7 Construction

7.1 Construction process

The constructability of the buildings played a major role in the design of the different buildings. Every design choice for one of the buildings is thoroughly checked whether it's constructable or not.
The factors that determine that are taken into account for this are:

- The builders at the location must be able to build it
- The materials have to be available on site or nearby
- No tensile stress is allowed to occur on the structure during the building process
- The use of scaffolding should be avoided
- The use of formwork should be kept at a minimum and must be reusable

The focus of the constructability was mainly on how to construct it with a minimum of the available materials instead of how to construct it fast or in an efficient way. In this strategy it is also assumed that the labor costs are low and that there are not very strict safety rules for the workers. This pushed this project in a way to come up with creative solutions instead of the obvious solutions.

In the following paragraphs first the materials are discussed, then the different construction types and at last the construction sequence of three of the main buildings.

7.2 Materials

The materials used are selected based on a few restrictions. The materials have to be available in or nearby the camp, must be easy to collect and should be cheap.

The buildings itself are mainly constructed with sand, clay, straw and water, which are available on site and nearby at the creek. The animal fat used for the mud plaster is collected from the chickens in the camp.
To support and guide the structures during the building process ropes, metal sheets, tent poles, aluminium poles, water tanks and tires are used which all can be obtained inside the camp.
To reach heights during the construction time crates and containers from the camp are used.

In table 7.1 on the right an overview of all the materials is given, included where the materials are applied and obtained.

7.3 Construction types

On the following pages the different construction types are discussed which are typical for this project and for building with adobe. From the foundation to the walls, floors and roofs different types and techniques are summed up based on the materials that are described above.
The main goals for the construction process are that it can be built with the use of local materials and that the supporting structures and materials are reusable as much as possible

7.3.1 Foundation

In figure 7.1 section is showed of a typical foundation for an exterior wall. The mud plaster contains animal fat which is a hydrophobic material that let the water flow from the building and from the slope at the ground floor.
The first meter of the wall contains rock stones because they soak less water than adobe bricks.
Rammed earth is used beneath the walls and the floors to keep everything in place and to flatten the floors.
The floors at the higher levels are also equalized with the mud plaster but don't contain the animal fat.

7.3.2 Walls and columns

The wall- and column size for most of the buildings are based on the brick size of 100x125x250. Only for the tower stones of a size of 150x200x400 are used.
In figure three possible wall types are shown which are a multiplication of 250 mm.

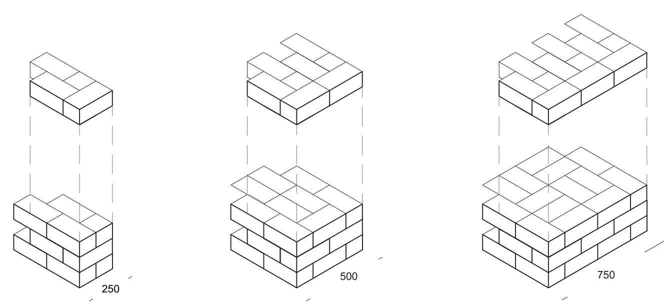

Figure 7.2 Isometric view of three wall types with a thickness based on a multiplication of 250 mm. source: own

	Sand	Clay	Straw	Animal fat	Rope	Metal sheet	Tent pole	Aluminium pole	Water tank (slice)	Tire	Crate	Container
Application	Foundation Flooring Bricks Mortar Coating	Foundation Flooring Bricks Mortar Coating	Flooring Bricks	Coating	Compass method Pulley system	Cross vault	Cross vault	Cross vault	Arched window Door	Arched window	To reach height	To reach height
Source	On site	Creek 1km west of the camp site	Creek 1km west of the camp site	Chickens inside the camp	UNHCR tents	In the camp	In the camp	Fences surrounding the camp	In the camp	In the camp	In the camp	In the camp

Tabel 7.1 Overview of all the materials used for the building itself, as formwork and to reach heights during the construction, source: own

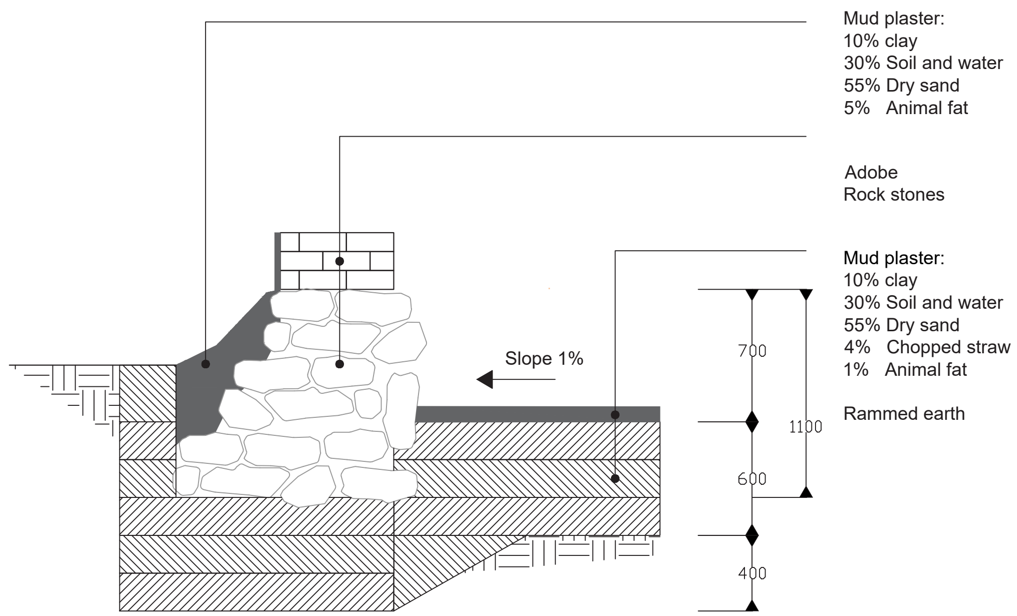

Figure 7.1 Section of the foundation and an exterior wall which is typical for every building in the complex. source: own

7.3.3 Openings

Two types of openings are used in the buildings to create either windows or doors.
The first type used for windows and doors are the arched openings.
The second type is called the 'mashrabiya' and is actually a way of bricklaying so that openings are created between the bricks.

7.3.3.1 Arched window

The arch in the window is based on the size of a big tire with a diameter of 50 cm, which is a material that can be easily found in the camp.
When building the wall from the ground at the location of the arched opening a tire is placed that supports the arch during the construction process, which is visualized in figure 7.4.
After the arch is completed and the keystone is placed the tire and stones beneath it are removed to create the desired opening.

7.3.3.2 Arched door

The construction process of the arched door is based on the same principle as the arched window, but instead of using a tire a slice of a water tank is used. The diameter of a watertank is approximately the desired two meters that is needed foor the door, see figure 7.3.

The small gaps between the arch and the bricks above it can be filled with smaller rest pieces of adobe and with the mud plaster which is described above.

7.3.3.3 Mashrabiya

The mashrabiya's are made with stone lengths of 125 mm, which is half the stone of the wall. The pattern is chosen in a way that the mashrabiya fits in the wall pattern.

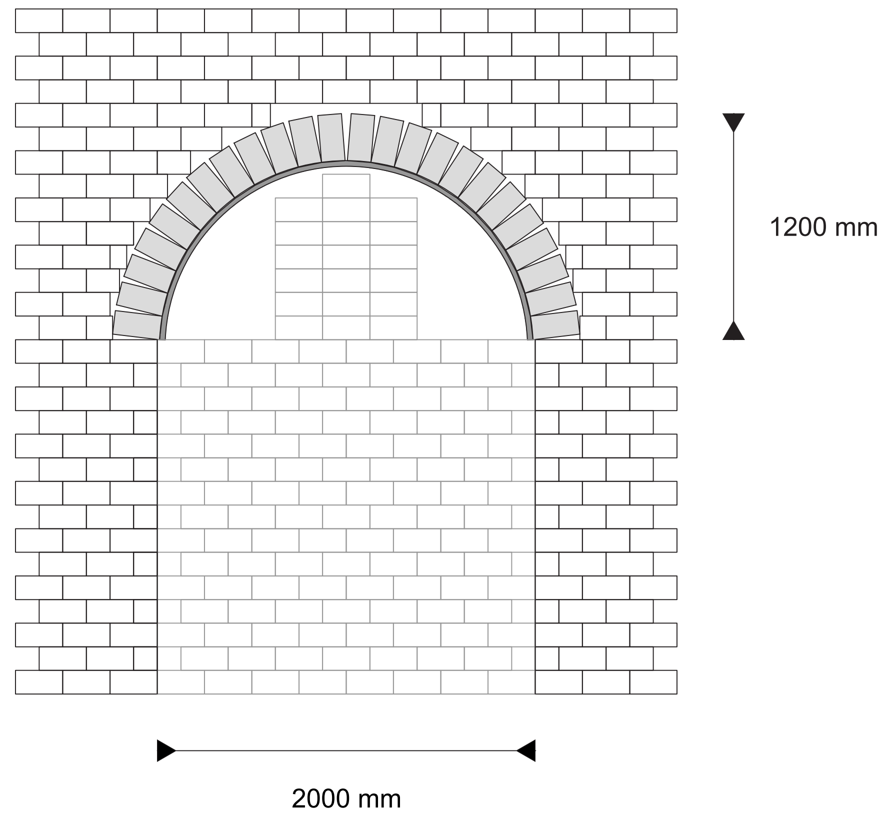

Figure 7.3 Front view of an arched door with in lightgray the supporting bricks and in dark grey the slice of a watertank. source: own

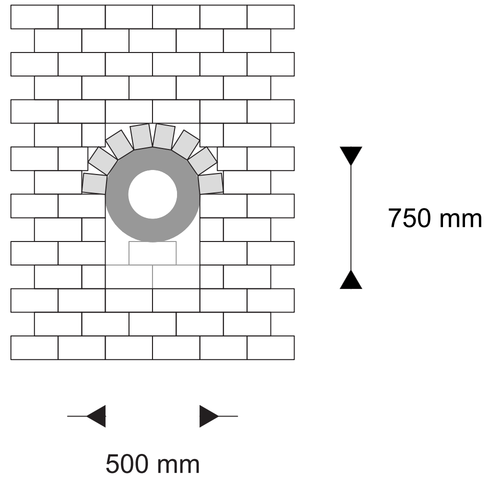

Figure 7.4 Front view of an arched window with in lightgray the tire and the supporting bricks. Source: own.

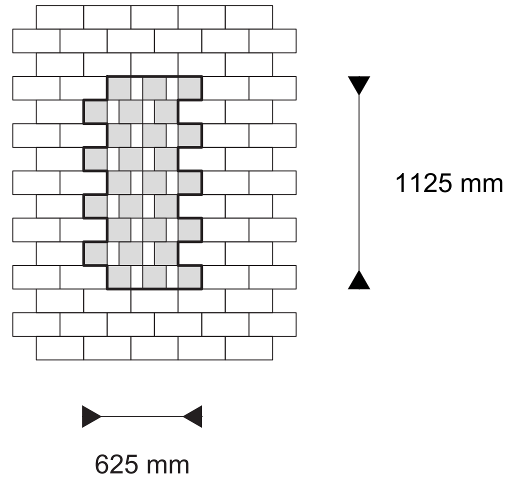

Figure 7.5 Front view of a mashrabiya based on bricks of 100x125 mm. source: own

7.3.4 Cross vault

The first roof type that is discussed is the cross vault. This vault can be built on top of four columns.
The starting point for making this vault is to avoid the use of scaffolding and to create a formwork in a way that it is reusable.

7.3.4.1 Formwork

To create the ribs in the cross vault a jig is needed to support the arch while it is being constructed, since the rib can only stand on its own after being completed.
A corrugated metal sheet is used as formwork. The choice for this material is based on the fact that those sheets are plenty available in the camp, can absorb tensile stresses, have low mass and can be bent easily.
After the sheet is bent into the right shape and is placed at the right spots on the columns of the construction, the sheet will be supported with a bigger tent pole in the middle and with a few smaller aluminium fence poles on the side. Those poles can be stamped a bit into the ground to clamp in between the ground and the sheet.

7.3.4.2 Building sequence

Figure 7.6 gives an overview of the building sequence of the cross vault.

- First two types of formwork are created based on the right shape of the rib as described above.
- Then this formwork is placed between the columns to create the first diagonal rib.
- Once the first is completed the jig is removed and reused for the other crossing rib.
- After this the four ribs on the sides are created with another jig.

When the ribs are completed the formwork can be reused for the construction process of another cross vault with the same size. The final step is to use bricklaying to fill in the spaces between the two ribs.
The bricks that are used for this vault have a size of 125x125x250.

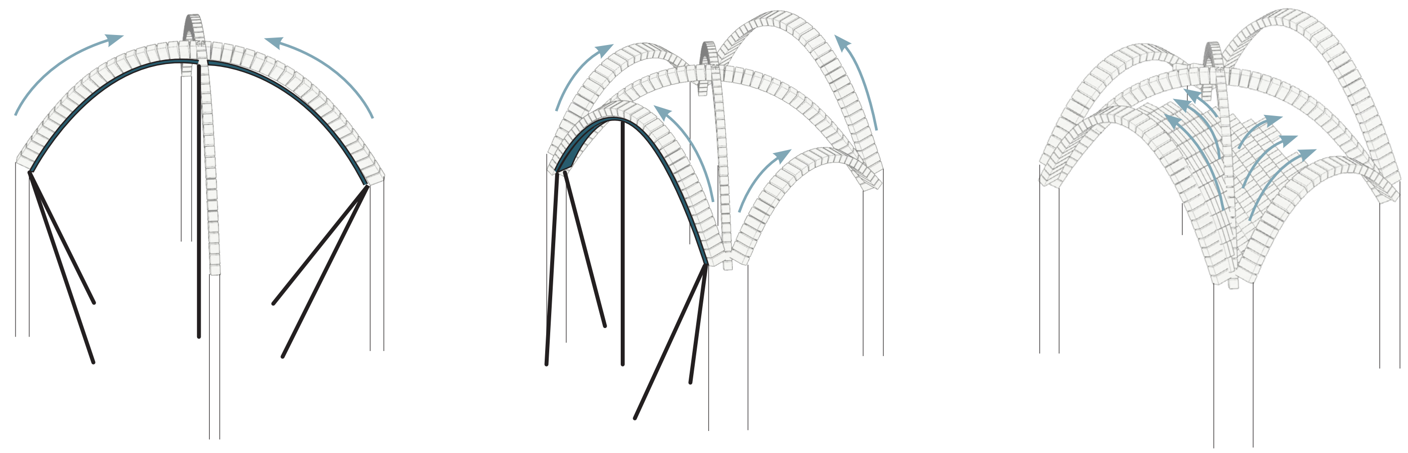

Figure 7.6 Building sequence of a cross vault using two different jigs to support the ribs during the construction process, source: own

7.3.5 Barrel vault

The second roof type that is discussed is the barrel vault. This vault can be built from the ground up immediately or can be built on top of two walls.

7.3.5.1 Nubian technique

The technique used in this building is called the 'Nubian technique' where the arches of the barrel vault are inclined towards the supportive wall so that no scaffolding is needed during the construction process. Figure 7.7 is a reference for this technique.

In figure 7.8 a section of a typical barrel vault of a building in the complex is shown. On the left the supporting wall is drawn with on the right the different layers of the barrel vault build against that wall with an inclination which is about 80 degrees with the horizontal axis. In this case the barrel vault has a thickness of three layers of stones vertically above each other.

7.3.5.2 Construction sequence

Figure 7.9 shows the construction sequence of a barrel vault which is built on two straight walls.

First the walls are built from the ground and then supportive wall is built with already the rough shape of the barrel vault. After this the shape of the barrel vault is drawn onto the wall with the technique which is described on the right.

The first arch is then glued to the supportive wall with an inclination towards the wall as in figure 7.8 and worked from both sides to the center.

This process is repeated until the end of the barrel vault is reached.

The barrel vault is now stable on its own and the supportive wall can be removed optionally.

7.3.5.3 Drawing the shape of the arch

Drawing an ellipse on the wall can easily be done on site. The builder only has to know the location of two points on the wall and attach a string with a given length to it. Then attach a chalk to it and draw the ellipse.

In figure 7.10 the principle is made visual. The two dots are the focal points of the ellipse. Placing the dots closer to each other will have a wider ellipse as result. Imagine when the points are at the same location and then the ellipse becomes a circle.

The length of the string determines the major axis of the ellipse, in this case that determines the height of the ellipse.

Figure 7.7 Reference of a building where a barrel vault is built with the Nubian technique. In this case the two vaults are built on the supporting wall in the middle. Source: Pinterest

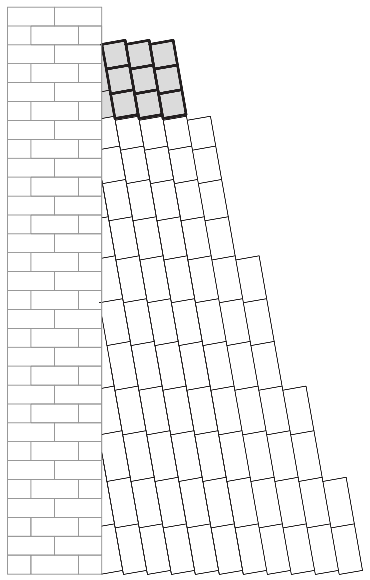

Figure 7.8 Section of a typical barrel vault based on the Nubian technique. The bricks have an inclination of 80 degrees with the horizontal. source: own

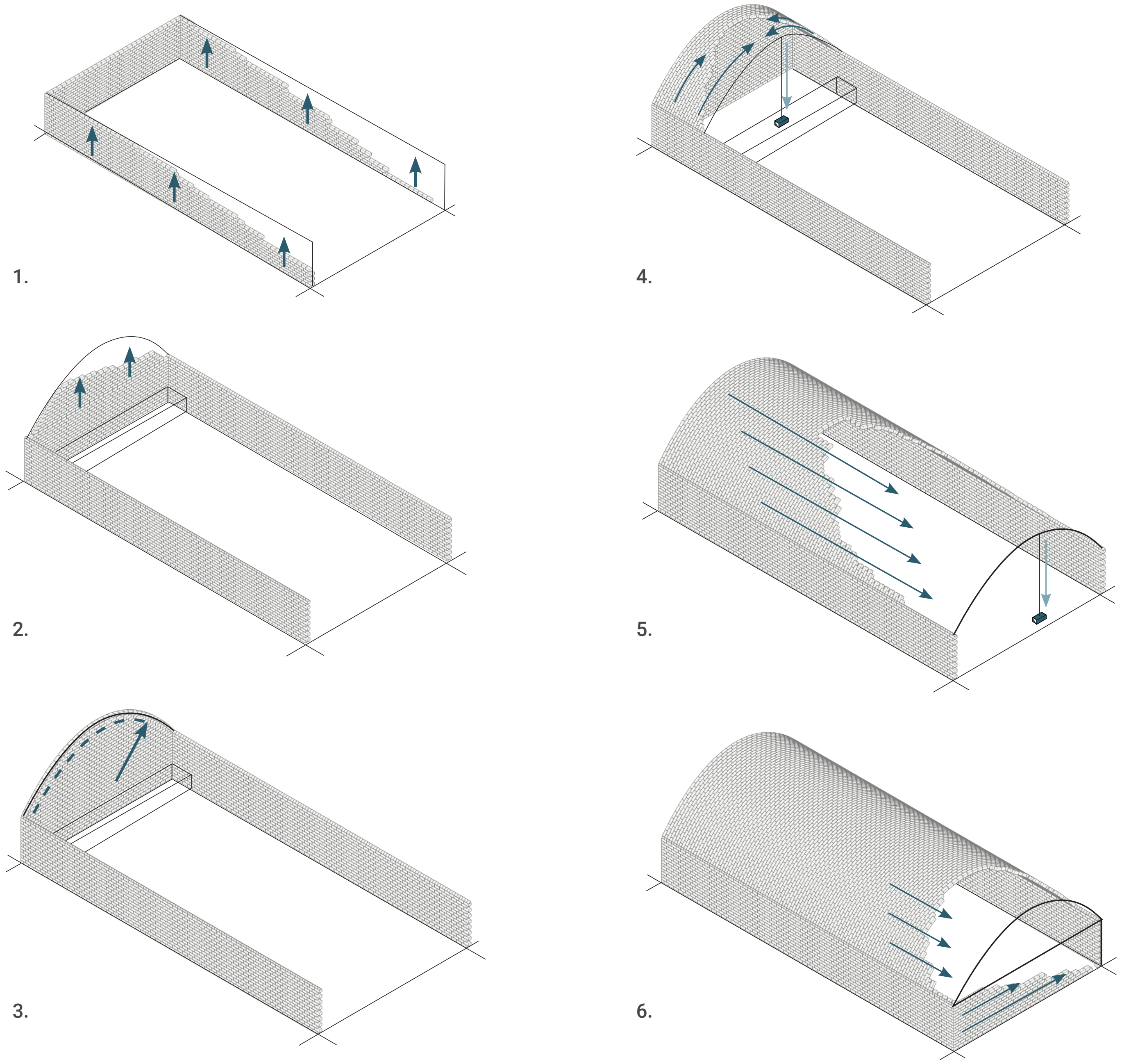

Figure 7.9 Building sequence of a barrel vault based on the Nubian technique. source: own

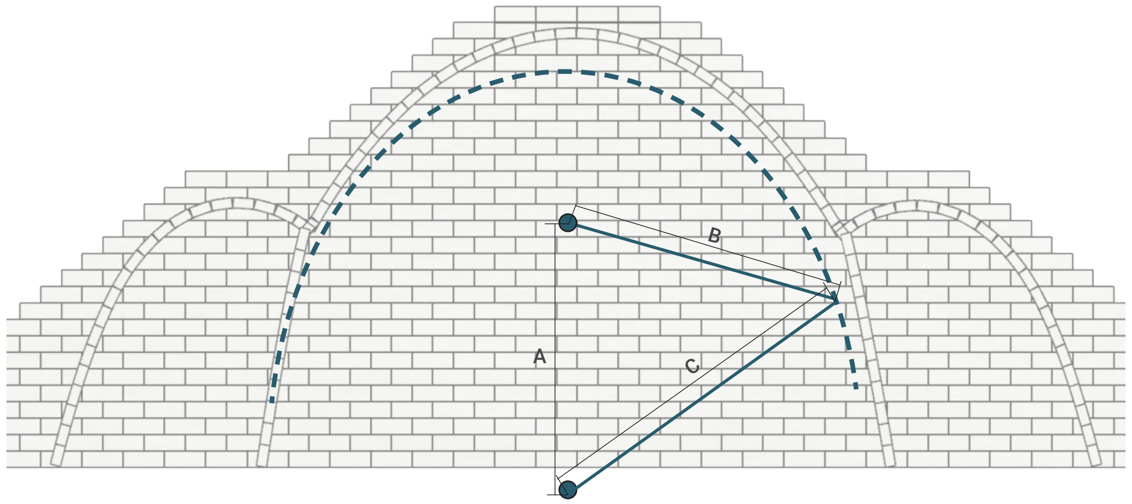

Figure 7.10 Illustration of the drawing method of an ellipse with a rope. The two blue dots are the focal points of the ellipse from where the ellipse is drawn. source: own

7.4 Construction sequence

The building sequence of three of the main buildings is presented on the following pages:

- The theatre
- The entrance
- The radio tower

See figure 7.11 for an overview of the complex.
For every building it is discussed how it can be easily build with the materials from the site and with building technics which are suitable for building with adobe.

The main goals are to build in a way that during the construction sequence tensile forces on the construction are avoided and that no scaffolding is needed.

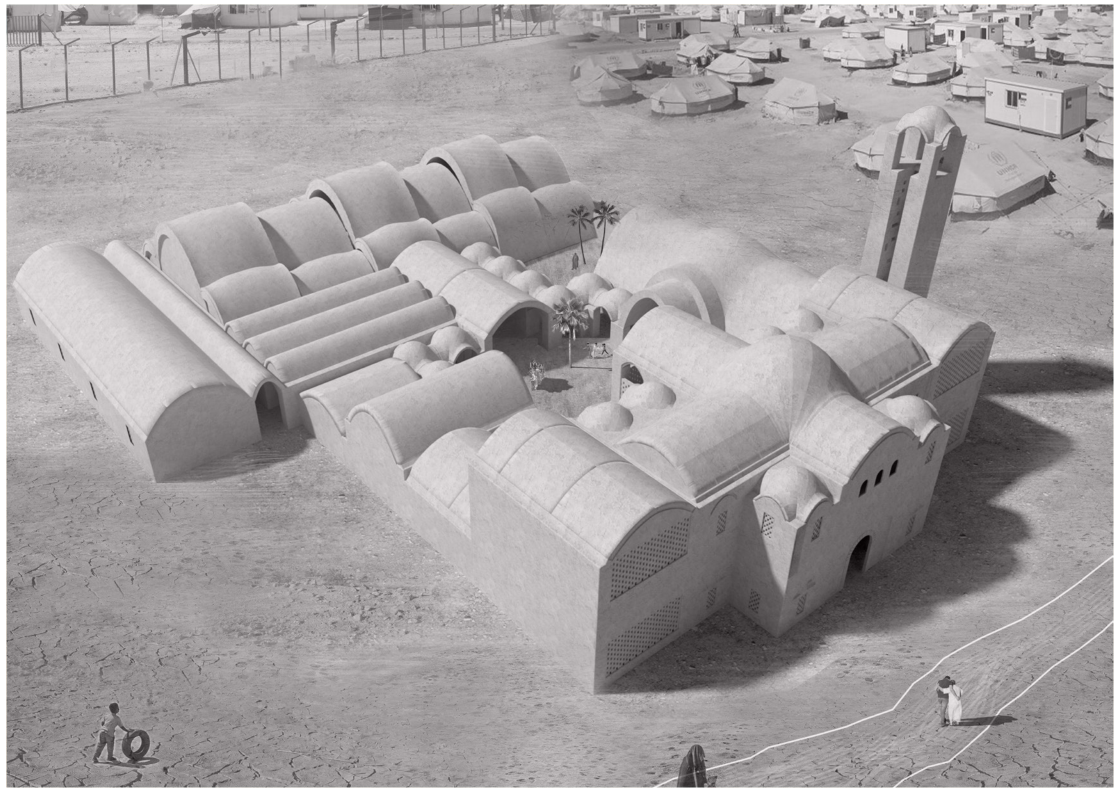

Figure 7.11 3D view of the complex with in the front the entrance building, on the right the tower and at the back the theatre. source: own

7.4.1 Theatre

Below the building sequence of the theatre is presented. Figure 7.13 gives an summary of the different materials, techniques and bricks that are used in this building and which are explained in paragraph 7.3.

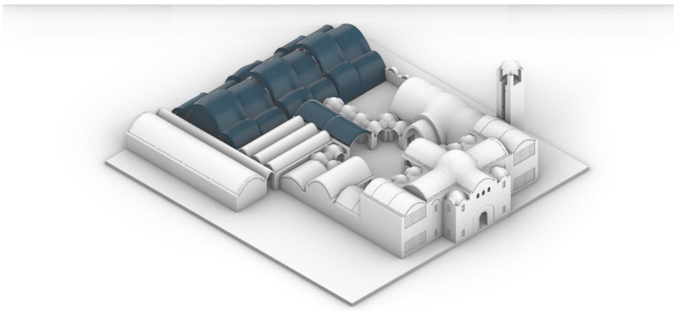

Figure 7.12 3D view of the complex with the theatre highlighted in blue. Source: own work. source: own

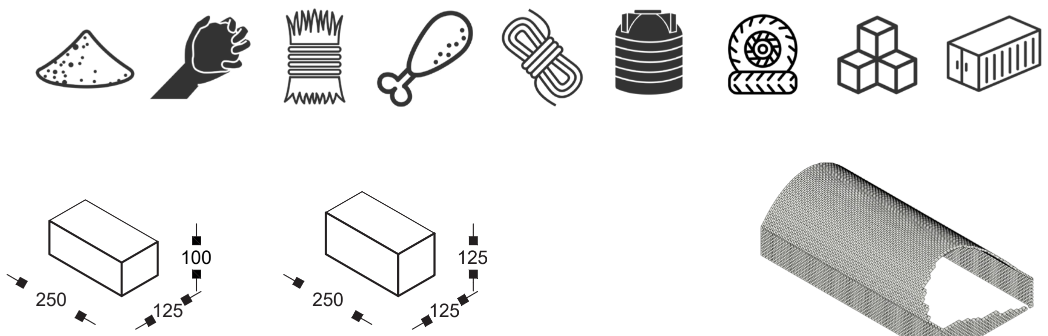

Figure 7.13 Pictograms of the materials, brick types and construction type that are used for the construction of the theatre. source: own

Step 1

The first step of creating the theatre is making the foundation as described in subparagraph 7.3.1. On top of that the first exterior wall is constructed that serves as supporting wall for the barrel vault.

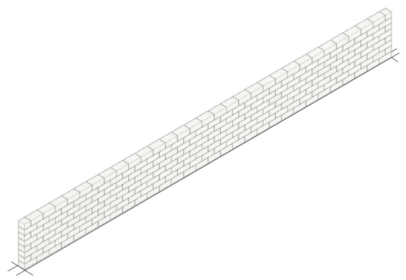

Figure 7.14 Isometric of the step 1 of the building sequence of the theatre. source: own

Figure 7.15 Section of the step 1 of the building sequence of the theatre. source: own

Step 2

Notice that the supporting wall is already made in the rough shape of the arch. The precise shape is drawn with the technique as described in paragraph 7.3.
A container is placed next to this wall so that the builders can reach the height of six meters. This container moves with the building to the right, since it's on wheels.

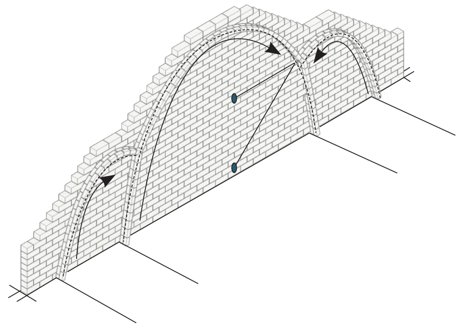

Figure 7.16 Isometric of the step 2 of the building sequence of the theatre. source: own

Figure 7.17 Sections of the step 2 of the building sequence of the theatre source: own

Step 3

The first row of bricks is glued to the supporting wall following the Nubian technique where the bricks are placed under an angle towards the wall, as in figure 7.8 in paragraph 7.3.5.
To ensure that the vault will be perfectly horizontal a rope with a stone will be used a guide.

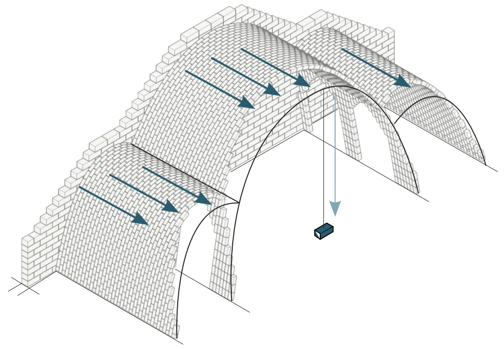

Figure 7.18 Isometric of the step 3 of the building sequence of the theatre. source: own

Figure 7.19 Sections of the step 3 of the building sequence of the theatre. source: own

Step 4

When the first barrel vault is completed, a second supporting wall is built to construct the next, lower vault.
The gap that arises between that wall and the vault is used to let in fresh air and daylight.

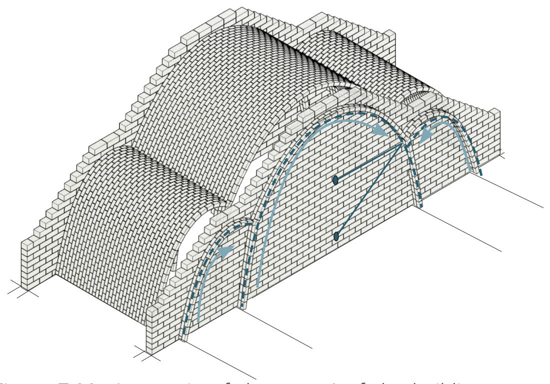

Figure 7.20 Isometric of the step 4 of the building sequence of the theatre. source: own

Figure 7.21 Sections of the step 4 of the building sequence of the theatre. source: own

Step 5

In step five the same construction method is used as in steps two and three to create the lower barrel vault.

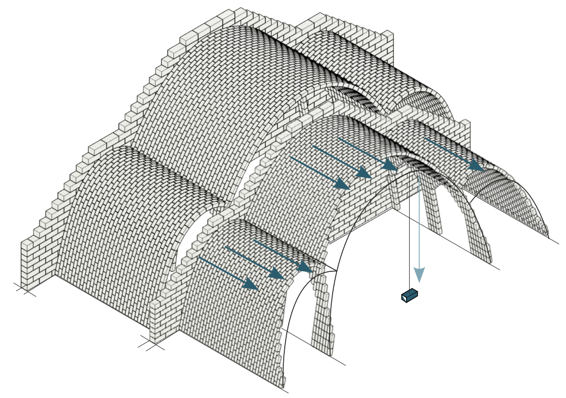

Figure 7.21 Isometric of the step 5 of the building sequence of the theatre. source: own

Figure 7.22 Section of the step 5 of the building sequence of the theatre. source: own

Step 6

Instead of creating a new wall from the ground to support the new higher barrel vault, an arch is built on top of the lower vault. This saves a lot of time and the gap there had to be closed anyway since it's not facing north.

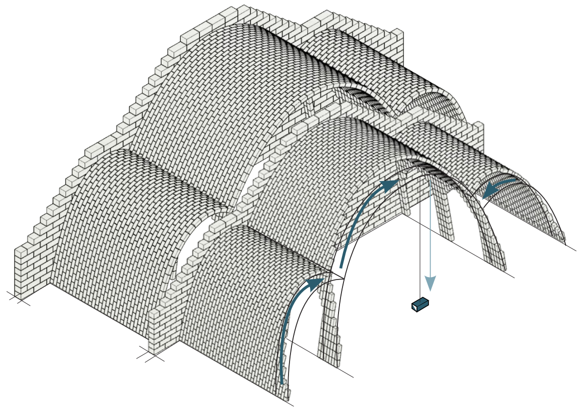

Figure 7.23 Isometric of the step 6 of the building sequence of the theatre. source: own

Figure 7.24 Section of the step 6 of the building sequence of the theatre. source: own

Step 7

All the previous steps are repeated until the end of the building at the right. A row of stones is placed between the gaps to prevent water flowing into the building.

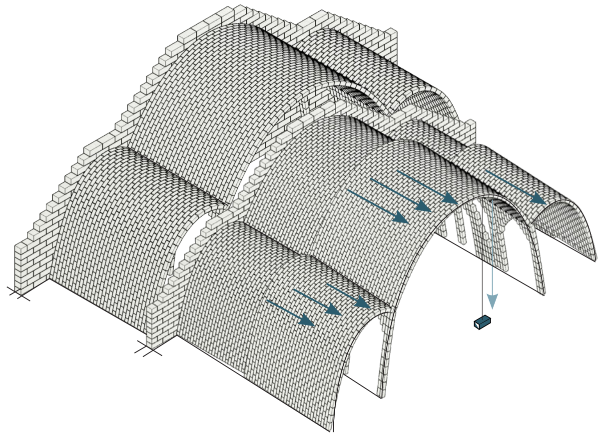

Figure 7.25 Isometric of the step 7 of the building sequence of the theatre. source: own

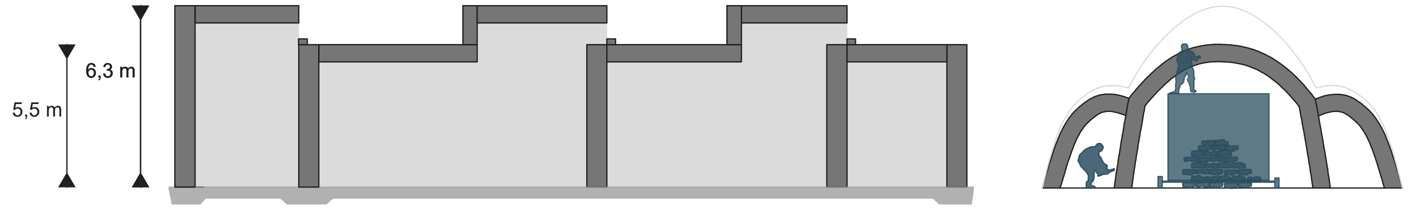

Figure 7.26 Section of the step 7 of the building sequence of the theatre. source: own

Step 8

The two supporting walls in the middle of the building are removed to make place for the stage and the seating and to create a clear view as in figure 7.27.

Figure 7.27 IImpression of the inside of the theatre. source: own

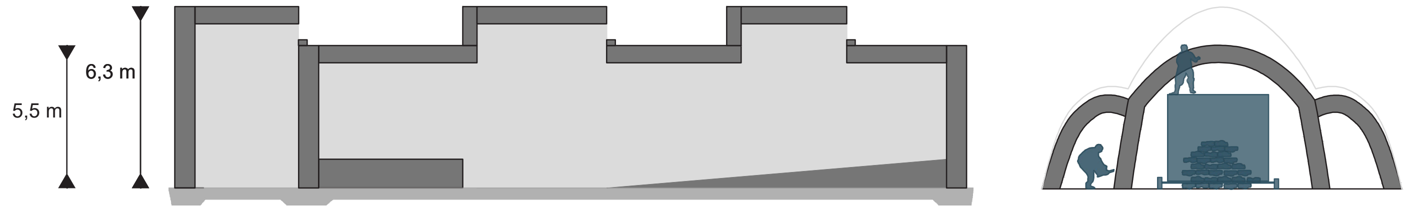

Figure 7.28 Section of the step 8 of the building sequence of the theatre. source: own

7.4.2 Entrance

Below the building sequence of the entrance is presented. Figure 7.30 gives an summary of the different materials, techniques and bricks that are used in this building and which are explained in paragraph 7.3.

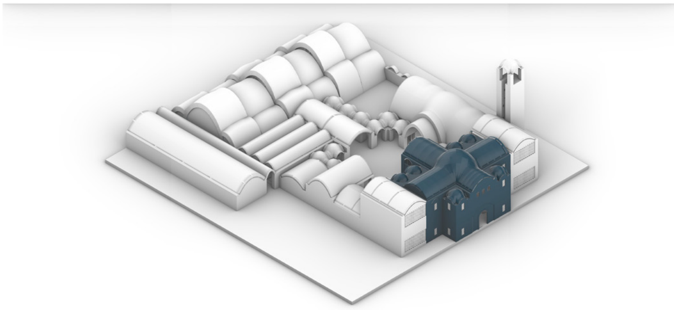

Figure 7.29 3D view of the complex with the entrance highlighted in blue. source: own

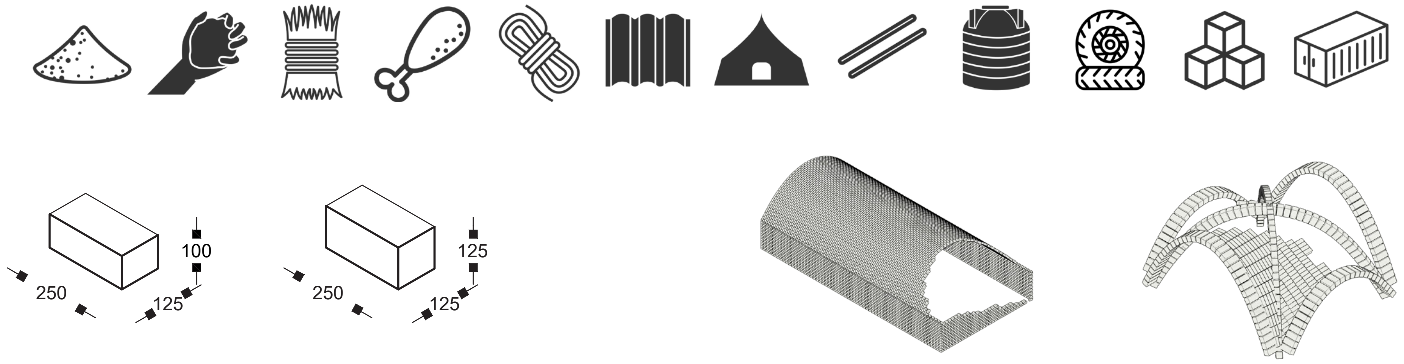

Figure 7.30 Pictograms of the materials, brick types and construction type that are used for the construction of the entrance. source: own

Step 1

After creating the foundation the walls and columns are built at ground level. Sand bags and crates are used to reach the higher parts.

The openings in the walls are created at the same time using the technique as described above.

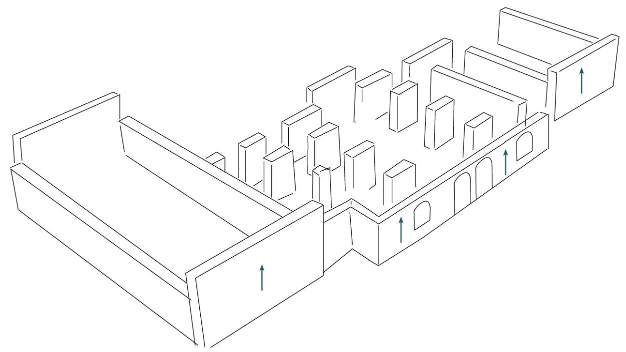

Figure 7.31 Isometric of the step 1 of the building sequence of the entrance. source: own

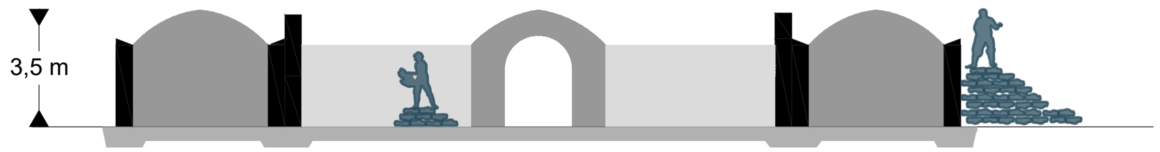

Figure 7.32 Section of the step 1 of the building sequence of the entrance. source: own

Step 2

Some of these walls also act as the supporting walls for making the barrel vaults and cross vaults inside the entrance.

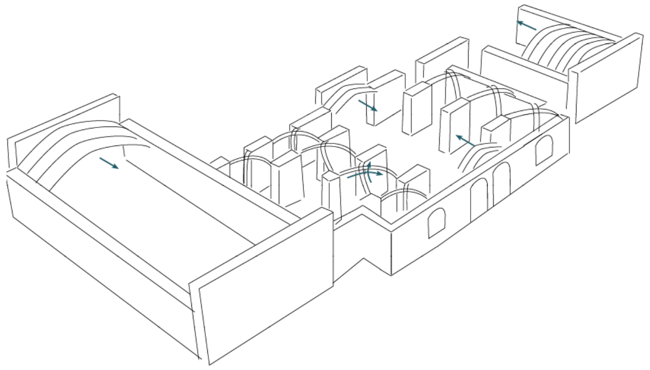

Figure 7.33 Isometric of the step 2 of the building sequence of the entrance. source: own

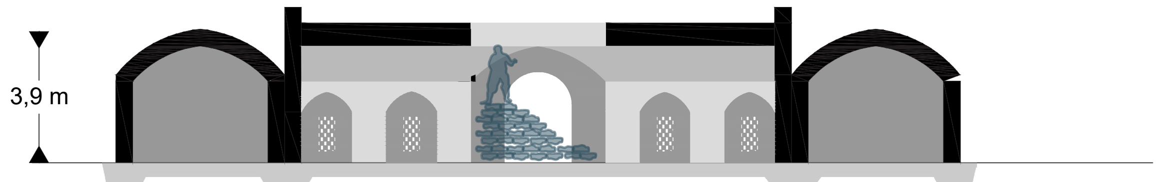

Figure 7.34 Section of the step 2 of the building sequence of the entrance source: own

Step 3

On top of the walls, barrel vaults and cross vaults the second floor has to be constructed. To do so the vaults will be equalized with at least 20 centimeters of mud plaster. At the places where the vaults are lower even more plaster is added. This plaster forms also the surface of the floor at the first level.

To reach this height a container of the camp is placed next to the structure, the same as used for building the theatre.

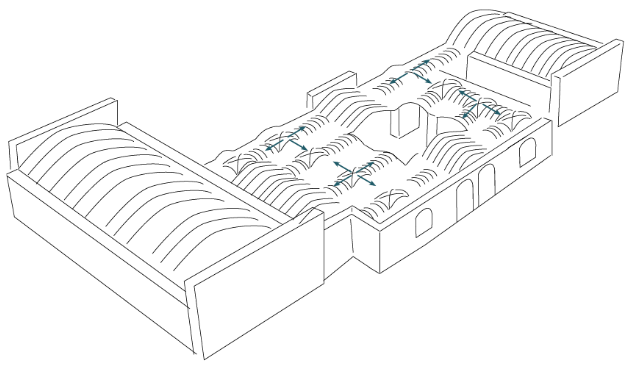

Figure 7.35 Isometric of the step 3 of the building sequence of the entrance. source: own

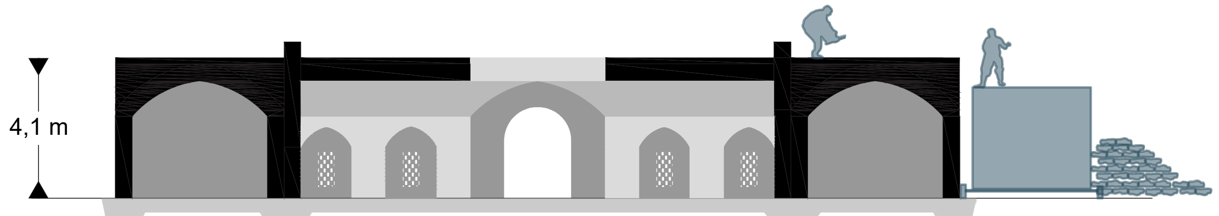

Figure 7.36 Section of the step 3 of the building sequence of the entrance. source: own

Step 4

The walls and vaults on the first floor are created in the same way as on the ground level. The first level can be reached via a stairs on the inside and via the container.

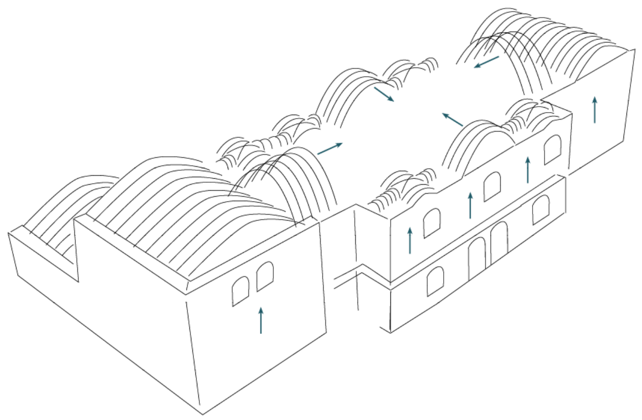

Figure 7.37 Isometric of the step 4 of the building sequence of the entrance. source: own

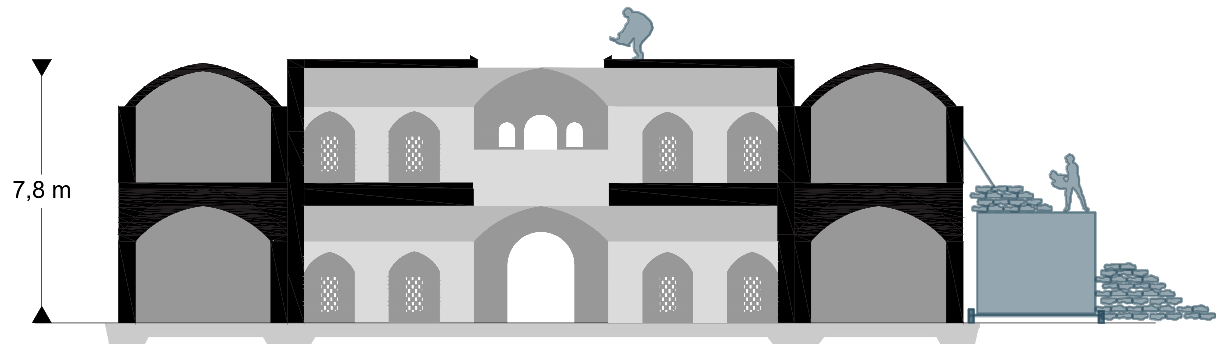

Figure 7.38 Section of the step 4 of the building sequence of the entrance. source: own

Step 5

After the roofs are placed the dome can be build, which consists of a compression ring. Builders can reach this dome from the roofs of the second floor.

Once the building is completed unnecessary supportive walls can be removed and the finishing mud plaster can be placed on the roofs and the walls on the outside.

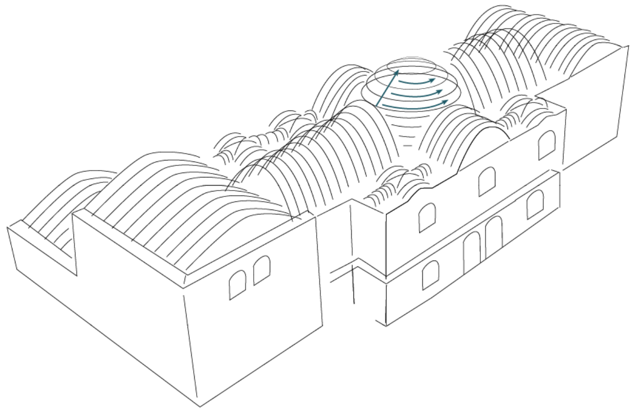

Figure 7.39 Isometric of the step 5 of the building sequence of the entrance. source: own

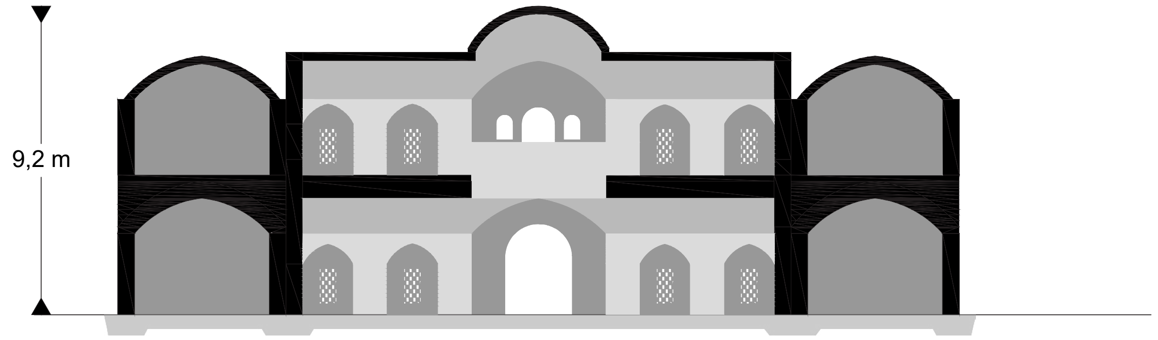

Figure 7.40 Section of the step 5 of the building sequence of the entrance. source: own

7.4.3 Tower

Below the building sequence of the tower is presented. Figure 7.42 gives an summary of the different materials, techniques and bricks that are used in this building and which are explained in praragraph 7.3.

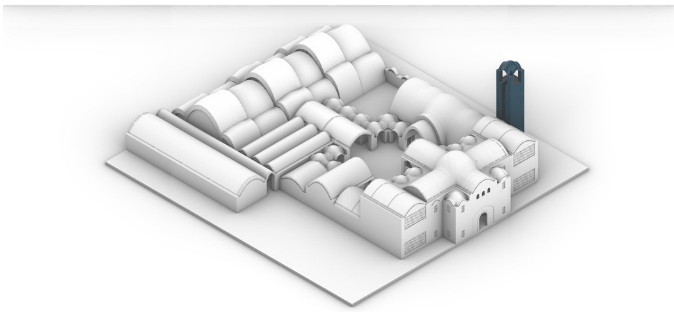

Figure 7.41 3D view of the complex with the tower highlighted in blue. source: own

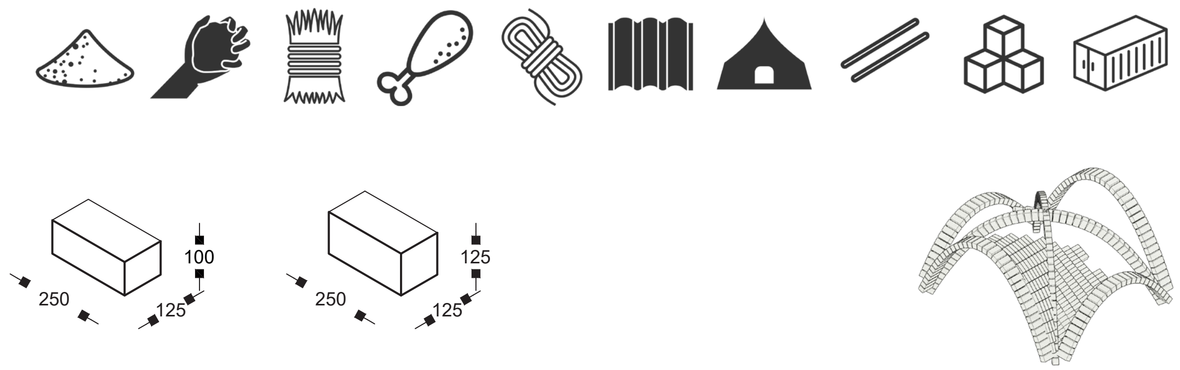

Figure 7.42 Pictograms of the materials, brick types and construction type that are used for the construction of the tower. source: own

Step 1

The base of the tower is built with large bricks with the size of 150x200x400 mm.

The tower remains massive until the first floor.

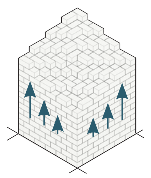

Figure 7.43 Isometric of the step 1 of the building sequence of the tower. source: own

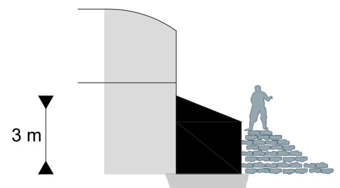

Figure 7.44 Section of the step 1 of the building sequence of the tower. source: own

Step 2

At the first floor level a gap is created inside the wall with the opening towards the entrance building. In this gap the maintenance stairs are created as described in subparagraph 5.5.1.
A container is placed next to the tower to reach the new height.

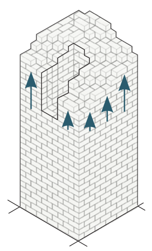

Figure 7.45 Isometric of the step 2 of the building sequence of the tower.
source: own

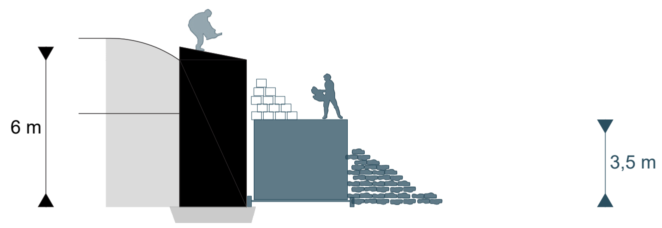

Figure 7.46 Section of the step 2 of the building sequence of the tower.
source: own

Step 3

When the tower is even too high to reach from the container the stairs inside the tower is used to reach the top. The materials are then transported to the top with a pulley system and tent ropes.

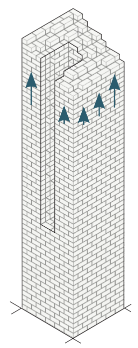

Figure 7.47 Isometric of the step 3 of the building sequence of the tower.
source: own

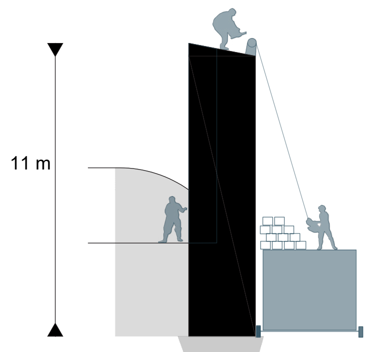

Figure 7.48 Section of the step 3 of the building sequence of the tower.
source: own

Step 4

At the very top of the tower a cross vault is created with the same size and technic as discussed above.

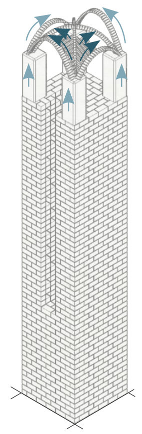

Figure 7.49 Isometric of the step 4 of the building sequence of the tower.
source: own

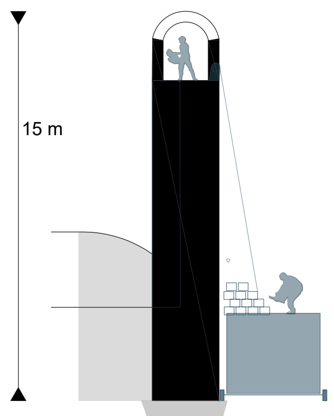

Figure 7.50 Section of the step 4 of the building sequence of the tower.
source: own

Step 5

The total height of the tower is 15 meters, which is achievable when taking into account both the constructability and the structural analysis.

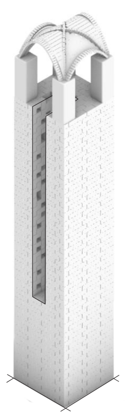

Figure 7.51 Isometric of the step 5 of the building sequence of the tower.
source: own

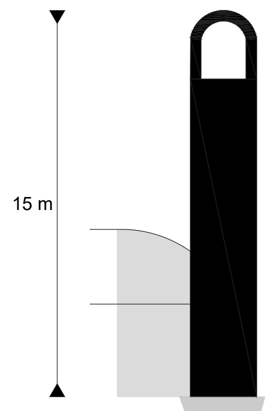

Figure 7.52 Section of the step 5 of the building sequence of the tower.
source: own