Group 05

Tarab_ طرب

AR3B011 - Earthy 2020

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1 Introduction

28 July 2012 is the date that the Za'atari refugee camp opened, due to the Syrian conflict. From that day onwards it evolved into the world's largest camp for Syrian refugees. Nowadays the number of refugees stays around 80.000 while the peak was at April 2013 with more than 200.000 refugees.
Although the camp was started as a temporal solution, it is gradually evolving into a permanent solution. This can also be seen in the shift of housing, from tents towards container boxes. The boxes itself became part of the new urban layout. People are relocating them to form courtyards, clusters and neighborhoods. This indicates the needs of people to transfer the camp into a city, to make it a permanent, livable place.

1.1 Problem statement

The amount of people and the period the people are living in the camp shows that it is no longer a short-term solution. This means that the Za'atari refugee camp is evolving into a permanent settlement, a city.
In this city, the basic needs are covered. There are schools, supermarkets, water tanks and houses instead of tents. However, there is a lack of other functions, which makes a city a city. For instance a bazaar, a hammam, a cinema, a theater and a square. These functions are necessary to make the Za'atari refugee camp a more livable place, a place where people can develop themselves and forget their problems for a moment.

Therefore, our problem statement is:

"The Za'atari refugee camp is in size and numbers a city, but not in its functions."

1.2 Design vision

As explained in the problem statement, the Za'atari refugee camp needs to become a more livable place, a place where people can develop themselves.
Besides that, the people living next to each other come from different places with different backgrounds and different languages. There is only one language spoken by all people on earth, and that language is called music. Music connects people, let people enjoy their lives for a moment and lets people develop their skills.

That is the reason the design vision is:

"Design a safe place for people to enjoy musical and cultural activity, so the Za'atari refugee camp becomes a more livable and enjoyable place."

At the moment there is no such a thing as a music school or a theatre. Our building is going to fill in that gap.
In the urban context the goal is to place the building in a location that is easily accessible for everyone in the camp. To find the right spot, analyses are made of the infrastructure and population of the camp. Main focus points are to find a spot in the dense area and located at one of the main roads in the camp.
Visibility of the building in the camp is important to let everyone keep in touch with the building. It can be a guiding point in the camp and serve as a landmark. To be able to reach this goal the building should be big enough or high enough to create an icon in the surrounding.
A building with such a social value should also improve the direct surroundings. To achieve this it should be well integrated in the urban context.

1.3 Design goals

The starting point for the design goals is the following general concession: "Music is a language that everyone can understand". With this kept in mind it the design goals have been made which are as following:

- design a safe place for people to enjoy musical and cultural activity
- Making the refugee camp a better place for everyone
- Design a new landmark where people can spend leisure time
- Add culture through music, theatre, and radio
- Use local materials from the site to build this large span structure (reduce the transportation cost and involved the refugees in the construction process)
- Design a climate responsive design

1.4 Design principles

We are using the following design principles in order to design our building:

- Sketching
- Rendering
- Computational design
- Generative design

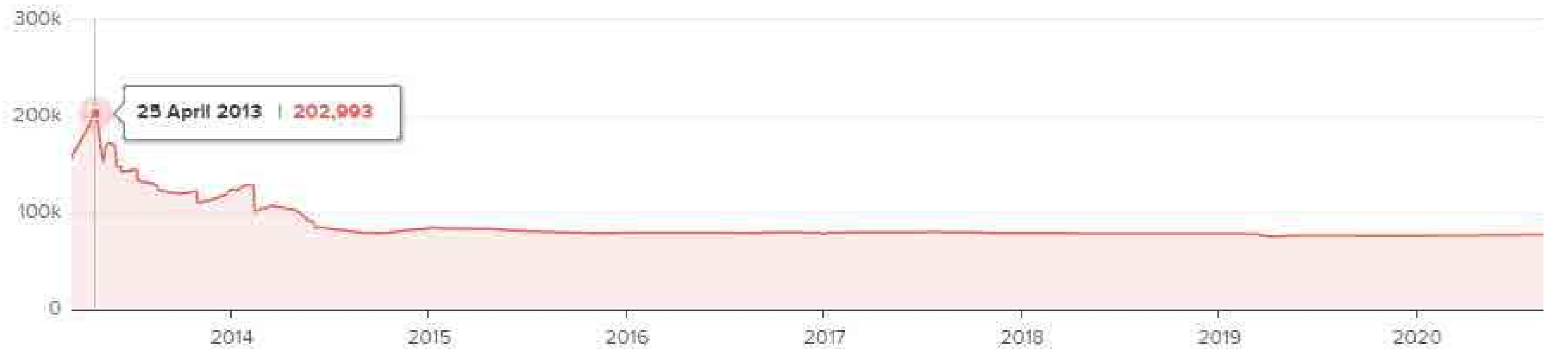

Figure 1.1 Total persons of concern Za'atari refugee camp, source: UNHCR

2 Research background

2.1 Traditional Syrian Architecture

The most significant elements of the traditional Syrian architecture are the following:

2.1.1 Courtyard

it is used for aesthetics and privacy. It performs an important function as a modifier of climate in the hot arid areas. It allows outdoor activities with protection from wind, dust, and sun. During the day the heated air rises, convection current set up and airflow that in conjunction with fountain, ventilates the house and keeps it cool. (Rehabimed, 2015)

2.1.2 Iwan

The iwan is a hall that has three walls and a roof as seen in figure 2.1 and it is connected with the courtyard. It faces the southern direction and it is open to the north. It is used as a living place in the hot summer because it is cooler than other parts of the house. (Rehabimed, 2015)

Figure 2.1 Courtayrad and iwan in Sibai House in Damascus . Source: archnet, 2008

2.1.3 Riwaq or arcade

It is often built around the courtyard as a transition space between interior and exterior spaces. it used as a covered circulation walkway. Furthermore, it provides shades in hot summer and covers from the rain, figure 2.5.

2.1.4 Mashrabiya

It is a type of opening with craved latticework and it is traditionally used to catch and passively cool the wind and enhance privacy, figure 2.2.

Figure 2.2 wooden mashrabia in Damascus source: Islamic art lounge, 2018

2.1.5 Earthen building in Syria

Adobe bricks were used in both the city and the Rural areas and they still can be found in some of the buildings in the old city of Damascus and villages in the countryside of Damascus and Aleppo. The main building materials are mud and mortar. First, the mud is prepared and mixed with straw which provides strength, and then put into formworks in order to create the adobe bricks. The mortar is used as bonding between the adobe bricks it has the same contents. However, the mud used in the mortar is sieved and refined in order to make it smoother and easier to be applied.

The adobe walls are built on a stone foundation with a thickness of 50-75 cm and it rises about 50 cm above the ground level

The wall is built on these foundations at a thickness then space is covered with an adobe vault or dome. In the end, the walls and roof is covered with a lime cladding from outside making the surface smoother and providing projecting against moisture (Rehabimed, 2015)

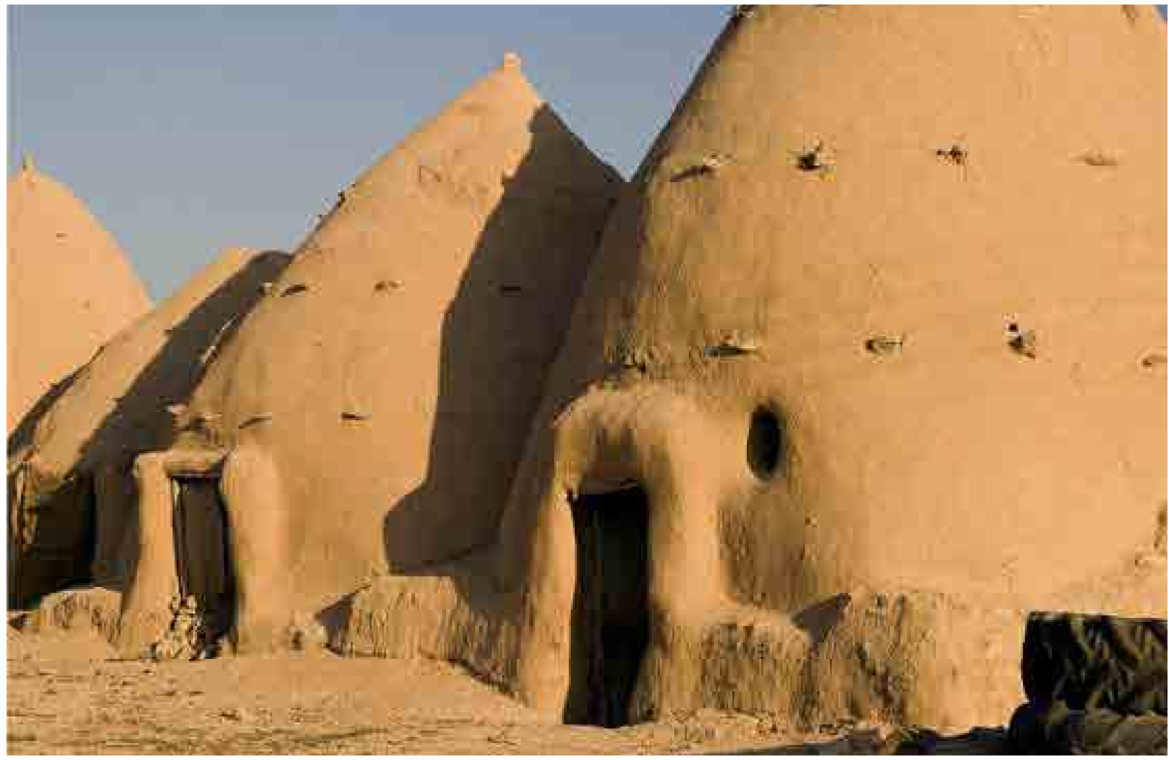

Figure 2.3 Beehive houses in north Suria. Source: greenprophet, 2011

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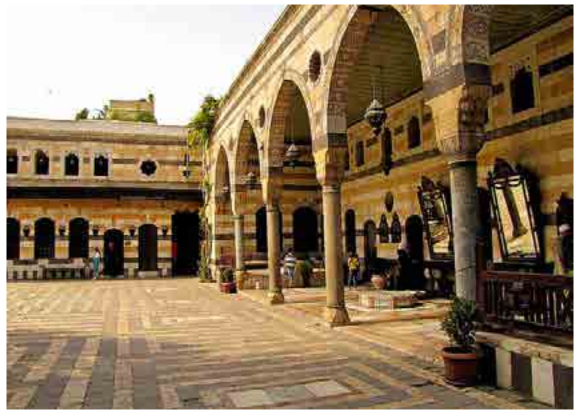


Figure 2.5 Riwaq , Azm palace in Damascus. Source: Flicker

Figure 2.6 Beehive houses in north Suria. Source: greenprophet, 2011

2.2 Location

Al- Zaatari is a refugee camp located in, as seen in figure 2.7, the north of Jordan, 10 km east of Mafraq. It is the world's largest camp for Syrian refugee. It was open in 2012 to host the Syrians fleeing the violence in Syria. The camp is connected to the road network by a short road which leads to Highway 10 (Wikipedia, 2020).

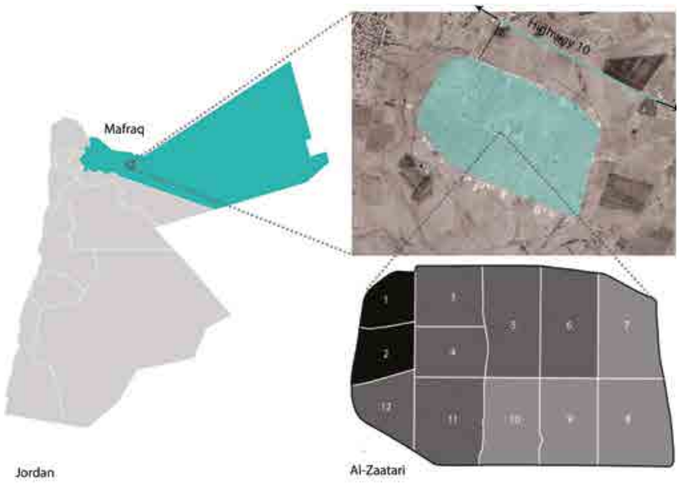


Figure 2.7 Al-Zaatari location. Source : own

2.2.1 Growth of the camp

The camp was opened in 2012. Since 2013 the population of the camp increased significantly. Currently around 80000 people live in the camp from which 56% of them are children and teenagers. The camp has 12 districts. However, it is important to mention that the emergence of the camp started from district 1 and 2. (UNHCR, 2019) figure 2.11 shows the urban growth of the camp from 2012 till 2014.

2.2.2 Climate analysis

The climate in Al-Zaatari camp is cold semi-arid. It experiences cold winter and dry, hot summer. The average high temperatures reach 32,3c in August and 12,5c in January and the average low temperatures are 16,4c in August and 2,2C in January. Furthermore, the average rainfall is 134 mm and the area experiences 300 sunny days per years with an annual irradiation of 2000 kw/m2 and that is nearly double the amount of irradiation in the Netherlands. The main predominant wind direction is west with an average speed between 5 to 10 km/h. The speed increases in summer and becomes less in winter. However, Extreme weather conditions such as sandstorm, heavy rainfall and snow also occur.

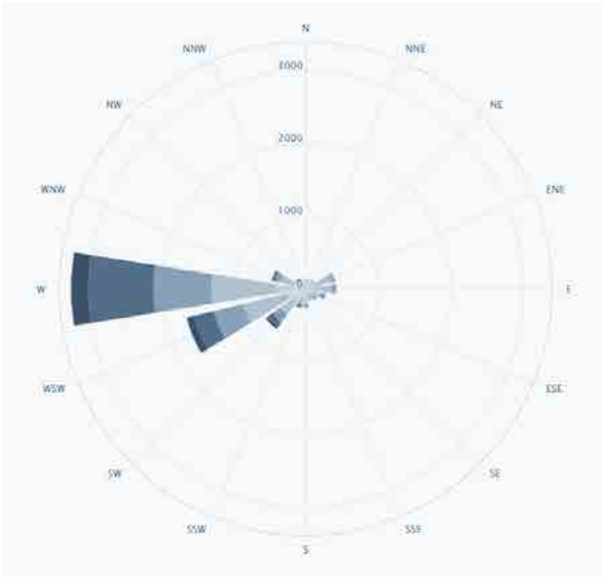


Figure 2.8 Al zaatari wind direction. Source : Meteoblue, 2020

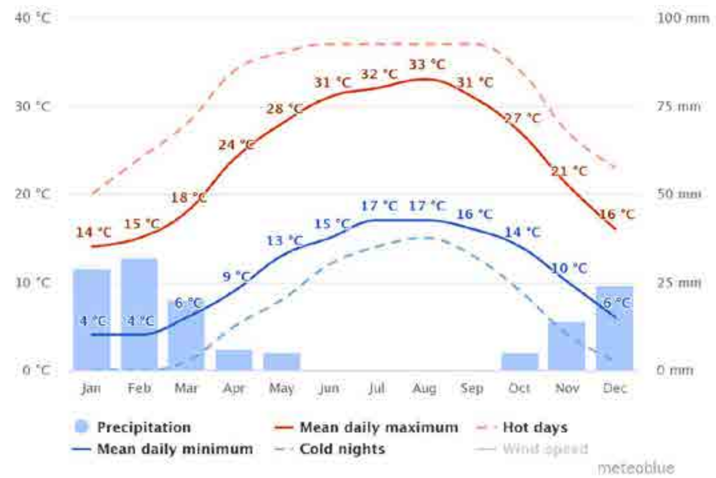


Figure 2.9 Al zaatari temperature average. Source : Meteoblue, 2020

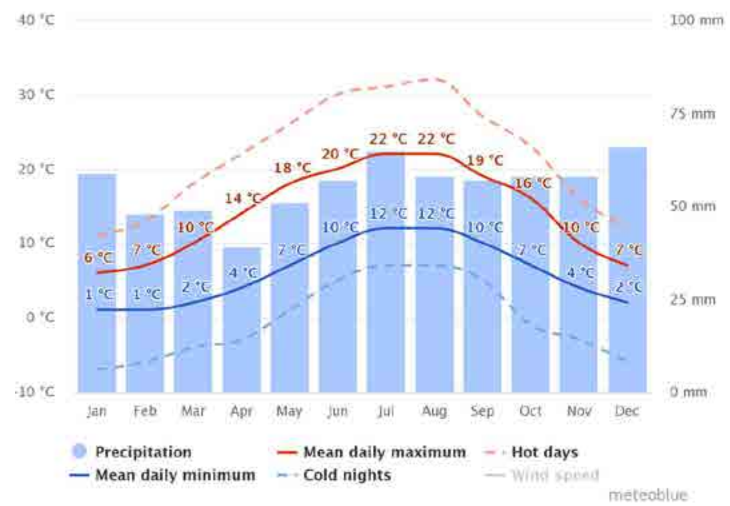


Figure 2.10 compersion the average temperature between Amsterdam and Mafraq. Source : Meteoblue, 2020

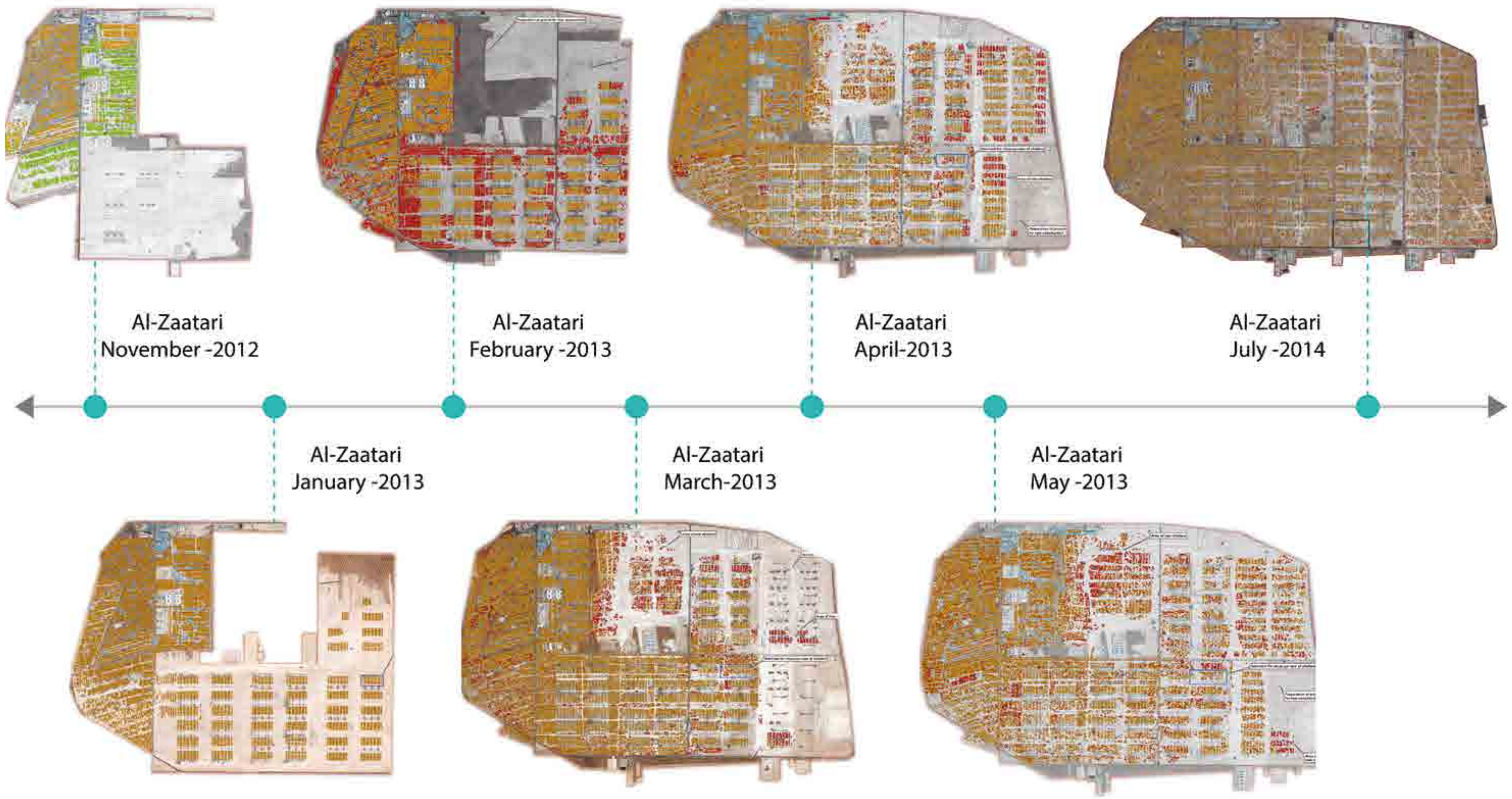


Figure 2.11 Al zaatari urban growth timeline. Source : own

2.3 Site analysis

The land use provided by UNHCR shows that the camp is becoming a city see figure 2.15.
The development of the camp as seen in the urban growth of the camp in the previous chapter reminds us of the developments of the city of Damascus figure 2.12, 2.13 and 2.14. The camp started with a regular grid but after less than one year the urban fabric became more organic due to the natural growth based on the occupants needs. Furthermore, Within the old city of Damascus there are two main perpendicular roads which intersect in the main city square where the Umayyad mosque is located. This square is the heart of the old city and it gives it its own identity. The camp has also two main roads. However, the intersection between these two roads is not treated well and there is no square or any type of landmarks. Therefore, placing a building that acts as a landmark at the intersection would help enhancing the identity of the camp.
To take this further, the serviceability of the communal facilities was investigated as seen in figure 2.16, 2.17 and 2.18. From that it could be seen that by placing the theatre at the intersection would improve the serviceability and increase the covered area.

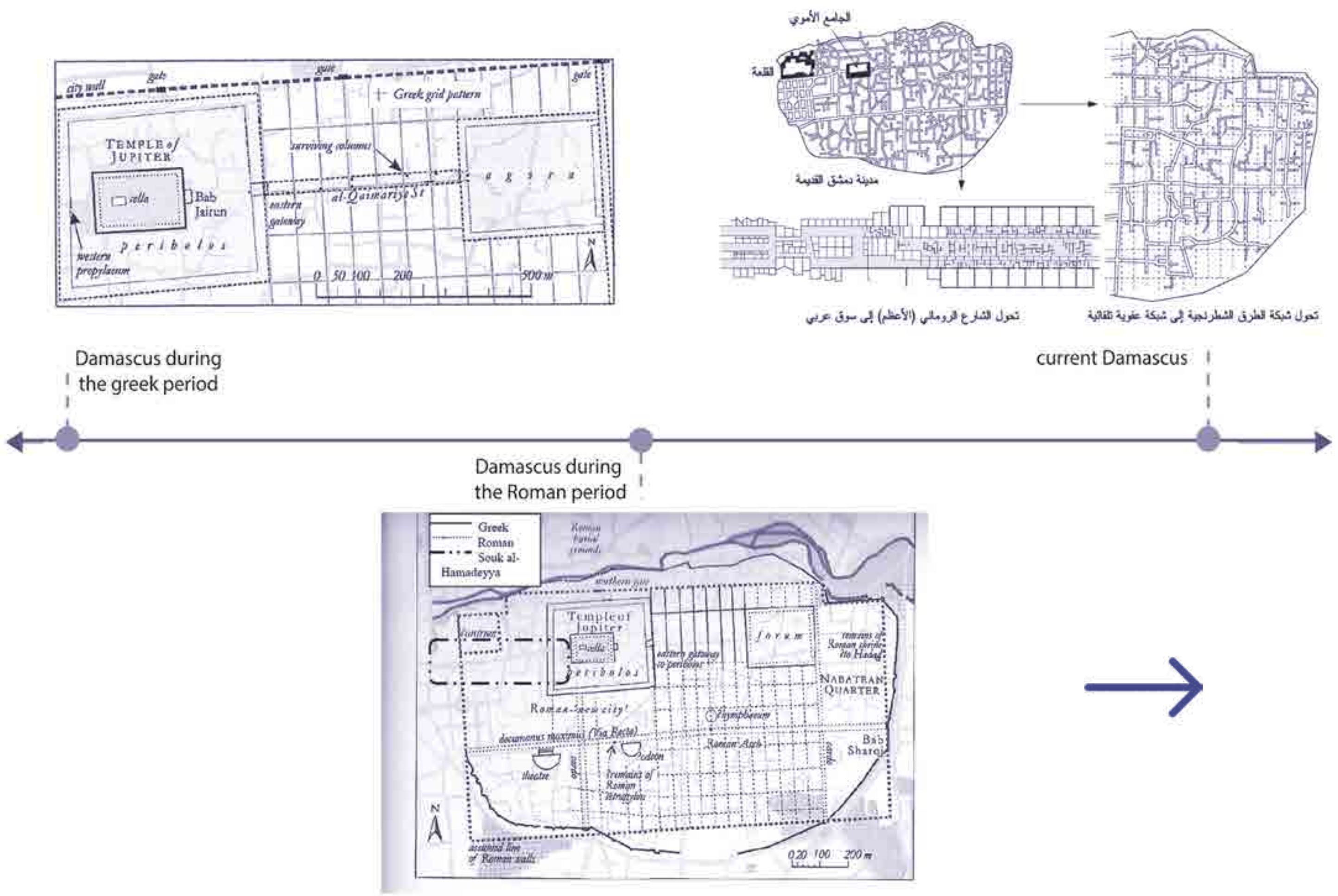


Figure 2.12 Urban growth of Damascus. Source: own

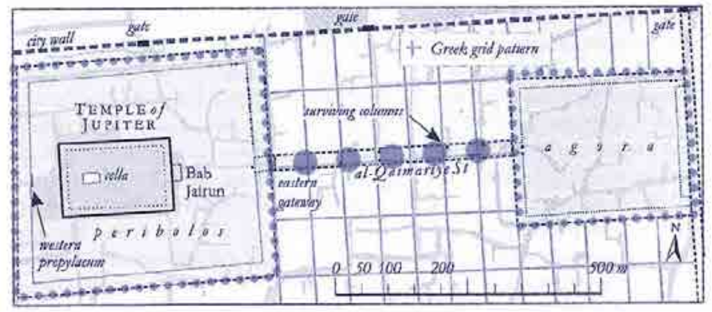


Figure 2.13 Damascus in the greek period the main square and road

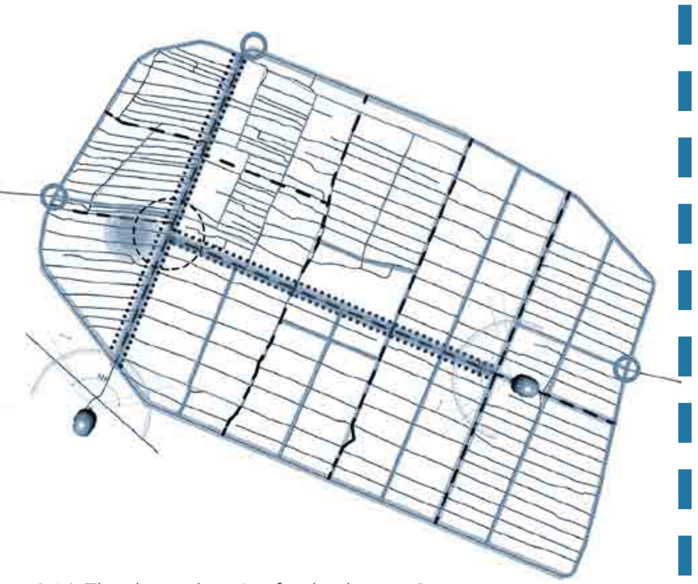


Figure 2.14 The chosen location for the theatre. Source: own


Figure 2.15 Landuse in AL-Zaatari refugee camp. Source: UNHCR

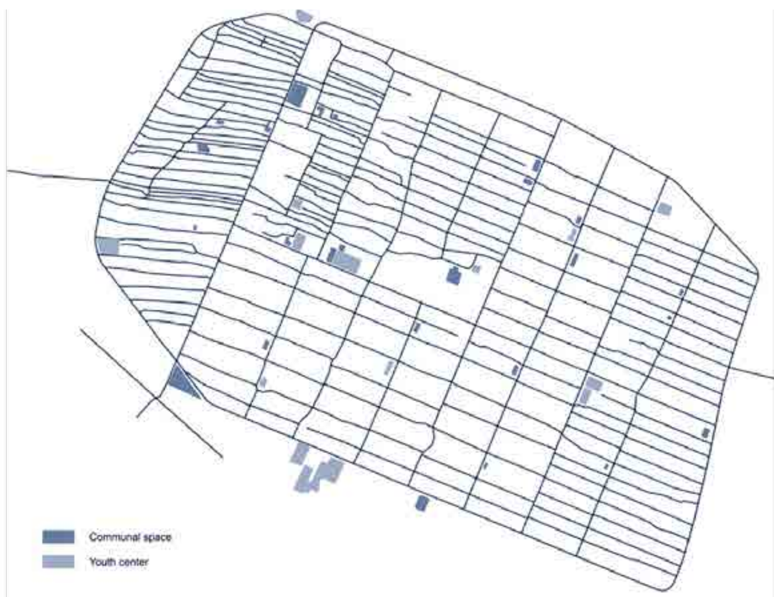


Figure 2.16 Communal facilities in Al-Zaatari. Source: own

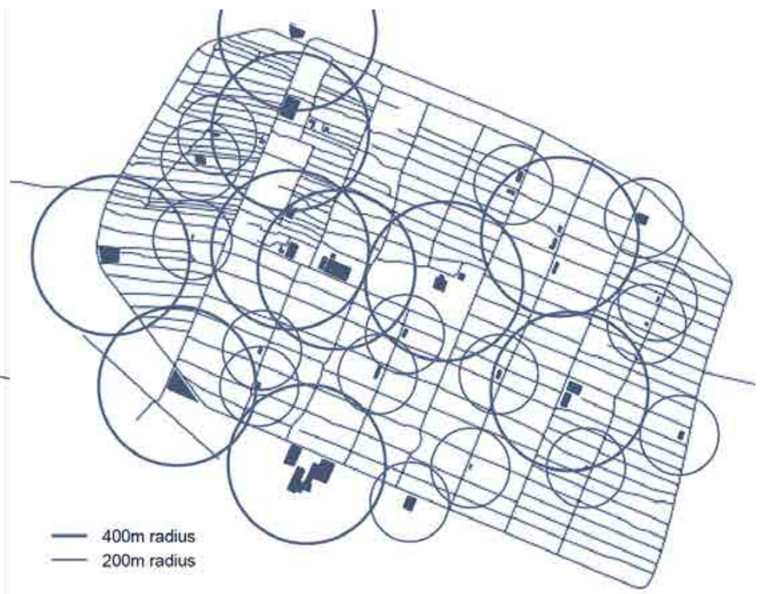


Figure 2.17 The serviceability of the communal facilities.Source:own

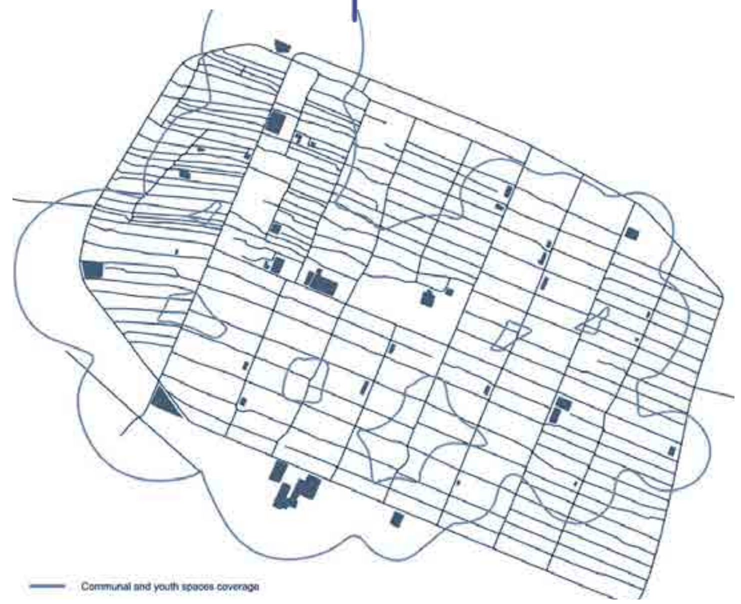


Figure 2.18 The serviceability of the communal facilities.Source:own

3 Configuring

3.1 Flowchart

The flowchart had many different forms, evolving during the project. The final one is structured into the three phases of the project; configuring, shaping and structuring. At every stage multiple processes are performed, resulting into a variation of results. These results are combined into a data container before the next step can be started.
At two stages, a condition is added. Within this condition, the previous data containers are checked whether they fulfill the condition or not. If not, the process does a step back and another iteration starts. This continues until the condition is met. The milestones will be performed once, so will be skipped in the next iteration.

Finally, the whole project will be documented into a presentation and a report.

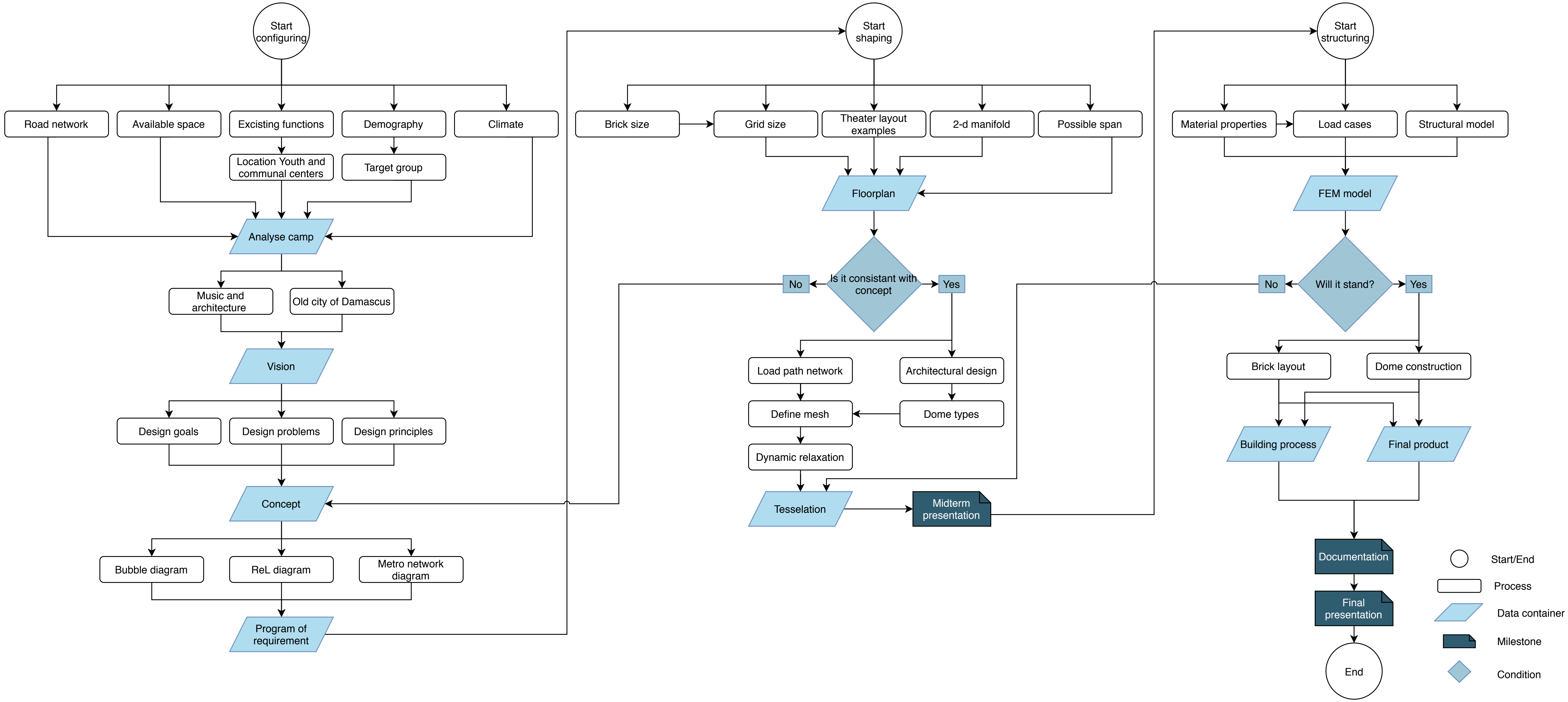


Figure 3.1 Flowchart, source: own

3.2 Program of requirements

From the site analysis and the design vision it became evident that the Zaatari camp could benefit from a theatre. The functions and spaces that will be placed in the theatre should focus on enhancing the quality of the space and the camp. Secondly, it is also important that all spaces can be utilized during different periods in the day. The types of spaces that are chosen are derived from multiple workshops and desk research of similar buildings.

The first table (number of visitors) depicts the amount of anticipated people per function in the theatre. These numbers are used to estimate the sizes of the spaces.

The second table focuses on the different activities per function. To make optimal use of every space in the building, an analysis is made on the occupation throughout the day. Most rooms will be used for one function, such as the radio station. However, bigger rooms will have multiple functions and should be able to adapt to different user groups, i.e. the multi-functional room could be used for educational purposes, but also as a communal space where workshops can be given.

The spaces that require the most amount of space are the theater, the courtyard and the multi-functional room. Secondary spaces i.e. the Iwan, radio station or rehearsal rooms will be occupied by less people at the same time. Most of the rooms require a minimum height of 2.5 meters except from the theater which requires at least 4 meters height.

The minimum square meters per space are calculated according to the Engineering Toolbox and also previous works of students. The final square meters are mostly more than the minimum to create comfortable and spacious rooms. They are used as an estimate for the design process. Most of the spaces such as the Theater/Cinema require a minimum of 0.6 m^2 per person. That number represents the clear space required for the seating and circulation whereas the staging and backstage area are not included, so the final surface area is bigger. The Multifunctional Room is given 1.5 m^2 per person due to the flexibility in terms of circulation within the space. The Rehearsal rooms need approximately 2 m^2 per person and a maximum of 10 people occupation. The record room and the radio station need 10 m^2 per person due to the great amount of equipment needed (monitors, computers). The office space can host up to five people with a 5 m^2 per person. For the cafeteria 3 m^2 per person is enough while it can also be combined with the courtyard as well as the circulation space of the complex. The storage is added as a percentage of 5-15% for each function. The surface area of the courtyard is set at 100 m^2, but could be adjusted to the needs of the building during the design phase. For the circulation within the complex 30% is added. The gross area is considered as an addition of 25-30% added to the net area of the complex. This space is calculated for installations, Adobe wall thickness, etc.

	Number of visitors		
Function	**Capacity [# of people]**	**Space per person [m2]**	**Minimum [m2]**
Theater/Cinema	200	0.6	120
Rehearsal Rooms	8	2	16
Record Room	2	10	20
Radio Station	2	10	20
Courtyard	200	-	-
Iwan	6	5	-
Multifunctional Room	50	1.5	75
Office	4 to 5	5	4 to 28
Small cafe	3	4	12
Storage	-	-	-
Toilets	30	1.5	45
Entrance/Lobby	-	0.6	-

Table 3.1 Number of visitors, source: own

	Activities-Daily Use		
Function	**Morning**	**Afternoon**	**Evening**
Theater/Cinema	Classes	Performances/Movies/Classes	Performances/Movies/Classes
Rehearsal Rooms	Practising / classes	Practising / classes	Practising
Record Room	Recording	Recording	Recording
Radio Station	Broadcast	Broadcast	Broadcast
Courtyard	Social gathering	Social gathering	Social gathering
Iwan	Reading/Listening to music	Reading/Listening to music	Reading/Listening to music
Multifunctional Room	Classes	Classes	Communal space
Office	Work	Work	-
Small cafe	Coffee	Coffee	Coffee
Storage	-	-	-
Toilets	-	-	-
Entrance/Lobby	-	-	-

Table 3.2 Activities-daily use, source: own

	Program of Requirements						
Function	**Area in [m2]**	**Height [m]**	**Direction**	**Daylight**	**Noise**	**Special requirements**	**Open, Semi-open,closed**
Theater/Cinema	300	4	W	High (adjustable)	High	Acoustics	Closed
Rehearsal Rooms	25	2.5	W	Medium	High	Shading	Closed
Record Room	25	2.5	W	Medium	High	Acoustics/electronics	Closed
Radio Station	25	2.5	E	Medium	Medium	Electronics	Closed
Courtyard	100	-	-	Medium	Medium	Shading	Semi-Open
Iwan	30	2.5	S	Low	Low	-	Semi-Open
Multifunctional Room	100	3	-	High (adjustable)	Medium	-	Semi-open, closed
Office	1 to 24	2.5	-	Medium	Low	-	Closed
Small cafe	30	2.5	-	Medium	Medium	-	Semi-open
Storage	20	2.5	-	Low	Low	-	Closed
Toilets	45	2.5	-	Low	Low	Waste management	Semi-open
Entrance/Lobby	15	3	E	High	Medium	-	Open

30% Circulation	**402**	m2
Net Area	**1340**	m2
Gross Area (+25 - 30%)	**1742**	m2

Table 3.3 Program of requirements, source: own

3.3 Relation diagrams

3.3.1 REL diagram

The Relation diagram is based on the program of requirements. It shows direct connections with a double +, and indirect connections with a single +. This diagram is important to create a hierarchy of connections between certain functions.

The courtyard will be the central element, around which almost all functions will be organized. Next to the main entrance, back entrances are added to improve the circulation of multiple user groups.

3.3.2 Bubble diagram

The diagram on this page shows the conversion of the program of requirements and the REL-chart to a bubble diagram.

From this diagram it is visible that the courtyard will serve as the main transition space between different functions. However, there will also be multiple possibilities to go from one function to another without entering the courtyard.

The toilets are split into two bubbles, because they have different user groups. One is placed next to the theater, while the other is connected to the offices and radio station.

The Iwan is directly connected to the café, so it can be used as terrace.

3.3.3 Metro network diagram

The connection between the spaces can also be seen in the metro network diagram. To improve the user group circulation, the backstage has a back entrance. Therefore, the musician does not have to come across with his public before the actual performance. The café has a back entrance as well to be use by the chef and to throw away the garbage.

Lastly, two emergency exits are added in case something happens.

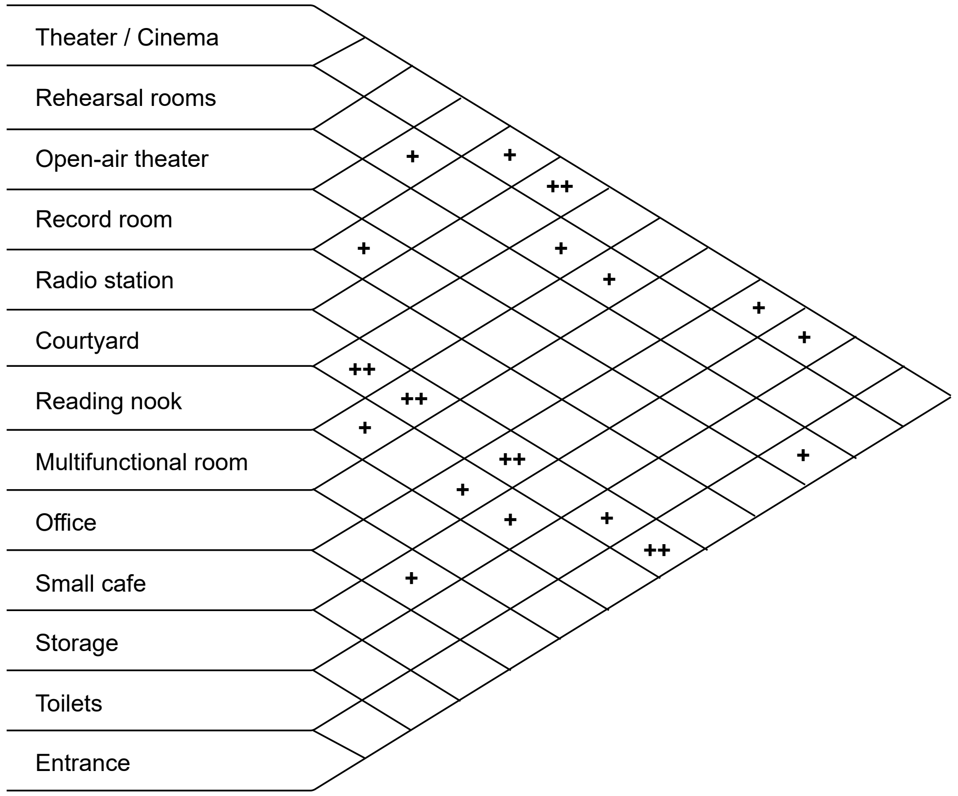


Figure 3.2 REL-diagram, source:own

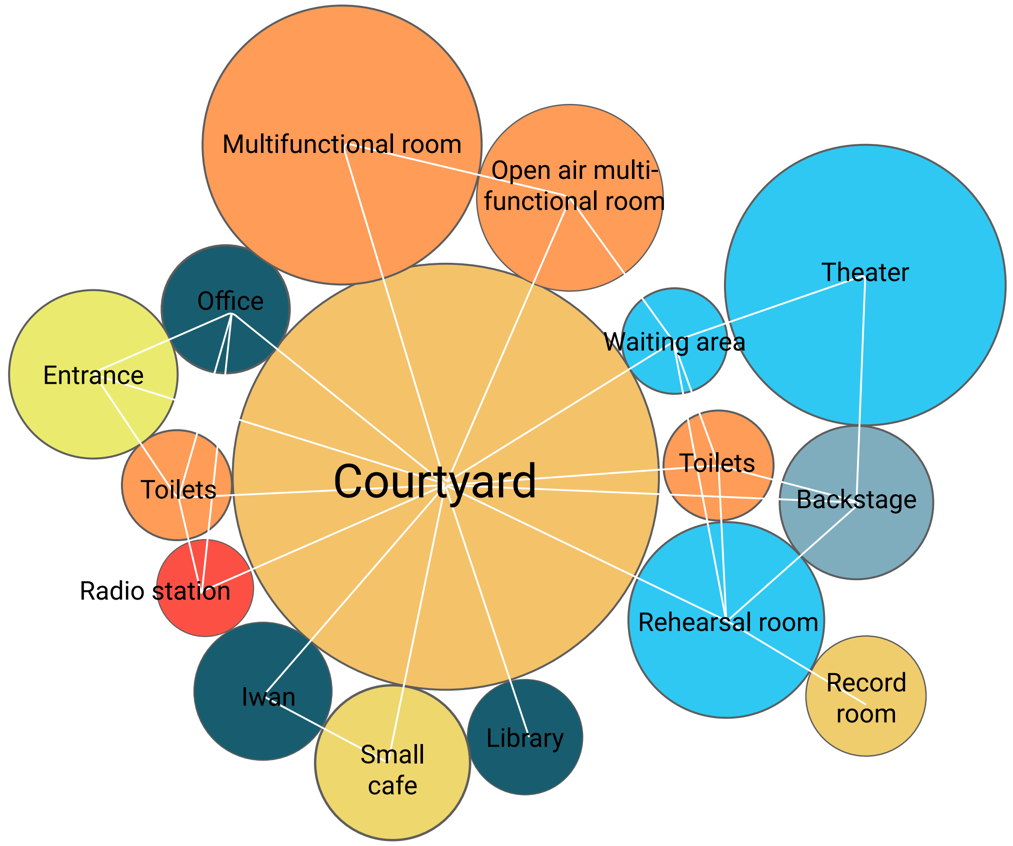


Figure 3.3 Bubble-diagram, source:own

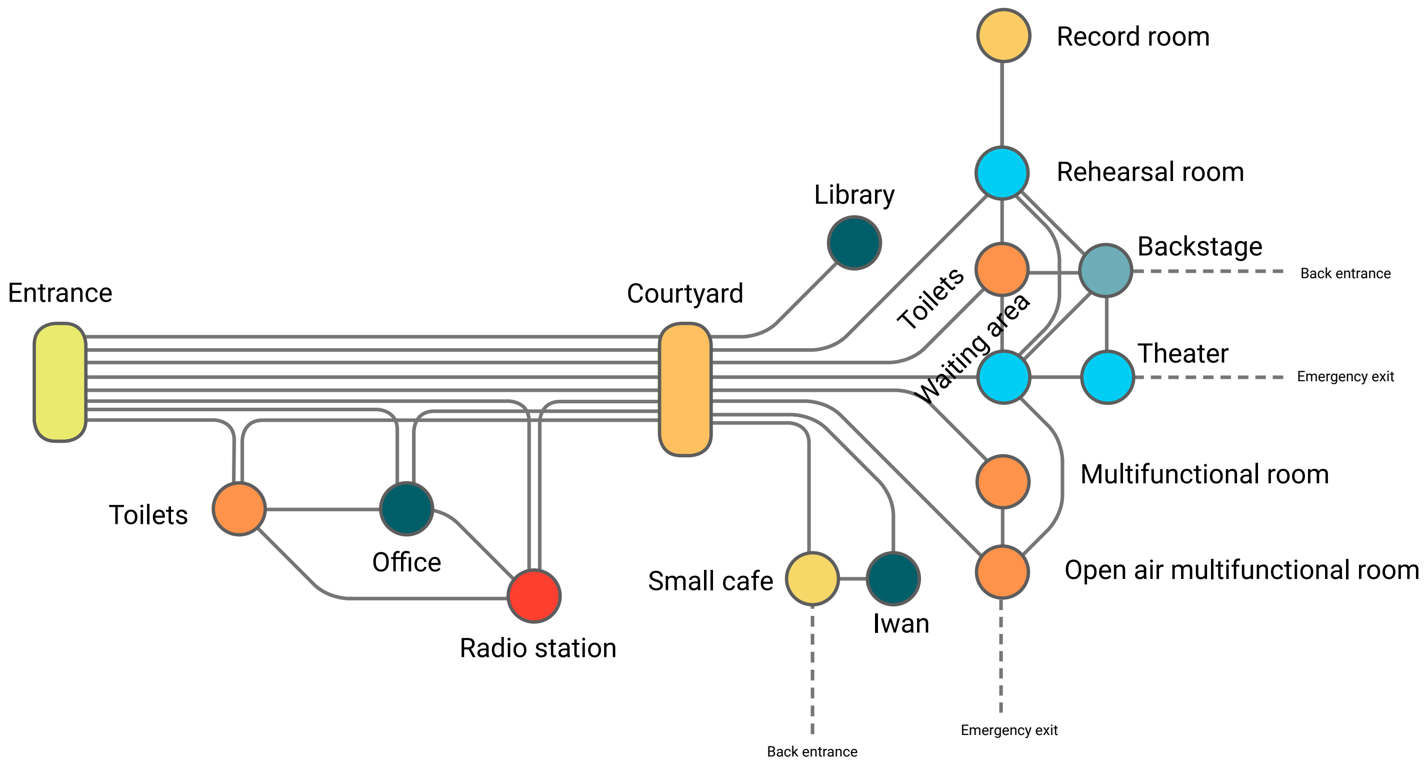


Figure 3.4 Metro network diagram, source:own

3.4 Floorplan evaluation

The final floorplan is derived from multiple processes and interventions that took place during the entirety of the project. The first set of floorplans have been created using both manual and computational methods. Floorplan 1 to 5 have been manually created using different design visions, and floorplan 6 to 7 have been generated using a relaxation script[13] that allows different weight factors to control the attraction and orientation between different rooms. The key parameters for evaluating the performance of a floorplan are based on previous research mainly derived from the relation diagram and the program of requirement. Different weight factors are assigned to ensure that the floorplan functions according to the vision of the team. The goal of the first set of floorplans is to determine a first initial layout of the building, that can later be used to refine according to the project needs. The evaluation process has mainly been done manually. However, some criteria are more quantifiable as others, for example routing and footprint.

Floorplan 5 scored the most amount of points based on the stated evaluations.

The second phase is to refine the floorplan and to improve on it. The main focus of the floorplan iterations is to improve the circulation of the building figure 3.7. To achieve this a few functions have been rotated, as can be seen in figure 3.6.

		Evaluation sheet						
Function	**Factor**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**
ReL- Diagram	2	8	4	6	6	8	6	8
PoR - Orientation	2	6	4	8	4	8	4	4
PoR - Daylight	2	8	6	8	4	6	6	6
Routing	2	6	6	6	8	8	4	6
Clarity	1	3	2	2	3	5	1	3
Aesthetics	1	3	3	3	4	4	2	3
Footprint	1	3	1	4	5	3	3	3
Grid adaptation	1	4	4	2	4	4	2	3
Emergency	1	4	4	4	3	4	4	4
Relationship with surrounding	1	4	2	4	3	3	3	2
	Total	**49**	**36**	**47**	**44**	**53**	**35**	**42**

Table 3.4 Floorplan evaluation sheet, source: own

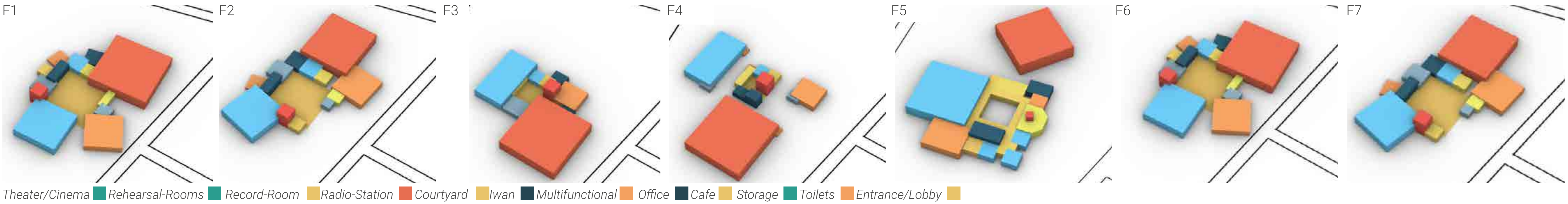


Figure 3.5 Initial floorplan configuration 1 to 7. Source: own

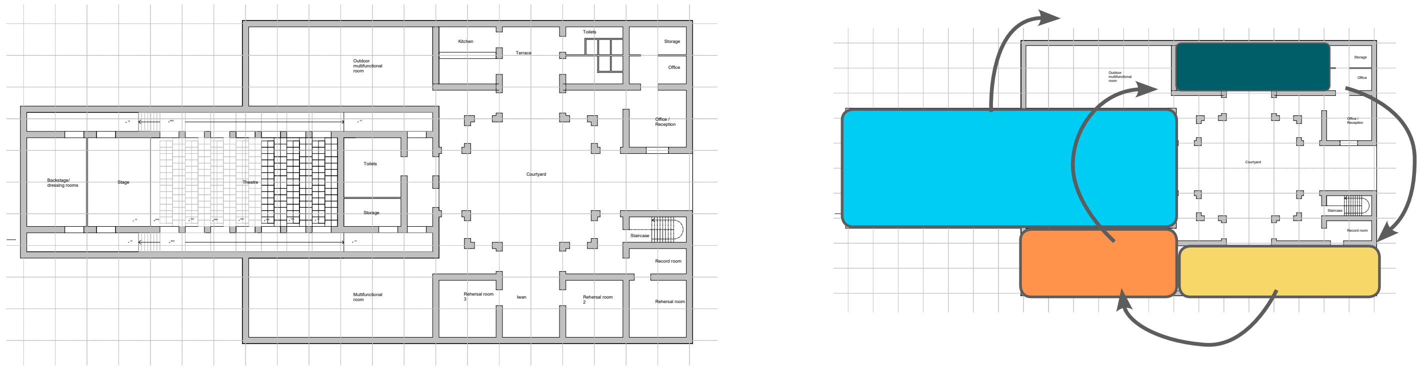


Figure 3.6 Floorplan update. Source: own

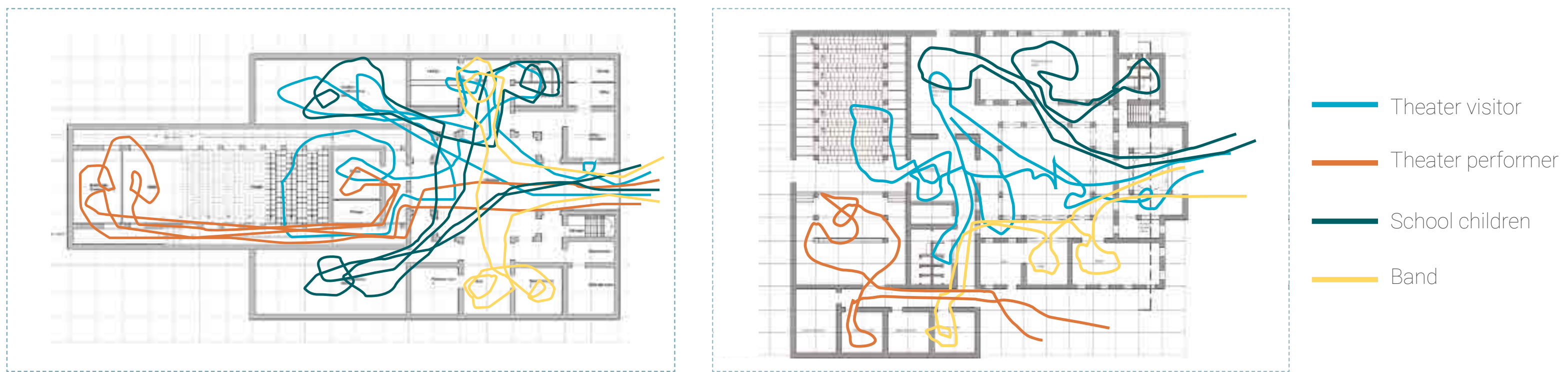


Figure 3.7 User group circulation. Source: own

3.5 Final Floorplan

The main entrance is located on the east side and in front of the main road of the camp that connects the north side to the south side. The entrance is supported by a reception desk that controls the inflow and outflow of visitors in the theater complex.

The courtyard has a dominant role since almost all the main functions are organised in its perimeter. The arcade embraces the role of the connector between the several functions and acts as a buffer between them.

The theater is located on the west side with a northern orientation so that it accumulates the ambient light of the north. To access it the visitors need to be waiting for their tickets to be checked in a semi-open area that also serves as a waiting area during a performance 's interval. This space also connects to the cafeteria on the south side through the arcade. It also connects the courtyard and the open multifunctional room located on the north side.

The multifuntional room is found on the north side and has 2 outdoor connections, one to the courtyard and one to the open air multifunctional space. Indoor activities especially the ones that concern younger aged groups can be combined with the outdoors.

The library and the Iwan are located on the south side, while the Iwan can be acessed by th cafeteria. The rehearsal and record rooms are supporting the theater on the south side. Musicians can practice in these rooms and immediately be transfered to the theater. The theater which has a capacity of 200 people has one emergency exit on the west side. Another opening is also located next to the back of the house. It can be accessed by the musicians during the day and also be used for the garbage disposal of the cafeteria while off peak hours.

The second floor accomodates the radio station and the offices. The tower can be accessed from the 2nd floor by the workers of the radio station. There is a void and a balcony between the radio station and office so that the people from different levels can see each other and the courtyard.

1. Entrance
2. Reception & Small Office
3. Library
4. Toilets
5. Iwan
6. Cafe
7. Multifunctional Room
8. Open Multifunctional
9. Rehearsal Room
10. Record Room
11. Waiting Area
12. Theater
13. Courtyard

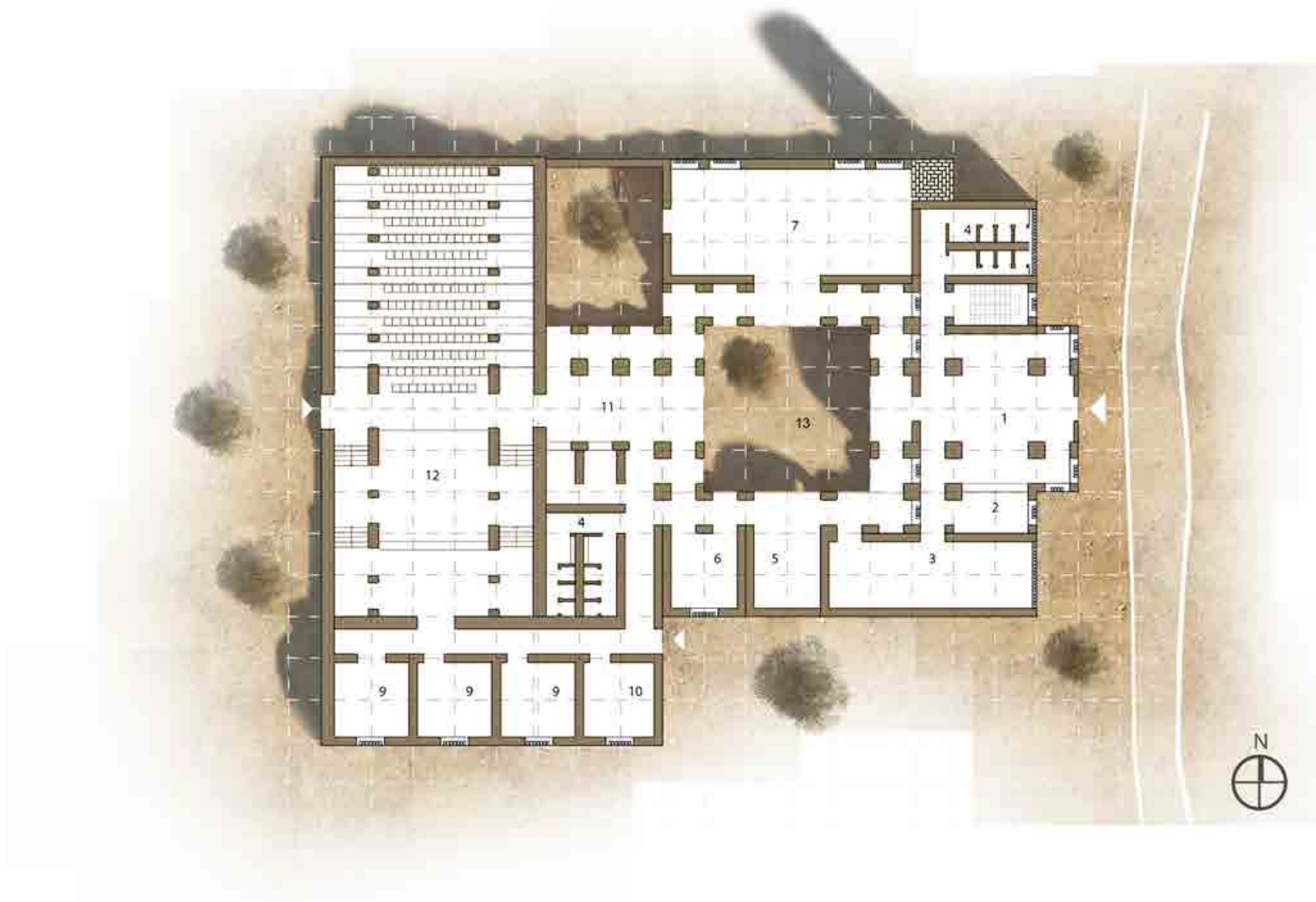


Figure 3.8 Ground Floorplan (+0.00). Source: own

1. Radio Station
2. Office
3. Balcony

Figure 3.9 1st Floor (+4.00). Source: own

3.6 Sections

The 2 sections are depicted below.

Section A-A' shows the theater the backstage and the rehearsal rooms. The seating is placed on a slope so that there is a better view of the stage. The roof of the Theater creates steps which allow ambient light to enter the space without blocking the viewing towards the stage. In the section is is visible that there is a strong connection of the theater to the backstage area and the rehearsal rooms, an element important for the good coordination of the function.

Section B-B' concerns the entrance, the courtyard the waiting room and the theater. The specific heights of the buildings are leveled out to the human level by the arcade, around the courtyard. The theater (6.00 meters) and multifunctional room (6.50 meters) are almost the same height, following the entrance (9.50 meters). The tower (15.20 meters) is significantly higher than the other functions and serves as a main attraction point and acts as a beacon for the complex.

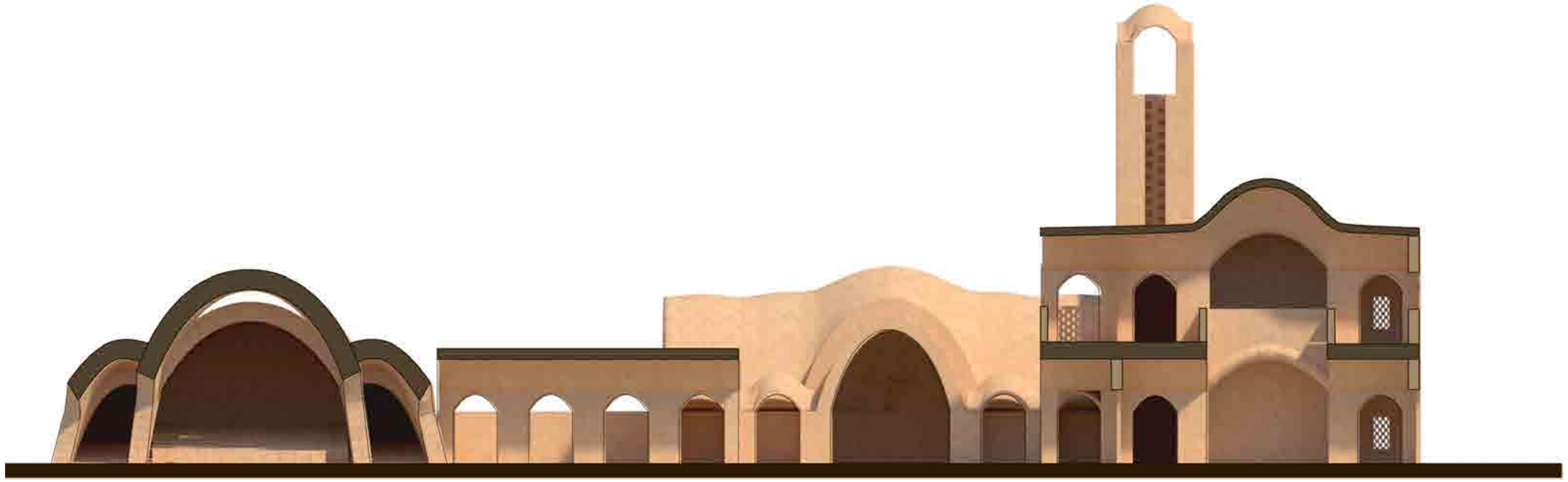


Figure 3.10 Section B-B' Source: own

0.00 2.50 5.00 10.00

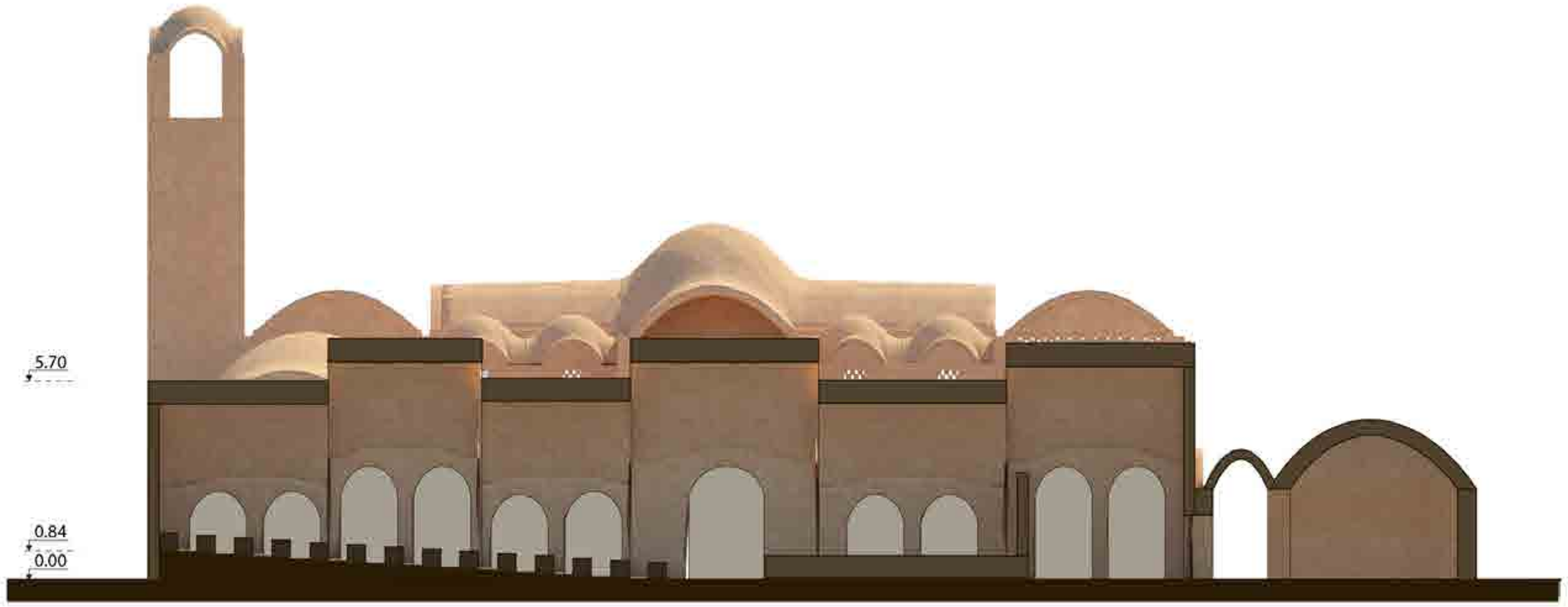


Figure 3.11 Section A-A' Source: own

0.00 2.50 5.00 10.00

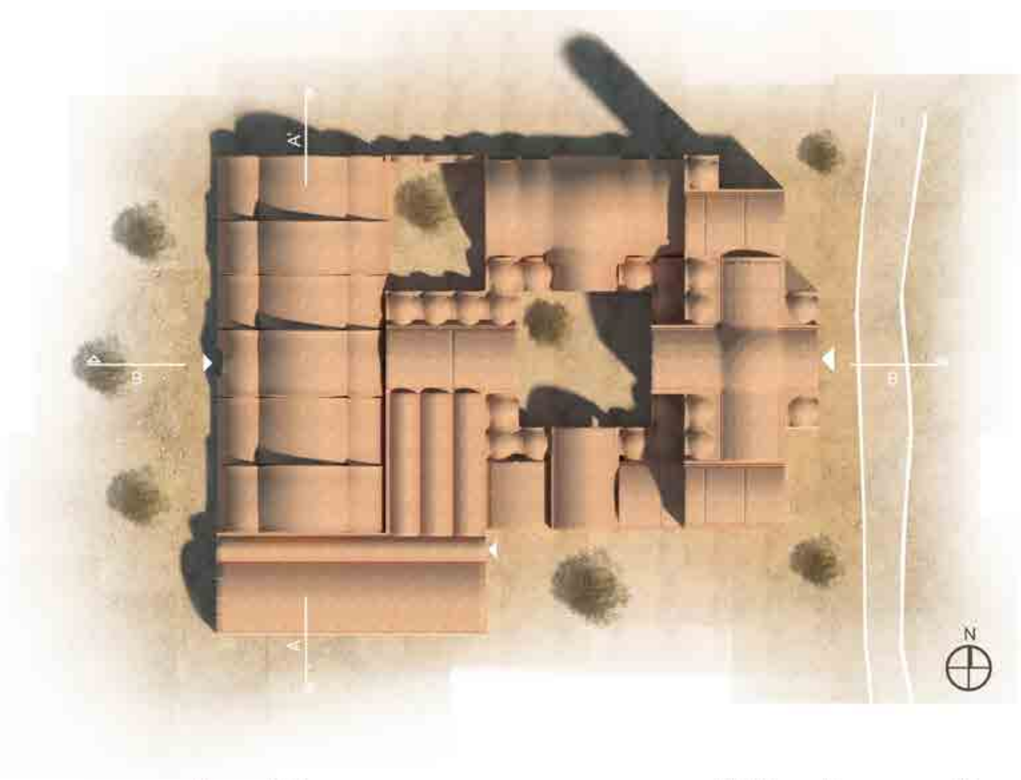


Figure 3.12 Topographic plan, Source: own

4 Shaping

4.1 Meshing

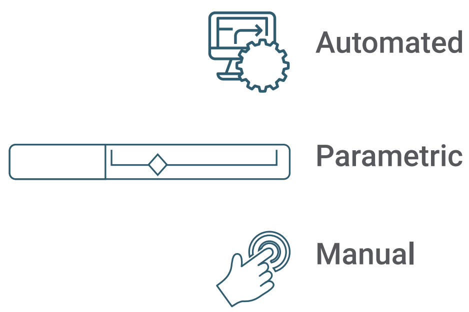
The next step after configuring is to turn the 2d -configuring into 3d-space. Since the whole complex is built with only adobe bricks which are known not to have tensile strength, the structure has to be only under compression stress. Therefore, to achieve that dynamic relaxation method is utilized using Grasshopper plugin called Kangaroo. After that, the mesh is checked structurally using the FEM structural engineering tool named: Karamba3D.

Different approaches for meshing the vaults and domes were used to get to the final result. The goal was to make all the models parametric with as little as a possible input to function and to have parameters that would allow the vault to change within the given design goals. The following images have been created to explain the working of the script, without going into to much detail. Figure 4.2 shows three different icons that will be used in the following diagrams. The first icon: 'automated', is a step in the process where the user has no influence, this step will run using the input generated from the previous steps. The second icon allows for more input from the user: 'parametric', this means that at this stage in the process the user can change the design within the boundary conditions of the script. The last icon requires the most work for the user of the script. This part needs to be done by the user completely, wheres the previous icons don't require any input and can run on default settings, this step needs action by the user to be able to function.

4.1.1 Initial shaping

This first script, shown in figure 4.1 is the initial trail that was created for the entrance of the building. This part of the building consists of multiple different nubian vaults with different spans. The script takes the input of multiple rectangles for creating the domes. Based on the given mesh density it will provide anchor points alongside the long edges of the rectangles, to ensure a span in the shortest direction. A dynamic relaxation script will tessellate the domes based on a force provided on the mesh. The script provides an overview of the heights of the domes, and their height differences. Using the force parameters these height differences can be tweaked. The last step, as for most scripts, is to check the structural integrity of the created shell structure using the FEM structural engineering tool named: Karamba3D.

The second script, graphically displayed in figure 4.2, shows the initial trail that is used for the construction of the arcade. In the first stage of the process the final grid size was still unclear, therefore it needed to be able to adapt to it by changing the footprint dimensions. After the footprint is entered the columns and anchor points for the cross arch are generated. In this case a mirrored version of the same mesh is used to prevent the arch from arching inward. An almost equal opposite force is introduced by stitching the same domes to all four edges. After the final mesh is isolated it can directly function as an input for the Karamba model.



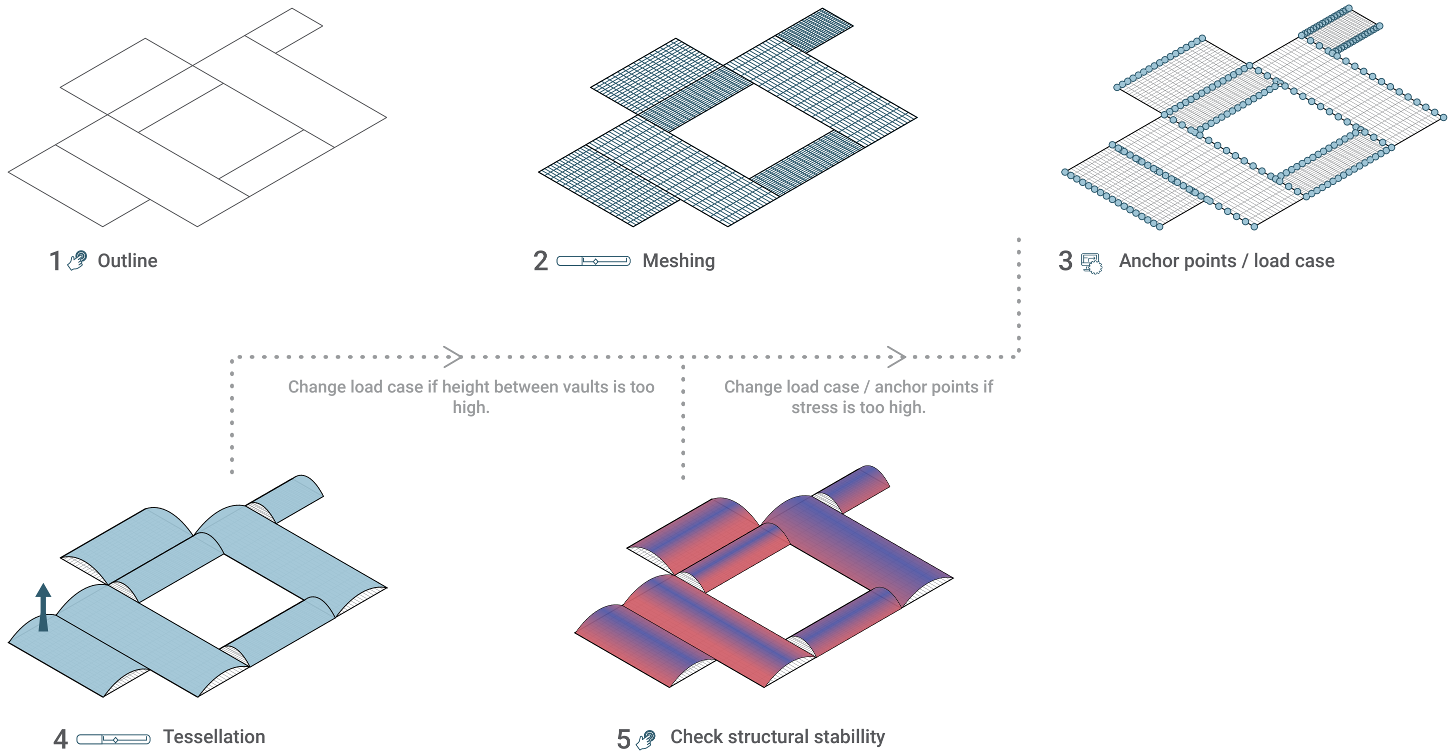


Figure 4.1 Visualization of the entrance script . Source: own

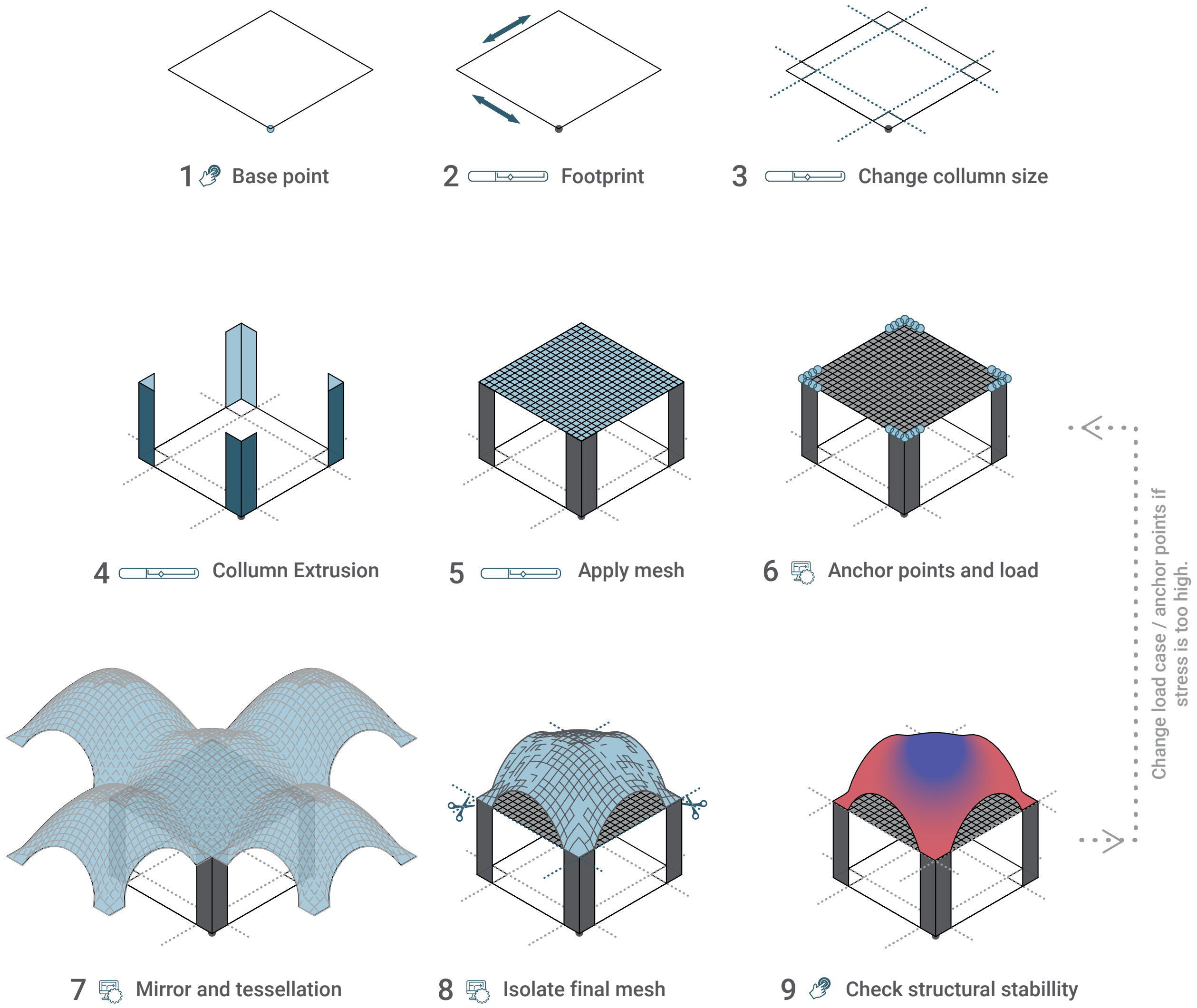


Figure 4.2 Visualization of the entrance script . Source: own

4.1.2 Final meshing

Aften that another meshing and tessellation was tested. This methods was to divide the buildings into clusters, define the supports and openings positions then tessellate and relax the roof for each cluster as a one mesh, as seen in figure 4.3. However, the result of this approach was dissatisfying. Because using united mesh for relaxation resulted in irregular shape that was undesirable as the geometry was too complex to be built using only adobe bricks by low-skilled labour.

Therefore, a further development was needed and eventually for all of the building except for the theatre and the multi functional room the the following steps was used:

- Breaking the building into smaller modules based on the function.
- the smallest is 2.5 * 2.5 m.
- Defining the supports position and force flow for each module
- each module has it own supports so that the shear forces would not travel along the structure and caused as desired deformation especially that the modules have different self-weight.
- Defining the type of vault for each module and based on that creating the initial tessellation for each module.
- Creating smaller subdivision for the mesh using Weaverbird Constant Quads split subdivision. This command gives quad and same looking subdivision for the original mesh.
- Dynamically relaxing the mesh using Kangaroo. In order to reach the desire shape for each module, the anchors were imported manually from Rhino, vertical loads and edge length were assigned to certain values. Moreover, we had to make sure that the ground-floor roof has to be less height than the first-floor roof.
- Connecting the different module together. One of the challenges was to connect all the module especially that there is a difference between the height of the modules and eventually more options for each module based on how it would connect with the vault next to it the solution shown in figure 4.4 was utilised.

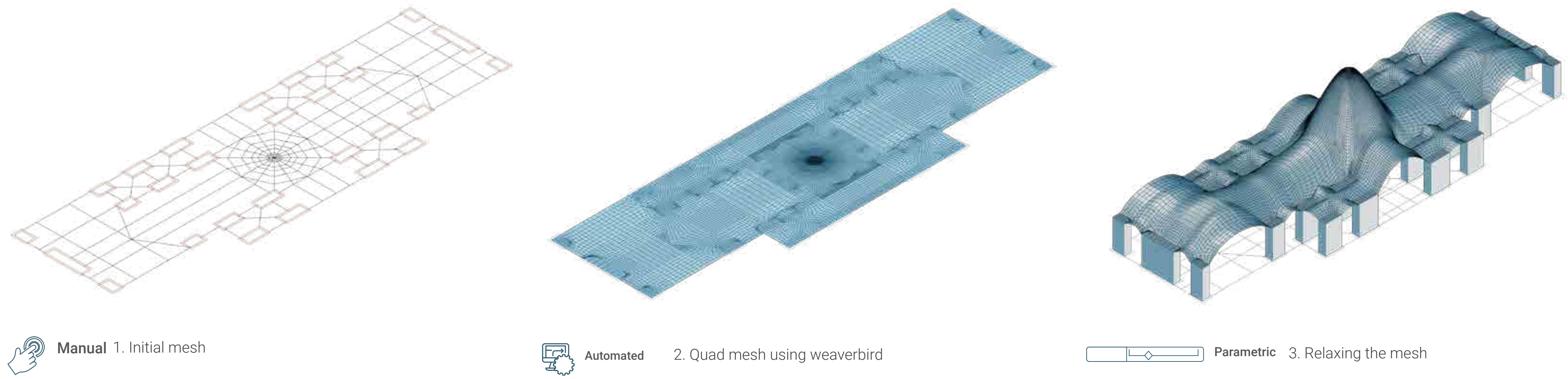


Figure 4.3 Mesh as one. Source: own

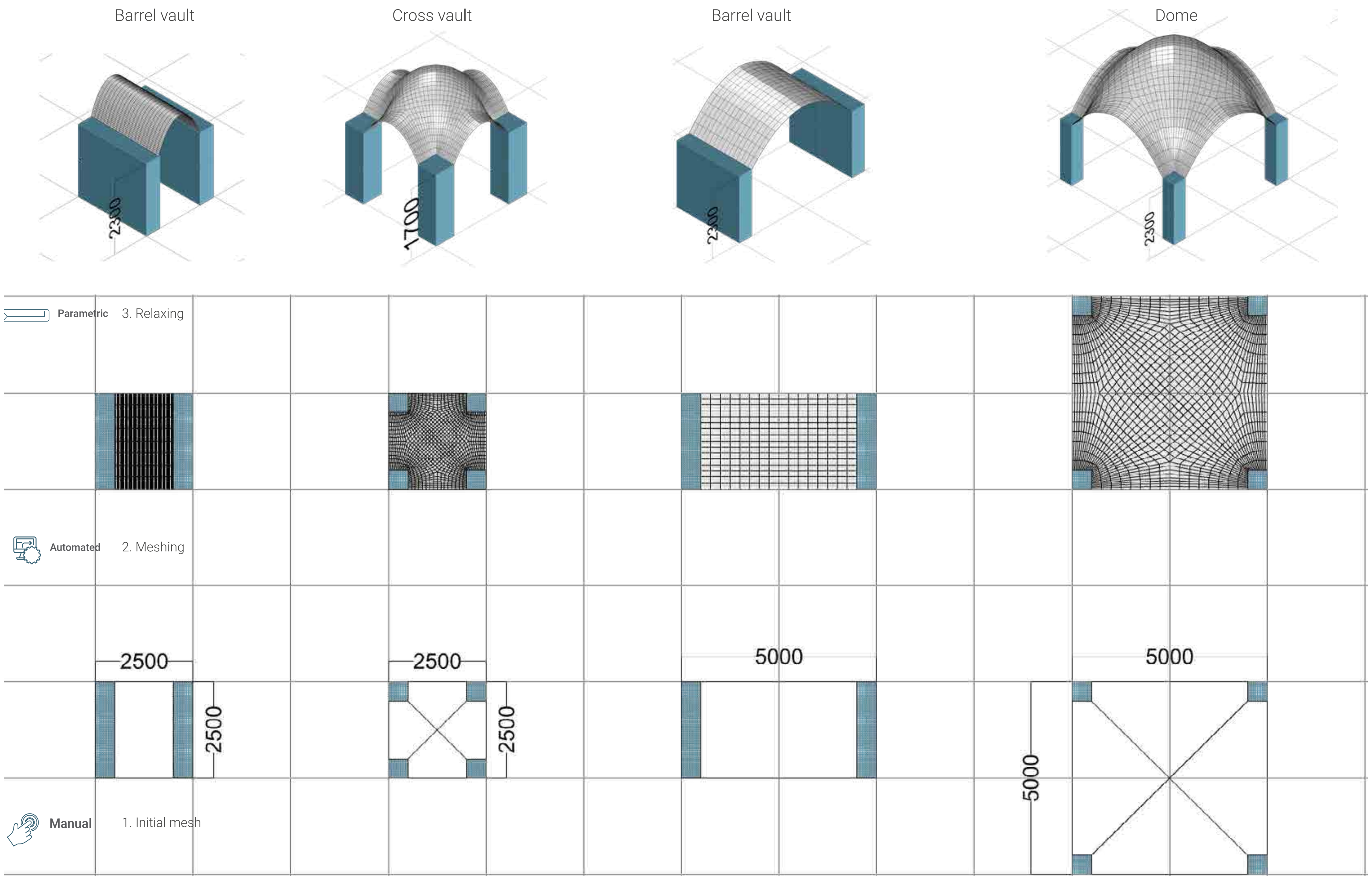


Figure 4.4 The final modules. Source: own

4.1.3 Multifunctional room and Theater

For the multi funcional room different methos as used becaue we have large span we have to make sure that the space has to be covered with one large vault
Figure 4.5 shows the creation of the lunette vault for the multi functional room. The design rules for this vault in particular are that: the entrance should be in the middle and span two units, and that there should be windows on each grid unit at the back side, with the exception of the units that align with the entrance. Therefor the script is able to adapt to different unit sizes, and it will automatically determine the middle for the entrance, and all the location for windows. The only required input is a single base point, and the user is still able to change the window size if it turns out that the structural properties of the dome are undesirable. Furthermore the script uses the same approach as the script in figure 4.6 for controlling the boundary edges of the mesh

The last image, figure 4.6 , shows how the mesh for the theatre is created. This script takes a different approach since the walls and door openings ought to be incorporated in the mesh as well. Again the script only takes a single point as input, and is able to change within the boundary conditions with parameters that fit the design rules. The size for the vault and the buttresses are determined using parameters, the rectangles are extruded and the proper faces are selected and stitched together. The user is also able to change to location and the size of the doorways. In the final part ..

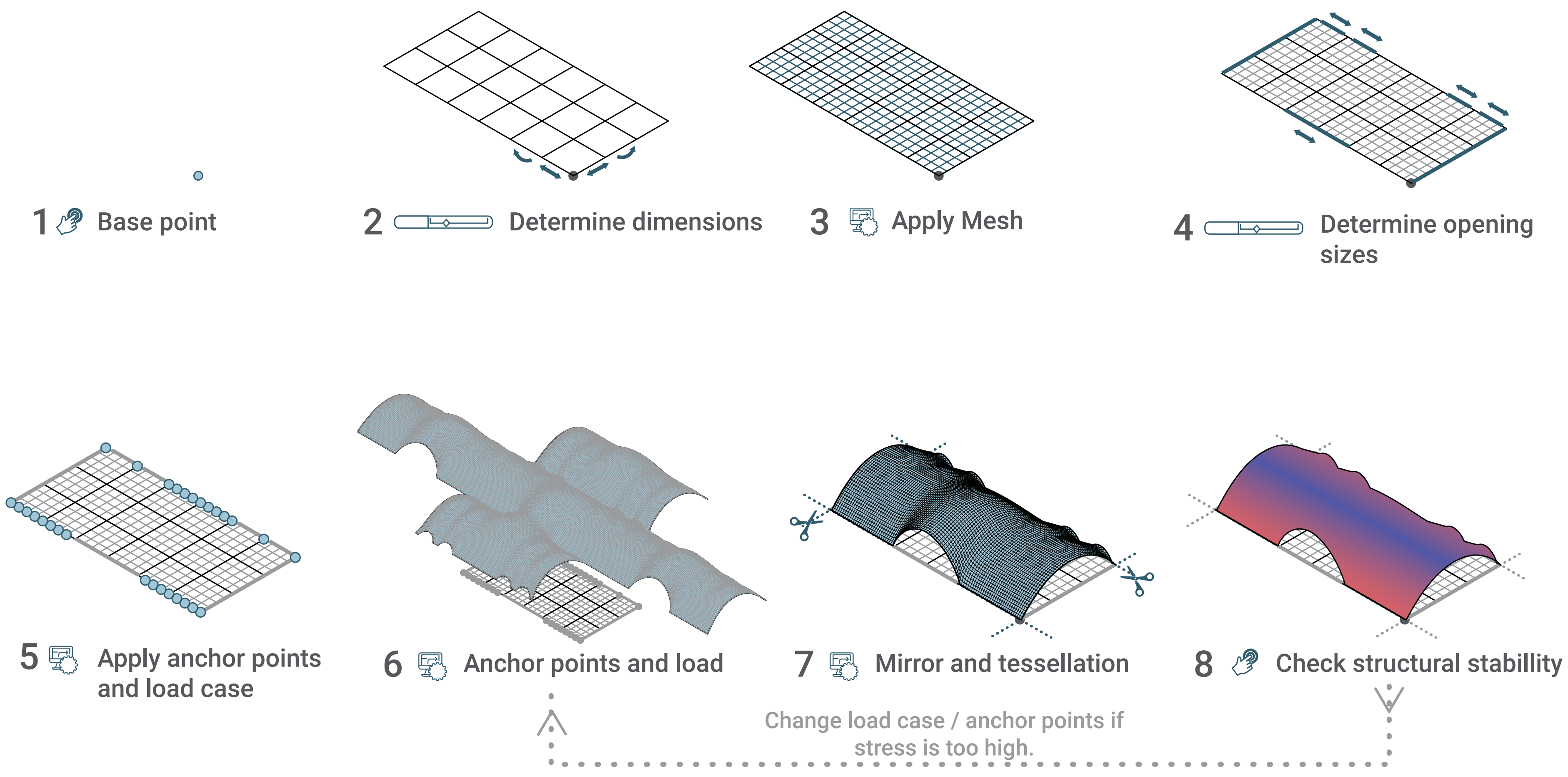


Figure 4.5 Visualization of the lunette vault script. Source: own

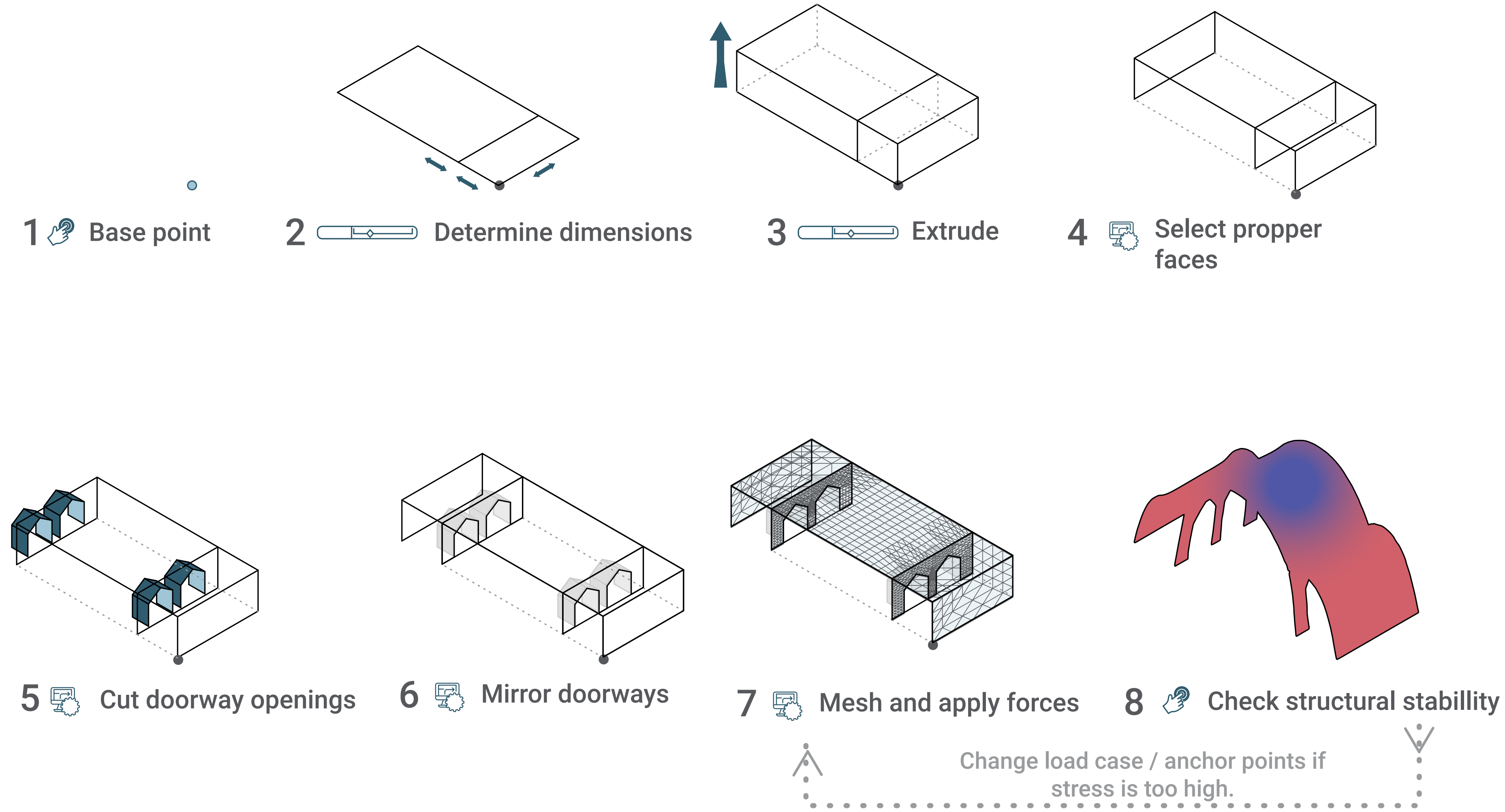


Figure 4.6 Visualization of the lunette vault script. Source: own

4.1.4 Final tesselation

Figure 4.8 shows the differnt options for the modules
For instance for the barrel vault we have four different options one with load bearing vault, one with row of arches , one with three walls and one with four walls and openning for windows
Figure 4.9 shows the connection between the cross vault, barrel vault and the dome at the entrance where the cross vault has less height and no intersection with the barrel vault but with the load bearing vault.
Figure 4.7 shows the final vault tupes and their location in the complex

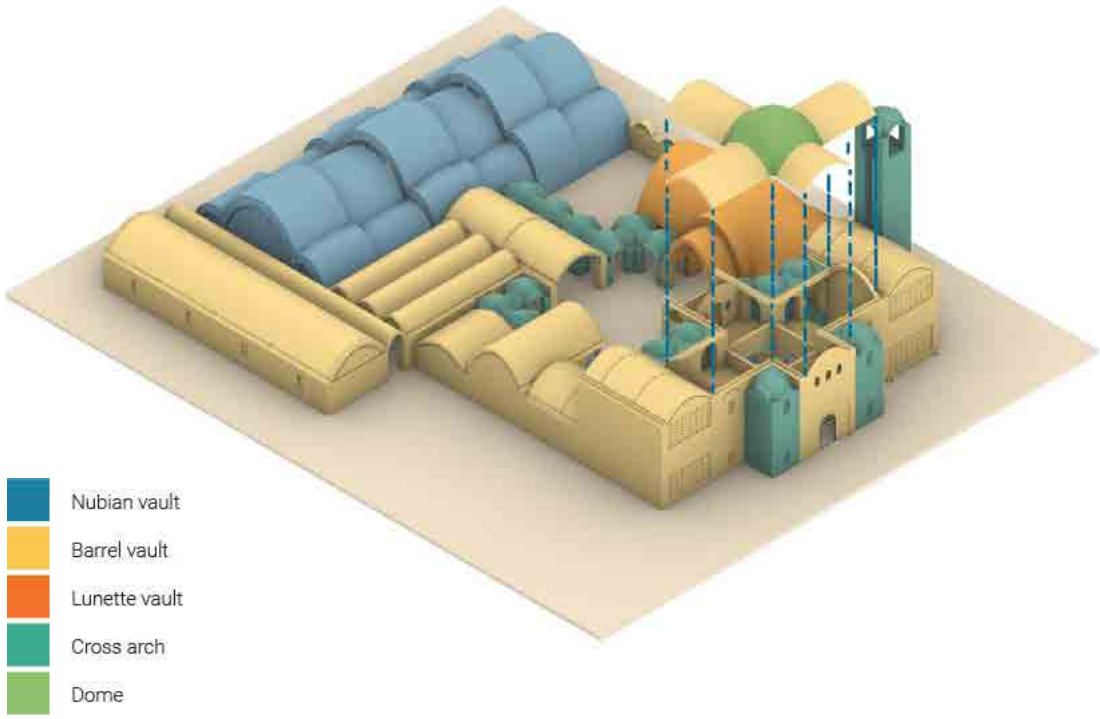


Figure 4.7 Overview of the vaults types in the building. Source: own

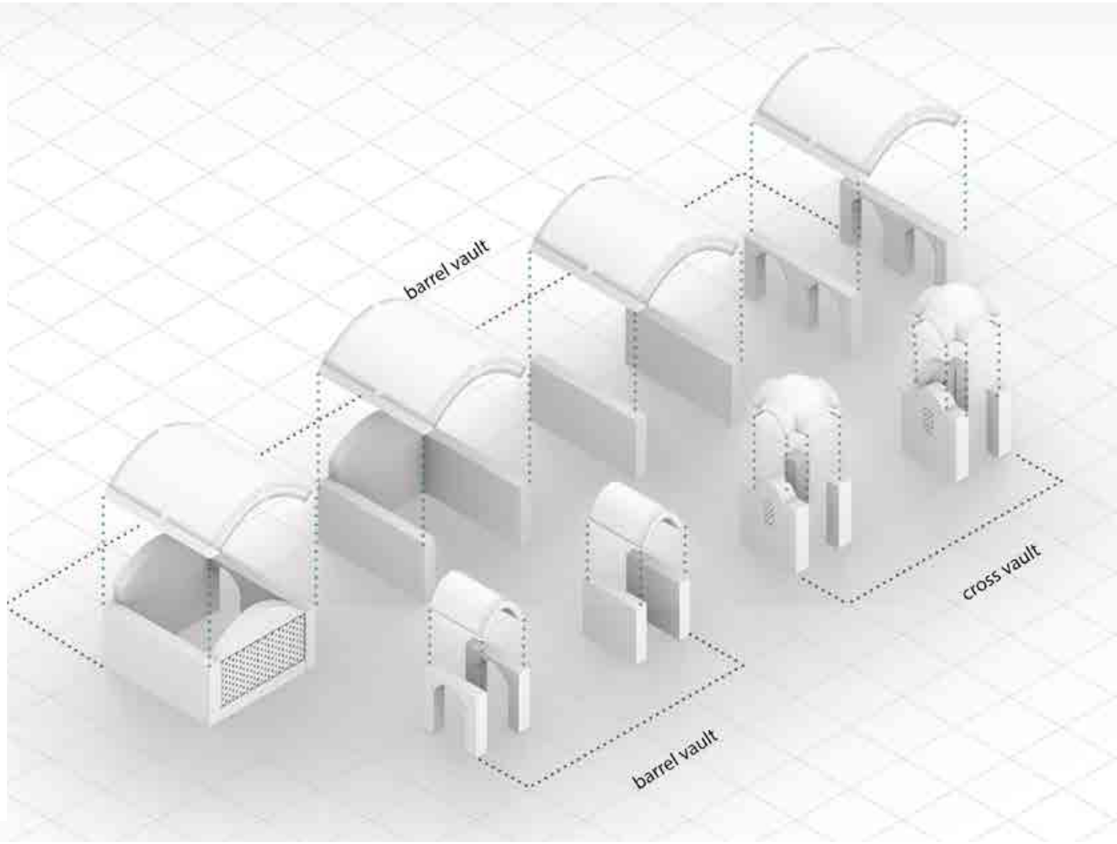


Figure 4.8 Different options for each modules. Source: own

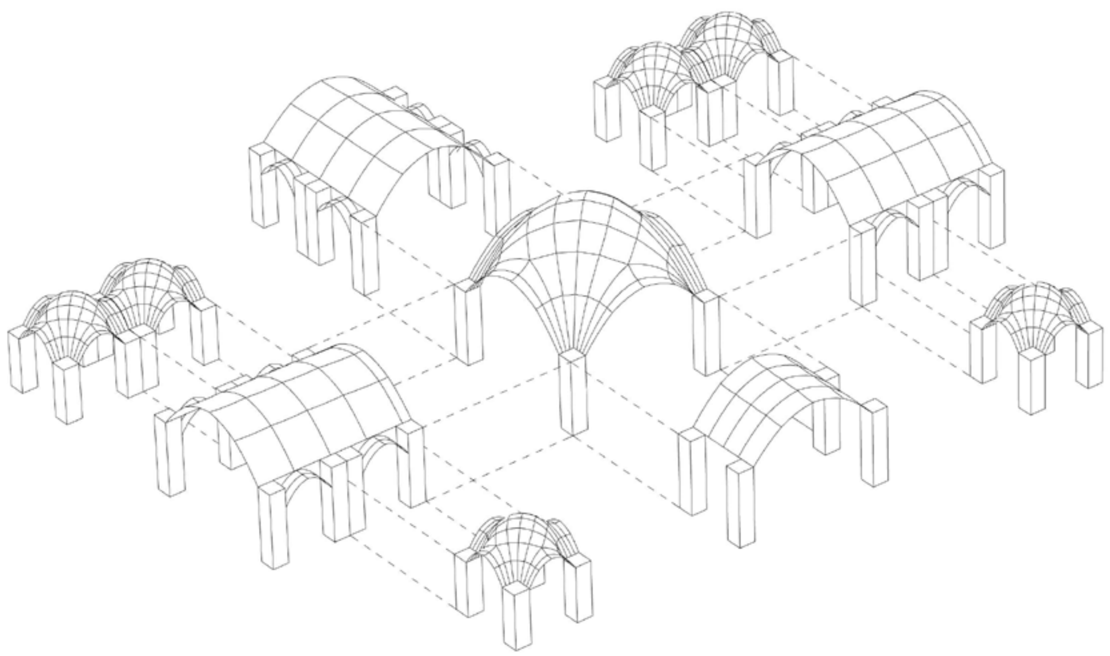


Figure 4.9 Connection between different vault in the entrance second roof. Source: own

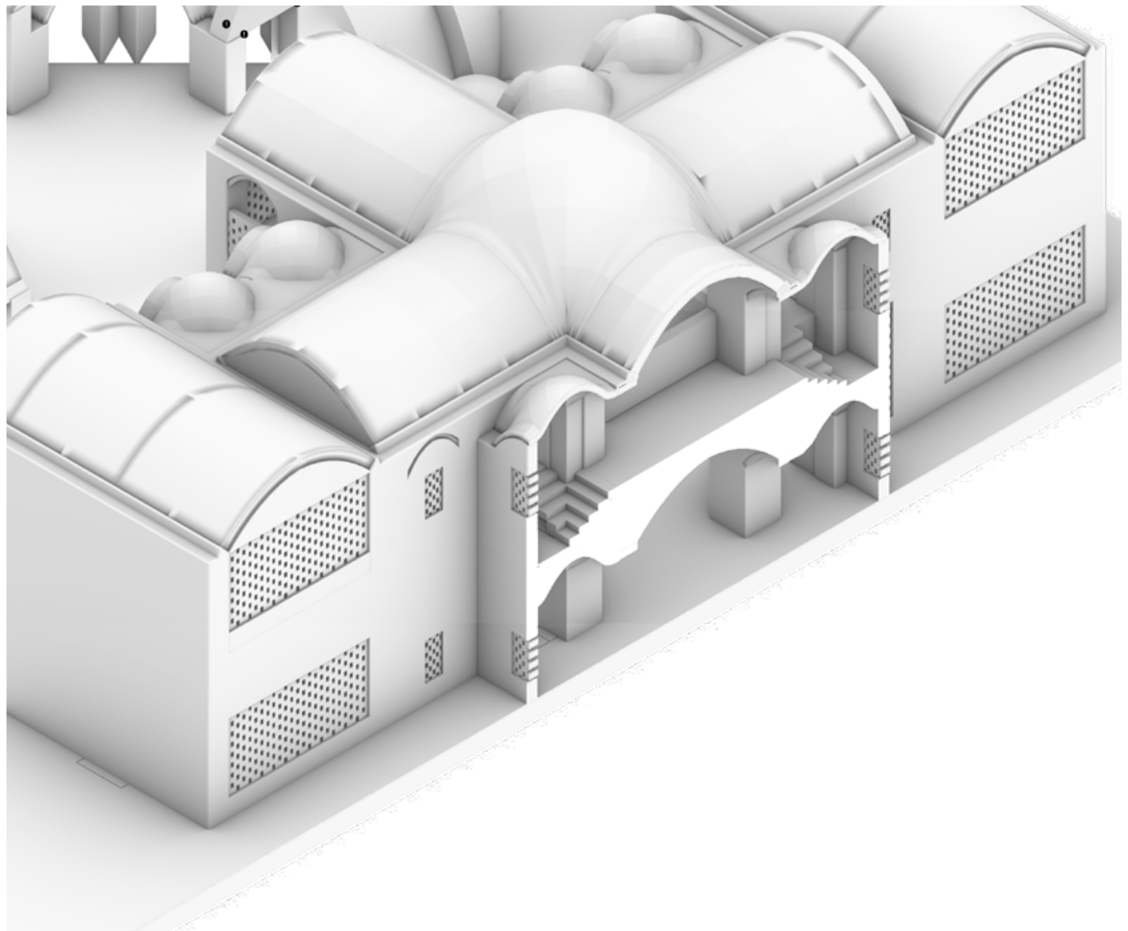


Figure 4.10 Section in the entrance. Source: own

4.2 Draping method

Multiple different experiments have been conducted during the process of creating the building complex. However, many of these did not make it into the final result because it was later concluded that it would not be an optimal approach or because it would add no additional value to the process. The draping method is one example of the researches that did not make it into the final design. It is however an interesting side research that could still be implemented in the project using different means or goals, and has therefore as an example still been included in the final report.

The draping method has been researched in order to be able to create a second skin over the tessellated roofs. The goal of the first skin is to create an optimal tessellated shape that is purely in compression. This shape can be used to construct the different spaces. However, a second skin could be required on-top of this skin to connect multiple elements together, and to allow for a drainage system that prevents water accumulation in certain parts of the building. To fix this issue the draping method has been tested. This method can generally be explained as draping a piece of cloth over some shapes. The result will be a smooth surface between these shapes. Figure 4.11 shows the primary shapes that will be used for the draping.

Figure 4.12 and 4.13 show the result of a rough and fine mesh that are created using a default Rhino command: drape. This command is able to drape the entire complex relatively fast. However, it was decided to look into more computationally controllable methods that could function inside a script.

Figure 4.14 shows the result of a draping test using the plugin Kangaroo for Grasshopper. This plugin has previously also been used for the dynamic relaxation process for the domes. In this case additional collision objects (displayed in white) are created that will collide with the cloth (displayed in blue). This method was in comparison much more demanding than when using the rhino command, it would however add the benefits of having more control over the final result.

Figure 4.15 shows the result of a draping test using the plugin Flexhopper. Flexhopper allows for physics simulations that can simulate particles and fluids but also textile and spring systems. It runs on an open source interface that uses the physics engine NVidia Flex. Because of this interface, the plugin allows for a much less computationally intensive process than when using Kangaroo. Besides, it offers a lot of additional simulation options that could prove useful for the project.

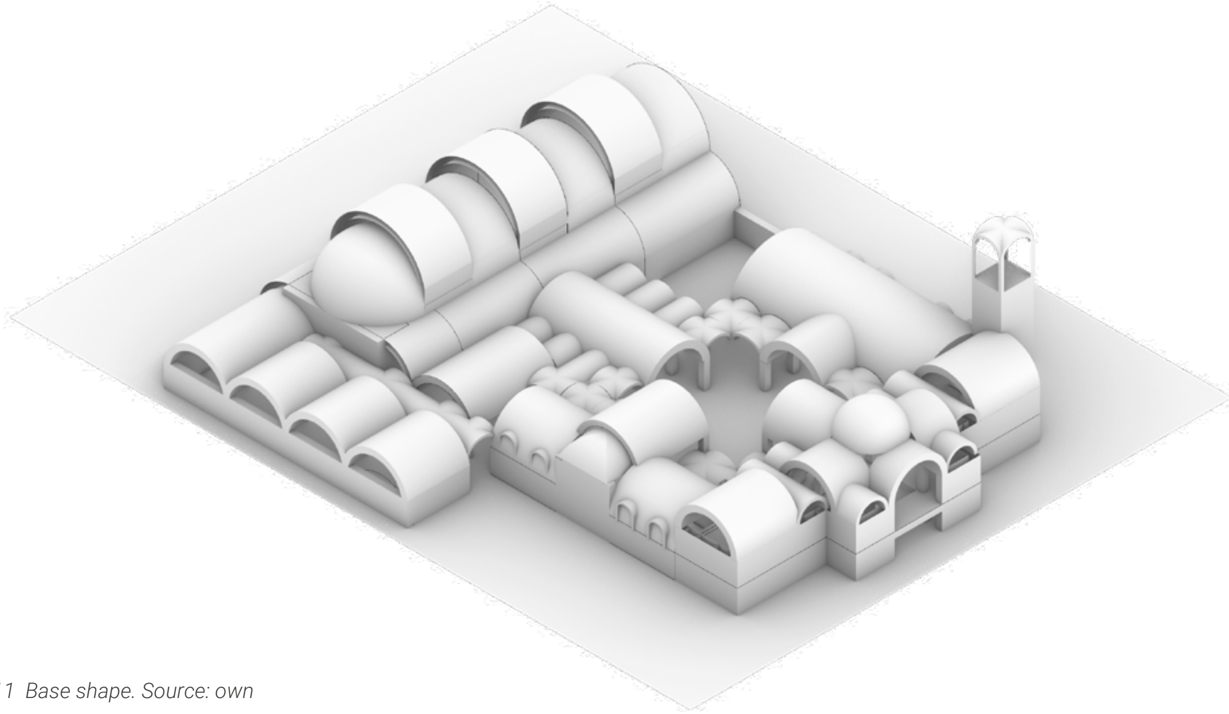


Figure 4.11 Base shape. Source: own

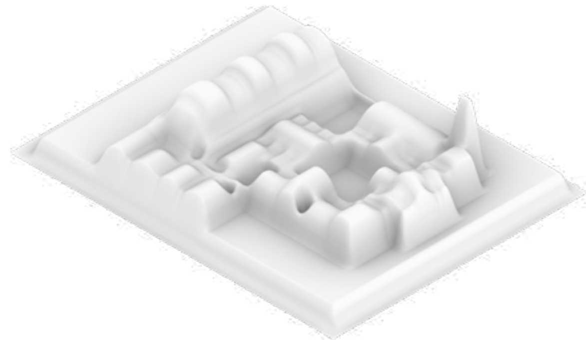


Figure 4.12 Draping result 1. Source: own

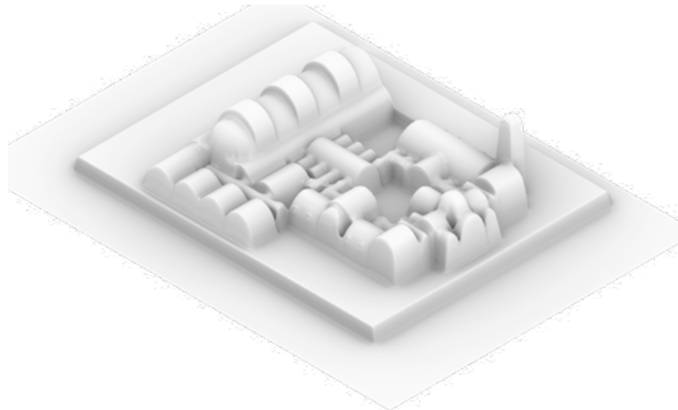


Figure 4.13 Draping result 2. Source: own

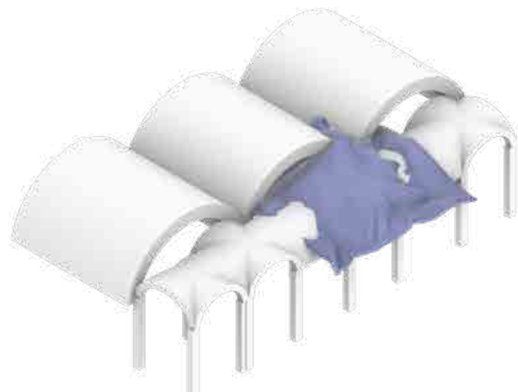


Figure 4.14 Draping result 3. Source: own

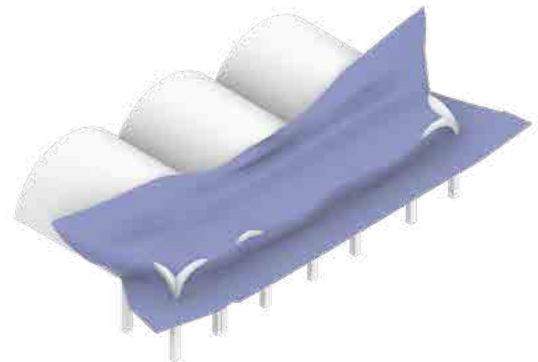


Figure 4.15 Draping result 4. Source: own

5 Structuring

5.1 Introduction

The main focus of this chapter are the loads working on the building. The loads applied on the building are the horizontal and vertical loads. When using these loads in calculations, safety factors are applied. The structures are tested in Karamba 3d Finite Element Analysis. The building is divided into multiple parts, all tested separate:

- Entrance
- Theater
- Tower

These parts are the critical ones, focused on the structural analysis. If these will stand, then the smaller parts, such as the arcade, toilets, record room and rehearsal rooms will do as well.

5.1.1 Goal

The goal of the structural analysis is to check the structural ability of the building and optimize it to the wall thickness and its shape. So, the shape of the vault and its wall thickness are the changing parameters and the maximum displacement or tensile stress are the results. The shape can be altered to minimize the wall thickness; however, the constructability and architectural concept are taken into account as well.
The wall thickness can be increased by steps of 12.5 cm, corresponding to the thickness of the adobe bricks.

5.1.2 Design values

After the material research, the design values for the structural analysis are taken as follows:

Allowable compressive strength:	– **2.1 mpa**
Allowable tensile strength:	– **0.21 mpa**
Deflection span [m]:	– **span*0.0015**
Deflection tower [m]:	– **height/500**
Young’s modulus:	– **115 mpa**
Adobe density:	– **15 kN/m3**
Wall thickness:	– **x*12.5 cm**

5.1.3 Load cases

The horizontal and vertical load cases applied on the building are:

Self-weight:	– **15 kN/m3**
Filling load:	– **15 kN/m3**
Wind load:	– **2 kN/m2**
Live load:	– **2 kN/m2**

5.1.4 Safety factors

The safety factors are applied on the load cases, depending on the favorable or unfavorable case:

Permanent load unfavorable:	- **1.2**
Permanent load favorable:	- **0.9**
Variable load:	- **1.5**

5.1.5 Principle stresses

The Karamba software uses three different types of stresses; principle stresses 1, principle stresses 2 and Van Mises stresses. The difference between the principle stresses 1 and 2 is the orientation of the stresses. Therefore, principle stress 1 is leading on the tensile stress and principle stress 2 is leading on the compression stress. Lastly, the Van Mises stress is a combination of the first two.

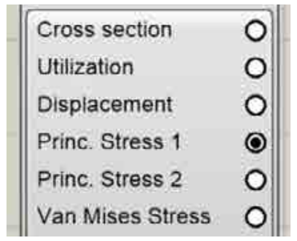


Figure 5.1 - Karamba stresses, source: Karamba

5.2 Theater

The theater is split up into segments with variable heights. In the model, the segments are not connected but in reality, they will be. Therefore, the loads will be more equally distributed than shown in the model.
On both sides, buttresses transfer the horizontal loads into the foundation, while the walls support a span of 7.5 meters. The width of the span is set because of the accessibility of the seating area, so only the height of the vault and the wall thickness can be adjusted.
The loads on the theater are the vertical self-weight and the horizontal wind load.

5.2.1 Conclusion theater

The displacement of the roof is constraining the theater. To stay below the allowable displacement of 1.125 cm, a minimum wall thickness of 87.5 cm is required. The vaults are made as high as possible to reduce the horizontal vector of the self-weight load.
Because the Karamba software needs to have one mesh as input, it is not possible to distinguish the thickness of the ceiling from the thickness of the walls. In possible future analysis, the expectation is that the ceiling can be made thinner compared to the walls. This will reduce the self-weight load on the roof.

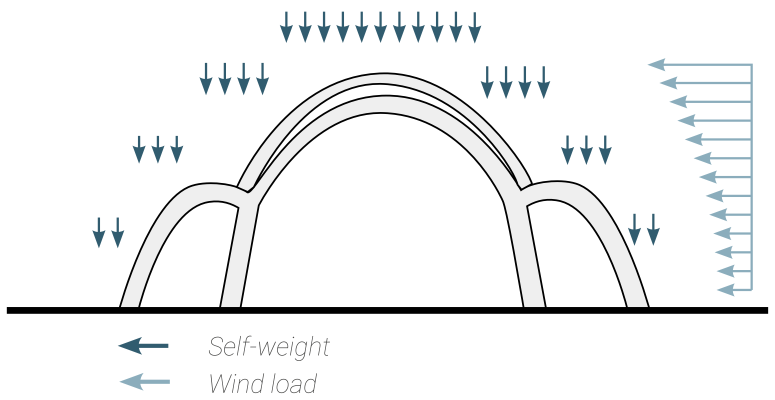


Figure 5.5 Loads on theater, source: own

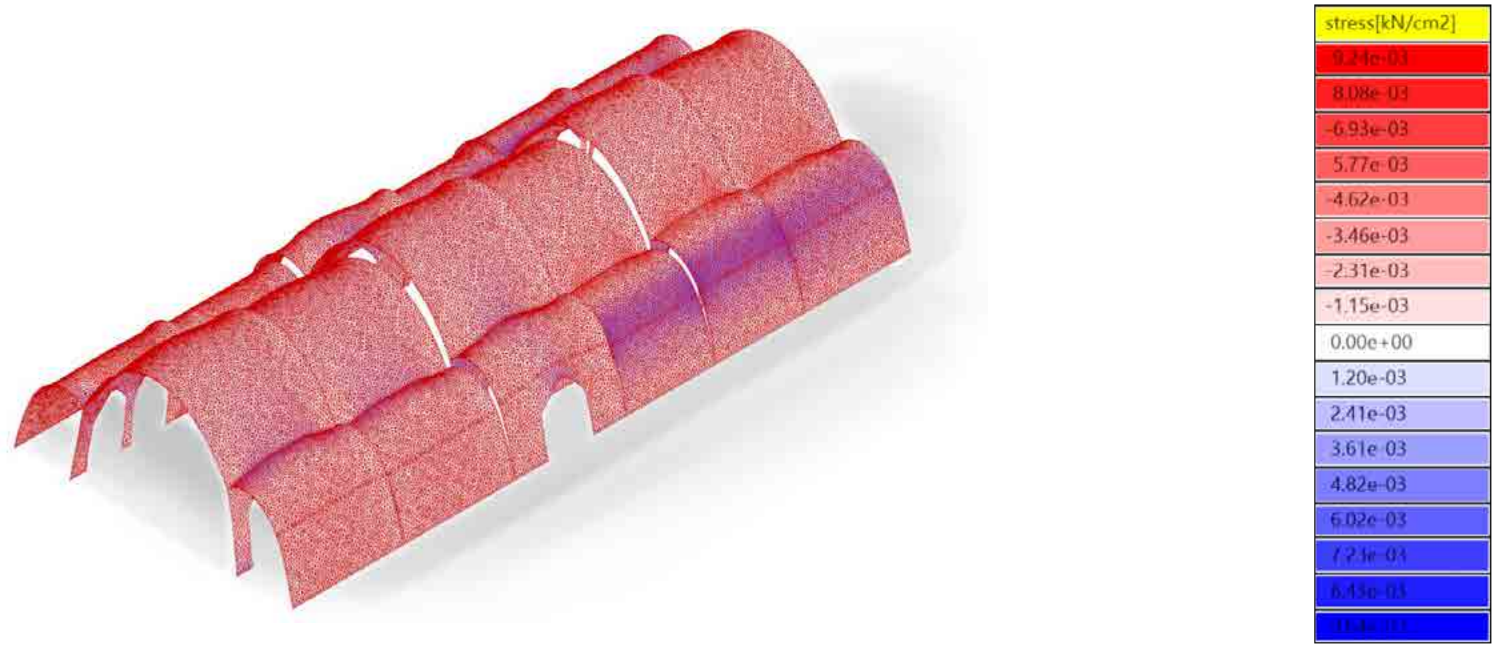


Figure 5.2 Principle stresses 1, source: Karamba

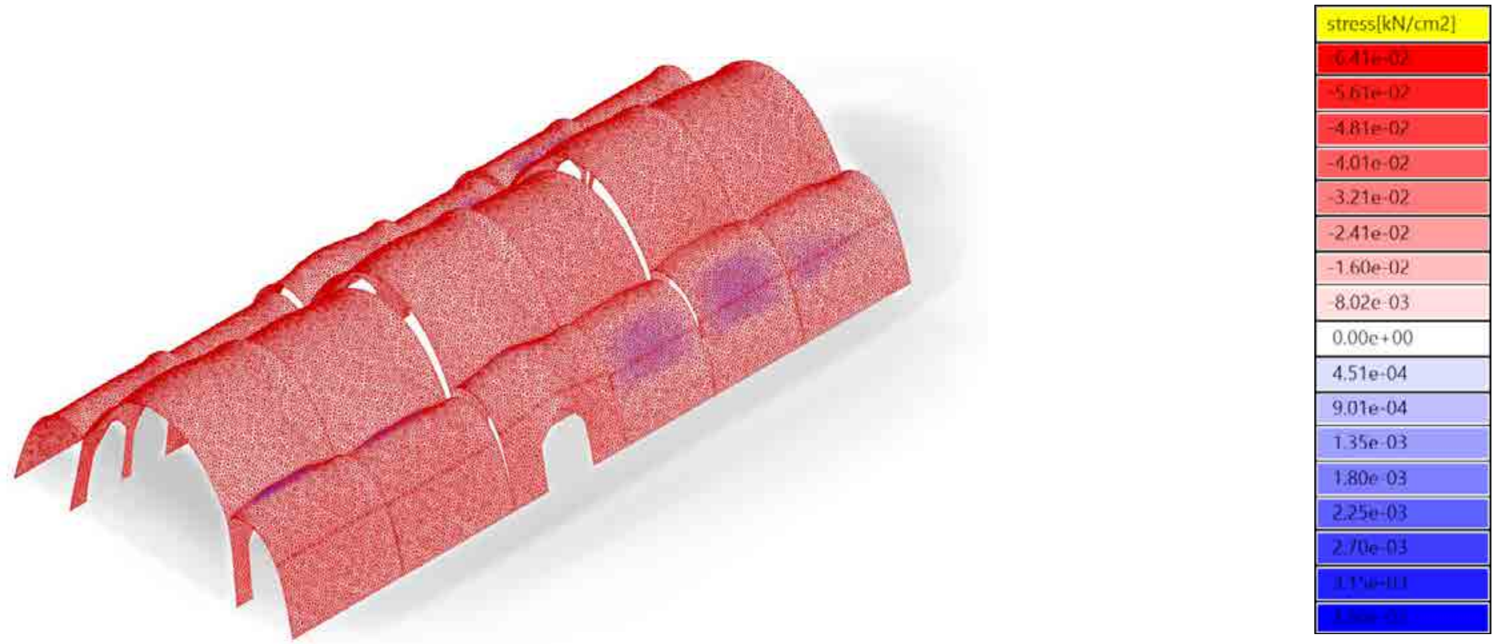


Figure 5.3 Principle stresses 2, source: Karamba

Figure 5.4 Displacement, source: Karamba

5.3 Entrance

The entrance is the only part with a second floor. To deal with the extra vertical loads, the spans of the vaults and arches at the ground floor are small, 2.5 meters. The loads on these parts are the self-weight of the structure, the filling load to level the floor (on average 30 cm earth) and live load (figure 5.6).

The loads on the second floor are less because there is no infill and no floor on top of it. However, during the construction process, people will walk on the roof, so an extra live load of 1 kN/m2 is added. Besides that, the loads for the second floor are the wind load and self-weight (figure 5.6).

The model is split into two, focusing on the roofs of the ground floor and the roof of the second floor. Because of time and complexity of the model, no walls are made at the entrance.

5.3.1 Conclusion first floor

To reduce the amount of earth needed to level the floors and to reduce the total height of the building, the arches, vaults and domes are made shallow. This is also done to stay in between the constructability restrictions. Because of the shallow arches and high loads, the required thickness is 50 cm.

This thickness is needed to reduce the tensile stress to an allowable level of 0.208 mpa (figure 5.7). The maximum deformation at this stage is 0.46 cm while the allowable deformation is 0.75 cm.

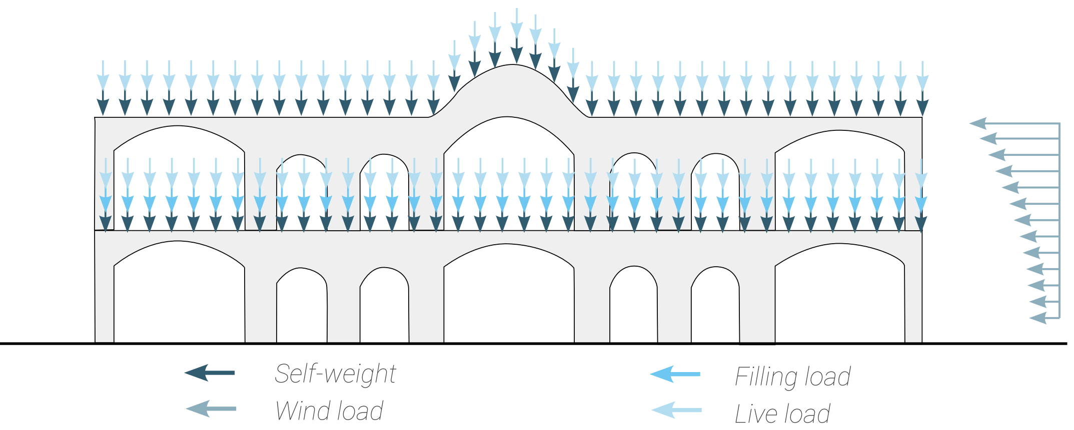


Figure 5.6 Loads on entrance, source: own

5.3.2 Conclusion second floor

In this case, the deformation is leading instead of the tensile stresses. The allowable deformation is 0.75 cm and a wall thickness of 25 cm is needed to keep the displacement below that (figure 5.9).

The self-weight of the vaults keeps the tensile stress as result of the wind load low. The maximum tensile of the ceiling stress is 0.08 mpa (figure 5.7).

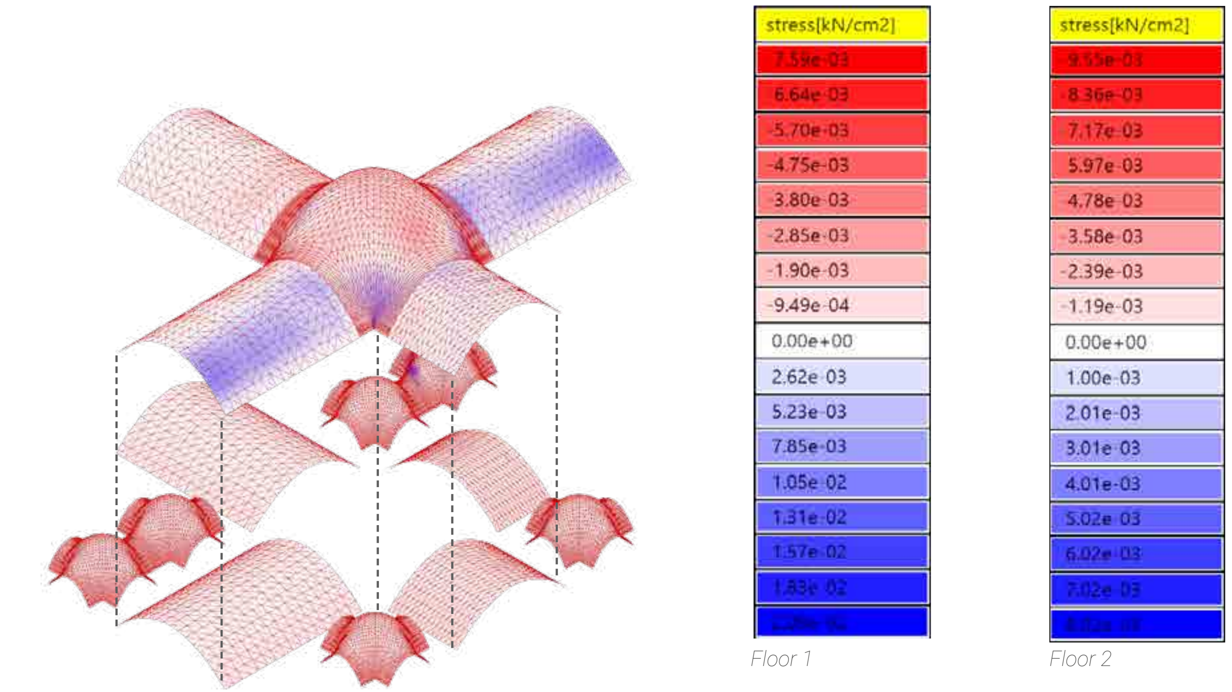


Figure 5.7 Principle stresses 1, source: Karamba

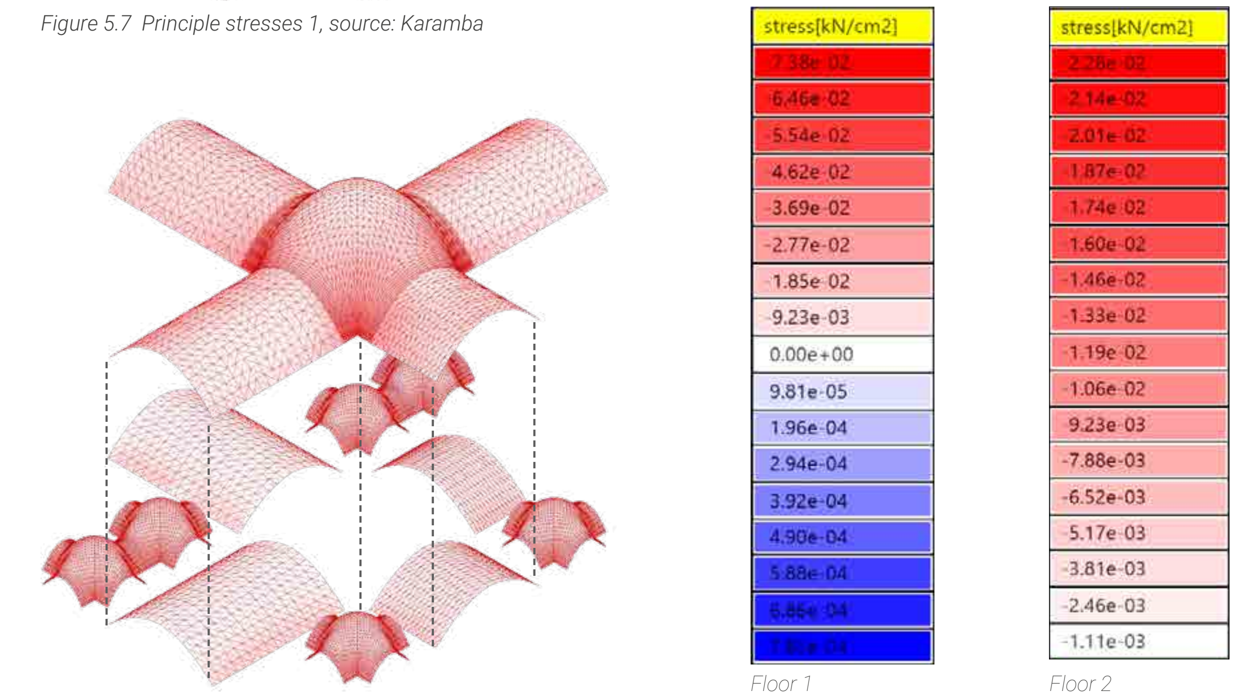


Figure 5.8 Principle stresses 2, source: Karamba

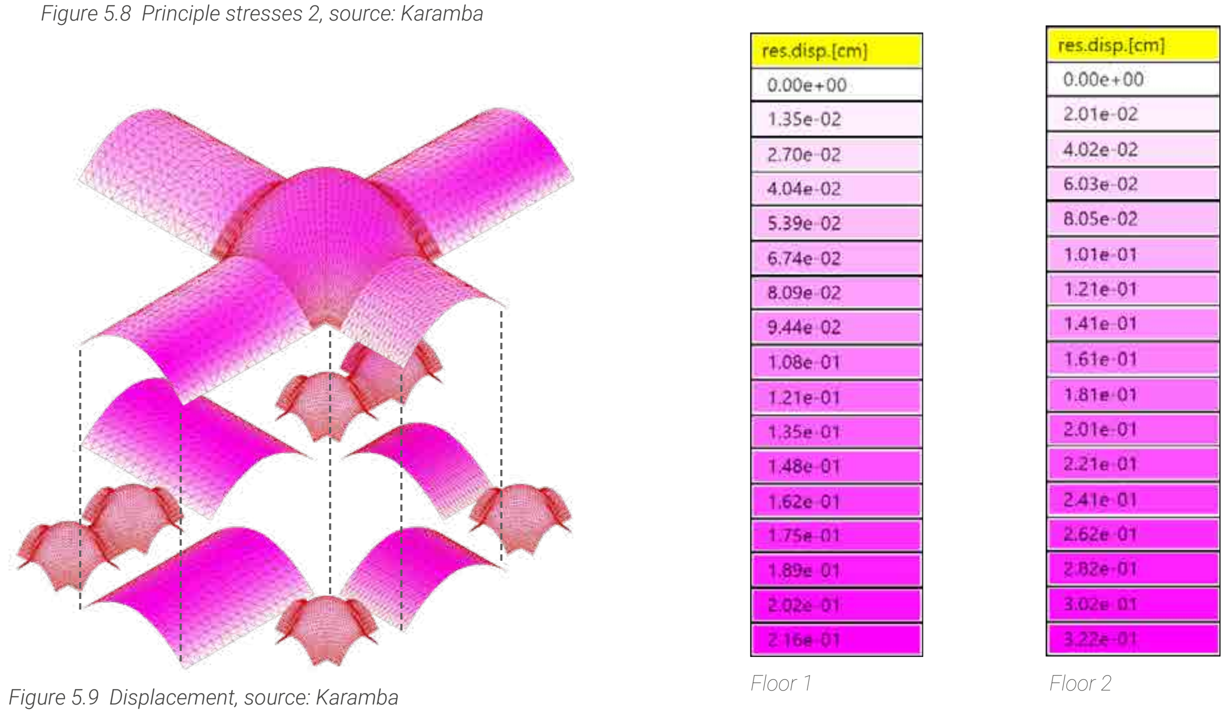


Figure 5.9 Displacement, source: Karamba

5.4 Tower

The goal of the tower was to push the boundaries; making it as high as possible with a footprint of 2.5 by 2.5 meters. The basic material properties of adobe are used as input of two different analyze strategies. The first one simplified the tower to a 2d beam and the second one to a 3d tube. In both strategies, the same loads are applied; wind load, self-weight and live load on top.

5.4.1 2d beam

Because the tower is a massive, only supported by its foundation it can be analyzed as a beam. On this beam; self-weight, wind load and on top; a permanent and live load are applied (figure 5.15). The permanent load on top is applied because of the extra cross vault and the live load because people need to go on top of it to repair the transmission equipment.
The parameter is the height, and it is analyzed on tensile stress, displacement and buckling.
Because the tower is massive, the tensile stress created by the wind is supersede. The maximum allowed displacement is depending on the height (height/500).

5.4.2 Conclusion

Because the tower is a solid unit, the vertical load is higher than the horizontal load. Therefore, the tensile stresses, created by the wind are supersede. Instead of that, the displacement of the tower is restricting the height. The maximum allowed displacement is the height of the tower divided by 500, using the rule of thumb in high-rise structures.
In the end, the maximum height of the tower is 12 meters, resulting in a displacement of 2.23 cm while 2.4 cm is allowed (figure 5.11).
An extra check is done to verify the possibility of buckling. However, the buckling factor at a height of 12 meters is 7.41, which is considered as safe.

5.4.3 3d tube

To verify the first model, another model is made. The strategy of this analysis is a 3d tube made of one mesh. On this mesh, the same loads are applied, including the vertical load corresponding to a solid unit. The height of 12 meters is used as input while the displacement, compression tresses and tensile stresses are the outputs.

5.4.4 Conclusion

The displacement of the tower is 2.26 cm (figure 5.14), which is similar to the displacement of the tower at the first analysis, 2.23 cm. On the other hand, the tensile stresses are higher in the 3d tube strategy; $4.45e^{-3}$ mpa compared to $8.53e^{-18}$ mpa of the 2d beam. However, these tensile stresses are below the allowable stresses, so the displacement of the tower is still leading.
Because the two different strategies have the same result, it can be concluded that the maximum possible height of the tower is 12 meters, considering a floor area of 2.5 by 2.5 meters and the standard adobe brick properties. The size of the bricks used at the tower is different than from the rest of the building, see paragraph 6.1.

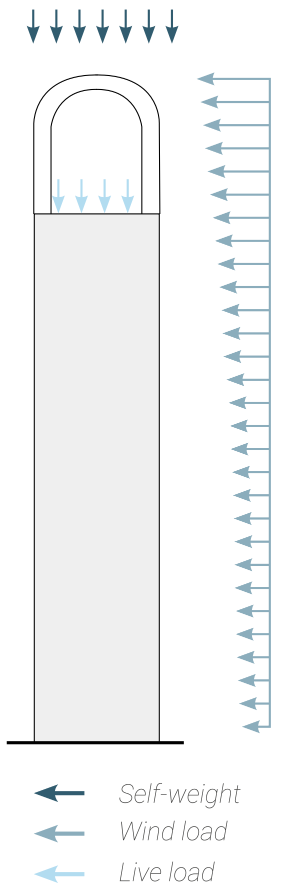


Figure 5.15 Loads on tower, source: own

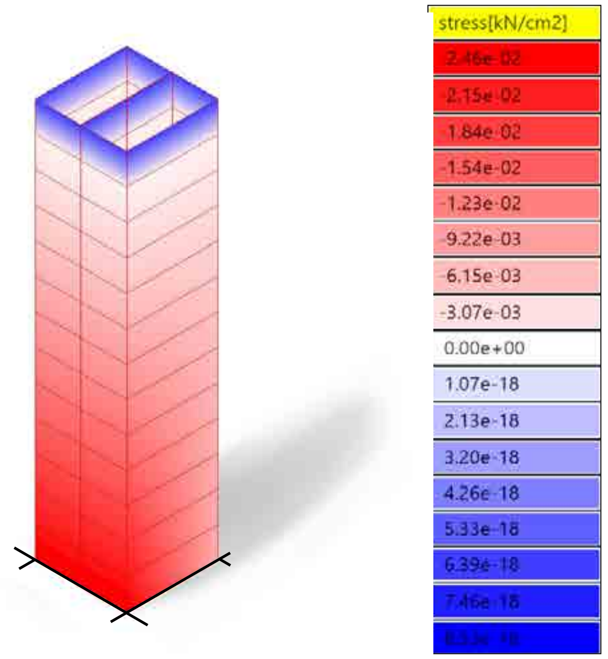


Figure 5.10 Axial stresses, source: Karamba

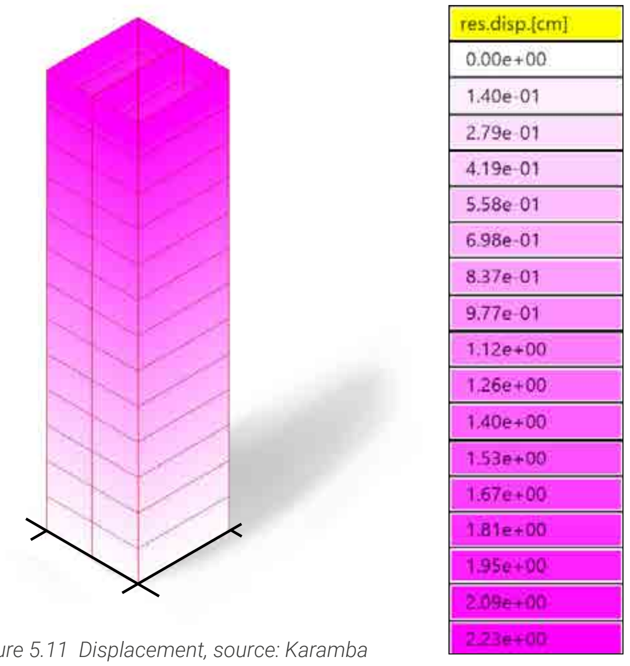


Figure 5.11 Displacement, source: Karamba

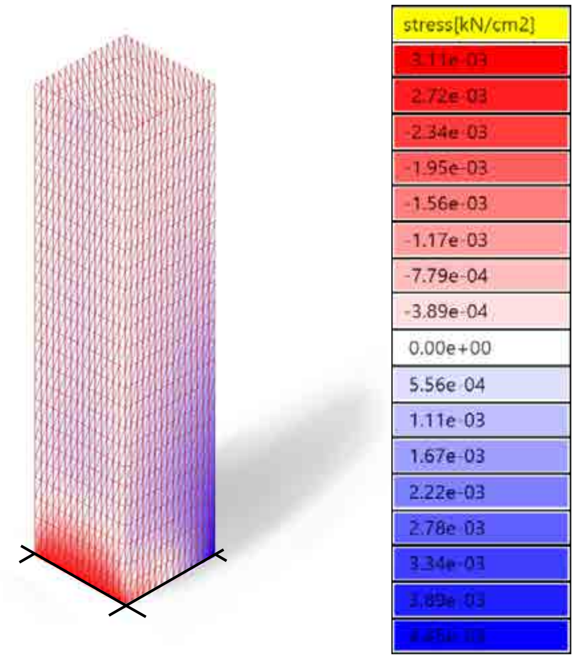


Figure 5.12 Principle stresses 1, source: Karamba

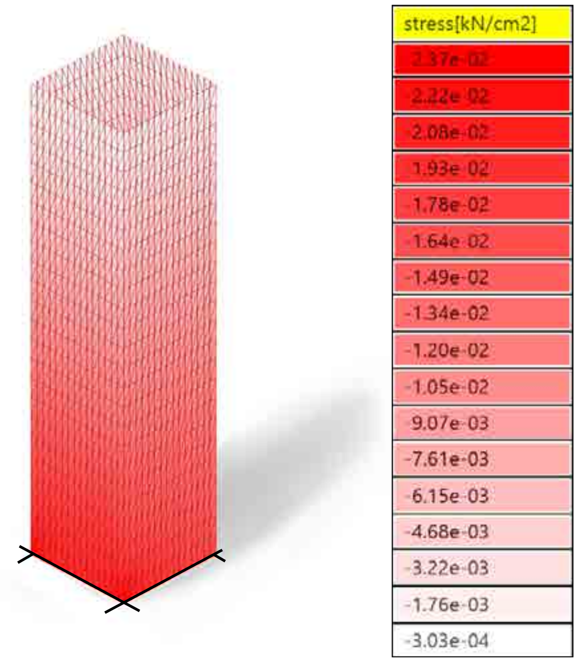


Figure 5.13 Principle stresses 2, source: Karamba

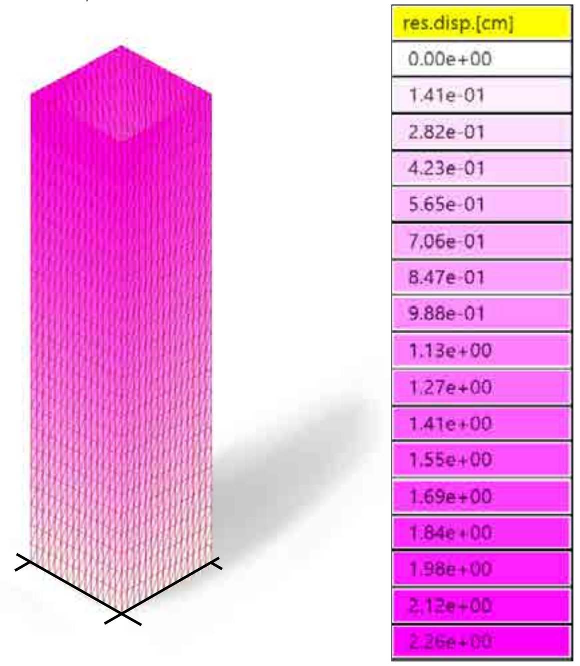


Figure 5.14 Displacement, source: Karamba

5.5 Adobe 2.0

The architectural idea of the tower is to function as bell tower. The bells are replaced by the radio antennas, and their sound is spread throughout the camp by the radios of the people. Instead of waking up every morning by the calls of the mosque minarets, people wake up from the calls by the Tarab tower.

Because of its function, only once in a while someone needs to go up; to repair or replace something. Therefore, another type of stair is used. Inside the tower, a slot is left open. Inside this slot, stones are removed from the three walls. Hereby, it is possible to climb the tower by placing feet and hands inside the gabs. In this way a stair is created with minimal user space and without a maximum height. This allows the tower to be slender, solid and stable.

5.5.1 Stairs

If a normal stair is applied at the tower, what is it impact? A stair can have multiple shapes, it can rotate around the building to the top, or it can be a giant ramp all the way from the bottom. Both solutions need a stair with 63 steps, resulting in a ramp of 15.8 meters long. If the stair rotates around the tower, the footprint of it will be 20.25 square meter instead of 6.25 square meter.

Both solutions do not meet the requirements and design of the floorplan. Also, the architectural image of the building will be changed. Lastly, the function of the tower does not require such a stair because it will not be climbed frequently.

To conclude, the way the stair is designed in the current model meets its requirements and function best.

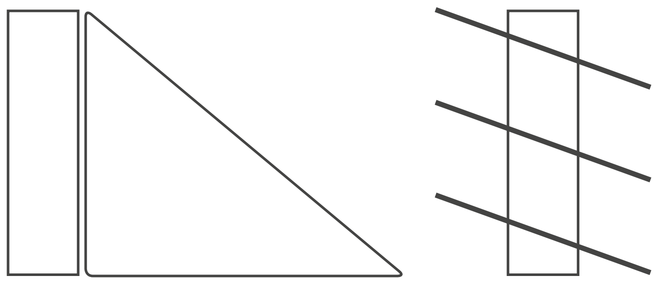


Figure 5.16 Stair concepts, source: own

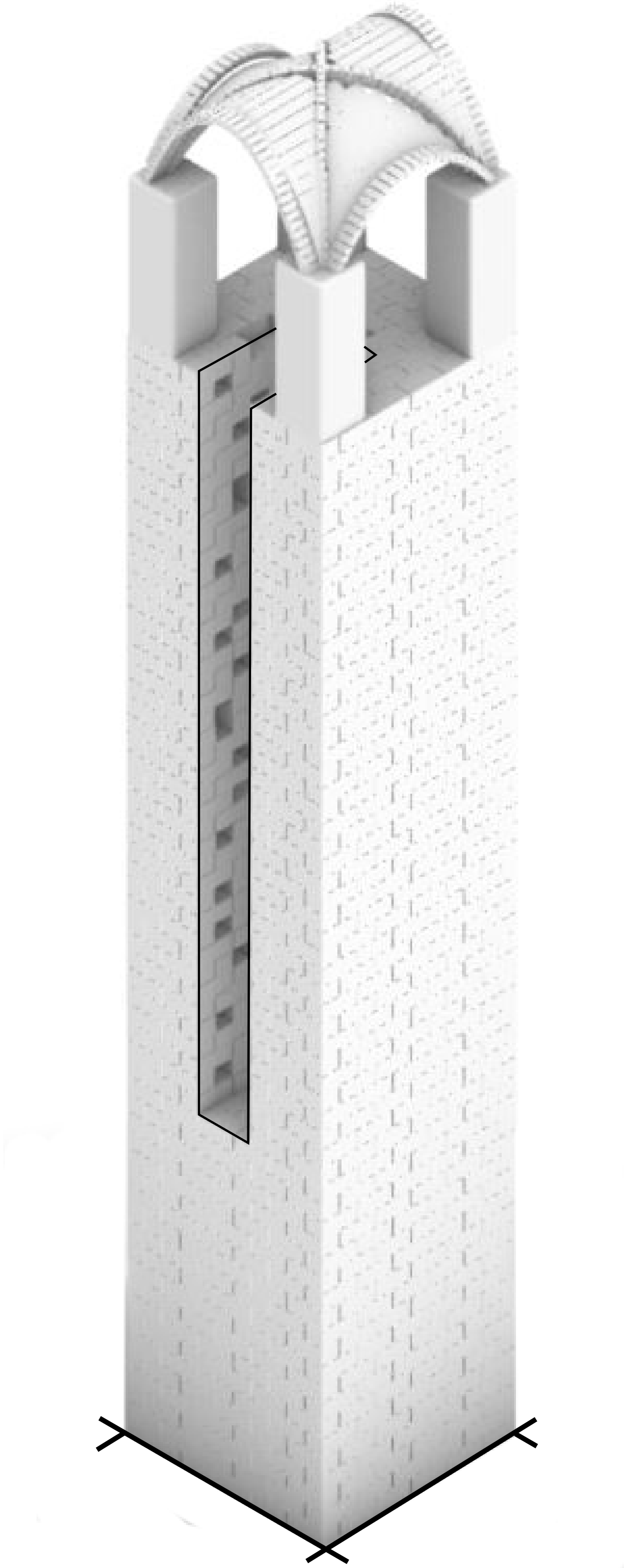


Figure 5.16 Final stair concept, source: own

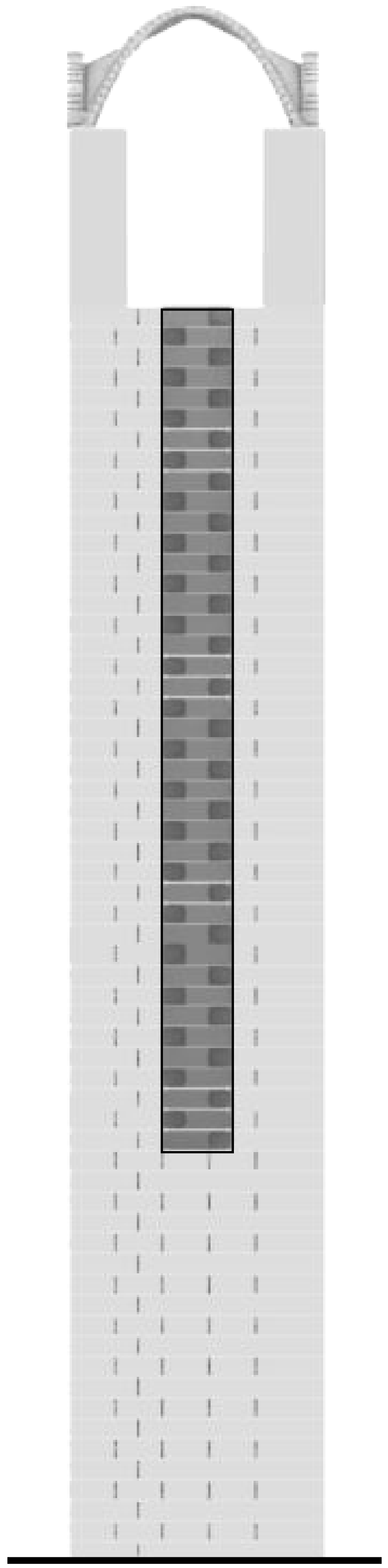


Figure 5.17 Final stair concept, source: own

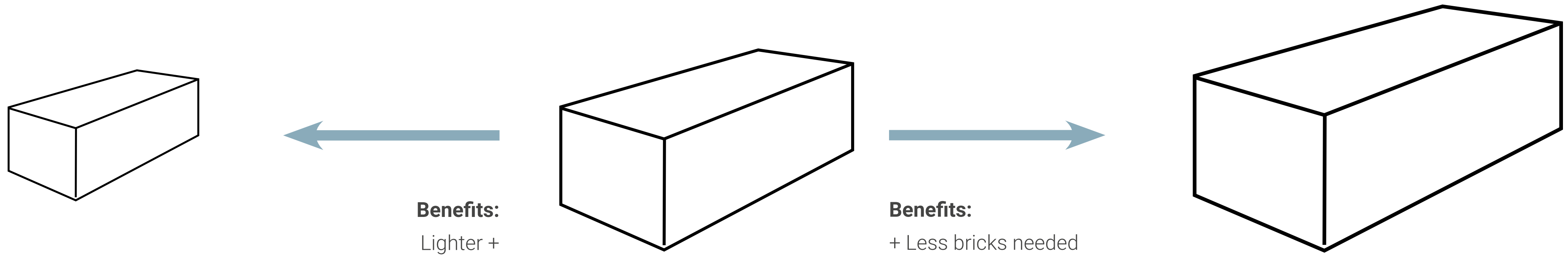
Figure 5.18 Urban Climbing, source: Wahlhuetter

6 Brick measurements

6.1 Brick size

The start of the determinization of the brick size is the grid size. The building is designed on a grid of 2.5 by 2.5 meters, leading to a brick with a length of 250 mm. Including the mortar layer, the first brick measurements are: 250x125x100. The width of 125 is set such that the brick can be rotated (125*2 = 250). The height is 100, so the vertical grid is based on steps of 100 mm.
The next step is to consider smaller and bigger bricks. What if we make the brick bigger, and what are the advantages and benefits of making a smaller brick. The importance of the benefits and disadvantages can be different per function of the structure. Within the building, three different types of structures are present: walls, roofs and the tower.

- The bricks in the walls need to be aligned with the grid to make sure the windows and doors are at the right location. So, the size of the bricks for the walls stay the same; 250x125x100.
- The bricks in the roof need to connect with the walls while their orientation is different. Therefore, a brick is needed with a height and width of 125 mm. A smooth surface will perform less considering the acoustic performance, all the sound will reflect to one middle point. Therefore, small bricks are not preferable. The brick size of the roofs is 250x125x125.
- The bricks in the tower need to be strong and stable, especially the bricks for the first two meters. Therefore, a brick length of 400 is perfect. To align two bricks perpendicular to one brick, the width needs to be 200mm. Lastly, the height is 150 mm. The weight of this brick will be 18 kg and will only be used for the foundation and first two meters. Because of the lower weight, the normal bricks of 250x125x100 are used for the rest of the tower.



Benefits:
Lighter +
Easy to lift by hand +
Fluent arches +
Dries more efficient – less possible cracks +

Disadvantages:
More bricks needed -
Less stability -
More mortar – more possible cracks and leakages -
Does not fit the grid size – problems with windows, doors -

Benefits:
+ Less bricks needed
+ More stability
+ Less mortar – less possible leakage – less possible cracks

Disadvantages:
- Heavier
- Less convenient to lift by hand
- Does not fit the grid size – problems with windows, doors
- Dries less efficient – possible cracks
- Less fluent arches

Figure 6.1 Brick size, source: own

	Length [mm]	Width [mm]	Height [mm]
Brick size wall	250	125	100
Brick size vault	250	125	125
Brick size tower	400	200	150

Table 6.1 Brick size, source: own

6.2 Brick material

The adobe bricks will be made from a mixture of clay, fine sand, coarse sand and an additive. This mixture will be made with water, which evaporates during the drying of the bricks. To much water makes the bricks to liquid and they will not stay in shape, to less makes the bricks brittle. In normal times, a part of the EARTHY course is to make the bricks ourselves and determine the mixture, additives, weight, strength and young's modulus. Due to the current circumstances, the workshop is cancelled, and the material properties are based on the research done by last year groups.

Table 6.3 shows the adobe properties used in the designs of group one to seven last year.
Concerning the mixture of the adobe, all groups are using the same; 30 percent clay, 30 percent fine sand; 40 percent Coarse sand and 10 percent water. This will also be the mixture of our adobe.
Most groups used straw as additive for their bricks. On one side this is done because straw improves the performance of the material, but the main reason to use straw instead of, for instance, woodchips, is that straw is available at the Za'atari refugee camp. Because of this reason our bricks will include straw too.

The design values of the adobe; compression strength, tensile strength and young's modulus are based on the results of the tests done last year too.

6.2.1 Compression strength

The compression strength used is the average of the compression strengths of last year. However, all the values above the 3.0 mpa are neglected, because those are too high compared to literature[2,3]. The average will result in a compression strength of 2.1 mpa.

6.2.2 Tensile strength

The tensile strength of adobe is 0.1 times the compression strength. This leads to a tensile strength of 0.21 mpa.

6.2.3 Young's modulus

The young's modulus tested by the groups of last year are between 5 and 25 mpa. Comparing this to the literature[1,2,3], it is to low. The young's modulus of adobe should be around 100 mpa. A comparison is made between three papers, taking the average of the young's modulus of these three. This results into a young's modulus of 117 mpa.

Paper	Young's modulus [mm]
1[1]	135
2[2]	117
3[3]	100
Conclusion	117.3

Table 6.2 Young's modulus, source: own

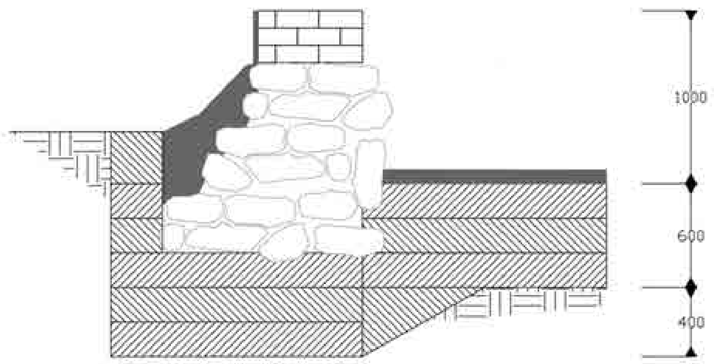


Figure 6.2 Wall build up, source: own

6.2.4 Waterproof layer

The Za'atari refugee camp is located at the border of the Arabian desert which means that the rainfall is little. However, if it rains, the water needs to be removed from the building as fast as possible. Remaining water can damage the adobe bricks and therefore the building.
Therefore, the lengths of the gutters are minimized, and the roofs are placed in such a way the water can always finds its way to a gutter. At the bigger gutters, the water is collected to be used for watering the plants.

To protect the building from the rain, the first 400 mm of the walls are made of natural stone. Above that, the adobe bricks are places.

Besides that, the outside of the building will be plastered with a waterproof layer. This layer consists the same materials as the adobe bricks, including animal fat as extra additive. This animal fat will provide the material a protection against water.
On the vertical surfaces, a plaster layer of 3 cm is added and on the horizontal surfaces 5 cm. At the foundation, rocks are used to improve the strength and stability of the walls and to ensure no water is coming into the building.

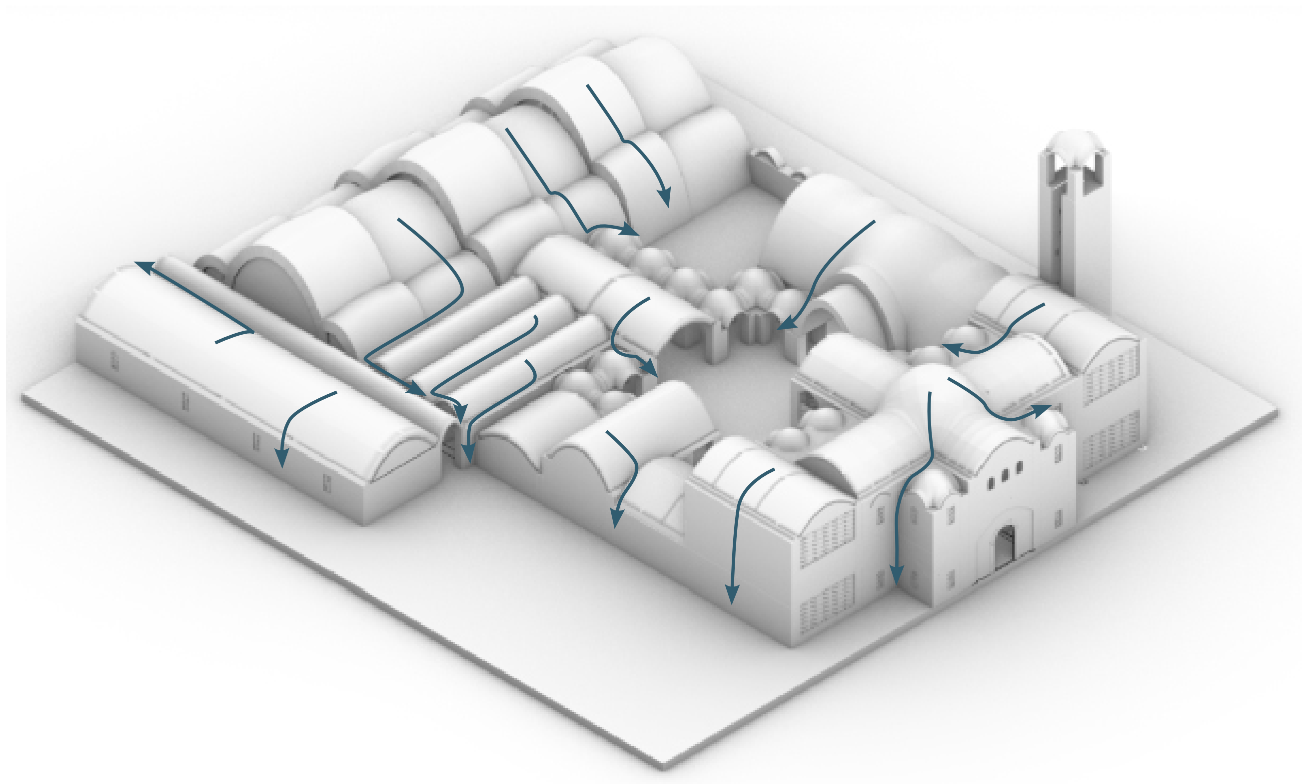


Figure 6.3 Drainage, source: own

	Clay [%]	Fine sand [%]	Coarse sand [%]	Water [%]	Additive
Brick properties	30	30	40	10	Straw
Plaster properties	10	55	30	10	Straw + animal fat

Table 6.3 Brick and plaster properties, source: own

6.3 Brick layering

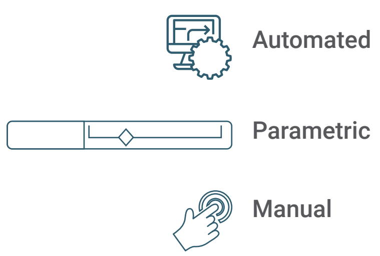
The scripts for the brick layering are created in order to assist and help cleairfy the construction manual for various parts of the building complex. The following building elements were neccisairy to create this manual:

- Tower
- Barrel vault
- Theatre
- Cross vault

Figure 6.4 shows three different icons that have been used and explained in the previous chapter: 02-01 Mesh Development

The tower, displayed in is the only truly solid structure in the building complex. The aim for this tower was to create a script that could create this solid tower using various base, height and brick dimensions. Furthermore, there needs to be a gap starting at a certain point in the tower that will allow for the placement of a ladder to be able to reach the top. The dimensions of this gap also need to be able to change. The script starts with creating a rectangle based on a single point and will fit the bricks in a stretcher bond along one side of the rectangle. After it will rotate these bricks along the center to create a perfect rectangle. The second row is created in the same way and mirrored to create the stretcher bond. The layers are placed alternately to create a solid tower. After all the bricks are placed a collision rectangle is used to cull intersecting bricks. The remaining half bricks that now create gaps in the tower are filled using the same box to slice the bricks in half. The script could be enhanced if the process of creating unnecessary bricks was eliminated. The current method uses unnecessary computing power to create bricks that won't be used.

Figure 6.4 shows the script for the barrel vault. This type of vault is most used in the project. Therefore, it would be optimal if a single script is able to create all the different types of needed widths, heights, lengths and arches for these spaces. It is also the goal to create the walls for the spaces together with the vault. A similar process of coping and mirroring as in the script for the tower is used to create a single row of bricks along a rectangle. The different rows of bricks are stacked until the desired height is reached. The top stack of bricks creates a new base for the barrel vault. The arch is created using a parameter. The user of the script should try to get the arch as close as possible to the tessellated shape of the arch. Once the arch is defined an alternating brick layering pattern is placed along the length of the wall. Lastly, the gaps of the barrel vault are filled with cut bricks. The current script does not allow for a input to create walls or doors. This is because the amount and placement of these wall openings vary greatly amongst different spaces, therefor the decision has been made to create these gaps manually after baking the final result. However, the script could be improved by adding an option for creating at least one door or window.



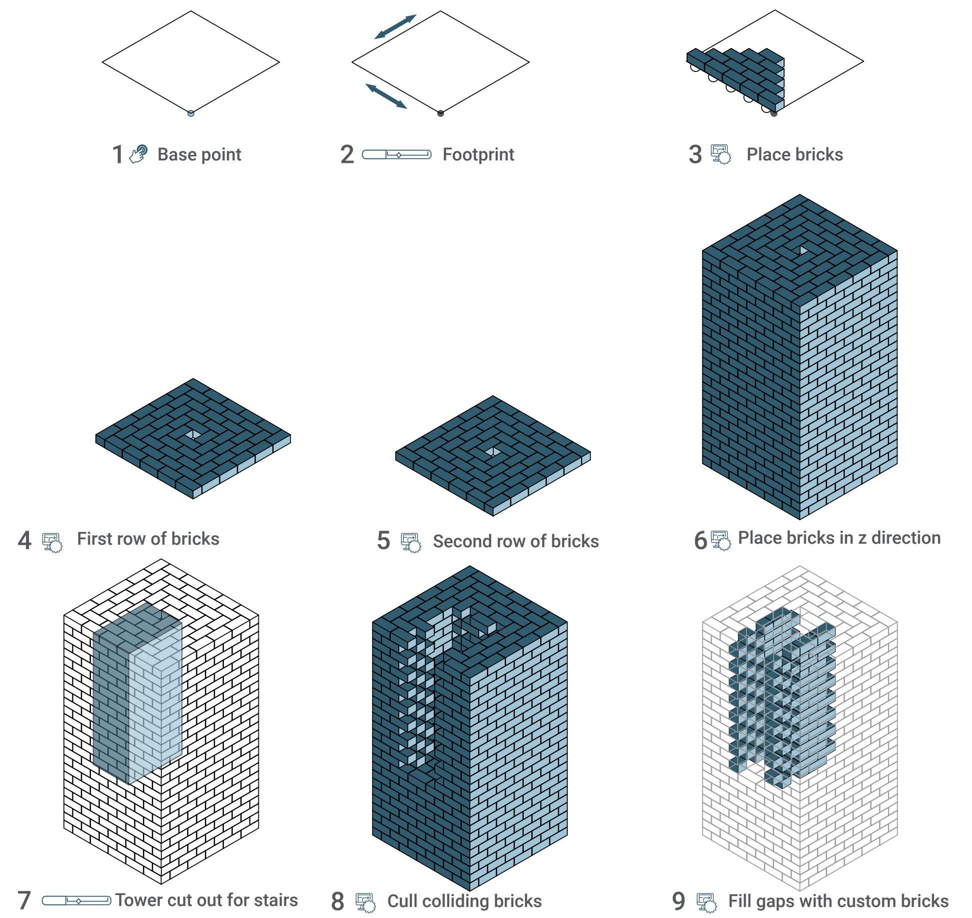


Figure 6.3 Visualization of the tower brick placement script, source: own

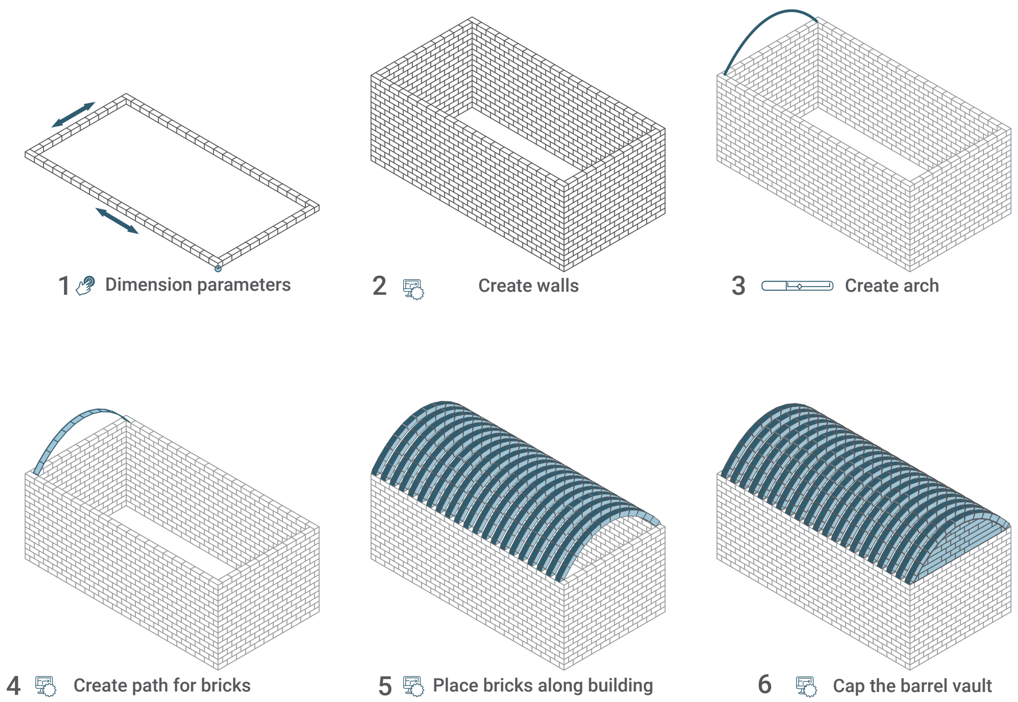
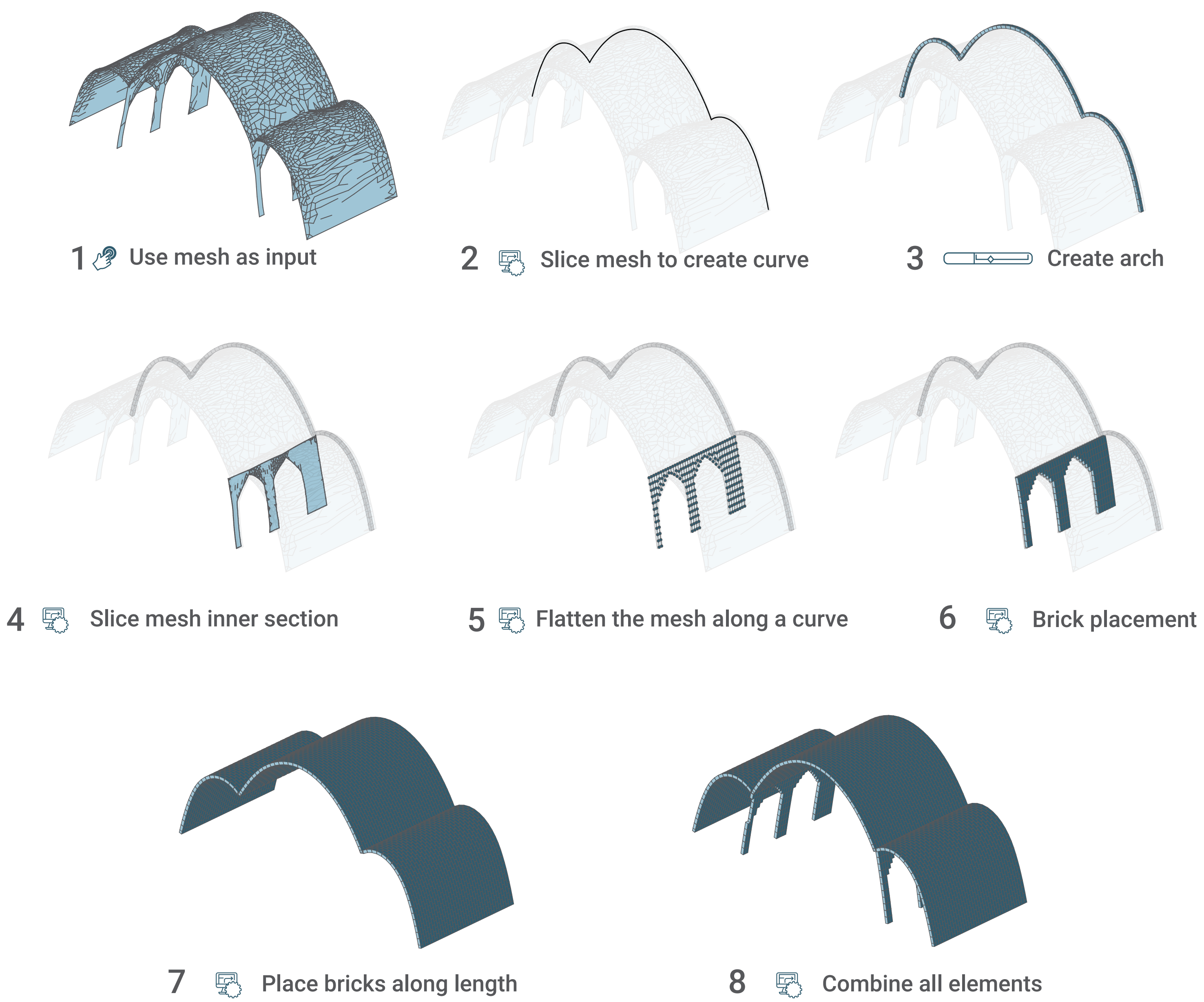


Figure 6.4 Visualization of the barrel vault brick placement script, source: own

The final script show in figure 6.5 is for creating the theatre. The aim for this script was to use the mesh as an input for the script. This decision was made because the different sections of the theatre vary greatly in height and wall openings. It is possible to convey these shapes into parameters that the user of the script can control. However, it would be a greater computational challenge to use the previously generated mesh as the only input, and not use the inputs from previous scripts. Because of these decisions this script requires the most amount of interventions by the user when comparing to the previous scripts.
Using the mesh introduces some challenges to the brick layering. Figure 6.6 shows the brick layering that would derive from using the mesh completely. A section of the mesh is taken to avoid the random placement of bricks and to allow for a more controllable final result. The first section is for creating the roof of the structure, the second section is for creating the inside walls and openings. The script can be improved by making it more user friendly.



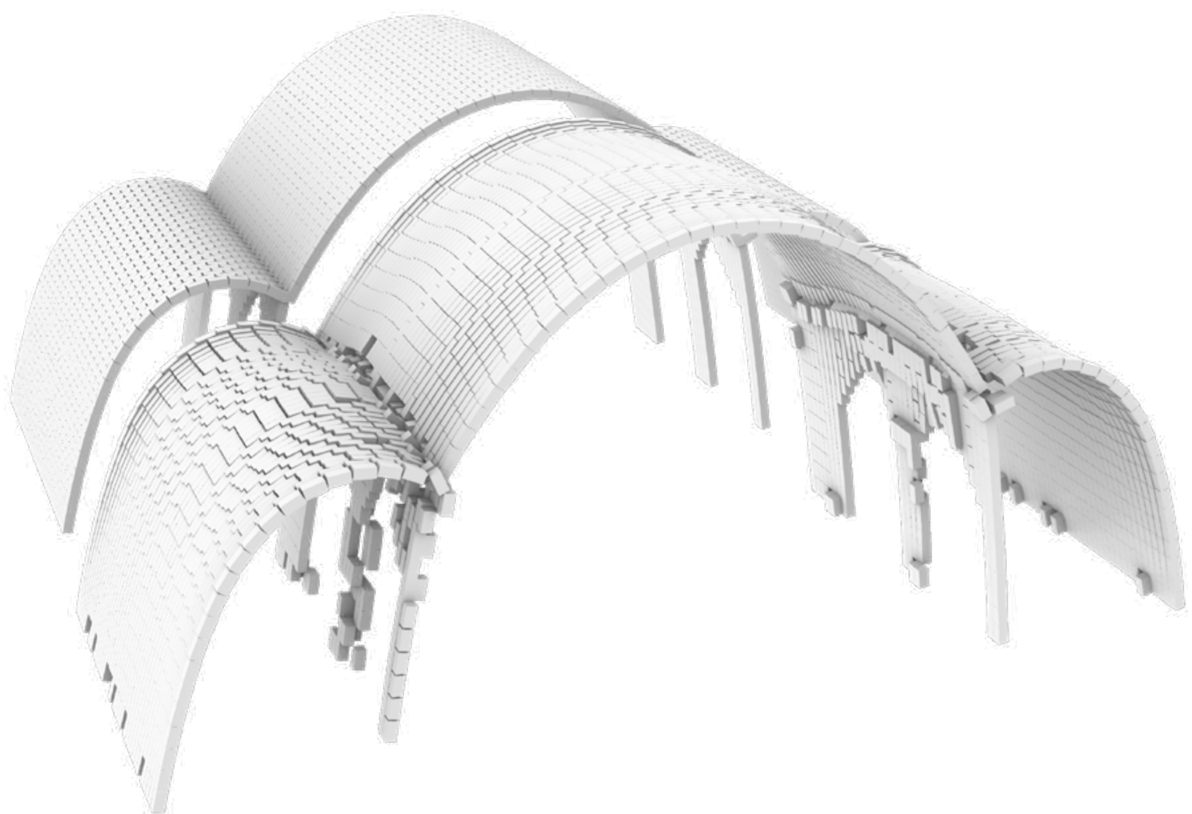


Figure 6.5 Visualization of the nubian brick placement script, source: own
Figure 6.6 Brick placement using the mesh as input, source: own

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.

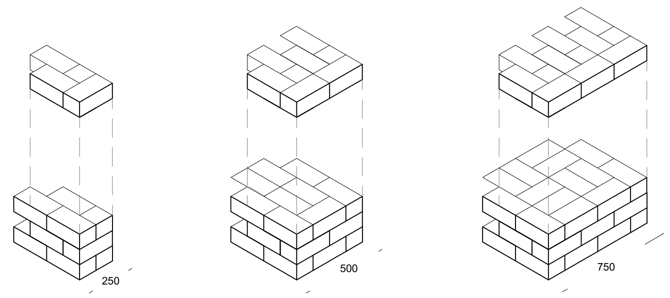


Figure 7.2 Isometric view of three wall types with a thickness based on a multiplication of 250 mm. source: own

	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

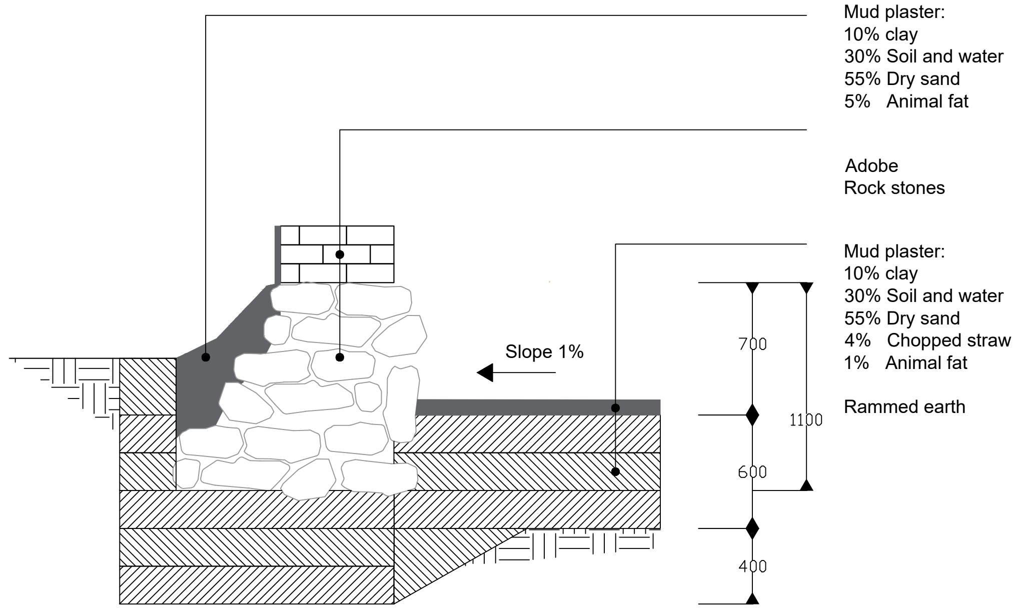


Figure 7.1 Section of the foundation and an exterior wall which is typical for every building in the complex. source: own

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.

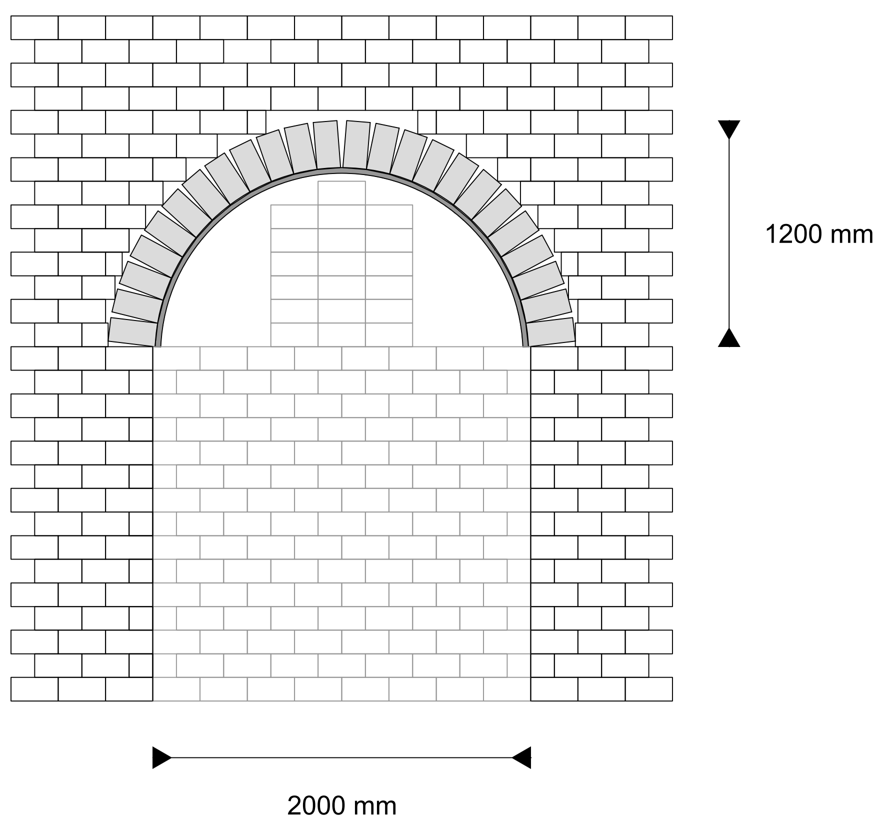


Figure 7.3 Front view of an arched door with in lightgray the supporting bricks and in dark grey the slice of a watertank. source: own

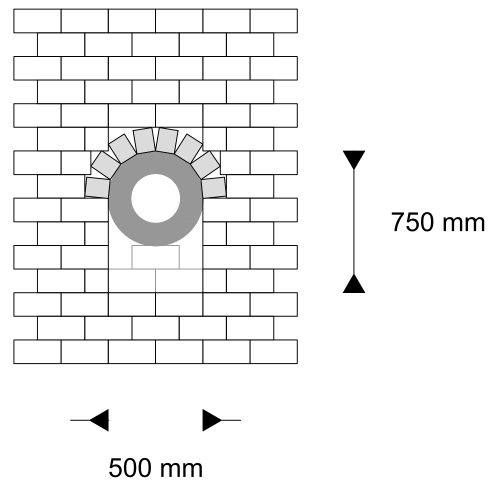


Figure 7.4 Front view of an arched window with in lightgray the tire and the supporting bricks. Source: own.

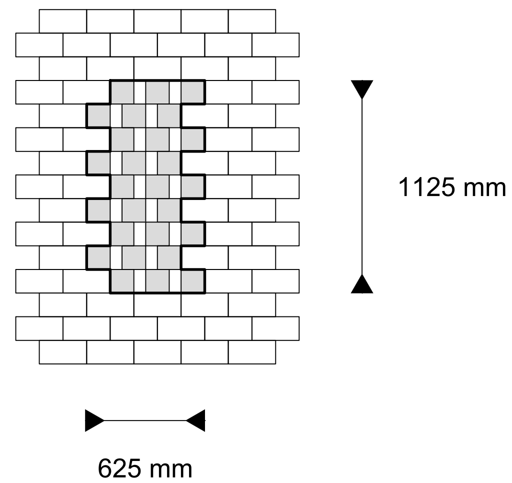


Figure 7.5 Front view of a mashrabiya based on bricks of 100x125 mm. source: own

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.

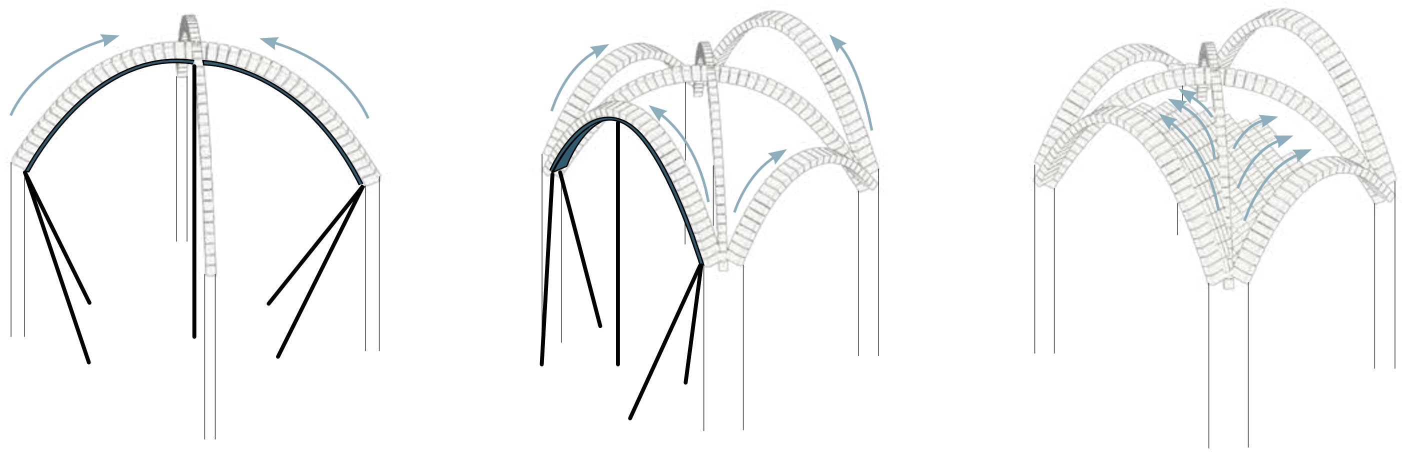


Figure 7.6 Building sequence of a cross vault using two different jigs to support the ribs during the construction process, source: own

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

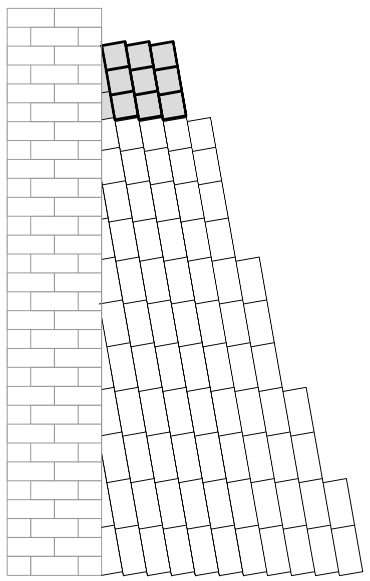


Figure 7.8 Section of a typical barrel vault based on the Nubian technique. The bricks have an inclination of 80 degrees with the horizontal. source: own

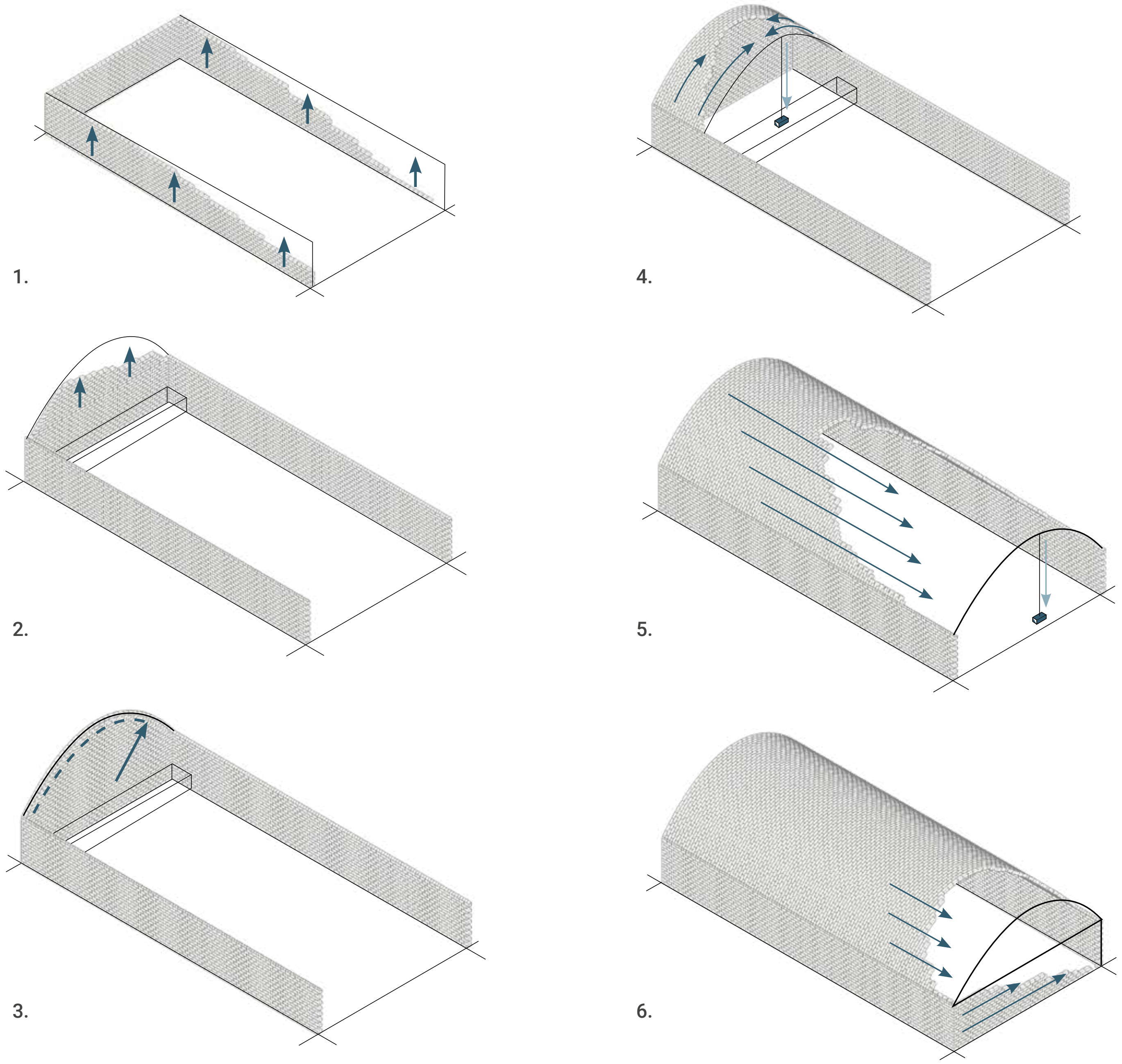


Figure 7.9 Building sequence of a barrel vault based on the Nubian technique. source: own

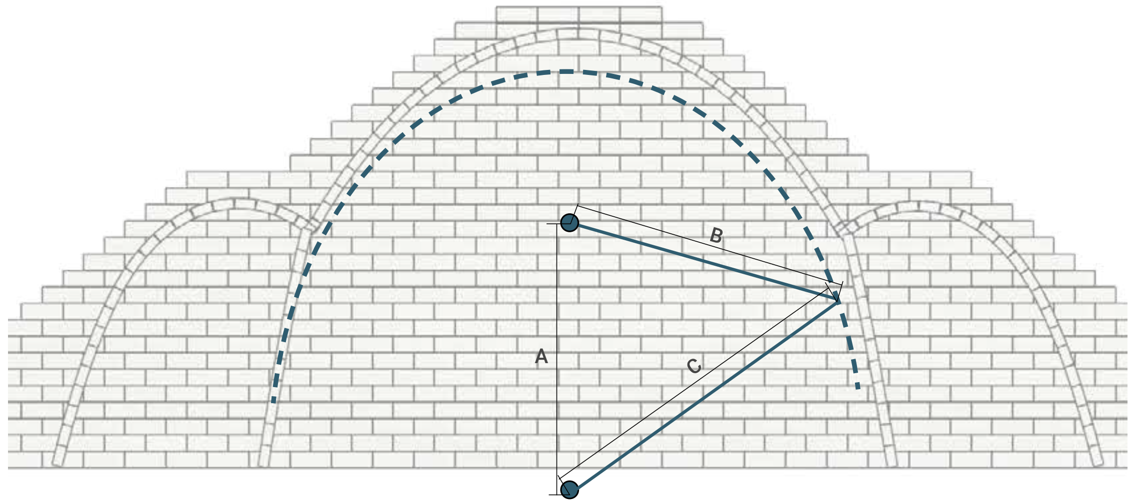


Figure 7.10 Illustration of the drawing method of an ellipse with a rope. The two blue dots are the focal points of the ellipse from where the ellipse is drawn. source: own

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.

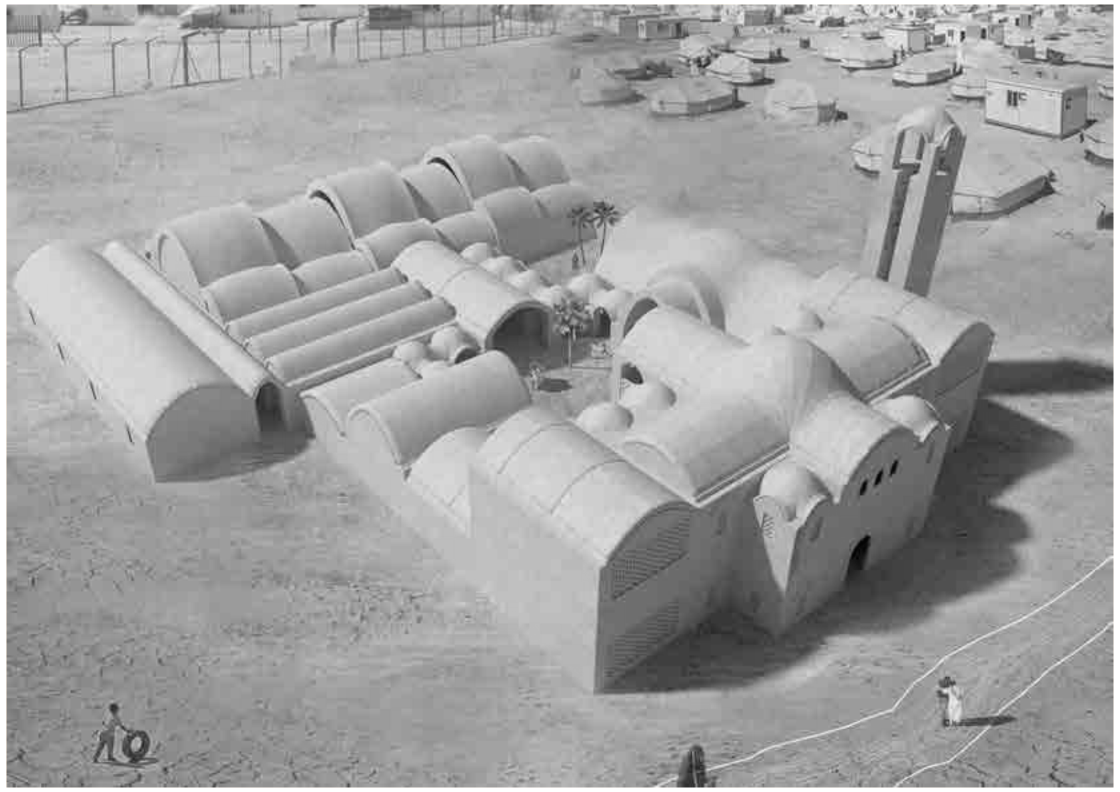


Figure 7.11 3D view of the complex with in the front the entrance building, on the right the tower and at the back the theatre. source: own

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.

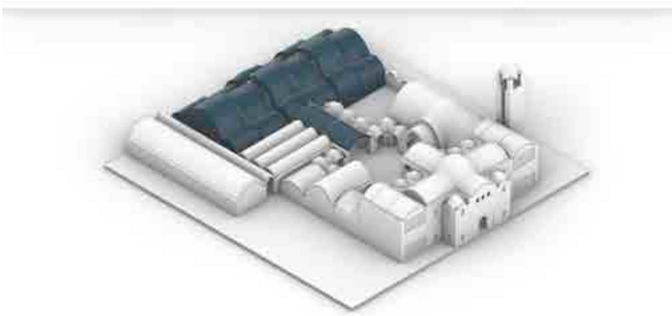


Figure 7.12 3D view of the complex with the theatre highlighted in blue. Source: own work. source: own

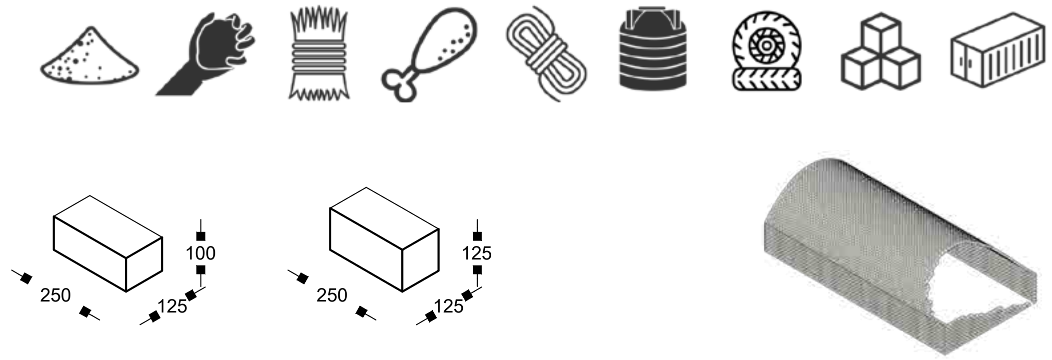


Figure 7.13 Pictograms of the materials, brick types and construction type that are used for the construction of the theatre. source: own

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.

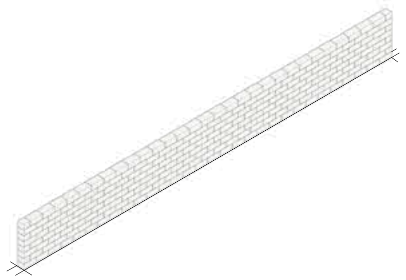


Figure 7.14 Isometric of the step 1 of the building sequence of the theatre. source: own

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.

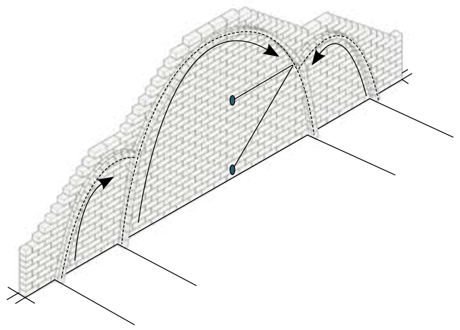


Figure 7.16 Isometric of the step 2 of the building sequence of the theatre. source: own

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.

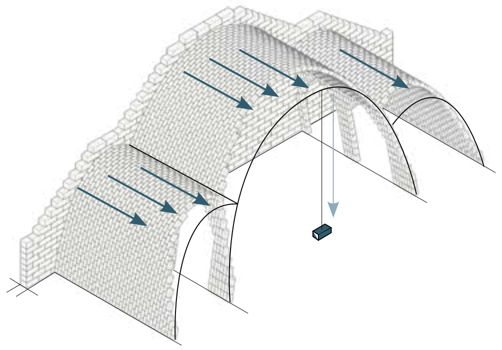


Figure 7.18 Isometric of the step 3 of the building sequence of the theatre. source: own

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.

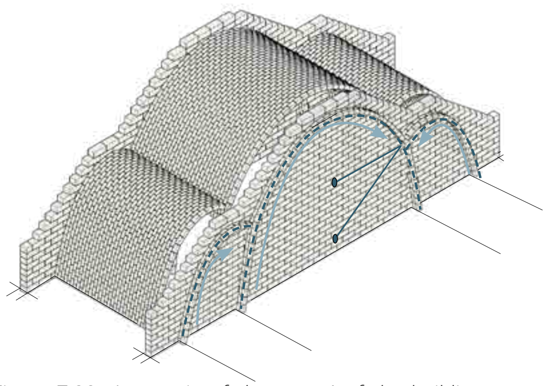


Figure 7.20 Isometric of the step 4 of the building sequence of the theatre. source: own

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.

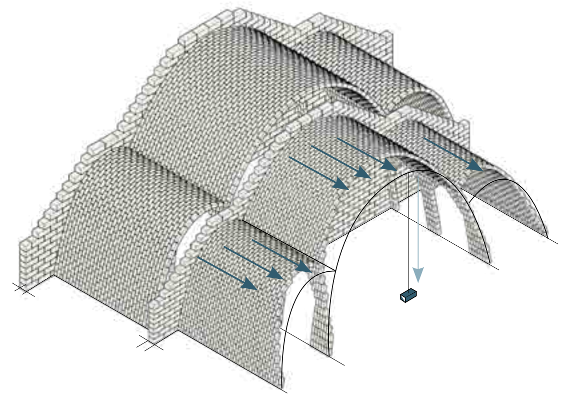


Figure 7.21 Isometric of the step 5 of the building sequence of the theatre. source: own

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.

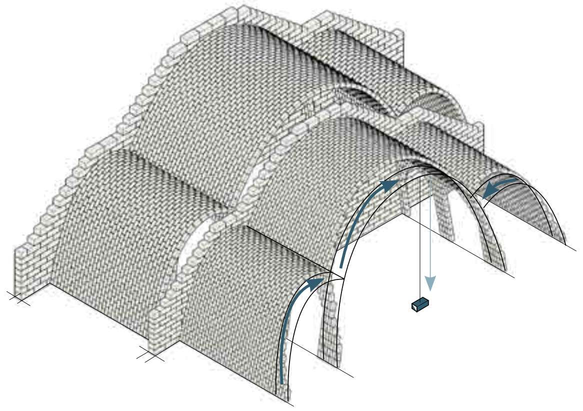


Figure 7.23 Isometric of the step 6 of the building sequence of the theatre. source: own

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.

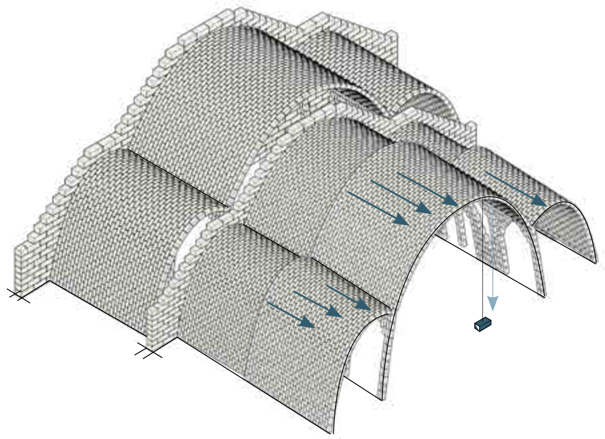


Figure 7.25 Isometric of the step 7 of the building sequence of the theatre. source: own

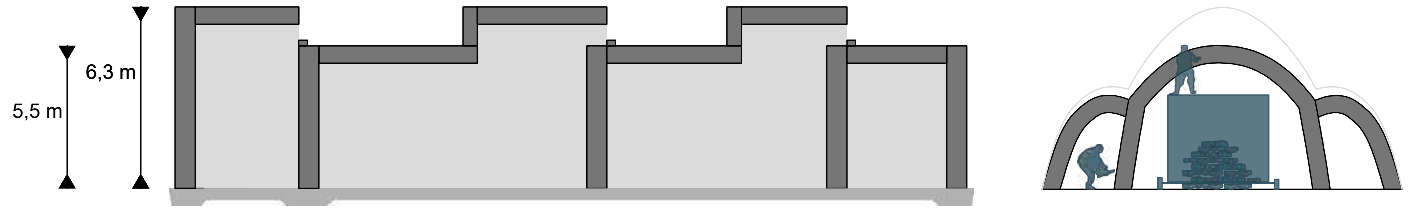


Figure 7.26 Section of the step 7 of the building sequence of the theatre. source: own

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

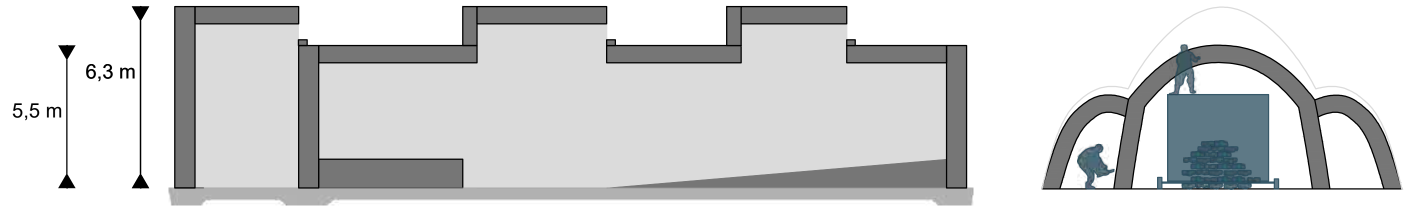


Figure 7.28 Section of the step 8 of the building sequence of the theatre. source: own

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.

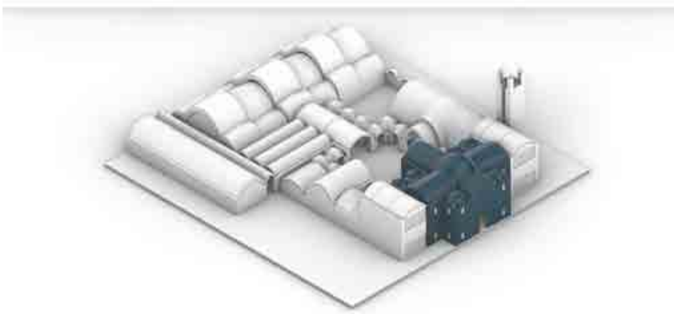


Figure 7.29 3D view of the complex with the entrance highlighted in blue. source: own

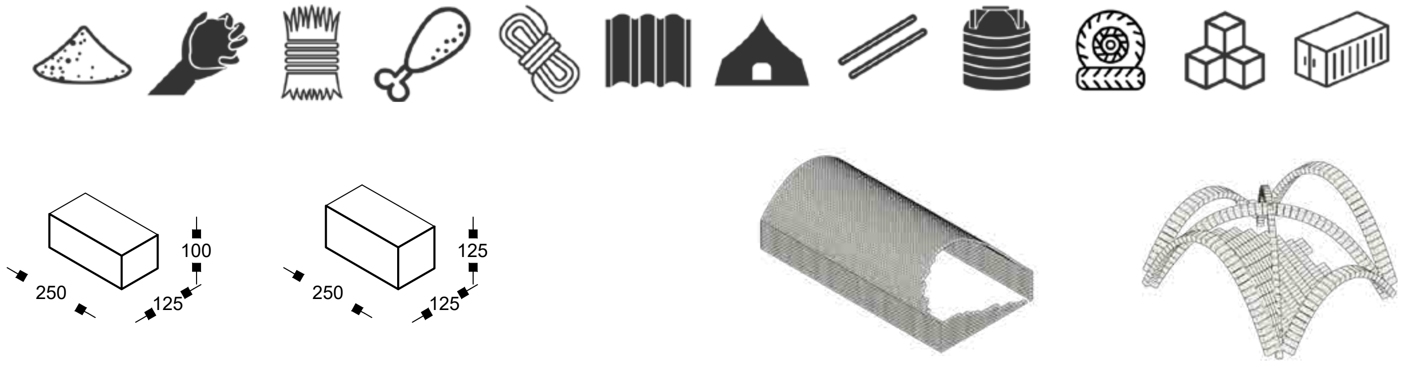


Figure 7.30 Pictograms of the materials, brick types and construction type that are used for the construction of the entrance. source: own

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.

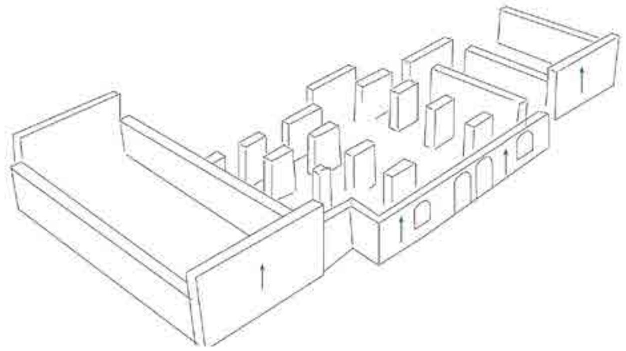


Figure 7.31 Isometric of the step 1 of the building sequence of the entrance. source: own

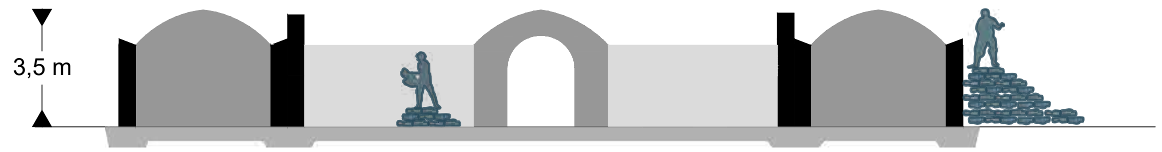


Figure 7.32 Section of the step 1 of the building sequence of the entrance. source: own

Step 2

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

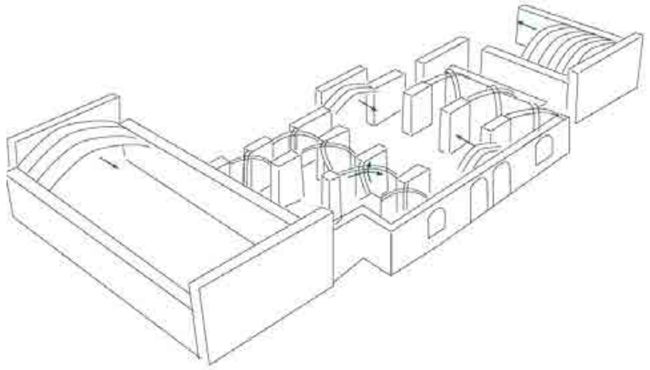


Figure 7.33 Isometric of the step 2 of the building sequence of the entrance. source: own

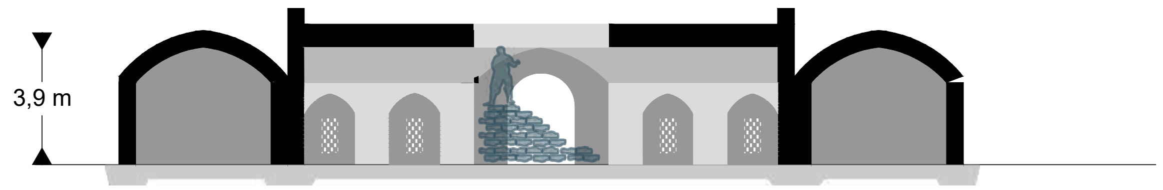


Figure 7.34 Section of the step 2 of the building sequence of the entrance source: own

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.

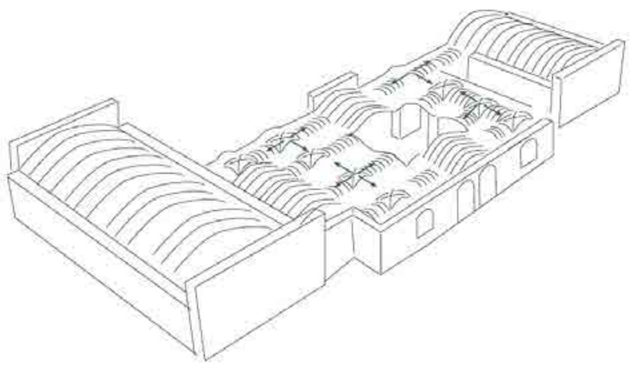


Figure 7.35 Isometric of the step 3 of the building sequence of the entrance. source: own

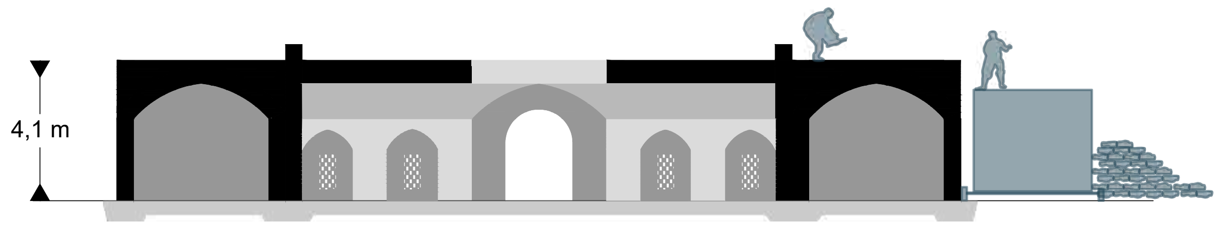


Figure 7.36 Section of the step 3 of the building sequence of the entrance. source: own

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.

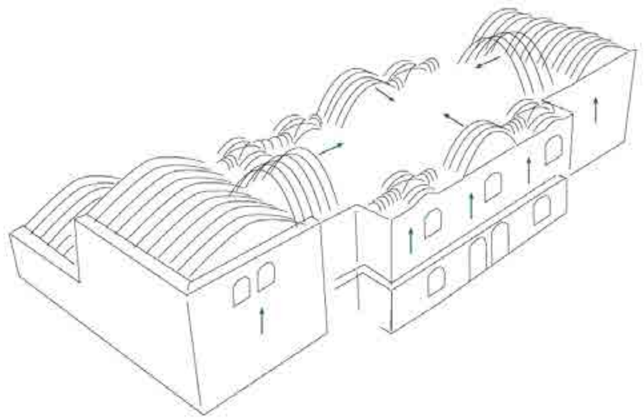


Figure 7.37 Isometric of the step 4 of the building sequence of the entrance. source: own

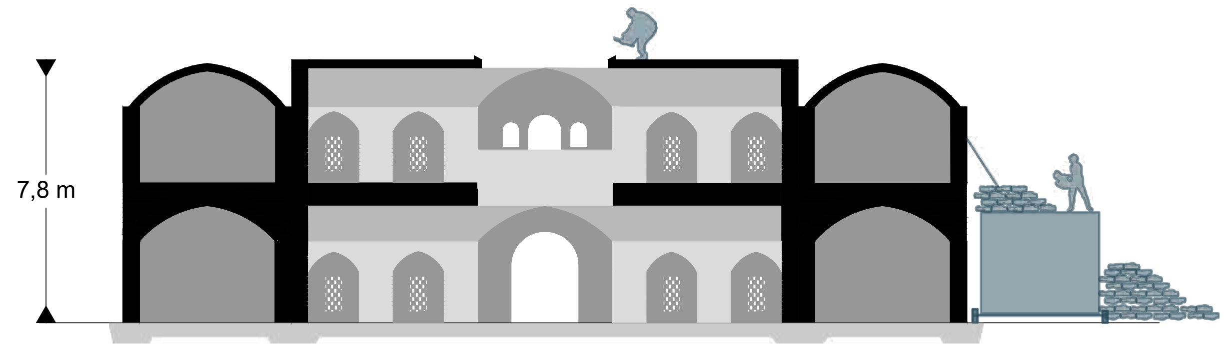


Figure 7.38 Section of the step 4 of the building sequence of the entrance. source: own

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.

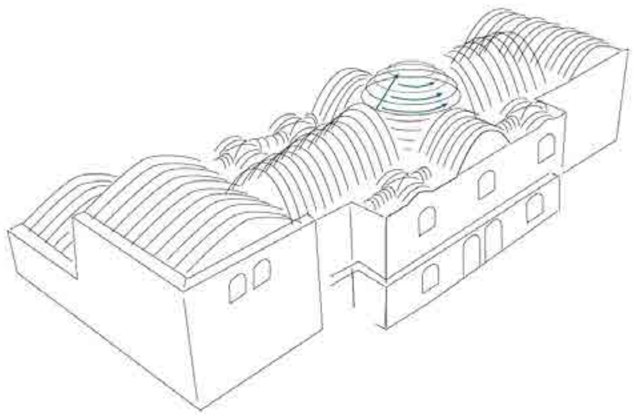


Figure 7.39 Isometric of the step 5 of the building sequence of the entrance. source: own

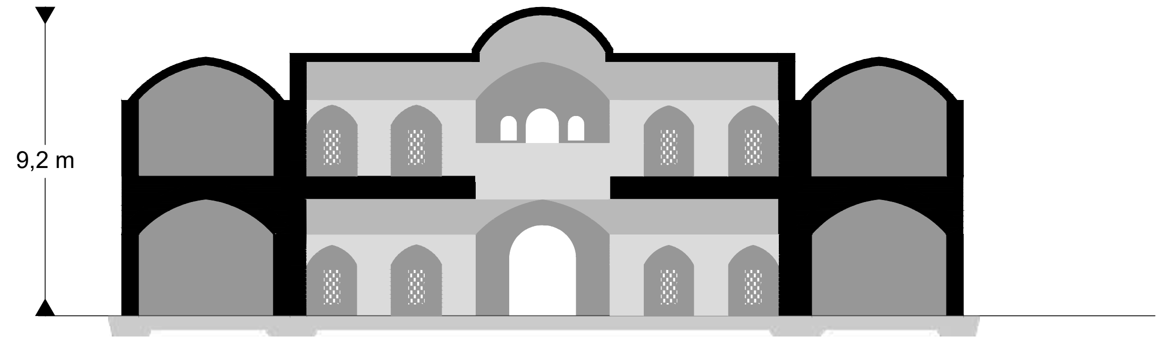


Figure 7.40 Section of the step 5 of the building sequence of the entrance. source: own

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.

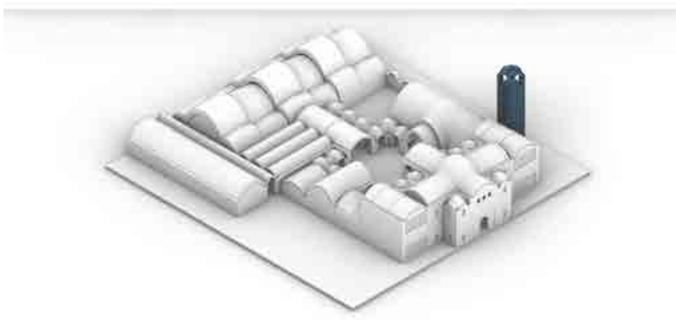


Figure 7.41 3D view of the complex with the tower highlighted in blue. source: own

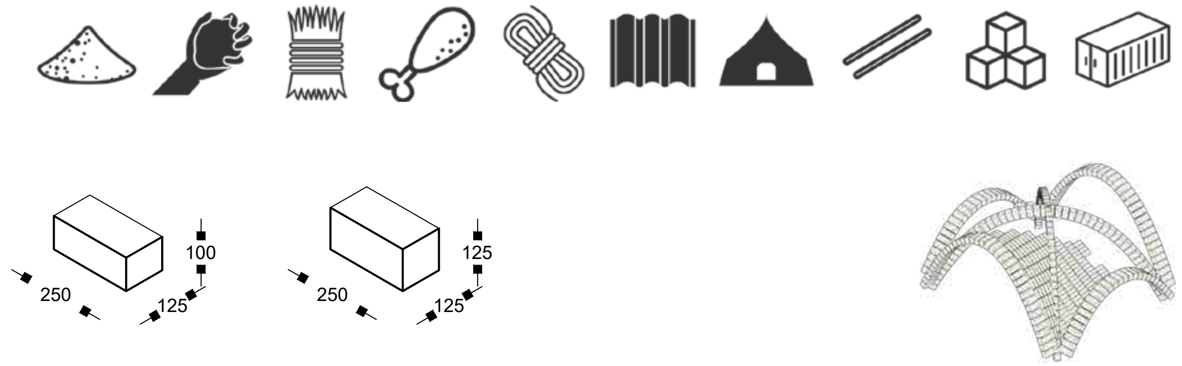


Figure 7.42 Pictograms of the materials, brick types and construction type that are used for the construction of the tower. source: own

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.

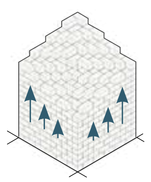


Figure 7.43 Isometric of the step 1 of the building sequence of the tower. source: own

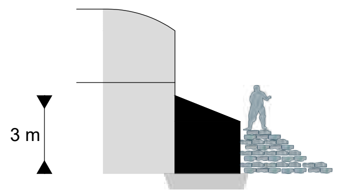


Figure 7.44 Section of the step 1 of the building sequence of the tower. source: own

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.

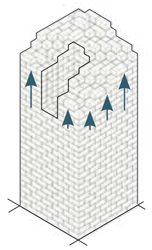


Figure 7.45 Isometric of the step 2 of the building sequence of the tower. source: own

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.

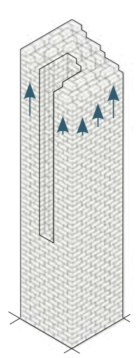


Figure 7.47 Isometric of the step 3 of the building sequence of the tower. source: own

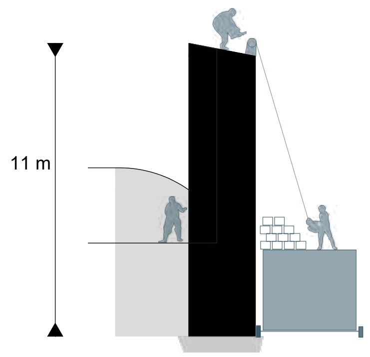


Figure 7.48 Section of the step 3 of the building sequence of the tower. source: own

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

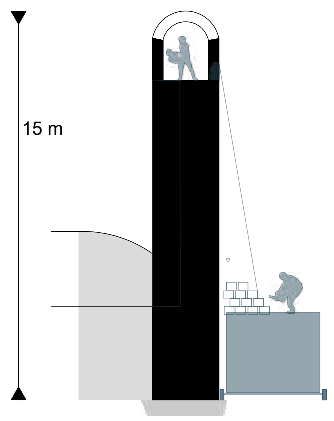


Figure 7.50 Section of the step 4 of the building sequence of the tower. source: own

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.

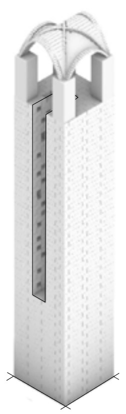


Figure 7.51 Isometric of the step 5 of the building sequence of the tower. source: own

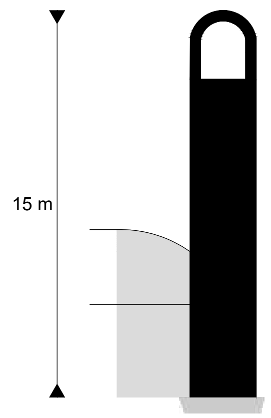


Figure 7.52 Section of the step 5 of the building sequence of the tower. source: own

8 Conclusion

Designing with Adobe has been a great challenge for the past few weeks. Not able to use standard scaffolding elements or structural steel elements made us think differently than normal. However, due to its limitless availability in Jordan and the fact that it can be extracted locally, it is the perfect material to be used for building a theater for the displaced community of Za'atari. Several steps have been made to achieve that including computational and manual methods.

8.1 Configuration

Both computational and manual methods were studied for the configuration. The plan was to use both methods to generate floorplans and then test which ones would give the best solution. The criteria are based on the program of requirements. The computational methods included the use of Kangaroo and its Magnet Components with respect to the restrictions. After the assessment, both methods had many common aspects but the manual one was perceived to be better due to its architectural integrity. A grid of 2.50x2.50 meters was applied to the configuration and the sizes of the corridors and rooms had to respect that. The Bubble and Metro diagram would describe the relation between the spaces. The final floorplan was further developed to match these. The main intention was to be able to read the floorplan through these 2 diagrams.

8.2 Shaping

For Shaping computational methods were used. Most of the components use as input the curves that outline the desired dome geometries. Then tessellations were created using the Weaverbird's components in grasshopper and the number of segments could be controlled per case. The more the mesh segments the greater the computational power needed to relax the mesh. Per case, that number was defined to match with a result appropriate for the bricklayering. Draping was also considered as an overview of the final form due to the fact that a second roof layer needs to be added on top of the tessellated roofs to prevent rain from entering the structural components.

8.3 Structuring

For the purposes of the Finite Element Analysis (FEA) the Karamba plug in was used in Grasshopper. The meshes created after the dynamic relaxation where shattered into smaller counterparts. These are analyzed, optimize to the wall thicknesses. After the analysis the building was realized as a feasible design solution in terms of structurability. The greatest challenge of all the building components is the tower which is described as an Adobe 2.0 structure because of its 2.5x2.5 meter base and 15 meters height.

9 Personal reflection

9.1 Jorrit

EARTHY 2020 has been a challenging project, because of its design brief and the studying circumstances. We as a project group had difficulties formulating the design question into concrete actions. At the beginning we were spending a lot of time finding out what to do and how to do it. Because of that, we were lacking behind, which did not help us during the consultations.

The consultations itself were mostly useful, however, putting the feedback of five different teachers into work was not always doable. Therefore, it seems that we did not listen to the feedback, but we just focused on different aspects.

The role of computational design was not clear from the start. Most lectures and workshops were focused on it; however, it was not mandatory to be used in the project. For me, the step was too big to learn a new program language while it was not mandatory.

It was a pity that the brick making workshop was cancelled, because the material aspect was the reason I chose EARTHY. I would have liked to have more lectures about adobe, how it is made, what to do with it and the structural aspects of it.

To conclude, I am proud on the result and think we made a realistic building which is a positive addition to the Za'atari refugee camp.

9.2 Daniel

EARTHY 2020 has been an interesting project for me since it forced me to think out of the box and we had to work with materials which I had never worked with before.

Working with adobe was for me the most fun part of the project, especially researching how to construct with it. The construction part was therefore also the main focus for me this project.

As a group we worked well together even with the circumstances of Covid-19. It was good that we had one person that was kind of the manager and checked constantly whether we were at schedule or not.

We had a bit of a slow start since we had to find out where we wanted to lay the focus on in the project. None of us had much experience already with computational design. Therefore it was not obvious for us what to do in the beginning and what are strategy would be.

I learned a lot from the consults, especially because we had many and with the focus on different topics of the project. At the same time it was sometimes confusing for us as a group where to lay the focus on, since we had so many different feedbacks every time.

As conclusion I'm proud of the result we have made as group and I learned a lot about designing with adobe.

9.3 Timmo

I choose EARTHY over SWAT because of the personal learning goals I set for myself when starting the master track Building Technology. My main learning goal is to dive more into topics regarding computational design. Although I am relatively new to this topic, this course helped me to spent more time learning about it. I value this learning curve greatly and think it is a great foundation to continue building upon. It was challenging at times to focus on a single task, simply because there were so many topics I would like to learn more about, i.e.: basic Python and agent based modeling.

The teamwork did run quite smoothly. Regular zoom work sessions and weekly structured meetings helped to divide tasks and work on the project.

In conclusion, I am happy with the final result and glad to be able to focus so much on learning more about computational design.

9.4 Isidorus

Earthy 2020 was something new for me. It was a good introduction to Python but I wish I could have used it more efficiently in the end. I expected to learn more about it during the past 2 months but I realized that in such a small period of time it couldn't work for me. When we started scripting and studying it we got feedback that we need to take a few steps back and change the floorplan which kind of took some time for us. It wasn't clear from the start on how we should incorporate computation in creating the floorplan apart from the bubble diagram. We tried to follow the steps of Group 1 (2019-20) in the configuration phase with the Kangaroo simulation and the magnet components but that didn't work out as expected so we decided to make it manually and give a computational edge on later phases of the project (tessellation, dynamic relaxation, etc).

The collaboration with my teammates went really well. I m really happy about that because even though there was not physical contact in the faculty we managed to stay in the group zoom meetings even for the whole day, which felt like we were working together. We assigned tasks amongst each other and there was always someone that checked that the final product is presentable and coherent in the end.

I m very delighted with the final result because it looks like we produced something feasible and well constructed. The architectural aspects of our project have a good quality!

9.5 Lama

Earthy is the course that I Looked forward doing it since the beginning of my master studies because it represents the traditional architecture of the Middle East. Furthermore, it gives sustainable solutions that use locally available resources and materials to address the needs of the people in Al Zaatari camp and that helps in reducing the building costs.

From this course I learnt new techniques to construct a compression-only structure using only earthy material with making sure that it is structurally functional, and it is possible to be built by low skilled labour.

However, because of the Covid-19 circumstances the course this year was done online which was a challenge for us as a group and things took us more time to be done than expected and we had difficulties translating the design assignment into a concrete final product.

In my opinion I believe that only two months was not enough for me to reach the goals that I aimed to achieve in this current circumstances.

Furthermore, Feed backs were mostly useful, and I totally understand the importance of them whether they are negative or positive. However, I think some of the feed backs were too strict and did not considered the effort that we put in order to create this design and it reduced our motivation in this course.

Overall working with Isidoros,Timmo, Daniel and Jorrit was great and learnt a lot from them. we were will organised group and I am proud of the final result that we achieved.

Thank you for reading!

10 Reference list

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