Computational Design for Resilient Shelter

Project Survey Report

South Sudan
Building Resources & Shelter Practices

STRUCTURAL XPLORATION LAB

EPFL Tech4Dev

UNIVERSITY OF JUBA

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ABSTRACT

Seasonal floods are a common and extended problem across several regions in South Sudan, causing considerable damage to houses, crops, and livelihoods. In this context, new housing and shelter solutions, besides being flood resilient, should take into account the native construction customs and locally available materials so as to better fit into the building culture in South Sudan. This report presents information about the housing construction in the country, including the building materials and skills that are available in local markets in South Sudan and the forms and functions of local housing. This information is useful for construction projects developed by NGOs, researchers, and practitioners. The methodology employed for the study comprised surveys in local markets and households, analysis of photographic records of shelters and tukuls, and consultation with on-site experts. The results provide insights into the most common construction techniques, materials, solutions, and average prices in the local markets. Besides, data was also gathered regarding cultural customs that shape the development of the shelters. Finally, although the data might be only representative of certain regions in South Sudan, it provides a comprehensive glimpse of the overall construction environment across the country.

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1. INTRODUCTION

Seasonal floods are a common and extended problem across several regions in South Sudan. Due to its location north of the Equator, the climate in South Sudan is tropical all year round, with a hot, dry winter and a rainy summer, which is a bit less hot than winter but more humid. This leads to a subsequent flood season from August to October, causing damage to houses, crops, and other livelihoods sources as well as infrastructures like roads, schools, and health facilities [1]. Over the years, the communities of the affected areas have developed resilience approaches to mitigate the impact of floods on their assets and livelihoods, relying mostly upon a nomadic lifestyle to tackle the episodic nature of the rise in water level. However, as society and infrastructure develop across the country, sporadic displacements impact negatively the lives of those living in flood-prone locations, especially after permanent settlements have been established to take advantage of the flood plain. As this situation is expected to worsen due to the climate change effects, action is required to relieve the flooding impacts across the country.

Among the most vulnerable communities, housing is the most affected asset during the flood season. However, the provision of flood resilient housing in South Sudan is constrained by the prevailing limitations in the availability of materials, skills, funding for building materials that must be imported [2], and the poor condition of the national road network that increases the cost of internal supply chains [3]. Additionally, the lack of construction skills, particularly in the rural areas most affected by flooding, hinders the development of more resilient housing. The relevance of this issue is reflected by the scale of flooding in South Sudan, with around 1 million people affected annually and with the trend towards more regular and more destructive flooding [4].

As the need for flood-resistant housing solutions in South Sudan increases, new construction approaches should be developed to enhance the resilience of the communities against increased water levels. Therefore, this report presents a data collection regarding local materials and construction customs aimed at providing the methodological basis for upcoming flood resilient constructions. The aim of the work presented in this report is to provide reliable data about the local context in South Sudan, so as to allow researchers and practitioners to propose solutions compatible with the local reality in terms of needs, traditions, and resources. Employing surveys, photographs, and in-site expert consultations, valuable local information has been gathered and organized across the different sections of the herein document. And although the data might be representative of certain regions in South Sudan, it provides a comprehensive glimpse of the overall construction environment across the country.

2. LOCAL MATERIALS AND SKILLS

This section summarizes the results of local surveys conducted across several regions in South Sudan in order to gain knowledge regarding the availability of local materials and skills for shelter/housing construction. The information presented below represents the joint work between EPFL, Medair, and Juba University, whose coordinated actions allowed to gather valuable information on site for use in the upcoming stages of this project.

The report compiles and documents information collected during field surveys by Medair staff and University of Juba students. Surveys were conducted in Juba during the period from July to September 2021.

The scope of data collection entails two important limitations. First, data was collected in Juba, the capital of South Sudan, while flooding and associated shelter assistance is typically provided in areas further to the north of the country. Given the highly unreliable nature of supply chain, the materials and skills that are available in Juba may not be available elsewhere in the country. Second, the highly volatile inflation and exchange rate environment in South Sudan entails sudden, significant changes in market prices. Thus, the prices defined in this report may not be valid later. Both of these limitations should be taken into account when specifying use of materials identified in the report.

2.1. MATERIALS AND SKILLS SURVEY METHOD

Data was collected during visits by Medair staff and University of Juba students to various vendors of construction materials and fabricators of construction products. This included, for example, vendors of steel, cement and timber, as well as producers of precast concrete blocks. Various materials and skills available at each survey site were documented two standard questionnaires (see Annex 1).

Details recorded in the materials questionnaire included the Surveyor name, date of survey, name and description of the material, material dimensions and other specifications, source and supply reliability, and price. Details recorded in the fabrication techniques questionnaire included the Surveyor name, date of survey, name and description of the technique, location, supply reliability and price. 48 completed questionnaire forms were received, including several in non-standard formats (notes) that each documented multiple materials and techniques.

Survey data was compiled at EPFL, yielding descriptions of 128 construction materials and 15 fabrication techniques. This list is not expected to be exhaustive. However, it provides a good overview of materials and skills that are readily available in Juba and may potentially be used in the design of flood resilient shelter solutions.

2.2. MATERIALS AND SKILLS SURVEY RESULTS

Complete lists of materials and techniques identified in the surveys are presented In Annex 2. Particularly notable is the wide range of wood, bamboo/grass, and steel products of various dimensions that are available from multiple sources in Juba.

Photographs of a selection of surveyed materials are presented in Annex 3, highlighting some of the formats and other qualities of available materials.

3. LOCAL CONSTRUCTION CUSTOMS

This section presents the results of the work conducted in order to better understand and detail the local building customs in South Sudan. Two different approaches were employed upon data collection: (1) analysis of photographs and reports of local tukuls and shelters, and (2) surveys conducted on-site by members of the University of Juba and Medair. Information regarding traditional vernacular construction, structural systems, and materials was gathered with both methodologies, and the main findings are discussed in the following subsections.

3.1. PHOTOGRAPH ANALYSIS

This section briefly outlines the forms of vernacular housing and the materials, structural systems and construction techniques involved, as obtained after analysis of photographs provided by the team on-site and open-access reports.

The primary form of vernacular housing in South Sudan is the tukul. Numerous variations in tukul design are apparent throughout the country. Variations in tukul design are associated with different geographic locations, and are hence expected to be associated with particular ethnic/tribal groups and associated customs. However, consistencies in tukul designs of different ethnic groups in different parts of the country suggest that, in addition to tribal customs, tukul designs are dictated by local availability of resources, such as local species/sizes of wood and grass.

Essentially, tukuls are single-room shelters with low, windowless walls and high-pitched grass roofs. Households may have one tukul or they may be comprised of multiple tukuls, with each serving a specific function, such as cooking, food storage, sleeping, or secure accommodation of livestock (Planning Alliance, 2013). Most daily activities take place outdoors in space adjacent to tukuls. For some households, the area of the tukul(s) and surrounding space is raised on an earthen plinth that provides protection against flood waters.

A selection of examples of different tukul designs are presented in Figure 1.

Two general variations in tukul plan are apparent: round and square. Plan dimensions of square and round tukuls vary from around 3-6m deep/wide (Planning Alliance, 2013). Square and round plan tukuls of different sizes may be observed within the same settlements, suggesting that variations do not relate to tribal customs. Rather, these variations perhaps stem from material availability. In comparison to round-plan tukuls, structures of square-plan tukuls use less timber members, though the timber members used are of greater girth (diameter) and include members of greater length. Thus, it may be that the round plan is used when wood of smaller length and diameter is available.

Generic structural design of round tukuls is presented in Annex 4a. Generic structural design of square tukuls is presented in Annex 4b.

In general, tukuls do not feature a raised floor, i.e., they feature earthen floors. Timber members – posts for the round plan and corner columns for the square plan - are buried (dug into) the ground, providing lateral and vertical stability. It is not clear to what depth the posts are dug into the ground, nor whether measures such as compaction of the earth or inclusion of other supports is undertaken to improve stability. Several tukuls with raised floors have been observed. These tukuls sit on timber platforms that are supported by timber posts embedded in the ground. It appears that such tukuls with raised floors are rare, perhaps due to the large amount of wood required for a structurally-stable platform. Two examples of tukuls with raised floors are presented in Figure 2. In one example, space created under a raised tukul is enclosed, perhaps for use housing livestock.

Wall systems differ significantly between round and square plan tukuls. Several incidences of tukuls with masonry walls have been observed (including adobe, fired clay brick and concrete block masonry); however, these appear to be rare. Typically, walls of round tukuls are built from a series of adjacent vertical posts dug into the ground along the perimeter of the round plan. Relatively narrow gaps between these posts are sealed with a mud layer, which may be either internal or external. The precise composition of this mud layer, including whether it incorporates a straw binder, is unclear. Walls of square tukuls are typically built from *wattle and daub* construction, which includes a matrix/lathe woven from grass, bamboo or branches (i.e. the *wattle*). These woven panels are fixed to corner and intermediary columns. The woven panels are then finished with an external mud layer (i.e. the *daub*). As with round plan tukuls, the precise composition of this mud layer is unclear.

Figure 1. Tukul design variations

Roof frame systems of round- and square-plan tukuls follow a similar pattern to wall structures. For round tukuls, the primary roof structure is comprised of many wood rafters. The lower end of these rafters rest on the vertical timber posts of the walls and extend beyond the walls by less than half a meter. The rafters converge at a single point. It is not clear how the rafters are secured together at this peak. Circular bands of sticks are tied together and tied to the outside of the conical roof structure, securing the rafters and supporting the grass envelope layer that is installed above. The spacing of these circular bands is unclear, though this spacing is perhaps determined by the length of grass used for the roofing. For square tukuls, the primary roof structure is comprised of four beams. The lower ends of these beams rests on the corner columns and at the upper end they converge to form a peak. The manner of fixing these found beams together at the peak is not clear. For some tukuls, it appears that interim beams are also installed, resting at the lower end on posts installed at the mid-point of walls. In addition to supporting interim beams, these interim posts provide a mid-wall fixing point for wattle and daub wall panels. Horizontal rafters span these beams using tied joints (i.e., rope or grass). The spacing of these rafters varies, and is assumed to depend upon the length of grass used for roofing that is fixed to the rafters.

Figure 2. Examples of elevated tukuls.

The pitch (steepness) of roofs varies from around 45 degrees to around 60 degrees. Roof pitch does not appear to be associated with plan type, but rather, it appears to be dictated by the morphology (form and material) of grass roofing. Steeper roof pitches are typically associated with shorter lengths of grass roofing laid in overlapping tiers. The length/extent of overlapping of tiers is not clear, however the external roof surface of each tier is typically around 50cm wide. Shallower roof pitches are typically associated with longer lengths of grass roofing laid without visible tiers or with only one or two tiers. It appears that, because longer grass sheds water more quickly, the availability of longer grass enables shallower roof pitches, which use shorter lengths of wood.

The depth of grass roofing and the manner of fixing grass to wood rafters (square plan) or round bands (round plan) is not clear.

3.2. SURVEYS CONDUCTED IN SOUTH SUDAN

In a second approach to better comprehend the local construction customs in South Sudan, a survey-based investigation was conducted on-site by members of the University of Juba and Medair East

Africa. The surveys aimed at collecting information about typologies, forms, materials, practices, and social requirements for shelters and tukuls as perceived by local communities. Therefore, a wide range of inquiries and topics were included in the surveys, being aware that in some cases not all the information is readily available for collection.

3.2.1. METHODOLOGY

A detailed survey with 24 questions was developed to collect on-field data regarding local construction customs in South Sudan. The proposed questions were quantitative and qualitative, based on the nature of the information to be collected. Besides, all queries were posed as open questions, giving freedom to the responder to answer as suits him best based on his experience and knowledge. The survey template can be found in Annex 5. As observed, the survey collected information regarding general shelter properties (size, cost, life span, among others), space distribution, common traditions and customs, structural solutions, materials and techniques, locations, and end-of-life scenarios. This way, a full understanding of the construction process and life service of shelters can be developed, aiming at providing valuable information for future phases of this project.

The surveys were conducted on-site by a group of bachelor students from the School of Architecture of the University of Juba. The group was briefed about the content and scope of the surveys and then deployed for data collection. Instructions were given to visiting aleatory households and conducting the survey by observation of the shelter and consultation with the owners. When it was not possible to collect precise data (such as shelter cost or constructed area), estimations were allowed based on the judgment of the surveyor. All households visited during the campaign were located in the city of Juba and its surroundings.

The surveys were conducted during the months of July, August, and September, coinciding with the flood season in South Sudan. However, none of the households surveyed was affected by floods. Surveyors were instructed to include only households that employed local vernacular customs, both in terms of materials and techniques. Therefore, constructions employing standard building solutions (such as concrete or masonry) were not included in the poll. On the other hand, given that all surveys were conducted in the city of Juba and its surroundings, some limitations are foreseen for the obtained results. Survey results are expected to be biased by location constraints since they are mainly representative of the Juba region. This is especially relevant due to the local availability of materials, where constructions customs are greatly influenced by the readiness of materials for collection from natural sources or acquisition from local markets. Future research will be required to expand the results of this survey to the regional or country level.

After completion of the surveys, scanned copies were sent to the EPFL team in Switzerland for analysis and data processing. The results gathered for each question are presented and discussed in the following section.

3.2.2. SURVEY RESULTS

This section presents the results obtained from the surveys on the local construction customs in South Sudan. In total, 38 surveys were analyzed and processed, and the data is presented quantitatively and qualitatively so as to better describe the observed results. For most of the queries under analysis, results are presented as a range of values as obtained from the different surveys, allowing a wide understanding of the overall shelter reality. In the followings paragraphs, each question in the survey template is presented and an overall analysis of the results is discussed.

3.2.2.1. Question 1: average size of shelters

The average size of shelters ranged between 10 m^2 and 25 m^2, with one third of the results being 16 m^2 (squared shelters measuring 4 m × 4 m). As expected, the size of the shelter is mainly related to the number of people that inhabits it. No significant correlation was found between the shelter size and its materiality or construction system.

3.2.2.2. Question 2: average people/shelter

Results show that the average number of people in a shelter ranges from 2 to 6, with a median value of 4. When these results are correlated to the size of the shelters, it is found that the average square meters per person is equal to 4 m^2, value consistent with the guidelines provided by the Sphere standard [5] which recommends 3.5 m^2 per person.

3.2.2.3. Question 3 average cost/shelter

The average shelter cost may vary from about 75 USD up to 2,000 USD depending on the materiality employed for its construction, the shelter size, and finishes. For instance, a 10 m^2 shelter that employs bamboo poles, mud, and grass, is estimated to cost around 115 USD (15,000 SSP). On the other hand, a 20 m^2 shelter employing a timber structure, mud bricks, and zinc roof, is estimated to cost about 2,300 USD (300000 SSP).

3.2.2.4. Question 4: expected life span

Well-constructed shelters and tukuls might last up to 10-20 years if proper yearly maintenance is carried out, as reported in the surveys. Such maintenance includes replacement of foundation poles, re-plastering of walls with mud or cement, refurbishment of the roof with new grass layers, and joint reinforcement. On the other hand, less robust temporary shelters are usually intended to last between 1 and 2 years due to periodic climate erosion.

3.2.2.5. Question 5: average height from ground to eaves

The average height of tukuls and shelters ranges from 2 to 4 meters, mainly depending on the structural solution employed. This pitched roof results as a solution to provide enough slope for water draining through the grass roof. For large community shelters, the average height of the shelter can be as high as 4-5 meters to allow proper ventilation and heat dissipation.

3.2.2.6. Question 6: most common materials employed for shelters

The materials employed for shelter and tukul construction depend mainly on the local market stocks and their availability in forests and bushes for collection by locals. As reported in the surveys, the most commonly identified construction materials in the Juba region are: mud, timber, rope, grass, bamboo, stone, clay, wood trunks, and thatch.

3.2.2.7. Question 7: existence of interior partitions in shelters

Internal partitions seem not to be common practice in shelters as tukuls, with two-thirds of the surveys reporting no partitions in the visited households. However, when internal partitions are installed, they are intended to be simple and removable, mainly employing plastic curtains or cardboard.

3.2.2.8. Question 8: common wall thickness in shelters

Walls for shelters are reported to be mainly built with a bamboo inner structure and mud plastering. In this scenario, the wall thickness ranges from 15 cm to 20 cm. In larger community shelters, the thickness can be as high as 25 cm. On the other hand, more elaborate solutions employ a web of wattle and daub as walls. In this case, the wall thickness ranges between 5 cm and 10 cm.

3.2.2.9. Question 9: existence of special facilities for cooking inside shelters

Surveys report that it is not a common practice to have cooking facilities inside the shelter. In most cases, cooking is carried out outside or in a specific kitchen shelter, if available for the hamlet.

3.2.2.10. Question 10: especial cultural requirements for shelters

No special cultural requirements were reported for the shelters and households studied. However, some surveys showed that certain hamlets require independent sleeping spaces for women and children, although it seems not to be an extended practice.

3.2.2.11. Question 11: average construction time for a shelter

The average construction time for single-family shelters as reported in the surveys ranges from 4 days to 2 weeks. It is mainly related to the availability of materials and labour. The latter is usually payed in food or community work.

3.2.2.12. Question 12: existence of particular local solutions for rain and wind

Due to the yearly rain season that affects South Sudan across all its regions, rain and wind protection measures are relevant for shelters. Results from the surveys revealed several solutions employed in the households in this regard. Using a pitched grass roof provides a waterproof affordable solution for the shelters, where several layers of thatch are piled up to keep the interior dry. Strong fixations are carried out with rubber rope to guarantee protection against the wind, and the roof usually extends about 50 cm beyond the wall to provide a dry corridor next to the shelter.

When possible, doors and windows are installed avoiding the wind direction, so as to prevent strong currents running through the house. The walls of the shelter are waterproofed by employing a plastering of cement and sand, this way extending the life span of the mud/clay finish. The cement plastering needs yearly maintenance to guarantee its durability.

3.2.2.13. Question 13: security requirements for shelters

Security requirements for shelters are carried out by installing bamboo fences around the household, employing heavy and sturdy doors with wood trunks or iron sheets, and minimizing the size of the windows. However, it should be noted that these measures are not commonly present in all shelters.

3.2.2.14. Question 14: existence of special spaces inside shelters for food and grains

In some cases, food and grains were reported to be stored inside shelters. A special space inside is reserved for big pots and buckets, or special shelfs are installed hanging from the roof. Some surveys also reported that shelters are mainly for sleeping and resting, and food is stored in separate kitchen shelters or special huts in the hamlet.

3.2.2.15. Question 15: local foundation solutions for shelters

Due to the yearly flood season in South Sudan, special care is given to the foundations of shelters. The most common technique reported in the surveys is wooden posts embedded into the ground in 40-50 cm pre-dug holes. To provide additional protection against water and humidity, some solutions pour concrete or grout along with the installation of the post. If concrete is not employed, the foundation poles need to be replaced periodically to prevent them from getting rotten.

3.2.2.16. Question 16: are shelters intended to be relocatable?

Results reported in 60% of the cases that shelter are intended to be relocatable. This might be a solution to escape from floods or if better land is acquired in the future.

3.2.2.17. Question 17: are shelter components intended to be reused?

Results reported in 90% of the cases that shelter components might be reusable. This is especially true for the most valuable components such as timber laths, iron sheets, bamboo poles, doors, or windows.

3.2.2.18. Question 18: are shelters intended to be upgradeable towards permanent housing?

Results reported in 80% of the cases that shelters are intended to be upgradeable to permanent housing. It will depend mostly on the material availability, the purchasing power of the household, and land ownership.

3.2.2.19. Question 19: existence of accessibility requirements inside shelters

Survey results report that accessibility requirements are not common for shelters in South Sudan.

3.2.2.20. Question 20: common location of shelters

Shelters are mainly located near principal towns, villages, or roads, depending on land availability and ownership.

3.2.2.21. Question 21: main drivers for selecting the location of shelters

Several drivers for selecting the location of shelters were reported in the surveys, such as: soil topography, flatness of the surface, high areas to avoid floods, availability of sources of materials and food, water and channels, grassing for cattle, space to erect the hamlet facilities, and sun protection (under trees).

3.2.2.22. Question 22: soil quality and soil-related problems upon shelter construction

Several surveys reported that rocky soils are available around the Juba region, providing a good foundation for shelters. No specific soil problems have been identified, although the presence of insects and termites was highlighted in some cases.

3.2.2.23. Question 23: termite prevention measures for shelters

Two main solutions were reported as termite prevention measures: plastering of wooden elements with mortar or cement, or employing used engine oil to bath poles, laths, and planks.

3.2.2.24. Question 24: vector mitigation for shelters

The main measures against vectors reported in the surveys are overall cleaners of the shelters, avoiding water accumulation in the surroundings, and good ventilation of spaces.

4. CONCLUSIONS

The range of construction materials available in markets in Juba is limited though compatible with the basic forms of housing that predominate. The range of materials identified in surveys of local markets include: cement and cement products, different types of masonry units, different structural and sheet timber products, bamboo and grasses, and a wide range of steel products. While problematic overland supply chains to Kenya and Uganda situation regarding regular availability of materials, survey data suggests a high degree of supply. The volatile currency exchange environment suggests similar volatility in material pricing, however the extent of price volatility cannot be determined from the survey data collected. In general, prices appear to be high in comparison with the same materials in Kenya, however currency fluctuations and limited information regarding material specifications limit price comparisons.

Based on information collected in survey and developed through analysis of vernacular housing, it appears that common skills for materials production and house building are rudimentary. Surveys of local markets identified skills relating to concrete prefabrication (e.g. concrete masonry block production) and metal welding. Skills market survey also identified craft-based skills such as weaving and pottery that use unprocessed materials such as clay, grasses and bamboo. This limited range of building skills is reflected in the limited range of skills that appear to be involved in traditional house construction – i.e., in the construction of tukuls. These basic, one-room shelters include undressed (i.e., unsawn) timber for structural elements. They also use woven panels, grasses, and mud plastering for envelope materials. Currently, inadequate information is available regarding jointing methods and the skills they entail, however, it appears that connections typically employ tied elements using either grasses or perhaps rope or string where available.

In order to collect on-field data regarding local construction customs in South Sudan, a detailed survey was developed and applied in the Juba region by members of the University of Juba and Medair East Africa. The survey template consisted of 24 quantitative and qualitative open questions, and aimed at collecting information regarding general shelter properties (size, cost, life span, among others), space distribution, common traditions and customs, structural solutions, materials and techniques, locations, and end-of-life scenarios. This way, a full understanding of the construction process and life service of shelters was developed.

As part of the campaign, 38 households were visited by the surveying team. Results revealed an average size for the shelter of 16m2 for 4 people, although variations were found based on the purpose of the shelter and purchasing power of the owner. Shelters are expected to last up to 20 years if proper maintenance is applied, with strategies such as plastering walls with mortar and cement or replacing the foundation posts periodically. Likewise, the most commonly identified construction materials in the Juba region are mud, timber, rope, grass, bamboo, stone, clay, wood trunks, and thatch. Besides, the components of the shelters are kept in good condition over the life span, they are intended to be reusable or the shelter to be upgraded towards a permanent house. Finally, several drivers for the shelter location were identified, such as soil topography, flatness of the surface, high areas to avoid floods, availability of sources of materials and food, water and channels, grassing for cattle, space to erect the hamlet facilities, and sun protection (under trees). Future research will be required to extend the scope of these results to regions other than Juba, allowing a better understanding of the shelter customs all across South Sudan.

5. REFERENCES

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6. APPENDIXES

6.1. APPENDIX 1: SURVEY FORMAT FOR LOCAL MATERIALS AND SKILLS

Computational Design for Resilient Shelter

Market Survey - Material data sheet

Date	
Surveyor name	
Material *e.g. sand, cement, steel, timber.*	
Description (format) *form/shape of the material, e.g. cement bag, steel hollow rectangular section*	
Dimensions *Write and/or sketch dimensions, e.g. weight, length, width, height, depth, thickness*	
Specifications *Quality or performance specifications, e.g. strength, density, species (for timber)*	
Source *local or imported (e.g. Kenya, Uganda)*	
Supply reliability *Always, occaisional, seasonal (provide details)*	
Price	

Market Survey - Fabrication techniques data sheet

Date	
Surveyor name	

Technique *e.g. welding, concrete precasting.*	
Description (skills & equipment) *types of skills and equipment used*	
Location *local or imported (e.g. Juba)*	
Supply reliability *Always, occaisional, seasonal (provide details) and output capacity*	
Price	

6.2. APPENDIX 2: SURVEY RESULTS FOR LOCALLY AVAILABLE MATERIALS AND SKILLS

Local Markets Survey - Materials

Ref	Material	Data source	Format	Dimensions A=area, Dia=diameter, H=height, L=length, Th=thickness, V=volume, W=width, Wt=weight,	Price	Currency	Supply source	Remarks
E1	Bamboo	MA	Round section	L3.5m	1500	SSP		
E2	Bamboo	JU	Round section	10pces	1200	SSP		
E3	Bamboo	JU	Round section	L3m_Dia3.5cm (10 pces)	5000			
E4	Straw	JU	Bundle	L3m_W1.8m	5000	SSP		
E5	Straw (Elephant grass)	JU	Bundle		1500	SSP		
E6	Thatch	JU	Panel	L2m_W1.7m	1500	SSP		
E7	Thatch	JU	Panel	L1m_W1.7m	1500	SSP		
E8	Thatch	JU	Panel	A10m2	1000	SSP		
F	**Metal**							
F1	Steel	MA	I-section	L6m_W10cm_H5cm	75	USD	Kenya/Uganda	
F2	Steel	JU	Square hollow section	L6m_W5cm_H5cm_Th2mm	18	USD	Kenya	
F3	Steel	MA	Square hollow section	L6m_W5cm_H5cm_Th1.5mm	20	USD	Kenya/Uganda	
F4	Steel	JU	Square hollow section	L6m_W4cm_H4cm_Th3mm	20	USD	Kenya	
F5	Steel	JU	Square hollow section	L6m_W4cm_H4cm_Th1.5mm	19	USD	Kenya	
F6	Steel	MA	Square hollow section	L6m_W4cm_H4cm_Th1.2mm	13	USD	Kenya/Uganda	
F7	Steel	JU	Square hollow section	L6m_W3cm_H3cm_Th3mm	17	USD	Kenya	
F8	Steel	MA-JU	Square hollow section	L6m_W3cm_H3cm_Th1.2mm	7-9.5	USD	Kenya/Uganda	
F9	Steel	MA	Square hollow section	L6m_W7cm_H7cm_Th3mm	57	USD	Kenya/Uganda	
F10	Steel	MA	Square hollow section	L6m_W6cm_H6cm_Th2mm	32	USD	Kenya/Uganda	
F11	Steel	MA	Square hollow section	L6m_W5cm_H5cm_Th1mm	13.5	USD	Kenya/Uganda	
F12	Steel	MA	Square hollow section	L6m_W5cm_H5cm_Th3mm	36	USD	Kenya/Uganda	
F13	Steel	MA	Square hollow section	L6m_W2cm_H2cm_Th1.2mm	6	USD	Kenya/Uganda	
F14	Steel	MA	Square hollow section	L6m_W2cm_H2cm_Th1mm	5.5	USD	Kenya/Uganda	
F15	Steel	JU	Rectangular hollow section	L6m_W10cm_H5cm_Th3mm	37	USD	Mombassa	
F16	Steel	JU	Rectangular hollow section	L6m_W10cm_H3cm_Th3mm	37	USD		
F17	Steel	MA	Rectangular hollow section	L6m_W8cm_H4cm_Th2mm	30	USD	Kenya/Uganda	
F18	Steel	JU	Rectangular hollow section	L6m_W8cm_H4cm_Th1.5mm	22	USD		
F19	Steel	MA	Rectangular hollow section	L6m_W8cm_H4cm_Th1.2mm	20	USD	Kenya/Uganda	
F20	Steel	MA	Rectangular hollow section	L6m_W6cm_H4cm_Th3mm	38	USD	Kenya/Uganda	
F21	Steel	MA-JU	Rectangular hollow section	L6m_W6cm_H4cm_Th2mm	27-28	USD	Kenya/Uganda	
F22	Steel	JU	Rectangular hollow section	L6m_W6cm_H4cm_Th1.2mm	16	USD	Kenya/Uganda	
F23	Steel	MA	Rectangular hollow section	L6m_W6cm_H4cm_Th1mm	13.5	USD	Kenya/Uganda	
F24	Steel	MA	Rectangular hollow section	L6m_W5cm_H2.5cm_Th1.2mm	13.5	USD	Kenya/Uganda	
F25	Steel	JU	Rectangular hollow section	L6m_W4cm_H2.5cm_Th1.2mm	12	USD		
F26	Steel	JU	Round hollow section	Dia75mm_Th2mm	25	USD	Kenya	
F27	Steel	JU	Round hollow section	Dia63mm_Th2mm	23	USD	Kenya	
F28	Steel	JU	Round hollow section	Dia42mm_Th2mm	10	USD	Kenya	
F29	Steel	JU	Round hollow section	Dia25mm_Th2mm	5	USD	Kenya	
F30	Steel	MA	Round hollow section	Dia2"_Th1.2mm	13.5	USD	Kenya/Uganda	
F31	Steel	MA	Round hollow section	Dia1"_Th1.2mm	6	USD	Kenya/Uganda	
F32	Steel	MA	Round hollow section	Dia2"_Th2mm	21	USD	Kenya/Uganda	
F33	Steel	MA	Round hollow section	Dia0.75"_Th1.2mm	5	USD	Kenya/Uganda	
F34	Steel	MA	Round hollow section	Dia0.25"_Th1.2mm	8.5	USD	Kenya/Uganda	
F35	Steel	MA	Angle bar	L6m_W6cm_H6cm_Th6mm	33	USD	Kenya/Uganda	

Local Markets Survey - Materials

Ref	Material	Data source	Format	Dimensions A=area, Dia=diameter, H=height, L=length, Th=thickness, V=volume, W=width, Wt=weight,	Price	Currency	Supply source	Remarks
A	**Quarried**							
A1	Sand	MA	*Unprocessed*	V.18m2 (sinotruck)	100000-130000	SSP		
A2	Clay (murram)	MA	*Unprocessed*	V.18m2 (sinotruck)	90000	SSP		
A3	Stone	MA	Aggregate	V.1m2	45	USD		
A4	Stone	MA	Aggregate	V.1m3	22000	SSP		
B	**Cementitious**							
B1	Cement	MA	Bag	Wt.50kg	4000-5000	SSP		
B2	Cement	JU	Bag	Wt.50kg	9.5	USD	Kenya	32.5R/32.5N Sahvana brand
B3	Lime	MA	Stone	V.4m3	50000	SSP		
B4	Stone dust (?)	MA	*Unprocessed*	V.1m3	16000	SSP		
B5	Gypsum	MA	Bag	Wt.25kg	7000	SSP		
B6	Gypsum	MA	Bag	Wt.25kg	11	USD		
C	**Masonry**							
C1	Clay brick	MA	Solid masonry unit	L9"_W4"_H3.5"	120	SSP	Local	
C2	Clay brick (baked)	MA	Solid masonry unit	L9cm_W4cm_H3.5cm	100-120	SSP	Local	
C3	Concrete block	MA	Hollow masonry unit	L40"_W20"_H20" (cm?)	420	SSP	Local	
C4	Concrete block	MA	Hollow masonry unit	L40"_W20"_H15" (cm?)	400	SSP	Local	Price includes delivery
C5	Concrete block	MA	Hollow Masonry unit	L40"_W20"_H10" (cm?)	300	SSP	Local	
C6	Concrete block	MA	Solid masonry unit	L40"_W20"_H20" (cm?)	450	SSP	Local	Price includes delivery
C7	Concrete block	MA	Solid Masonry unit	L40"_W20"_H15" (cm?)	420-430	SSP	Local	Price includes delivery
D	**Wood**							
D1	Timber	MA	Square section	L?_W2"_H2"	1000	SSP		
D2	Timber	JU	Rectangular section (teak/mahogany)	L4m_W6cm_H2cm	5.9-8	USD		
D3	Timber	JU	Rectangular section (teak/mahogany)	L4m_W4cm_H2cm	6.5	USD		
D4	Timber	JU	Rectangular section (teak/mahogany)	L4m_W3cm_H2cm	4	USD		
D5	Timber	MA	Rectangular section	W2"_H4"	1500	SSP		
D6	Timber	MA	Rectangular section	W3"_H4"	2000	SSP		
D7	Timber	MA	Rectangular section	W1"_H8"	3000	SSP		
D8	Timber (shelter ass.)	MA	Poles - Round section	L3.5m_Dia(small)	3500	SSP		
D9	Timber (shelter ass.)	MA	Poles - Round section	L3.5m_Dia(large)	5000	SSP		
D10	Wood	JU	Undressed teak	L3.3-4m_Dia12-13cm	10	USD		
D11	Wood	JU	Undressed teak	L3.3-4m_Dia15-16cm	10.5	USD		
D12	Wood	JU	Undressed teak	L4m_Dia12-14cm	4000	SSP		
D13	Wood	JU	Undressed teak	L4m_Dia16-17cm	5000	SSP	Central Equitoria	
D14	Plywood	MA	Sheet	L8'_W4'_Th3mm	4	USD		
D15	Plywood	MA	Sheet	L8'_W4'_Th6mm	8.5	USD		
D16	Plywood	MA	Sheet	L8'_W4'_Th8mm	11	USD		
D17	Plywood	MA	Sheet	L2m_W1.2m_Th3mm	2500	SSP		
D18	Plywood	MA	Sheet	L2m_W1.2m_Th6mm	4500	SSP		
D19	Plywood	MA	Sheet	L2m_W1.2m_Th12mm				
E	**Grass/Bamboo**							

Local Markets Survey - Materials

Ref	Material	Data source	Format	Dimensions A=area, Dia=diameter, H=height, L=length, Th=thickness, V=volume, W=width, Wt=weight	Price	Currency	Supply source	Remarks
F36	Steel	MA-JU	Angle bar	L6m_W7.5cm_H7.5cm_Th6mm	40-46	USD	Kenya/Uganda	
F37	Steel	MA-JU	Angle bar	L6m_W5cm_H5cm_Th6mm	29-33	USD	Kenya/Uganda	
F38	Steel	MA	Angle bar	L6m_W5cm_H5cm_Th4mm	20	USD	Kenya/Uganda	
F39	Steel	MA	Angle bar	L6m_W5cm_H5cm_Th3mm	13.5-17	USD	Kenya/Uganda	
F40	Steel	MA-JU	Angle bar	L6m_W4cm_H4cm_Th4mm	13-15.5	USD	Kenya/Uganda	
F41	Steel	MA-JU	Angle bar	L6m_W4cm_H4cm_Th3mm	11-12	USD	Kenya/Uganda	
F42	Steel	JU	Angle bar	L6m_W4cm_H4cm_Th2mm	14	USD	Kenya/Uganda	
F43	Steel	MA	Angle bar	L6m_W3cm_H3cm_Th3mm	8.5	USD	Kenya/Uganda	
F44	Steel	JU	Angle bar	L6m_W3cm_H3cm_Th2.5mm	11	USD	Kenya/Uganda	
F45	Steel	MA	Angle bar	L6m_W2.5cm_H2.5cm_Th3mm	8-9.5	USD	Kenya/Uganda	
F46	Steel	MA	Flat solid section	L6m_W6cm_Th3mm	9	USD	Kenya/Uganda	
F47	Steel	MA	Flat solid section	L6m_W2.5cm_Th3mm	6	USD	Kenya/Uganda	
F48	Steel	MA	Checkerplate sheet	L8'_W4'_Th1mm	35	USD	Kenya/Uganda	
F49	Steel	MA	Checkerplate sheet	L8'_W4'_Th1mm	33	USD	Kenya/Uganda	
F50	Steel	MA	Checkerplate sheet	L8'_W4'_Th3mm	68	USD	Kenya/Uganda	
F51	Steel	MA	Star blade	L8'_W4'_Th1mm	35	USD	Kenya/Uganda	
F52	Steel	MA	MS blade	L8'_W4'_Th1mm	33	USD	Kenya/Uganda	
F53	Steel	MA	MS blade	L8'_W4'_Th2mm	68	USD	Kenya/Uganda	
F54	Steel	MA-JU	Reinforcement bar	L12'_Y16	7200-4000	SSP	Kenya/Uganda	
F55	Steel	MA-JU	Reinforcement bar	L12'_Y12	3000-4200	SSP	Kenya/Uganda	
F56	Steel	JU	Reinforcement bar	L12'_Y10	3000	SSP	Kampala	
F57	Steel	JU	Reinforcement bar	L12'_Y8	2200	SSP	Kampala	
F58	Steel	MA	Sheet	34 guage			Kenya/Uganda	
F59	Steel	MA	Sheet	32 guage	3000	SSP	Kenya/Uganda	
F60	Steel	MA	Sheet	30 guage	3500	SSP	Kenya/Uganda	
F61	Steel	MA	Sheet	28 guage	4500	SSP	Kenya/Uganda	
F62	Steel	JU	Corrugated sheet		2500	SSP		
F63	Aluminium	MA	Profile L-section	L5.8m	9500	SSP		
F64	Aluminium	MA	Profile T-section	L5.8m	9500	SSP		
F65	Aluminium	MA	Profile Z-section	L5.8m	8000	SSP		
F66	Aluminium	MA	Profile Net-section	L5.8m	5500	SSP		
F67	Aluminium	MA	Profile Angle	L5.8m	8000	SSP		
F68	Aluminium	MA	Profile Binding	L5.8m	3500	SSP		
F69	Aluminium	MA	Profile Enter-lock	L5.8m	5000	SSP		
F70	Aluminium	MA	Profile Shatter	L5.8m	9500	SSP		
F71	Aluminium	MA	Profile Outer frame	L5.8m	17500	SSP		
G	**Polymer**							
G1	PVC	MA	Pipe	L6m_Dia2"	4000	SSP		
G2	PVC	MA	Pipe	L6m_Dia4"	6000	SSP		
G3	PVC	MA	Pipe	L6m_Dia6"	9000	SSP		
G4	Nylon Tarpaulin	MA	Sheet	L6m_W4m	4500	SSP		
G5	Nylon Tarpaulin	MA	Sheet	L6m_W5m	5500	SSP		
H	**Fixings**							

Local Markets Survey - Materials

Ref	Material	Data source	Format	Dimensions A=area, Dia=diameter, H=height, L=length, Th=thickness, V=volume, W=width, Wt=weight	Price	Currency	Supply source	Remarks
H1	Rubber rope	JU	Bundle		500	SSP		
H2	Nylon rope	MA	Rope	L (bundle)	2000	SSP		
H3	Copper	MA	Wire	L1m_Th2.5mm	1000	SSP		
H4	Copper	MA	Wire	L1m_Th1.5mm	800	SSP		
H5	Steel	JU	Binding wire	roll	3500	SSP		
H6	Steel	JU	Nails	L4"_Wt1kg	600	SSP		
H7	Steel	JU	Nails	L3"_Wt1kg	600	SSP		
H8	Steel	JU	Nails	Roofing_Wt1kg	1000	SSP		

Local Markets Survey - Skills

Ref	Material	Data source	Format	Price	Currency	Supply source	Supply reliability	Remarks
A	**Carpentry**							
A1	Furniture fabrication	MA	Timber splitting machine	300 per split	SSP	Local	(Occasional)	Uses locally-sourced timber
A2	Furniture fabrication	MA	Timber planing machine	1000	SSP	Local	(Occasional)	Uses locally-sourced timber
A3	Door/window fabrication	MA	Timber grinding (sanding) machine				Always	
A4	Door/window fabrication	MA	Timber router machine				Always	
A5	Door/window fabrication	MA	(Designing) machine				Always	
A6	Door/window fabrication	MA	Door panel fabrication	85000	SSP		Always	
A7	Door/window fabrication	MA	Door frame fabrication	40000	SSP		Always	
A8	Bamboo splitting	JU						
B	**Metalwork**							
B1	Aluminium window fabrication	MA	Aluminium drilling, cutting, riveting			Local	Always	Material supply and fabrication
B2	Aluminium recycling	JU	Furnace melting					
B3	Welding	JU	Furniture, gates, formwork, signs, etc.					
C	**Concrete and earthwork**							
C1	Concrete precasting	JU	Formwork, steel placement, concreting					
C2	Concrete block fabrication	JU						
C3	Clay work	JU	Pots, decorative elements, bricks					
D	**Other**							
D1	Weaving	JU	Basket, net, panel fabrication	4000-7000				

6.3. APPENDIX 3: PHOTOGRAPH RECORDS OF LOCALLY SURVEYED MATERIALS IN SOUTH SUDAN

Clay brick production

Clay brick firing

Cement block production

Mechanical production of cement block

Locally-quarried stone (cladding / paving)

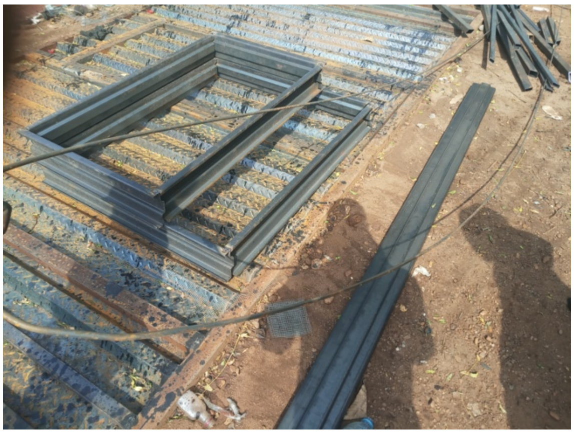
Steel sections

Steel sections

Steel sections

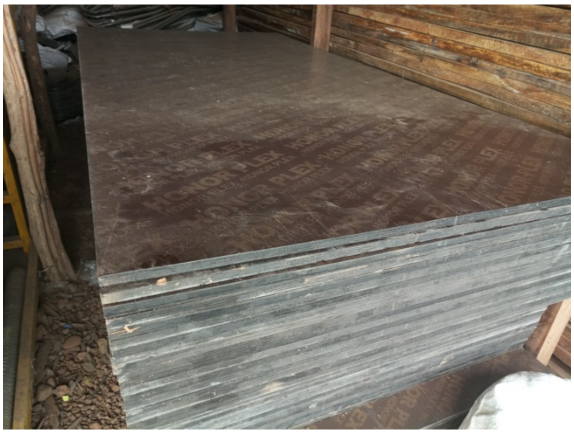
Steel sections

Steel sections



Welding – windows and gates

Welding



Plywood

Plywood

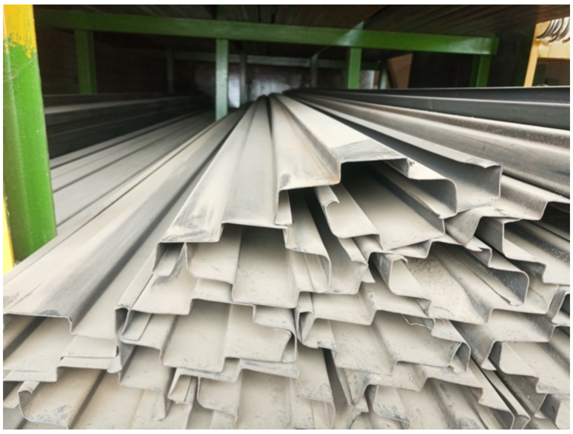
Aluminum sections

Polycarbonate window profiles

Polycarbonate window profiles

Polycarbonate window profiles

Steel sheet (checker plate)



Cold-rolled door frame sections

Steel sections

Steel sections

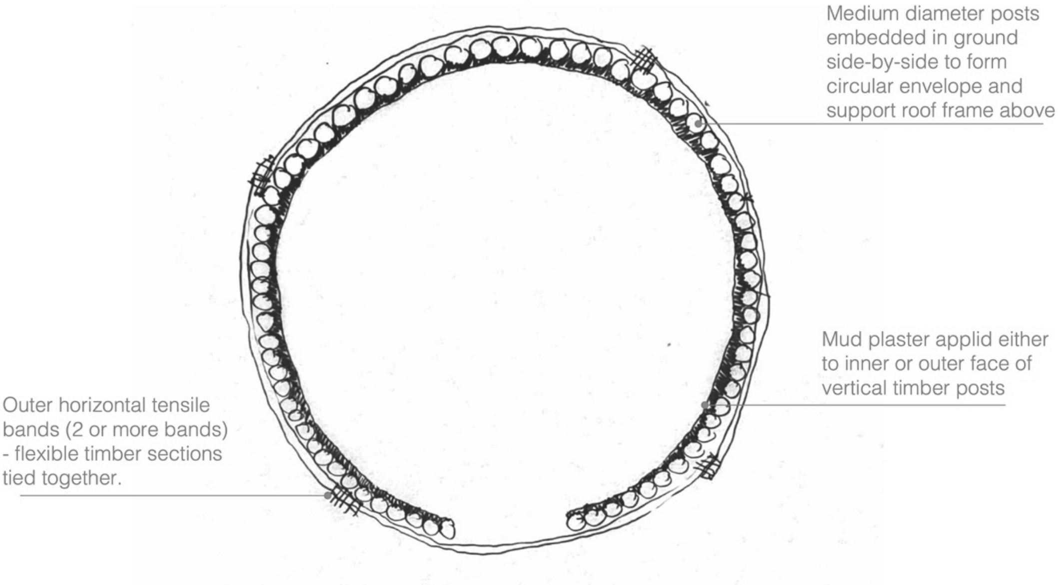
6.4. APPENDIX 4: DESIGN ANALYSIS OF TUKULS

Computational Design for Resilient Shelter

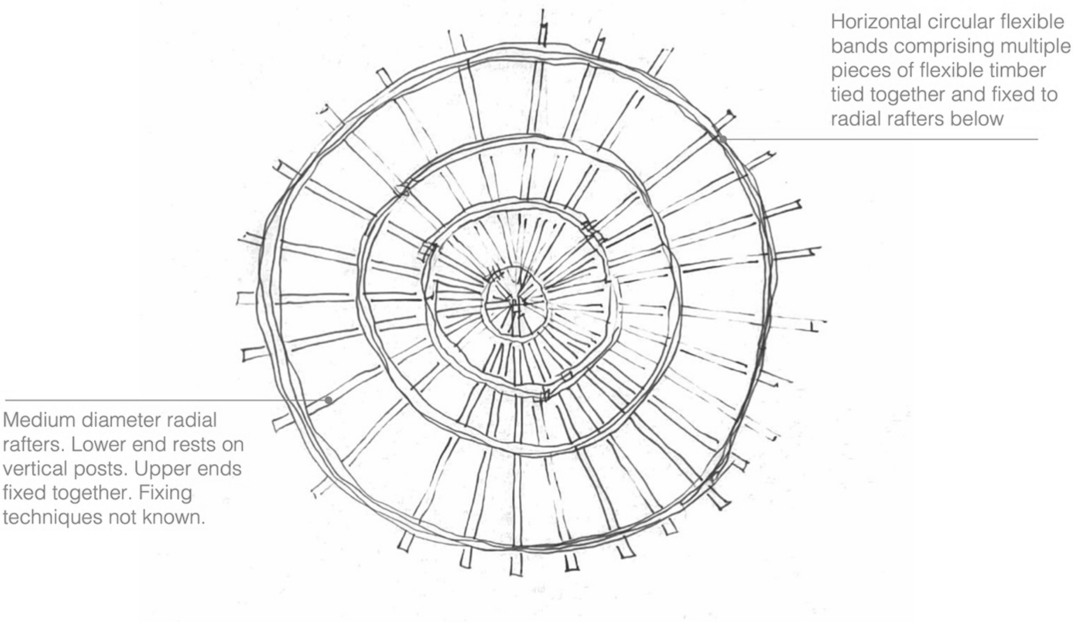
Tukul Design Analysis

Circular tukul type

a) Floor plan



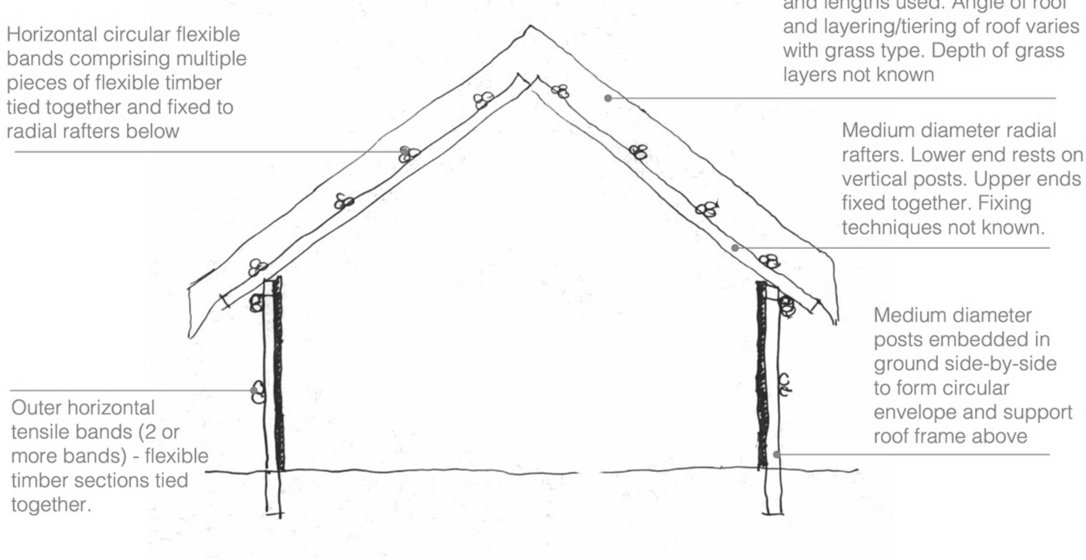
b) Roof structure plan



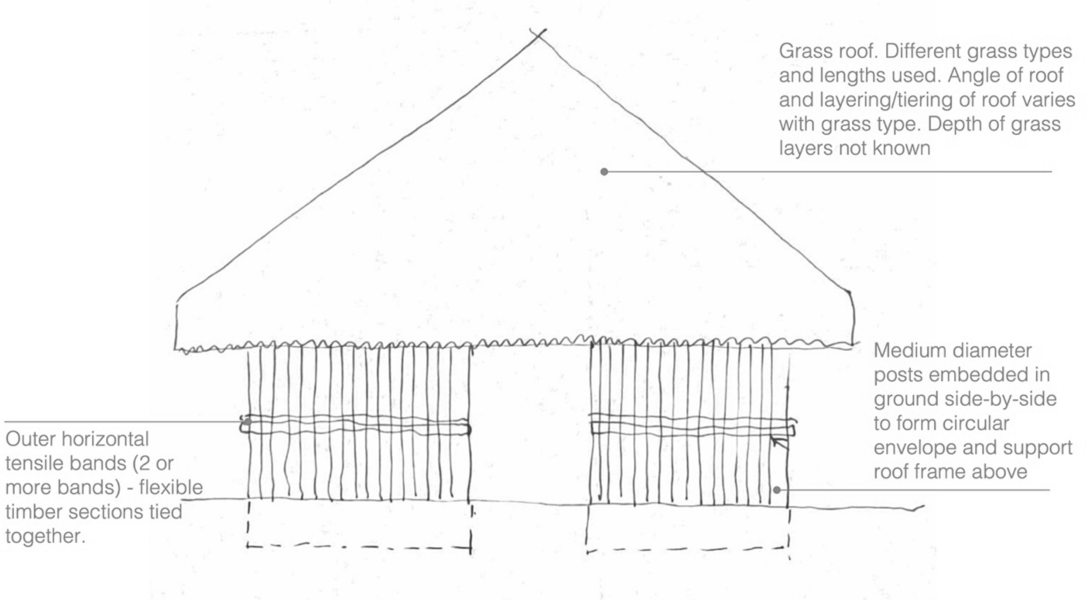
Tukul Design Analysis

Circular tukul type

c) Cross section



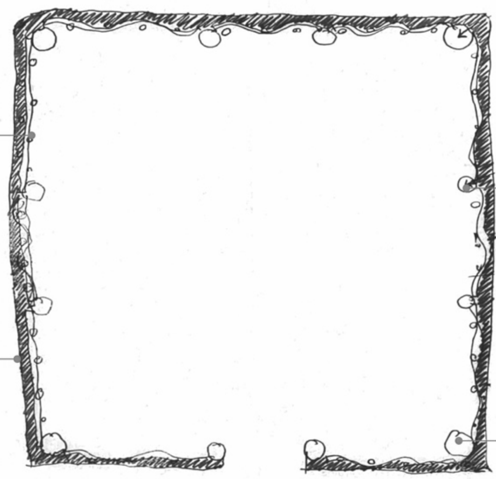
c) Elevation



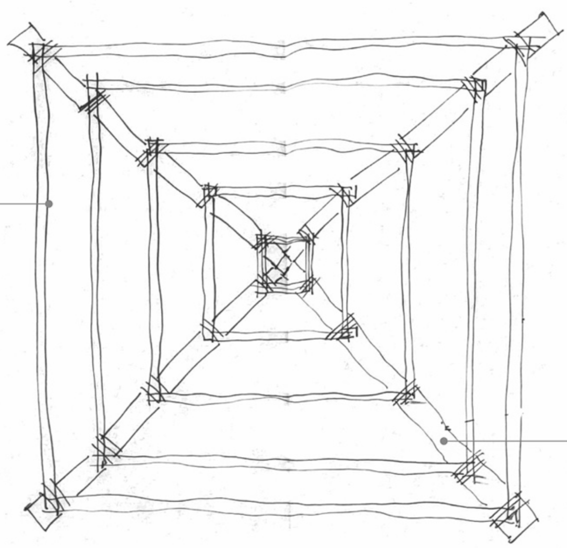
Tukul Design Analysis

Square tukul type

a) Floor plan



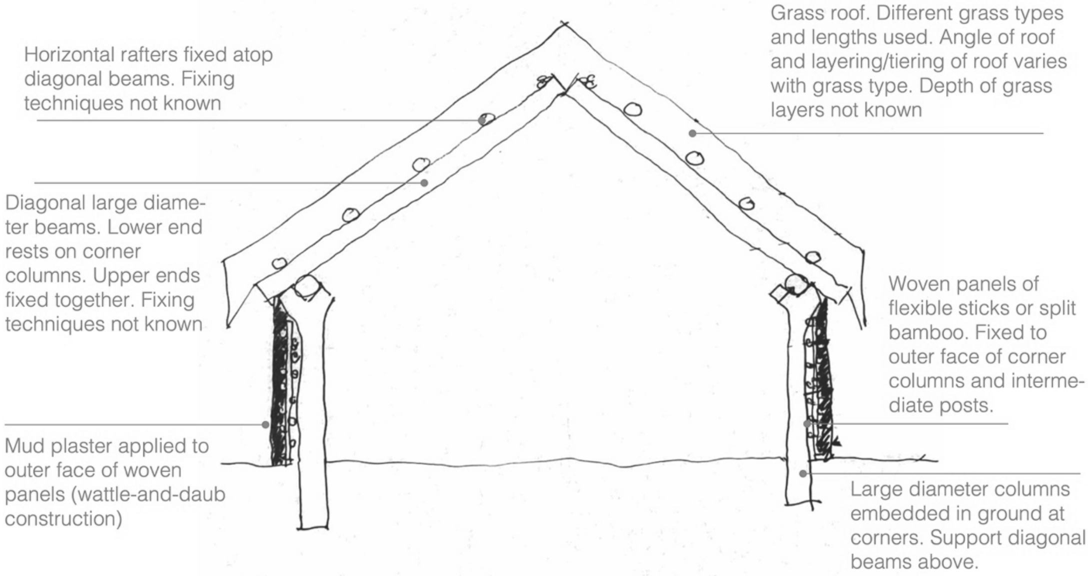
b) Roof structure plan



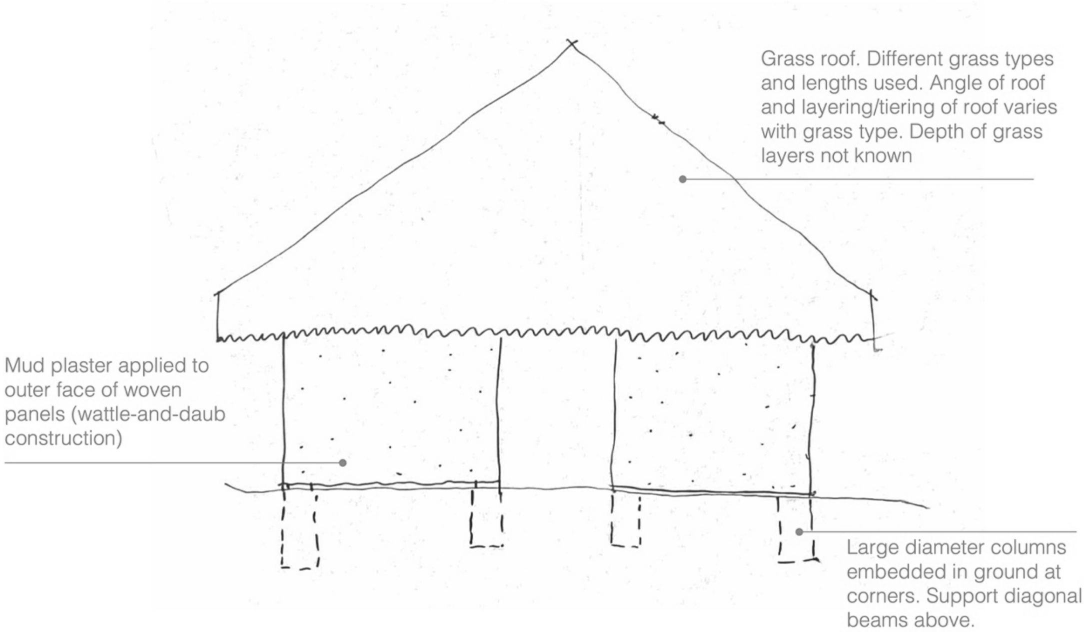
Tukul Design Analysis

Square tukul type

c) Cross section



c) Elevation



6.5. APPENDIX 5: SURVEY FORMAT FOR LOCAL CONSTRUCTION AND HOUSING CUSTOMS

Local construction and housing customs survey form

Parameter	Data	Additional comments
Average size [m2].		
Average #people/shelter.		
Average cost/shelter [SSP].		
Expected life span [months].		
Average height from ground to eaves [m].		
Most common materials employed for shelters		
Existence of interior partitions in shelters.		
Common wall thickness in shelters [m].		
Existence of special facilities for cooking inside shelters.		
Especial cultural requirements for shelters (religious, men/women, etc.).		

Average construction time for a shelter [days].	
Existence of particular local solutions for rain and wind.	
Security requirements for shelters.	
Existence of special spaces inside shelters for food and grains.	
Local foundation solutions for shelters (concrete, posts embedded into grounds, etc.).	
Are shelters intended to be relocatable?	
Are shelter components intended to be reused?	
Are shelters intended to be upgradeable towards permanent housing?	
Existence of accessibility requirements inside shelters (i.e., for elders, people with disabilities, etc.).	
Common location of shelters.	
Main drivers for selecting the location of shelters.	

Soil quality and soil-related problems upon shelter construction (if any).	
Termite prevention measures for shelters	
Vector mitigation for shelters	