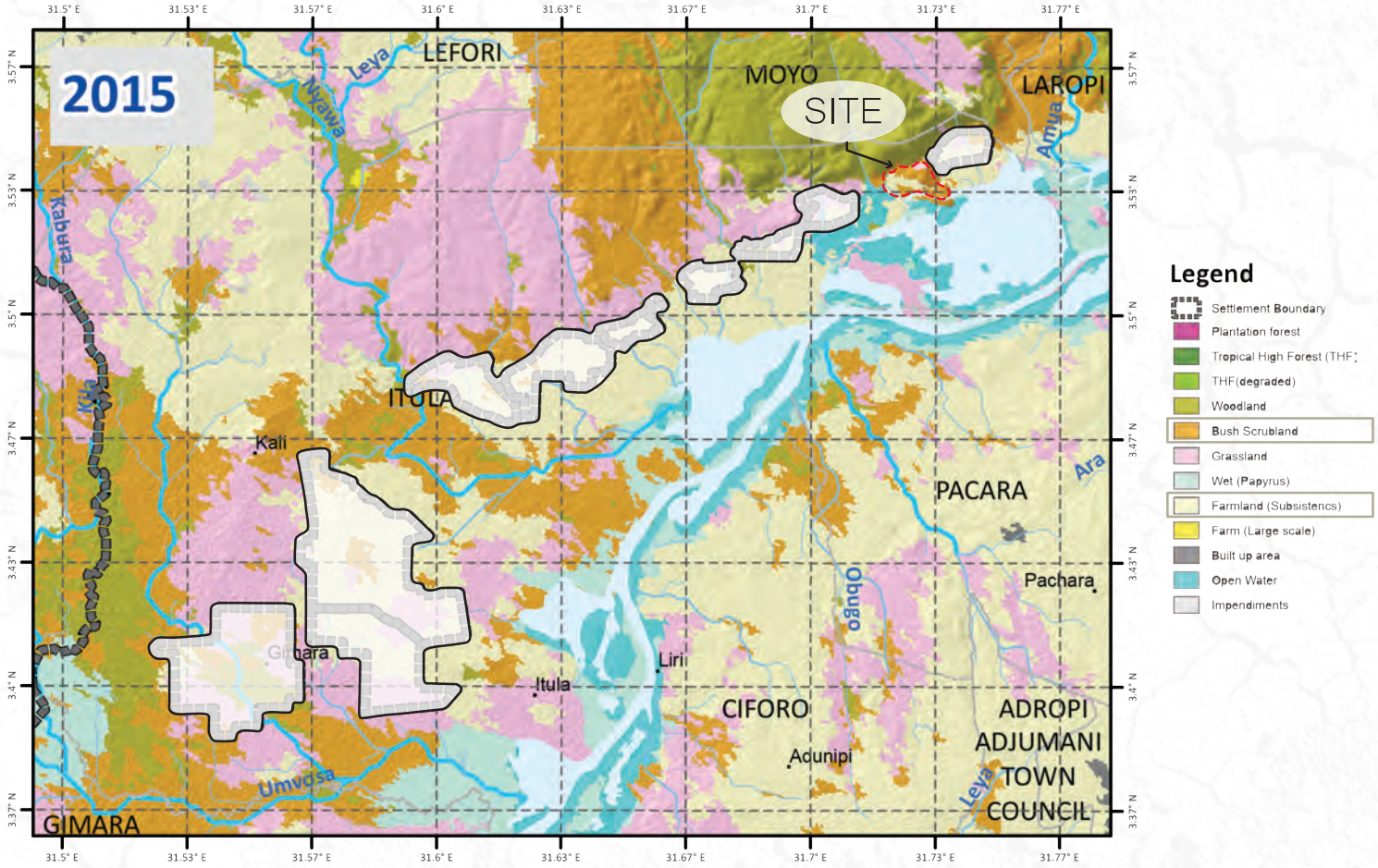
The Settlement is divided into three specific zones and the site is located within zone one. This site was chosen because of its proximity to the Albert Nile, where water can be accessed for construction needs without tapping into the refugees' drinkable water supply.

According to the UNHCR, the Palorinya Camp is the third largest refugee settlement in Uganda and hosts approximately 122,000 refugees to date [22].



The land topography within the site is compatible for the needs of the Crane Wasp 3d Printer. A research paper at Wageningen University shows that the two main soil types within this region are Vertisols, a rich clay soil with a high moisture content, and Arenosols, a sandy-textured soil that lies on the surface of the terrain [23] [24]

Fig.49 Kaizzi Kayuki, “Uganda Global Yield Gap Atlas”



The UNHCR states that the geography of the site consists of a mix between bush scrubland and usable farmland space [26]. This topography is beneficial due to its open buildable terrain and its potential for refugees to plant and farm near their homes, to provide for themselves and others.

Fig.50 "United Nations High Commissioner for Refugees: Palorinya Refugee Settlement -Moyo-Land use and land Cover Map"

SITE LOCATION:

LATITUDE: 3°31’32.37”N

LONGITUDE: 31°43’16.50”E

This is the specific site for the proposed project. The site runs adjacent to the Albert Nile and the main Palorinya Highway runs though the site, providing easy accessibility when delivering the needed materials.

Fig.51

Fig.52

Fig.53

Fig.54

Fig.55

Fig.56

Fig.51 Wikimedia Commons, “Bush encroachment at Waterberg in Namibia.”

Fig.52 Tommy Trenchard, “Children mill around as a storm brews over the Bidi Bidi refugee camp in northern Uganda, which is home to 280,000 refugees from South Sudan, more than half of them children.”

Fig.53 Gospel Radio-East Africa, “The Mountainous area of Moyo-Northern Uganda.”

Fig.54 “Mountain Otzi Forest Reserve Moyo District Northern Uganda.”

Fig.55 “Farmable Land.”

Fig.56 “Albert Nile.”

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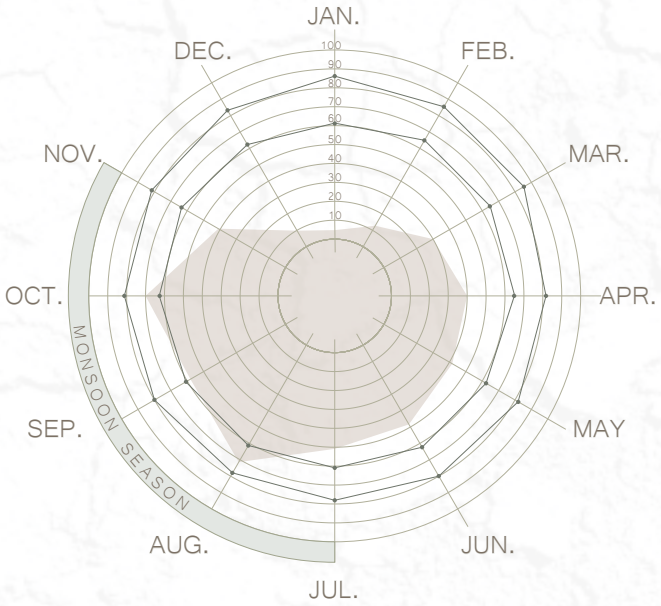
Fig.57 “Kidepo Uganda”



CLIMATE LENGEND

TEMPERATURE (FAHRENHEIT)

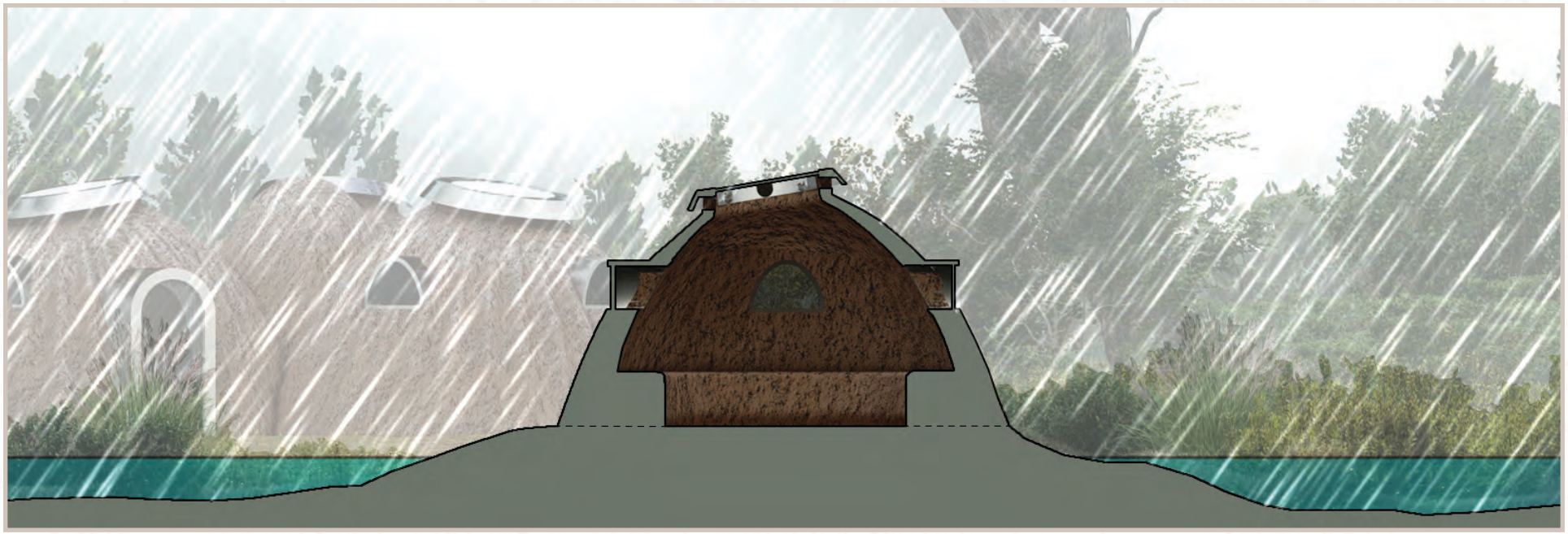
AVERAGE RAINFALL PERCENTAGE

Fig.58

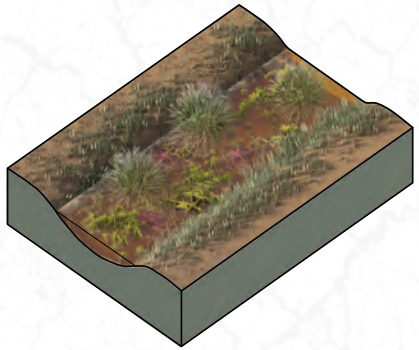
Fig.59

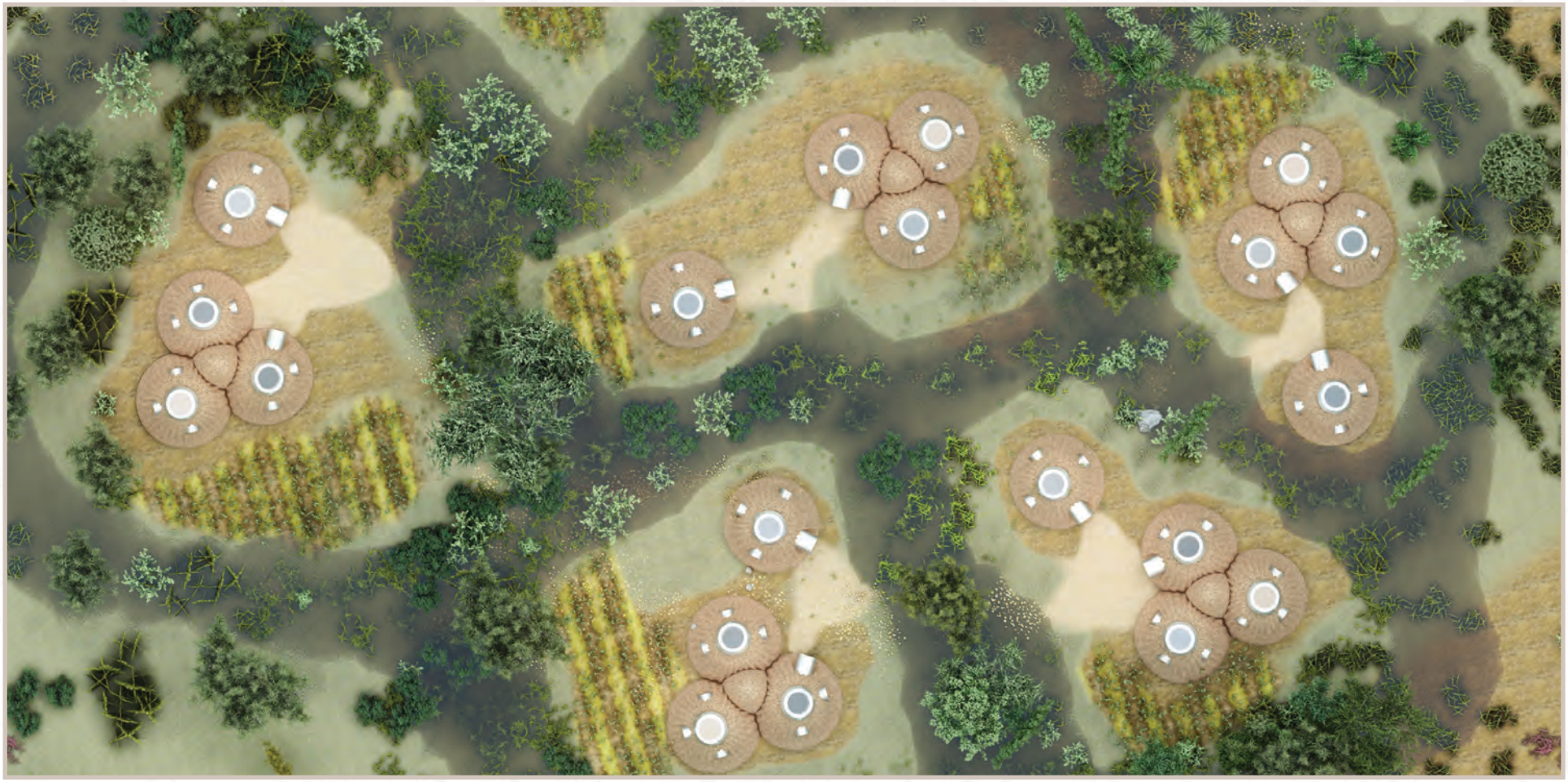
An important aspect to consider when designing the exterior form was the intense weather conditions that occur throughout the year in Uganda. According to the World Meteorological Organization, even though the temperature remains temperate between 60 to 80°F throughout the entire year, the average monthly rainfall varies greatly. From November to March the weather conditions in Uganda are relatively dry with a low average monthly rainfall of around 5-30%. However, the average rain fall begins to increase in April and continuously becomes more aggressive as the Monsoon season arrives, with the average monthly rain fall increases to 60-70% [27]. During the monsoon season, flooding and harsh rain fall provides significant challenges that need to be directly addressed.

Fig.58 Josh Estey, “Uror County South Sudan”
Fig.59 John Sparks, “White Nile Flooding”



When preparing to print the structured huts on site, it is necessary to plan a water drainage strategy to alleviate the flooding that takes place during the monsoon season. By printing the hut on a raised plinth or elevated topographical zone, water can be drained away from the exterior of the hut by implementing bio swales between huts which allows for the management of water runoff.





INTERVIEWS

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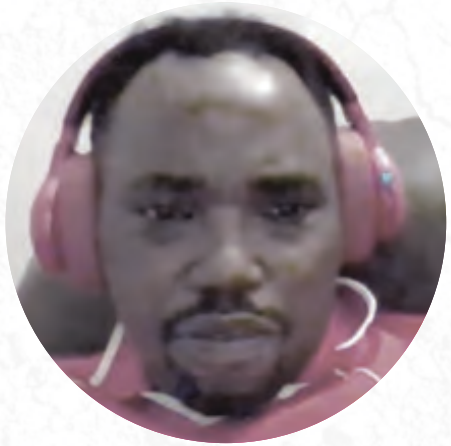
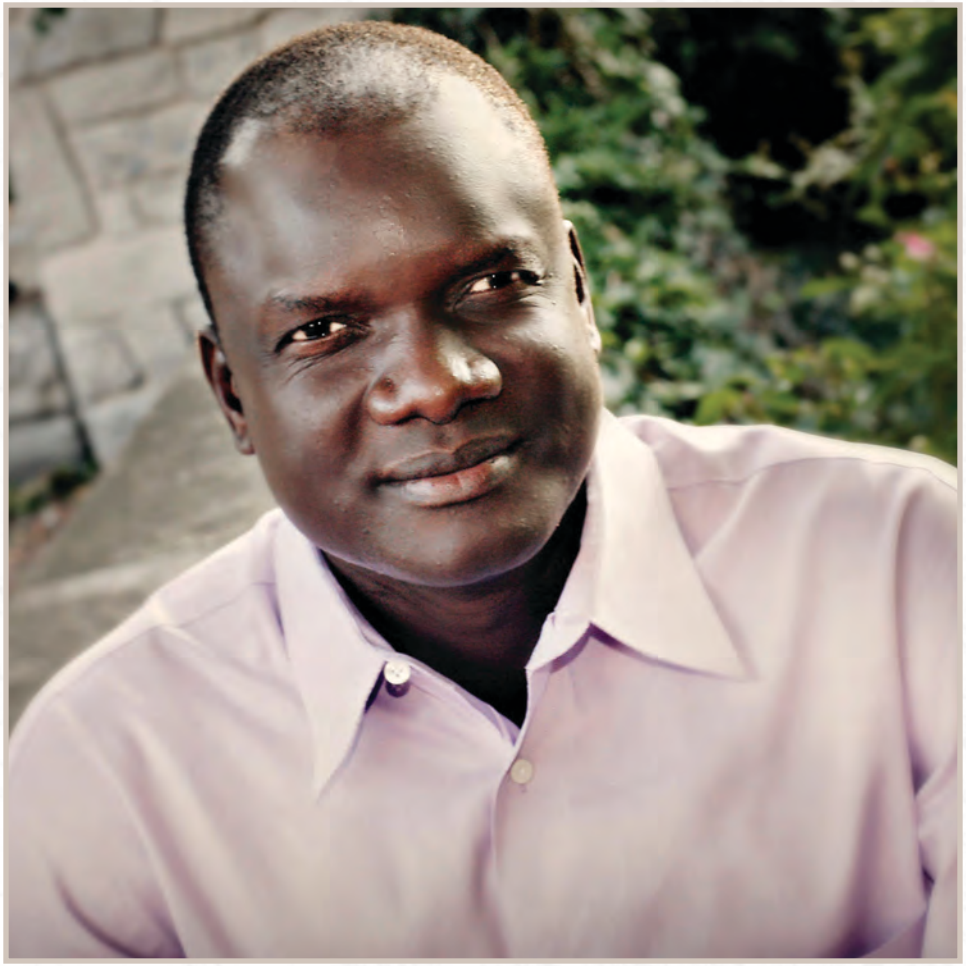




John Dau, a Dinka tribesman, and a human rights activist for the people of South Sudan, helped influence the overall design decisions of this project through his personal perspectives and cultural knowledge. John spent the first seventeen years of his life, living in Sudan and then as a wandering refugee in neighboring countries. He was one of the Lost Boys of Sudan and held one of the lead roles in the critically acclaimed documentary, "God grew tired of us", documenting the lives of Lost Boys of Sudan and their transition to becoming citizens of the United States. John now works within his home country, helping to improve the healthcare infrastructure through his nonprofit organization, the "John Dau Foundation".

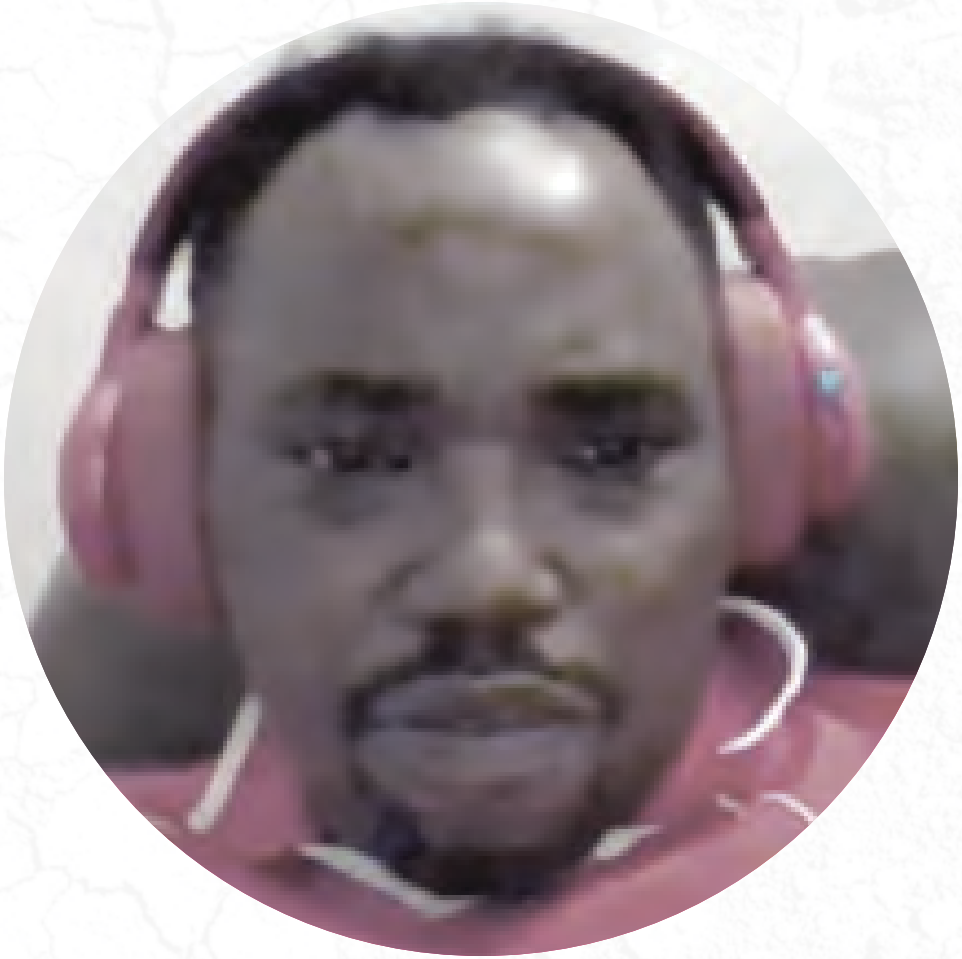
John's personal experiences as a Dinka Tribesman, helped to shape design decisions based on the traditional Tukul hut he grew up in, sharing what it was like to be a member of the Dinka Tribe, and the cultural activities he performed daily.

He also provided a first-hand perspective of what it was like to live in a refugee settlement as compared to his former life.

Fig.60 Kristi Evans, "John Dau"

Suman Sorg, the founding principle of Sorg Architects provided context to the Ugandan Refugee Settlements by sharing her personal experience helping to build housing in the Bidi Bidi Settlement. She provided insight into the lives of the refugees, through describing their daily activities such as cooking, farming, and collecting water, and shared personal stories of refugees who she encountered while working there. The knowledge she provided helped personalize the requirements of the design based on the day-to-day life of the people that lived in these settlements.

Fig.61 "Suman Sorg, FAIA"



Melchizdek, a regional settlement director of the Palorinya camp in Uganda, also provided context to the proposed site where the design takes place. Given that the site is in the Palorinya settlement, I intentionally sought out a personal account from the region to gather an accurate understanding of its current contextual conditions. Melchizdek provided insight on what the average housing conditions are like here, the organizational structure of the settlements, weather and terrain conditions, and the specific refugee needs within the Palorinya District.

Flavia, a native Ugandan citizen, provided insight regarding what it was like to live in Uganda, and witnessed how the South Sudan refugee crisis affected the Ugandan citizens. She also provided additional insights on the region-specific differences between living in Uganda compared to living in South Sudan.

DESIGN

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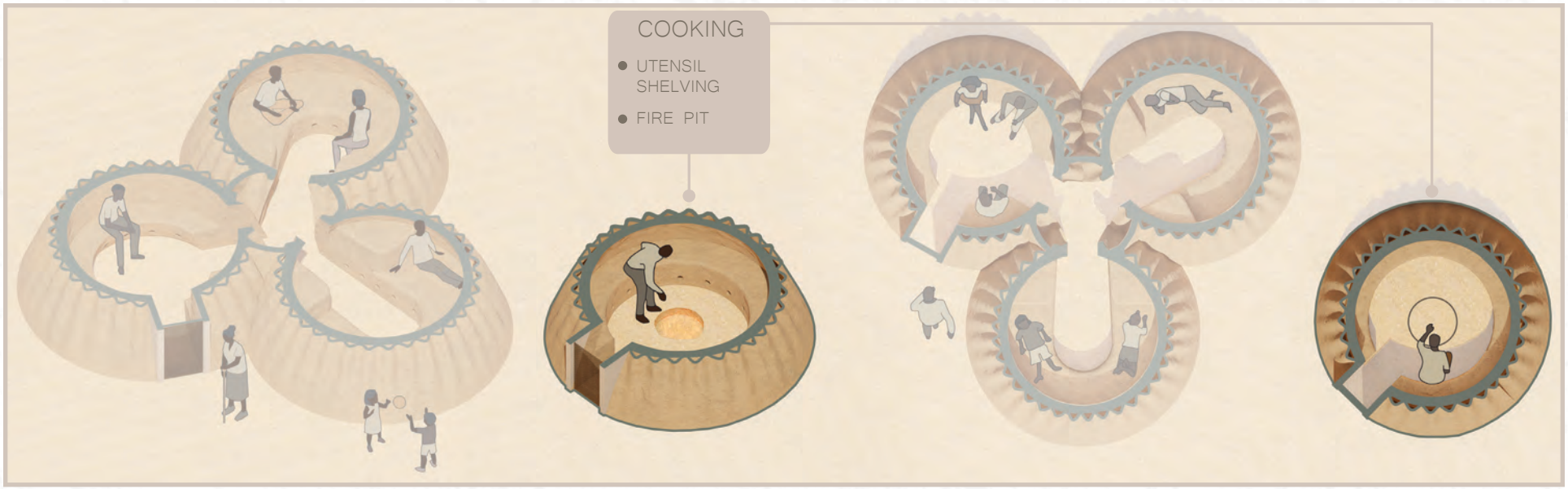
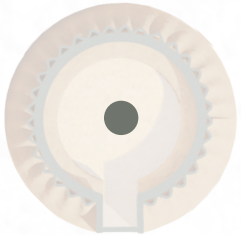
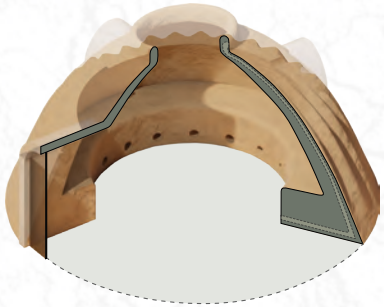
By gathering information from interviews with John Dau, Suman, Melchizdek, and Flavia, I was able to propose a plan for a typical hut unit based off of each of their shared experiences. A typical hut has three main functions. These include sleeping, socializing, and cooking.

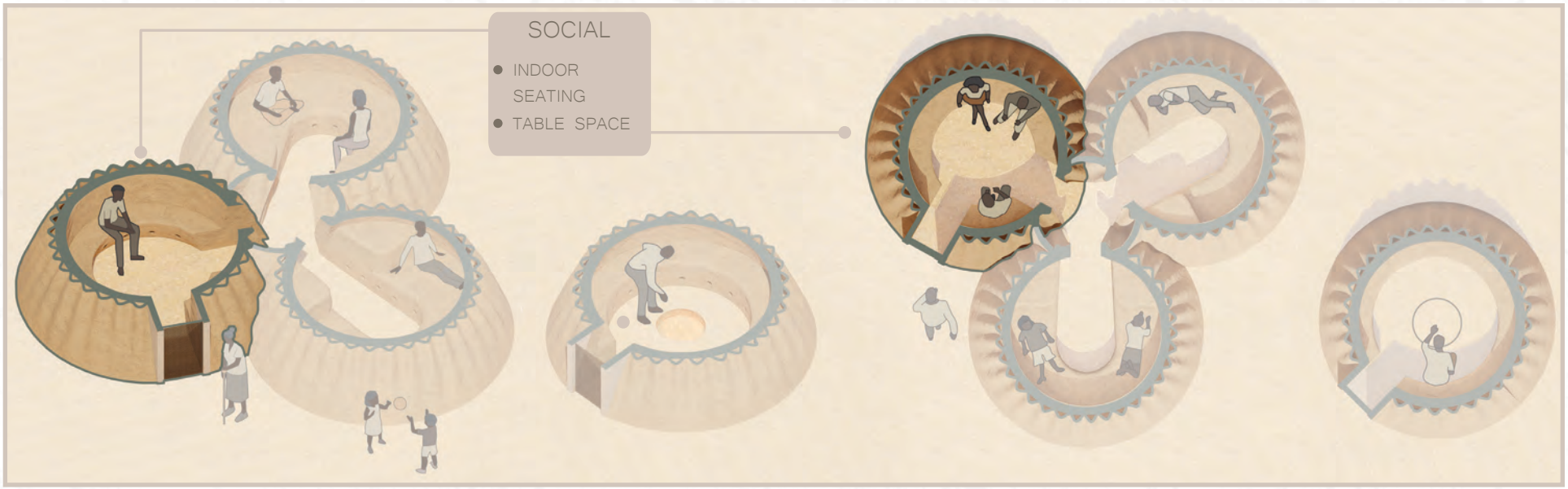


In a typical Sudanese tribe, cooking is performed either outdoors or in a small, but separate, Tukul hut. Usually, the cooking is performed indoors during the rainy season when the harsh weather conditions interfere with the cooking process. Because of smoke pollutants, and out of respect for cultural norms, the cooking unit is separated from the social and sleeping spaces.

Elevated dirt shelving lines the interior perimeter of the hut to provide storage utensils for cooking. In the center of the hut, there is a designated zone for a fire pit for cooking. Smoke is ventilated out through window openings and ventilation channels in the oculus cap. Air inlets are design within the base of the interior shelving that connect to the exterior airflow channels to provide adequate ventilation.



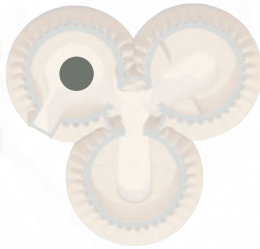


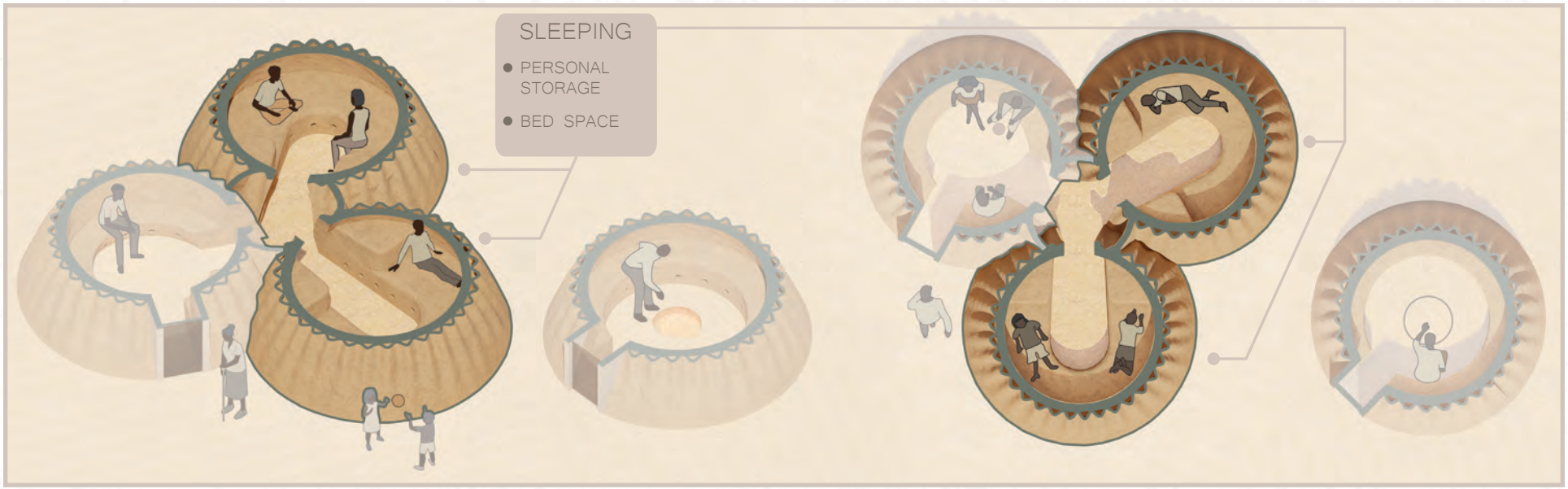


According to John Dau, it is uncommon for Dinka tribe families to eat together or gather indoors to socialize. This is due to the wide variety of tasks each tribal member holds, such as gardening, hunting for food, or tending to their cattle in faraway fertile plains. It is common for everyone to be split apart during the day, only returning to their huts to sleep.

However, according to Melchizdek and Suman, they described a very different scenario in the refugee settlements. Due to limited land that each refugee personally owns, and the fact that refugees have very little to do, it is common for refugees to gather inside to socialize and to eat to pass the time.

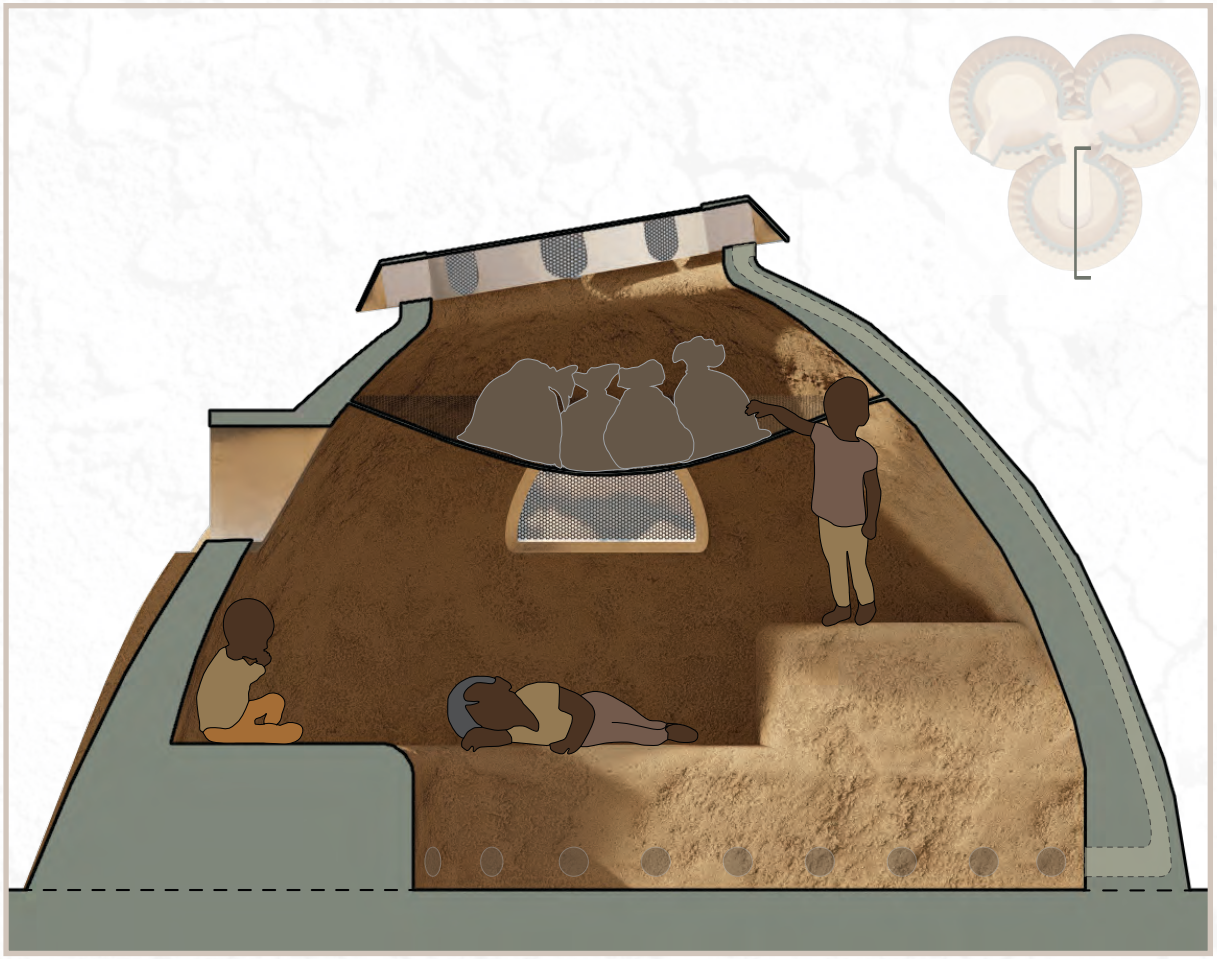
In the social hut, printed clay seating is provided along the interior perimeter, to provide gathering space to eat and socialize with one another. Air inlets are placed in the base of the seating area, that connect to the exterior airflow channels to help promote proper ventilation. The center of the hut is left open to allow refugees to create makeshift tables if wanted. This space also serves as the entrance to the hut, connecting both sleeping units.

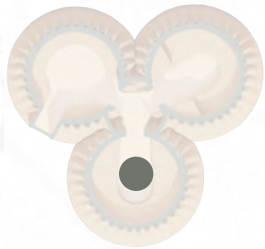


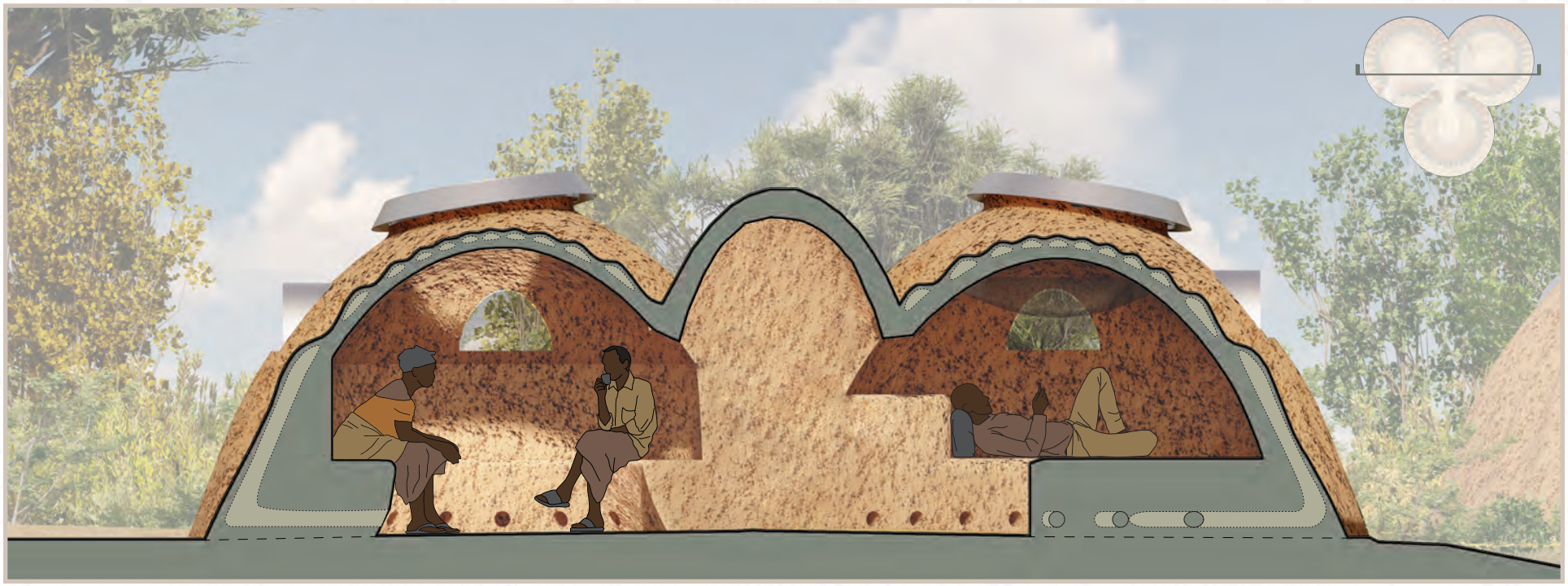


Sleeping will be the primary use for the printed huts. In a typical Dinka tribe, it is common for the women and men to sleep separately from one another. Consequently, there will be two proposed sleeping units where the men and women will sleep. While traditional tribal huts are independently separated from one another, when talking to John Dau, he stated that if it was possible to interconnect these units, it would beneficial and much appreciated within Sudanese culture. Connecting the sleeping and social units will help promote healthy connection between users and will condense the area for housing units within the refugees allotted land, and thus allow for more farming space. This design also adds a safety feature when because more people can share the unit together.

John Dau also stated that it was common for Sudanese people to sleep on the floor, using animal hides to rest on. However, when talking with Suman and Melchizdek, they stated that it was common for people to create makeshift beds in their huts to protect themselves from harmful insects or animals. To address these needs, an elevated clay sleeping zone was created that surrounds the interior perimeter. This allows users to sleep above the ground. It is also typical for the Sudanese to carry all their personal belonging in cloth knapsacks which are stored where they sleep. In this proposal, a netted tarp is to be hung inside the interior sleeping unit to allow for storage. Because most users are children, an elevated clay shelf is proposed to allow easier accessibility when placing belongings in this netted tarp. Air inlets are placed in the base of the elevated sleeping regions that connect to the exterior airflow channels to help promote proper ventilation within the interior.







GEOMETRY

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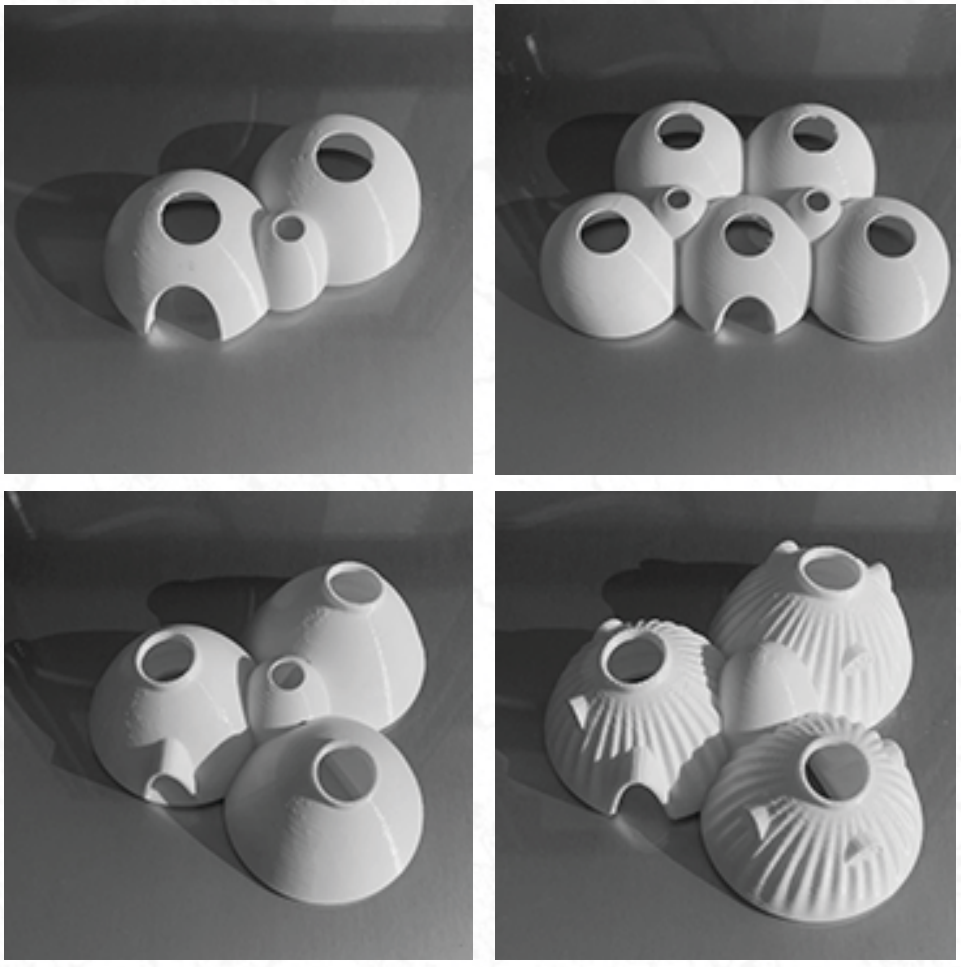
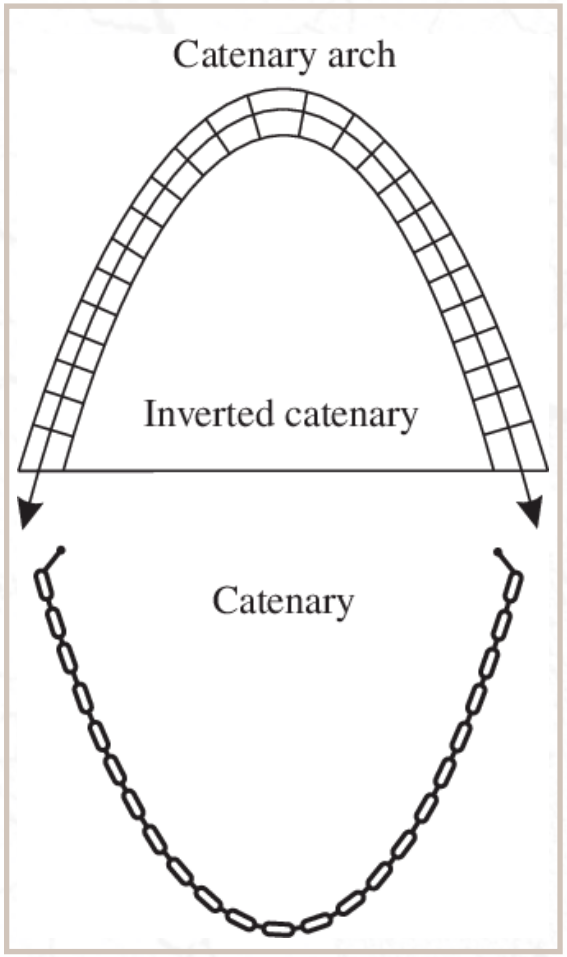
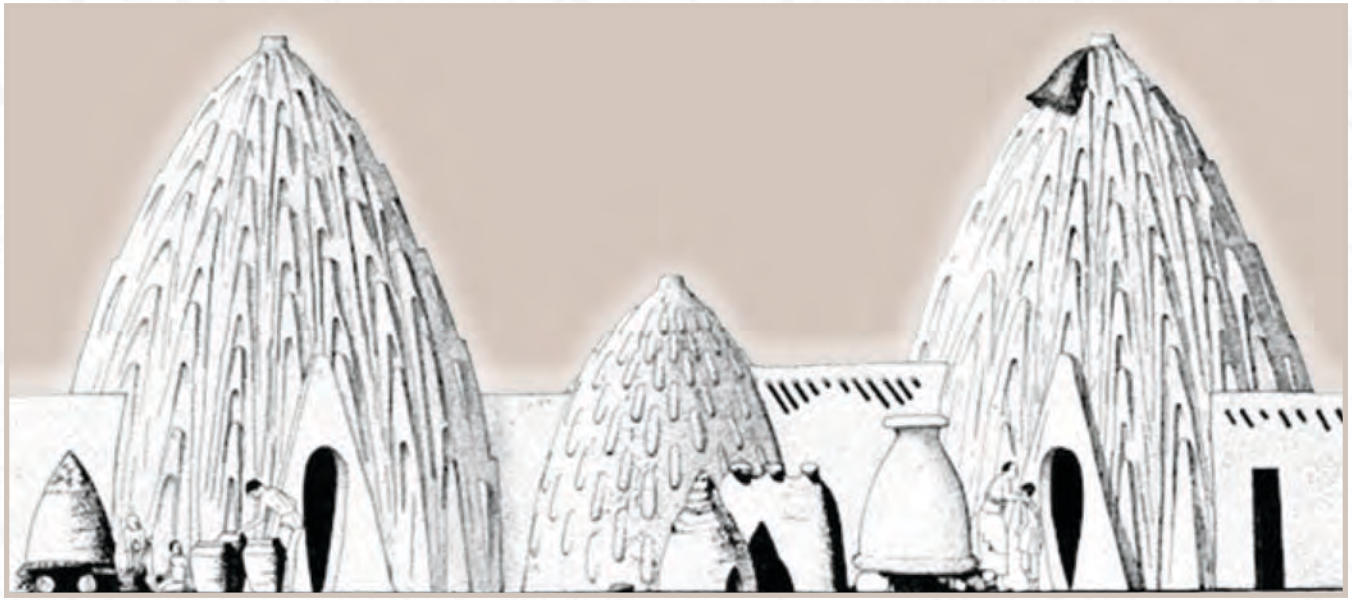
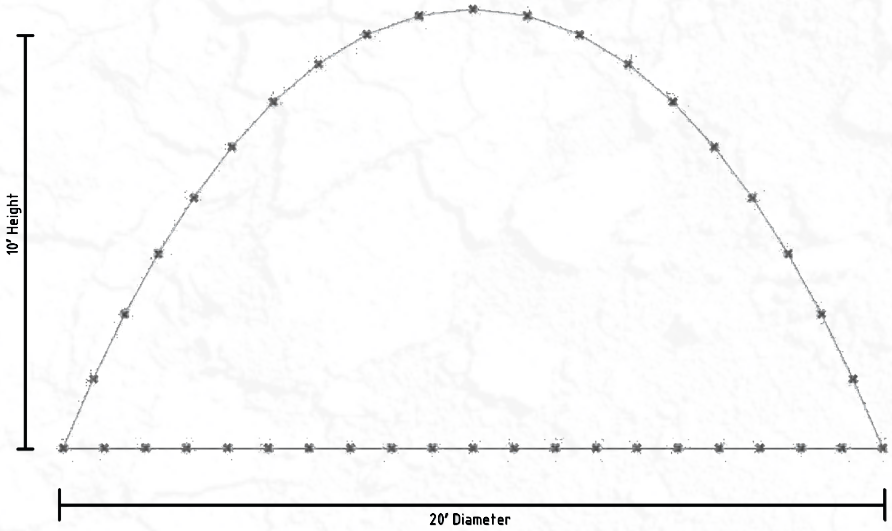


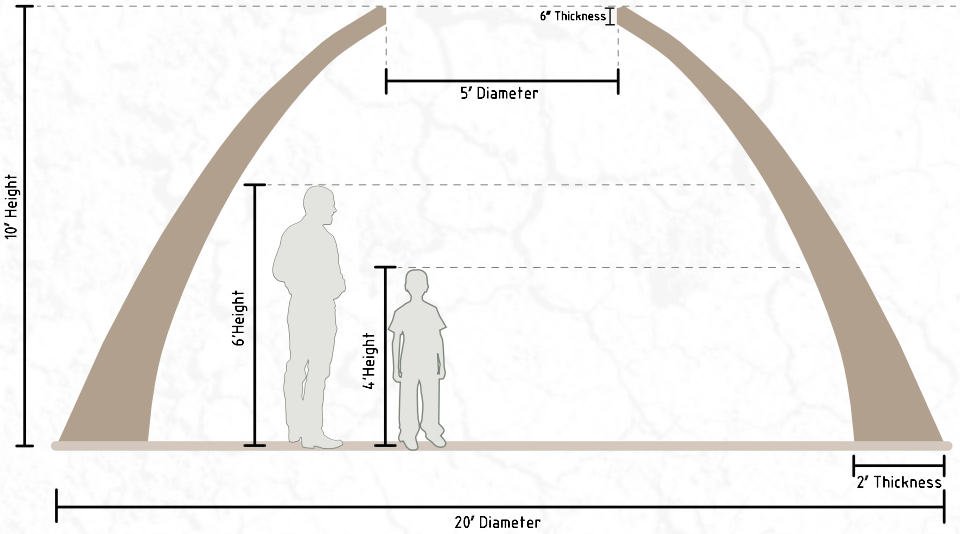




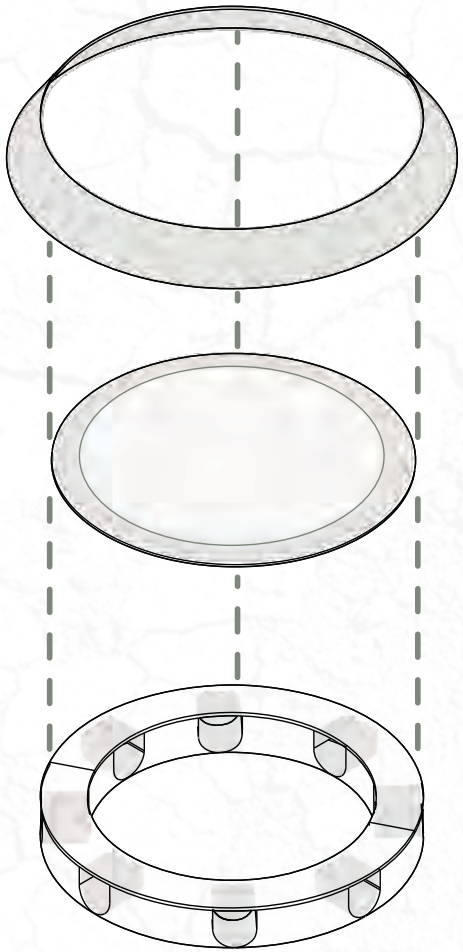
When designing the geometry of the housing unit, an important factor that needed to be addressed was structural support. The Catenary Arch is used as the shape for the domed exterior due to its self-supporting properties. In Cameroon, the Musgum tribe uses this shape for their huts for this reason. Because its shape is in complete compression, no additional structural support is needed to construct these huts [28] [29].

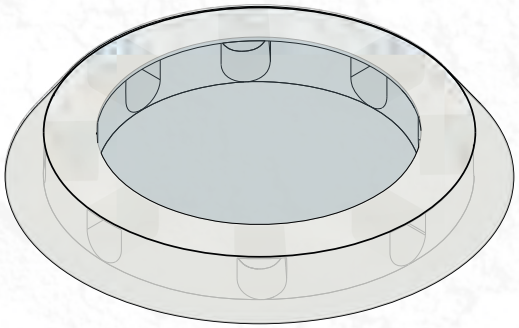
Fig.62 Coll, Vincent, and Mike Harrison. "A Catenary Arch and Chain."
Fig.63 Lucarelli Fosco, "Elevation of Musgum Mud Huts."

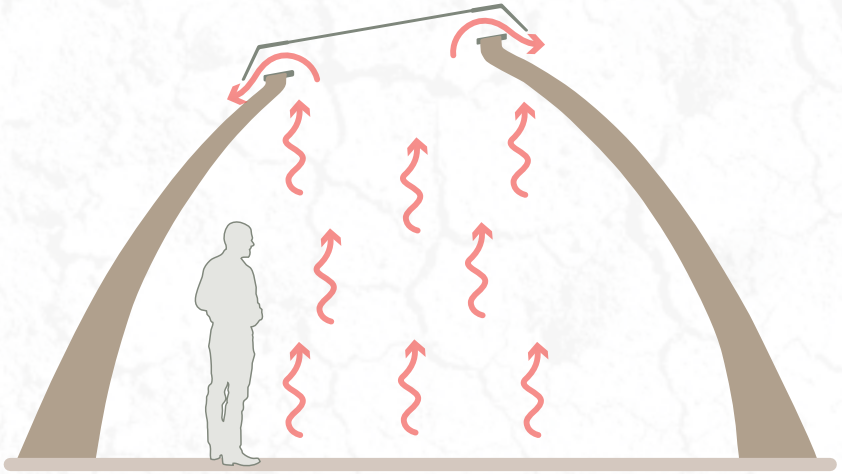




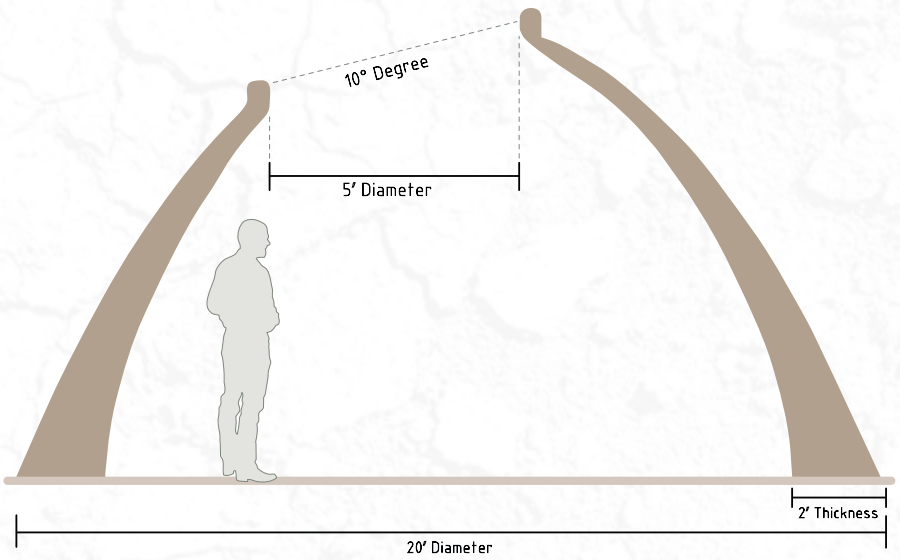
The diameter of each hut spans twenty feet. A two-foot thickness is used at the base of the wall and gradually decreases to six inches at the top. A five-foot spanned diameter is at the top to allow the machine to be removed once the print is completed.

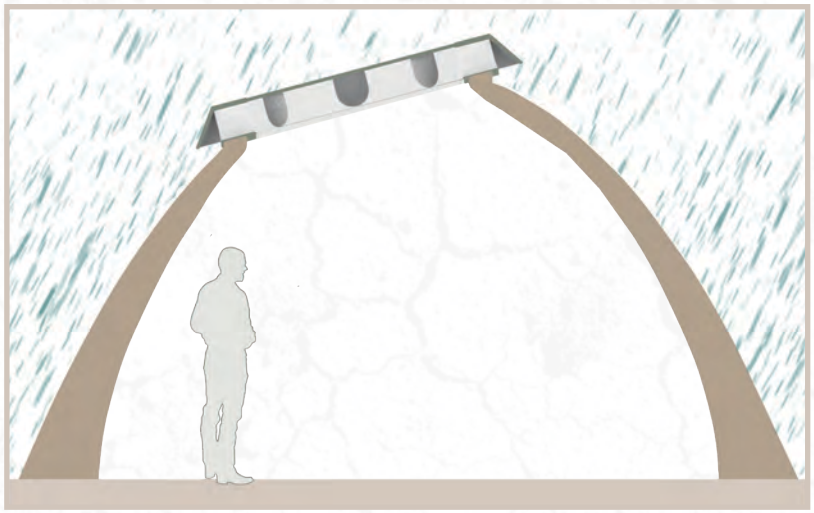




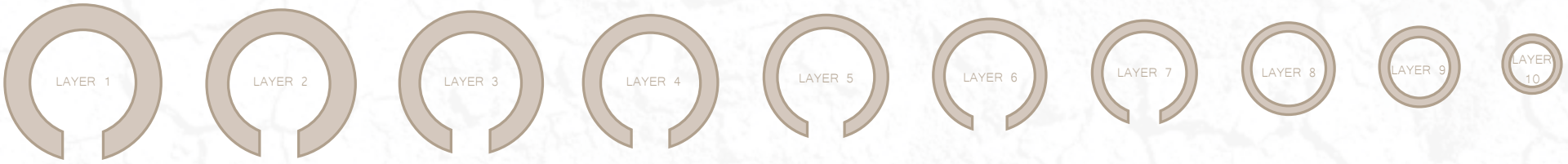


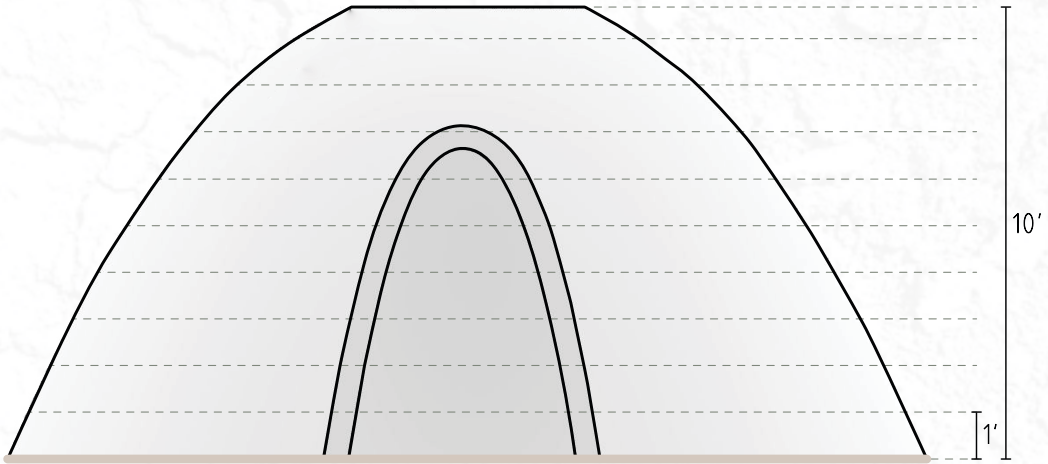
Another important feature of the hut is an oculus covering for the top of the hut. This covering must provide protection from harsh rain conditions, provide ventilation properties, and provides natural lighting into the interior space. The oculus is comprised of three specific parts to address these needs. The structured base of the cap provides ventilation holes running congruently along its exterior rim to allow interior heat to escape as it rises to the top of the hut. The grooved ventilation holes also allow for the cap to be secured on the lip of the exterior dome.

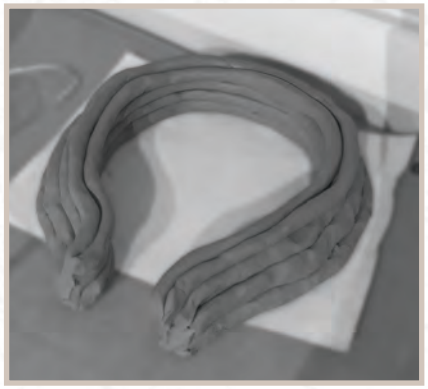


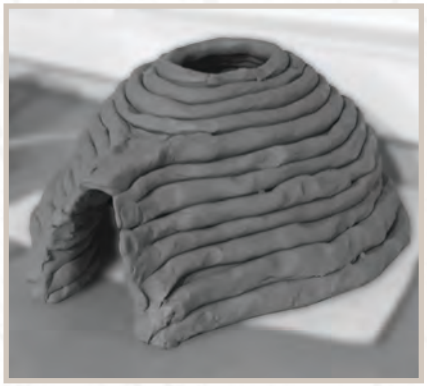


The radial shape of the top of the hut is shifted to ten degrees to allow water runoff once the oculus cap is placed on top of the hut. A glass sheet is placed on top of this structure to allow adequate daylight to penetrate the interior space. Lastly a metal frame is placed over the oculus cap, securing the glass sheet in place, and to block rainwater from entering the ventilation holes during harsh weather conditions.

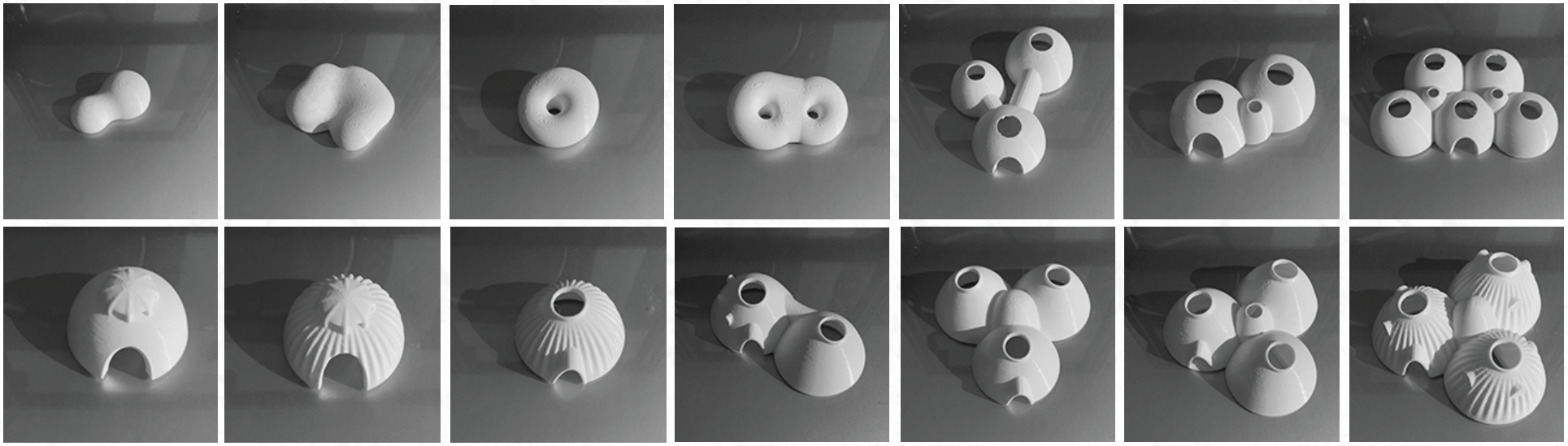








To test the structural capabilities of this shape, I created a 1":20' clay model mimicking the proportions of this design. Ten layers of modeling clay were used to create this model, each representing one foot of printed clay. This study provided validation that this form was self-supporting, even with a five-foot diameter oculus hole placed in the center top of the structure.



3d printed prototypes were used to create the final shape in the design. The first set of forms were used to explore different ideas and possibilities of self-supporting shapes that could be printed with a 3d printer. The second grouping of forms was an exploration of transitional spaces to see if it was possible to interconnect multiple units and to explore the variety of possible ways to do so. The third set of forms explored the traditional shape of a Tukul hut, investigating ways to approach the geometry in a more reserved manner. The fourth group explored how individual huts became interconnected using the transitional exploration from the second grouping and the information gathered from the third grouping. The final geometric form incorporates aspects and informed lessons from previous iterations.

VENTILATION

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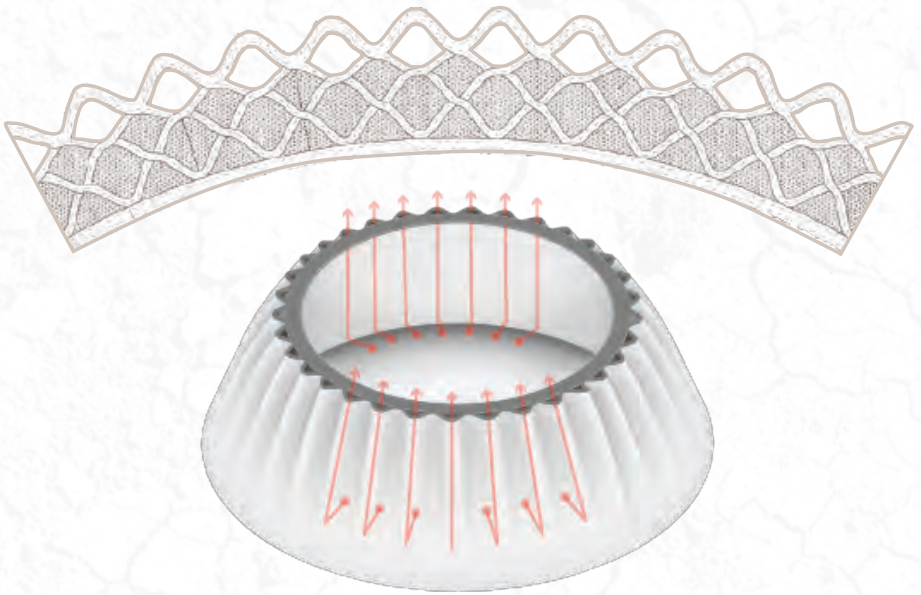
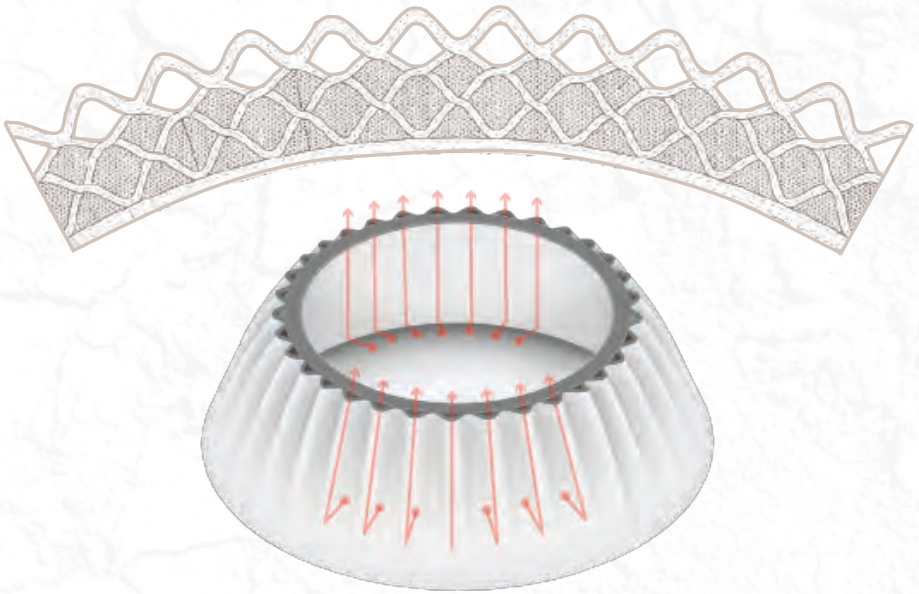
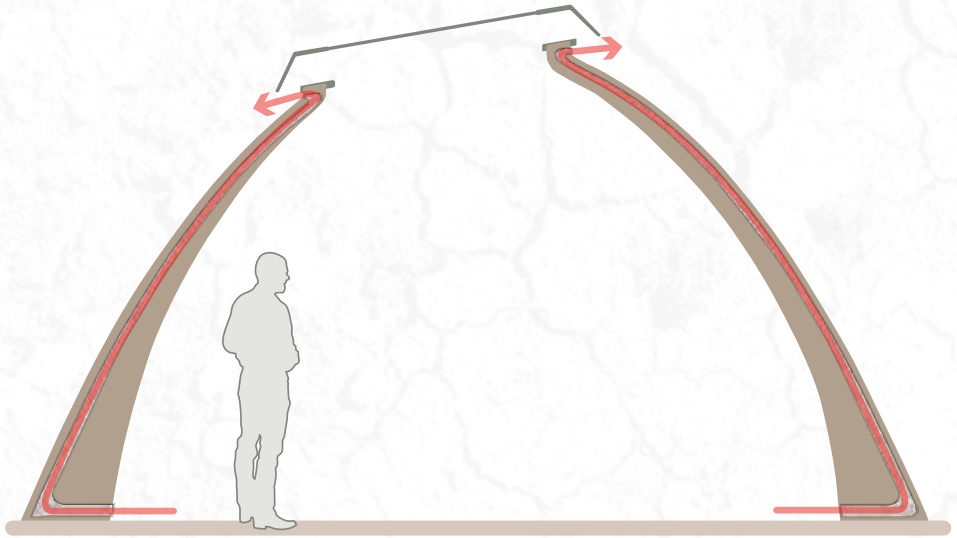


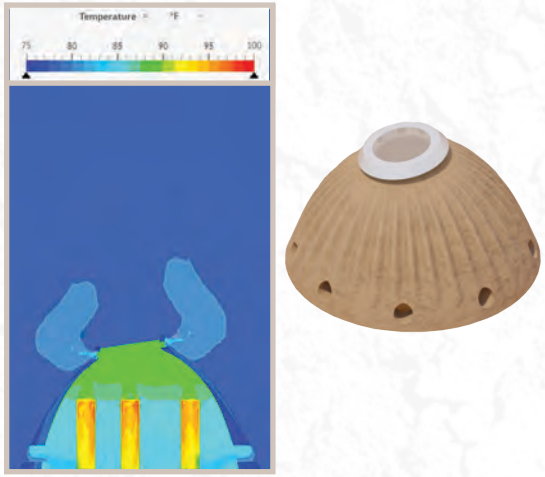




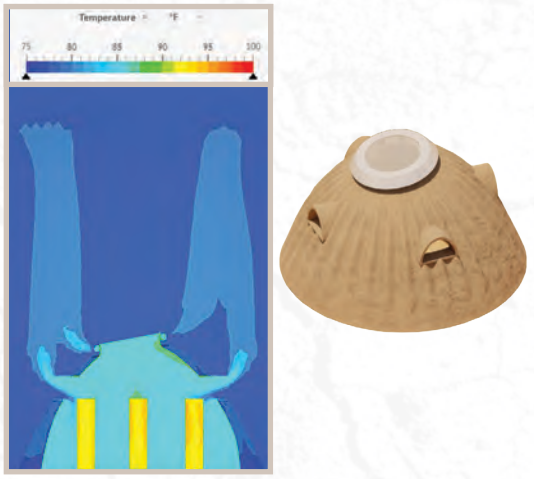
Because of machine precision parametric modeling, exterior wall geometry can be further optimized for sustainable purposes. A corrugated geometric form is added to the exterior of the hut to provide ventilation channels within the huts structure. Inlets placed within the lower interior walls are connected to exterior channels that feed into an exterior outlet at the top of the hut. The intended purpose is for air to be pulled out of the hut in these channels due to the movement of air created by exterior heat from sun exposure.

Fig.64 Alberto Chiusoli, “Natural materials and bioclimatic aspects.”

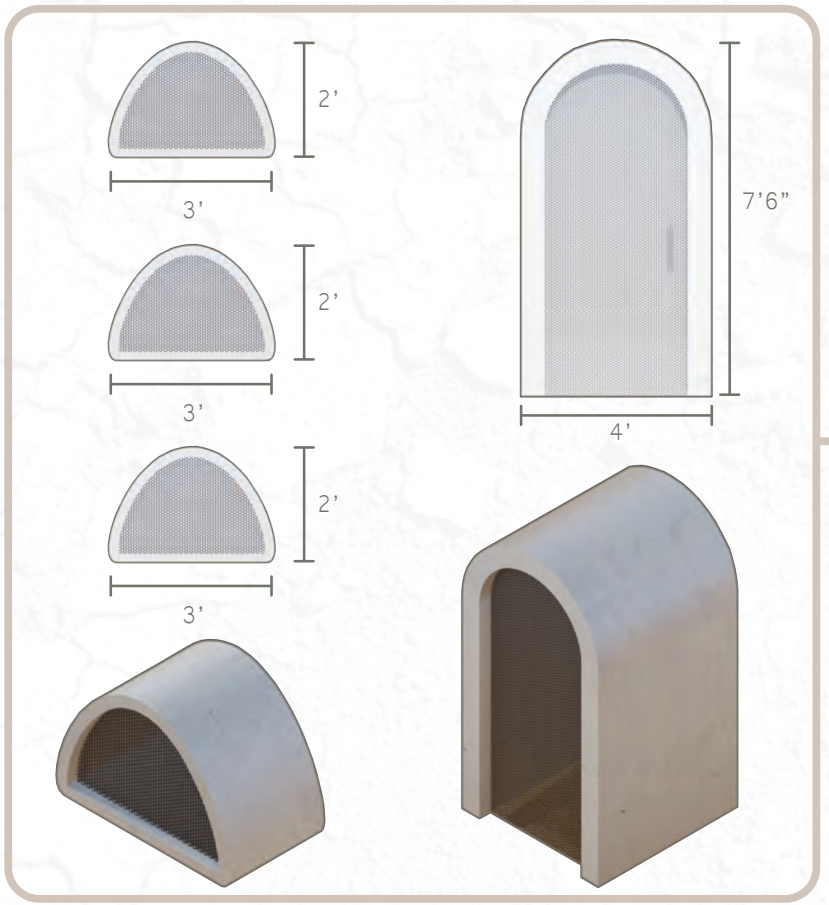
To get a better understanding of the interior heat, Simcale simulations were run to test airflow for window ventilation placements. In these simulations, three, six-foot occupants were placed in the structure to account for the average internal body heat radiated from each person. This is used to test the added internal heat load of a unit when occupants are inside. The first test relied only on the oculus ventilation outlets located at the top and demonstrated miserable heat conditions in the interior. The average interior temperature ranged from 95 to 100+ degrees and the simulated occupants were overheated.



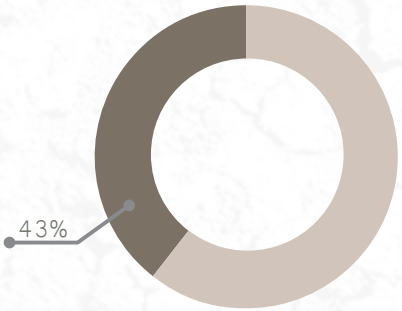
The second test was conducted with the oculus ventilation outlets at the top and with large ventilation outlets at the bottom of the exterior wall. This was hypothesized to be the best result due to the predicted effect of stack ventilation. However, because the ceiling was not high enough, stack ventilation was not as effective as predicted. While the conditions were much better than the first test, the simulation still presented 85–90-degree interior temperatures. The occupants were not overheated in this simulation but were shown to be uncomfortably warm.

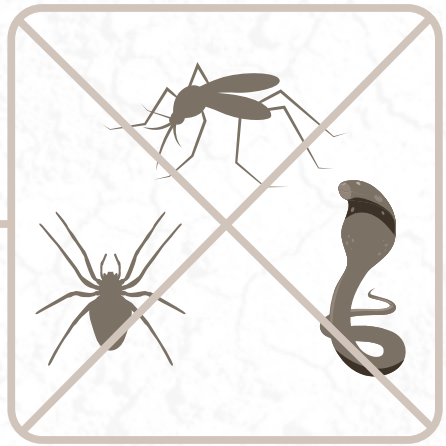


The third test was conducted with the oculus ventilation outlets and windows placed six feet above the hut floor. This simscale simulation presented to be the best situation that provided optimal ventilation. The interior hut maintained a steady 80–85-degree interior temperature, and the occupants remained comfortable. Based on these results, this proposed window placement became incorporated into the final design.



MOSQUITO PROBLEM 3RD TOP CONCERN





Cited in a survey from the REACH Initiative, mosquito problems were listed as one of the top complaints in the Palorinya settlement [9]. Other dangerous insects and animals were listed as a problem as well. To address this issue, the huts needed to provide safety from all exterior insect and animal threats. This design proposes the use of manufactured windows and doors with metal screening, to address these issues.

SHIPPING MATERIAL

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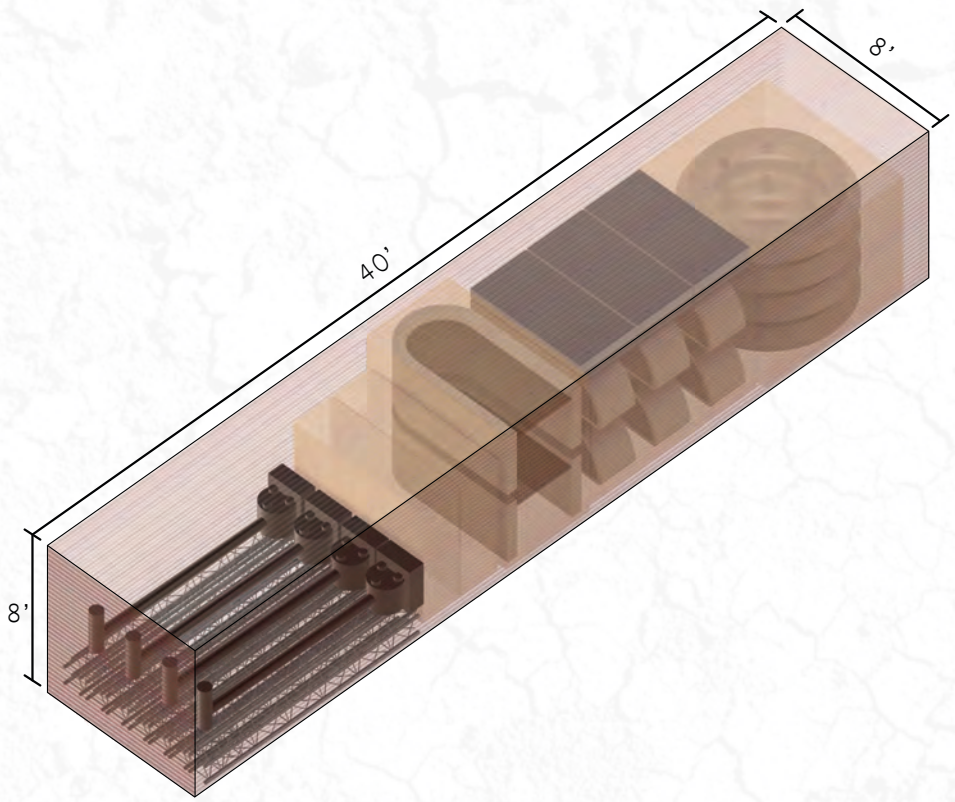


UGANDAN JOB OPPORTUNITIES

HOUSING MATERIAL NEEDS

The need for metal windows, doors, and oculus caps allows an opportunity for job growth development in the country of Uganda. One of the main complaints about refugee settlements in Uganda is the fact that refugees require excessive farmable land in their relocated areas. Because of this, Ugandans are making a sacrifice by giving up land to the south Sudanese refugees [30]. A possible solution to address this is to provide the opportunity for work-force development for all.

Instead of pre-manufacturing the required doors, windows, and caps, these can be manufactured locally from independent Ugandan metal fabricators. The intended outcome for this proposal would help provide more needed jobs for the citizens of Uganda so they can gain benefits from allowing the South Sudanese refugees into their country.

COMPONENTS

OCULUS RING: 4 units W7'6" x L7'6" x H1'6"
WINDOW: 12 Units W4 x L3" x H3"
DOOR: 2 Units W4' 6" x L7' 6" x H3'6"
SCREEN/NETTING: 2 Units W2' x L3'6" x H1'6"

SYSTEMS

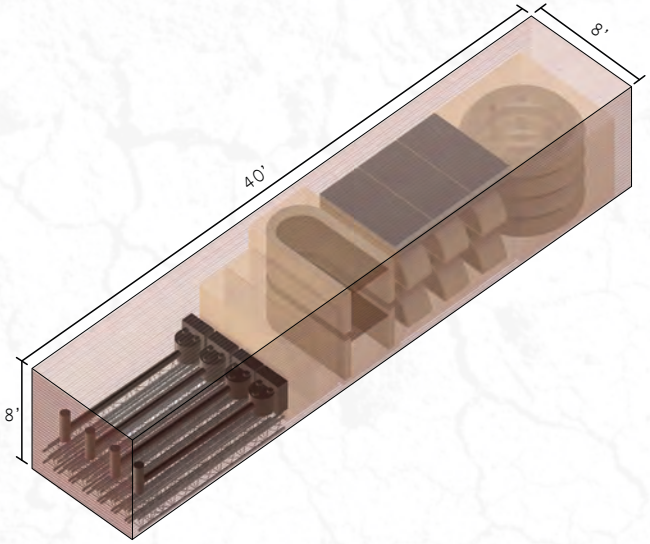
SOLAR PANELS: 6 Units W6' x L3' x H6"
BATTERIES: 2 Units W2' x L3'6" x H1'6"
CABLES: 2 Units W2' x L3'6" x H1'6"
PIPES: 2 Units W2' x L3'6" x H1'6"
WATER PUMPS: 2 Units W2' x L3'6" x H1'6"

VERNACULAR

SOIL: On Site
WATER: On Site

PRINTER

PRINTER: 4 Units W2' x L10' x H3'
TRUSS: 12 Units W1' x L2' x H1'



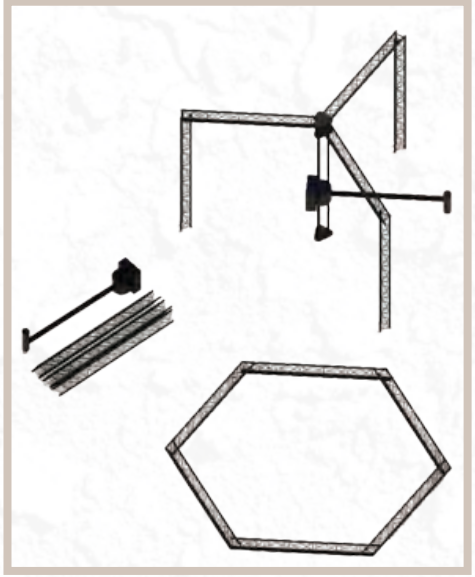
The needed materials for a family sized unit can be packaged in a typical forty-foot by eight-foot shipping container. The intended goal is for a unit to be easily transported on site via semi-truck. This consists of the 3D printer and structural supports, the metal doors, windows, and oculus roof, and the printer's power supply.

The community in the refugee settlement will be encouraged to contribute to the construction process, through easy task such as bringing materials onto the site, mixing the clay soil for the printer, and helping place windows and doors in the units. As a result, this design process becomes a community event and offers a chance for the refugees to connect with one another and to contribute to their community.

DELIVERY

The product is to be delivered and unpacked on site.

PRINTER SETUP

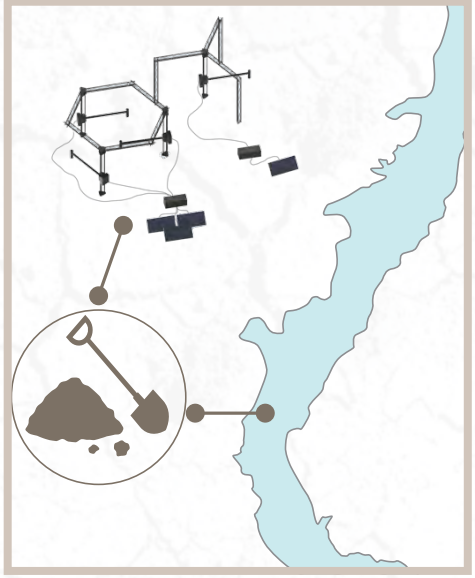


Next, the printer is set up by hand with a minimum amount of three people.

SYSTEM SETUP

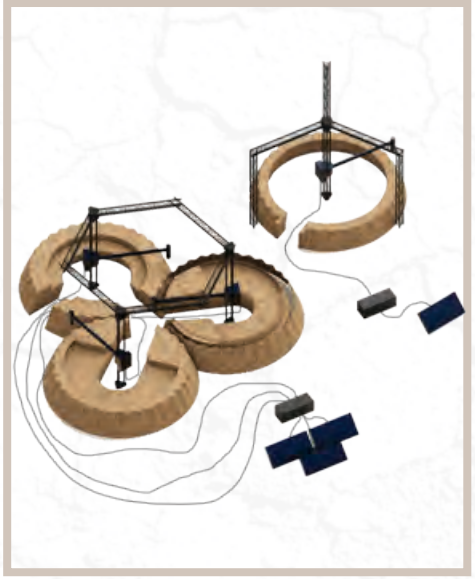
The solar panels, batteries, cables, and water pumps are then installed.

SOIL SETUP



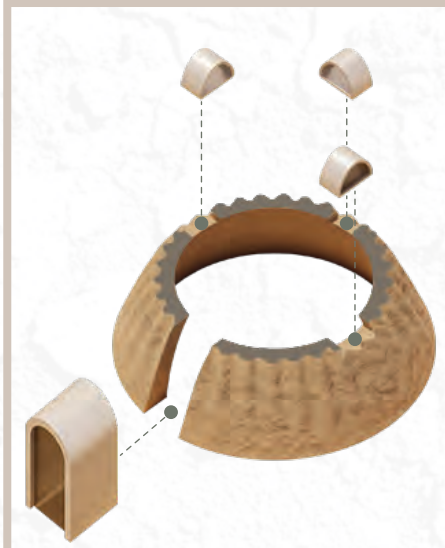
Once this is complete, the clay substrate is brought on site, mixed with water, and then processed into the machine for printing.

PRINT



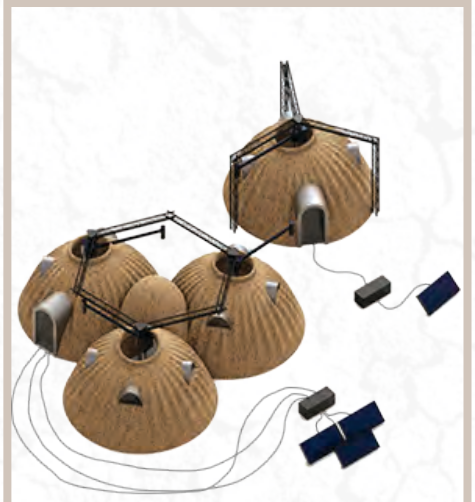
Once everything is ready, the printing process can begin to take place.

DOOR WINDOW PLACEMENT



Halfway through the print, the windows and doors are installed.

PRINT FINISH



The print continues, printing around the added elements, securing them into the build.

OCULUS PLACEMENT

Once the print is complete, the scaffolding is removed and the final oculus caps are placed on top, finalizing the unit.

CONCLUSION

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Fig.65 "Two Refugee Children from South Sudan Play Iin Zone Five of BidiBidi Refugee Resettlement Camp."

Fig. 133 Settlement Site Plan Image

When considering the exponential development of 3D printing technology within the past two decades, the predicted upward trajectory shows that this form of construction has the potential to become more accessible within the near future. This technological leap forward not only changes the landscape of construction methods but greatly affects the lives of its recipients. I believe once this technology reaches this approachable stage of development, it will have the opportunity to benefit impoverished areas throughout the world where adequate housing is desperately needed.

Areas in the world, like South Sudan, have not benefited from many of the construction benefits of the industrial revolution and this have continued to employ means of traditional vernacular construction, which unintentionally contribute to the housing problems that still plague the refugee settlements today.

For a positive change to take place, there needs to be a good enough reason for the adaptation of alternative construction practices. The smartphone is an example of how the improvements in accessibility have allowed people here, to skip a generation, allowing them to connect to the entire world, which wasn't available twenty years ago.

If the development of 3D printing reaches the point to where it can become accessible to these hard-to-reach areas and provides enough benefits to supplement the traditional forms of vernacular construction, it has the potential to affect positive change in these areas much like the smartphone has.

As of now, there needs to be continuous research, prototyping, and regional testing, to push forward this idea into a plausible reality. I am hopeful that this technology will develop to a point soon where it can have serious and beneficial impacts around the world, improving the lives of everyone it touches.

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Fig.66 David Azia, “Seven-month-old South Sudanese refugee Gire Karyot.”

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