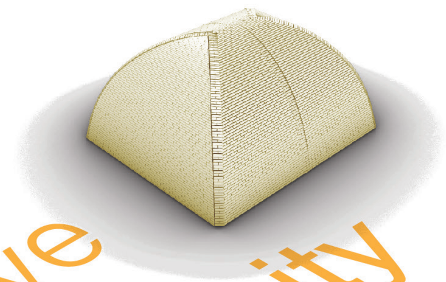

Adobe Creative Community

A Skill Based Community Center

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Contents

1 Introduction

The Syrian conflict in 2011 caused a large population to migrate from Syria to Jordon. To facilitate these massive populations, the Jordanian government has set up refugee camps which are a temporary solution (REACH, 2016). However, since 2011 the camp of Al Zaatari, Jordan, with the help of non-government agencies is developing to provide better habitat. Although because of the temporal nature of the camp, the current environment of these habitats is container boxes and makeshift tent structure which does solve the practical needs but lack humanitarian needs.

However, the struggle for refugees is multi-dimensional. The Syrians face a lot of humanitarian problems which does not support a good quality of life. The Youth sector of the camp ranging between 15-35 years holds the highest pressure to support their family and themselves. The employment opportunities are limited due to lack of facilities inside the camp. Due to this, the youth are forced to move out of the camp and work illegally. To improve the situation, it is imperative to understand the present condition of the youth population of the camp.

1.1 Problem Statement

According to American psychologist Abraham Maslow, every human being has five basic needs such as physiological, safety, belonging, esteem and self-actualisation (Hopper, 2019). This theory which is also known as Maslow's pyramid very well explains how these basic needs motivate people to climb up the ladder and fulfil their own needs to achieve a better quality of life. However, the Zaatari Camp only provides the physiological needs to the Refugees but lacks in facilitating or providing the other needs (Figure 1.1).

The youth of the camp need a platform to achieve safety in terms of employment and belongingness in terms of socio-cultural acceptance so that they can achieve their sense esteem back on their own after that. Therefore, a skill development centre focusing on skills and cultural development of the youth refugees can give the Youth Force of Zaatari a platform to become independent and develop their own identity.

Since the skill development centre must become a dynamic platform for the Youth population of the camp; it should also implicate an architectural language which belongs to Syria. The Adobe buildings made from earth has a potential of solving the functional and comfort requirements of the habitants. Since the refugee camp is in an arid region with an abundance of materials for adobe, this construction technology can be a better alternative for making temporary buildings which can also be developed by the people using it.

However, due to the lack of resources in the camp, it is imperative to understand that the adobe structures would be compression-only. Therefore, the design of the skill centre needs to respond structurally along with its activities and users. The structure will be the consequence of the many boundary conditions and restrictions set by the context and functionalities that must be incorporated as well as the available skills and manpower which can be achieved within the camp.

1.2 Design Vision

The Youth of Zaatari needs a platform to learn and develop their skills so that they can support their own as well as the needs of their dependents. Therefore, the vision pertains to design a skill development centre to provide vocational and technical training to help them climb up the two steps of Maslow's pyramid of needs. The skill centre designed for the users must respond to the architectural context inspired by vernacular architecture strategies while developed using high tech tools to provide low tech solutions of the people to build the centre by themselves: High tech design – Low tech construction.

1.3 Methodology

The design process has developed through different phases, as shown in Figure 1.2. Literature research and site analysis give us a rough site zoning plan and list of functions and their spatial requirements to be incorporated in the building. By means of gradient descent optimization we have created many possible layouts of the building, from which we have manually selected the most suitable and adjusted it. Next, this layout was used to research various meshing methods with the goal to reduce stresses in the structure of the building after dynamic relaxation with Kangaroo plug-in for Grasshopper. Simultaneously, material research is conducted on various mixtures of Adobe brick compositions to create bricks with increased compressive strength. The results of testing the brick's mechanical properties were used as input for analysing meshing results with Karamba 3D. Different structural solutions were chosen for different parts of the building, depending on their function and load cases. Lastly, the final obtained structurally optimized meshes were translated from continuous shapes into discretized shapes, so they could be built with discrete brick elements by the youth of Zaatari and with help of minimal supporting tools and materials.

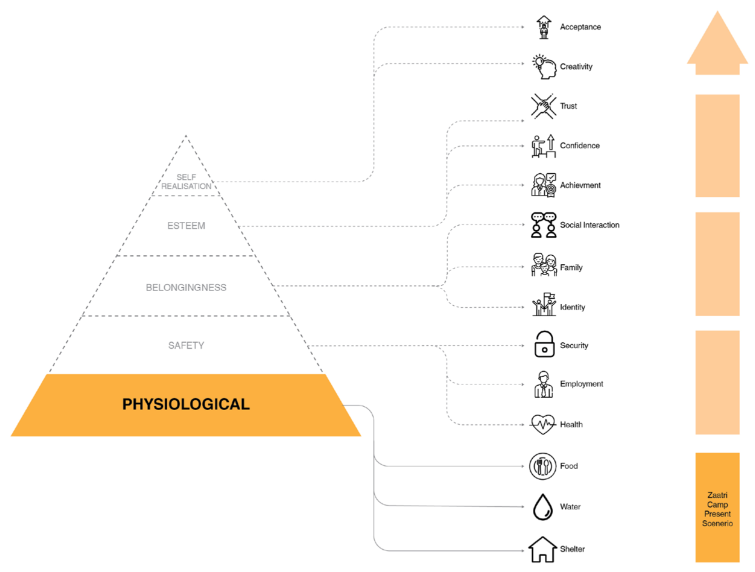


Figure 1.1 Maslow's Pyramid and present concern of basic need in the camp. Source: Authors.

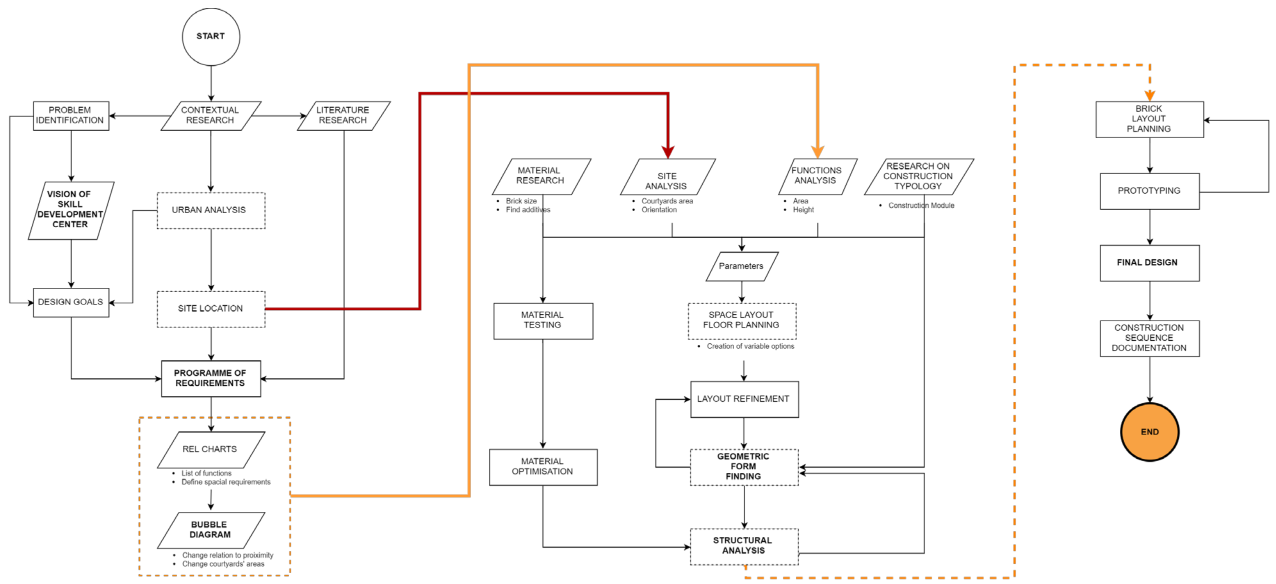


Figure 1.2: General Flowchart of the design process. Source: Authors.

2 Research & Analysis

2.1 Anecdotes

The Syrian conflict which started in 2011, has spanned eight years. Given the prolonged nature of the scenario the Youth ranging between 15-35 years are facing challenges regarding education, emotional growth and secure source of income to teem their families. The various Humanitarian agencies like UNHCR, REACH and so on are focusing on the Youth to provide opportunities to develop physiological, educational and skill-based needs (REACH, 2016).

However, the Youth both male and female has primary concern of accessibility of these community-based facilities on an urban scale (Figure 2.1). The primary reason can be narrowed down to distance, security and overcrowded nature of these centres. Therefore, it was imperative to analyse these problems on urban scale.

2.2 Urban analysis

2.2.1 Population Distribution Map with Youth Community Centres

For the purposes of site analysis and determining the potential location of the new Skill Based Community Center, distribution of youth population through the camp was prepared. Based on research data (REACH, 2015), the number of youths between 19-29 years old per each camp's district is represented on the map. Each dot represents one person. This step is crucial to correctly understand how the camp works and how it should develop in the future.

Currently, Al Zaatari Camp has 12 Youth facilities, ranging in size from 1294m^2 to 21393m^2. Although the presence of multiple available functions in the camp, it was not possible to assign them to a specific building. Further site analysis assumes that every facility provides all available functions and afterward they are considered as equal.

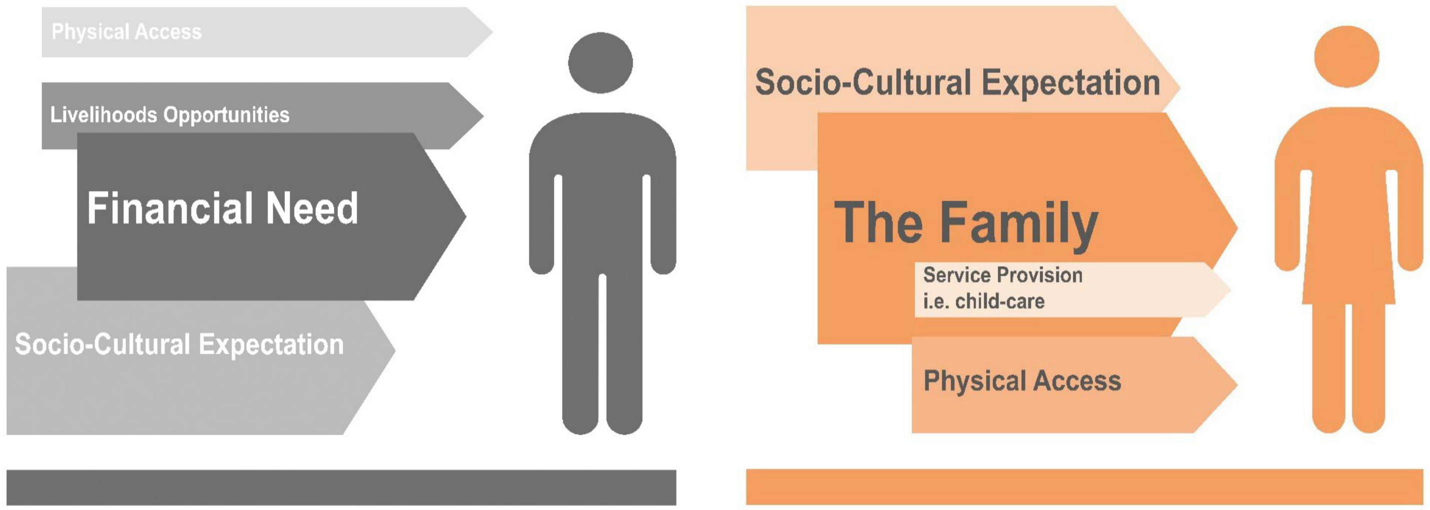


Figure 2.1 Intersecting factors for both male and female youth affecting access to existing youth centres. Source: REACH, 2016

2.2.2 Existing Coverage Map

An urban area that is considered to be in close proximity for pedestrians falls into a region that can be represented by a circle with a 400m radius. For the average pedestrian 400m distance in an urban district can be accomplished by 5min walk (REACH, 2015). To determine how many youths have more than 400m to the closest facility, Existing Coverage Map was made (Figure 2.3). Each circle with a radius of 400m represents one building where the centroid of the facility serves as a centre for the circle region. Union region of created circles, when overlapped with Figure 2.2,

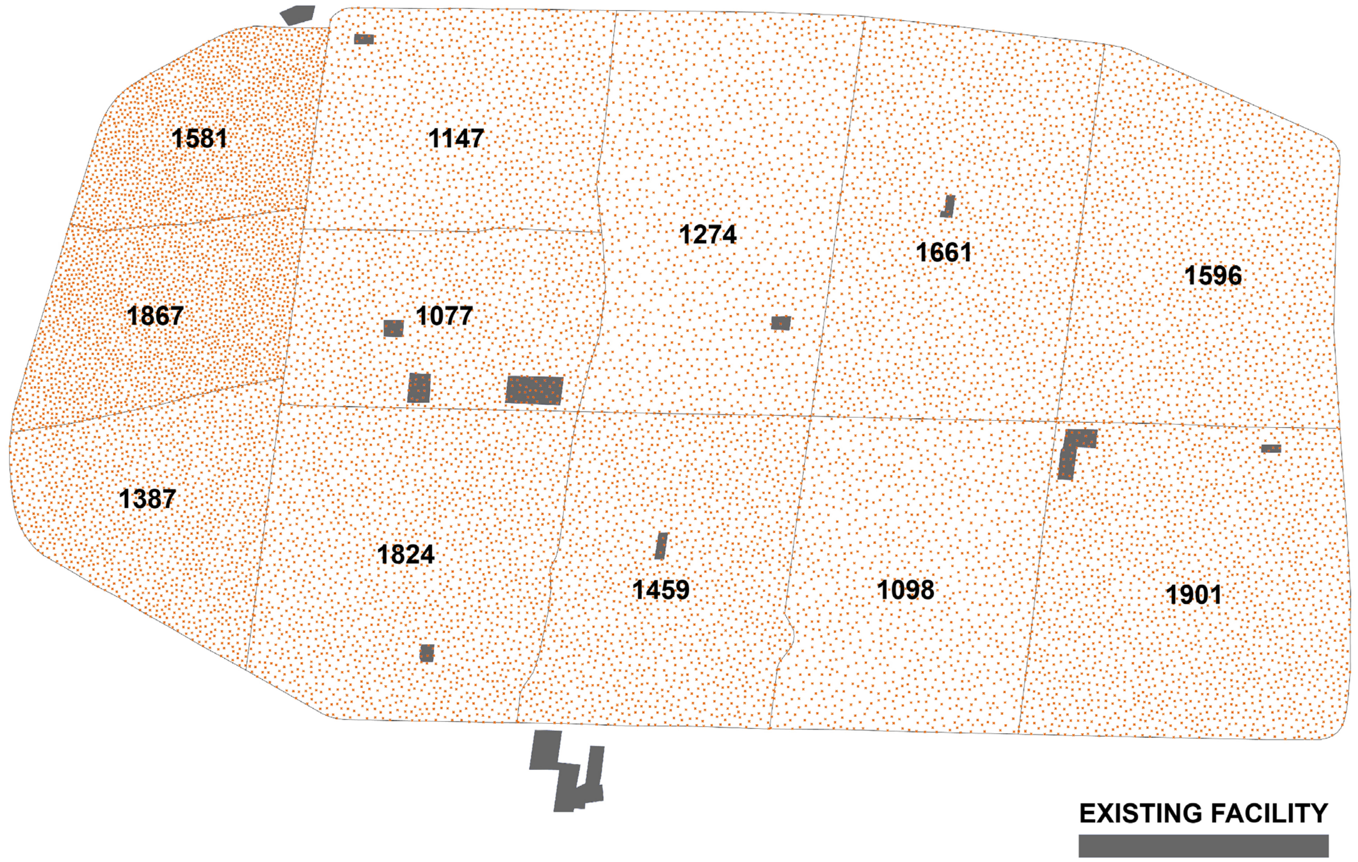


Figure 2.2:Population Distribution Map. Source: Authors.

determines the number of youths who live further than 400m from the closest youth centre.

Figure 2.3 shows that 45% (7987) of the youth population does not live close by any of the youth community centres. Those youths face a distance problem, which is defined as one of the main obstacles to discouraging them from participating in any youth community centre activities A large distance is associated with the need to overcome many streets and places, which can be subsequently defined as a security problem. This is a significant indicator for the youngest youths and female youths who are highly exposed to sexual harassment (YOUTH TASK FORCE MEMBERS, 2018)

2.2.3 Existing Stress Map

In addition to the distance and security problem, one of the most meaningful issue is the capacity of the building. If the facility is located in a highly dense part of the camp or is isolated from other facilities, most likely it cannot properly serve its function.

The Stress Map (Figure 2.4) shows a better understanding of this problem. The map is based on the Voronoi diagram and represents the area of camp with the smallest distance assigned to each of the youth community buildings. When Stress Map with Population Distribution Map, it is known how many youths belong to each facility. To calculate the current capacity (C) of each facility, equation 2.1 calculates the current capacity (C) of each facility, with an assumption that 60% of youths are unskilled.

$$C= A/(N*0.6)$$

Equation 2.1:Formula to calculate the capacity of each Youth Centre, where C is capacity of the building, A is the area of the facility (m2), N is the number of youths with the shortest distance to the facility. Source: Authors

The rule of 5-10 m² of the building per person was set as satisfactory and desirable for optimal use of the facility.

2.2.4 Urban Design Goals

From the analysis of youth centres with regards of coverage and capacity, it was possible to deduce the following 3 main urban problems:

1. Distance: 45% of the target population has more than 400m to the closest facility

2. Security: Most of the existing facilities have no access to main roads or public spaces

3. Capacity: 8 of 12 existing facilities serve less than 5m² per person

Those problems were directly translated to design goals:

1. Distance: To place a youth centre within walking radius of 400m

2. Security: Youth centre need to be located in the vicinity of public spaces and main roads

3. Capacity: Each youth centre aims to meet the requirement of 5m² per person

2.2.5 New Theoretical Locations

To reduce the impact of defined problems, theoretical regions for new youth centres were chosen manually to address the design goals. Those regions proposed are in proximity to main roads and public spaces and they should be incorporated into urban development masterplan.

Figure 2.5 shows that distance problem is significantly reduced. The percentage of youths with a distance larger than 400m to the closest facility dropped from 45%(7987) to 9%(1685).

Figure 2.6 with new proposed locations (12-17) shows that the capacity of most of the existing facilities increased. A few of them were released enough to meet the determined criteria of a minimum of 5m² per person.

The precise location of the site for a new building was found with the use of computational tools. The precise location for the new centre site was found with the help of computational tools. The image sampler component helped in identifying the empty spaces in the camp as seen in Figure 2.7 and further subdividing it into grid cells of 64m²(8m square cells).

Using the Delaunay triangulation method as explained in Figure 2.8, the existing youth centre points are divided into Delaunay triangles, ensuring no point lies inside these triangles. A new point is created at the centre of the largest circumcircle to maximize the distance from the existing youth centres. As the circumcentre lies outside the camp boundary the point is moved in using the afore mentioned design goals, the three criteria were mapped to find the most ideal location for this point:

1. Distance: The point can move within a radius of 400m.

2. Security: The point should not be farther than 50m to a public space and 10m to the main road curves.

3. Capacity: The point should have an empty space of 60 adjacent cells (3840 m²) around it. This was checked using the empty space grid cells.

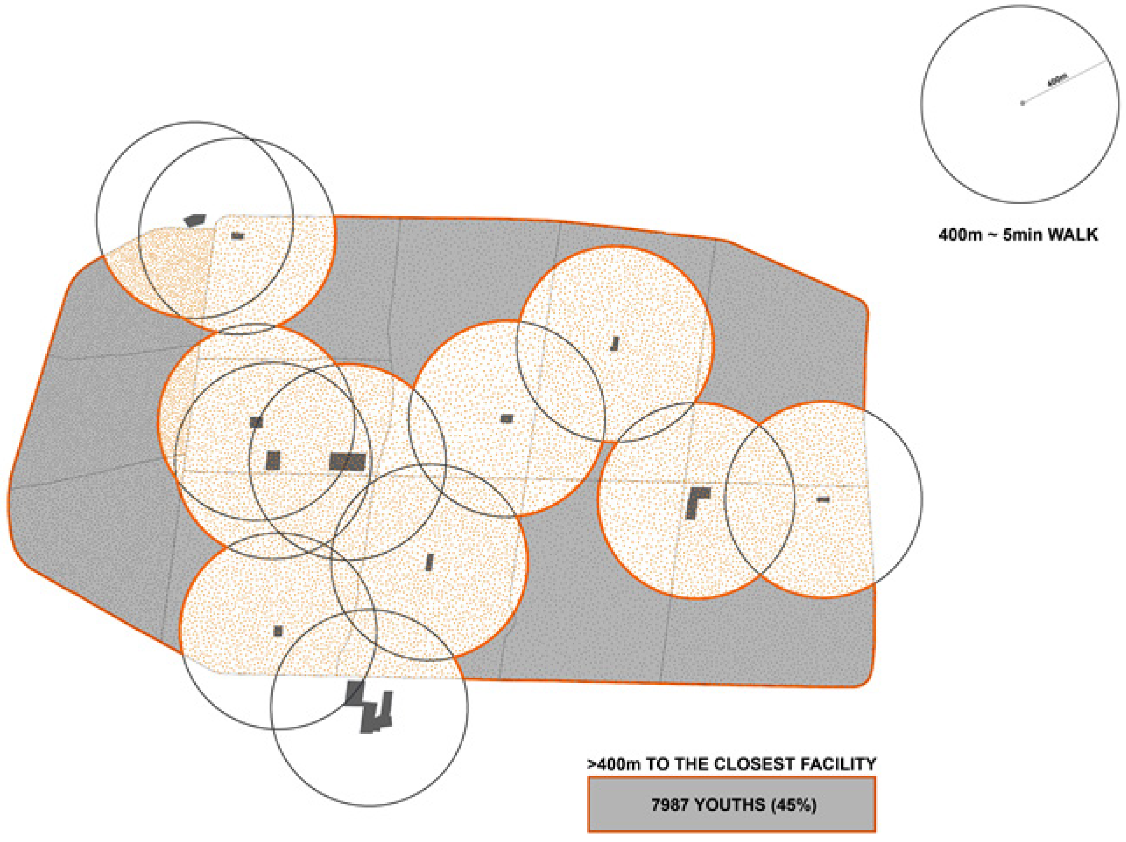


Figure 2.3:Exiting Coverage Map. Source: Authors.

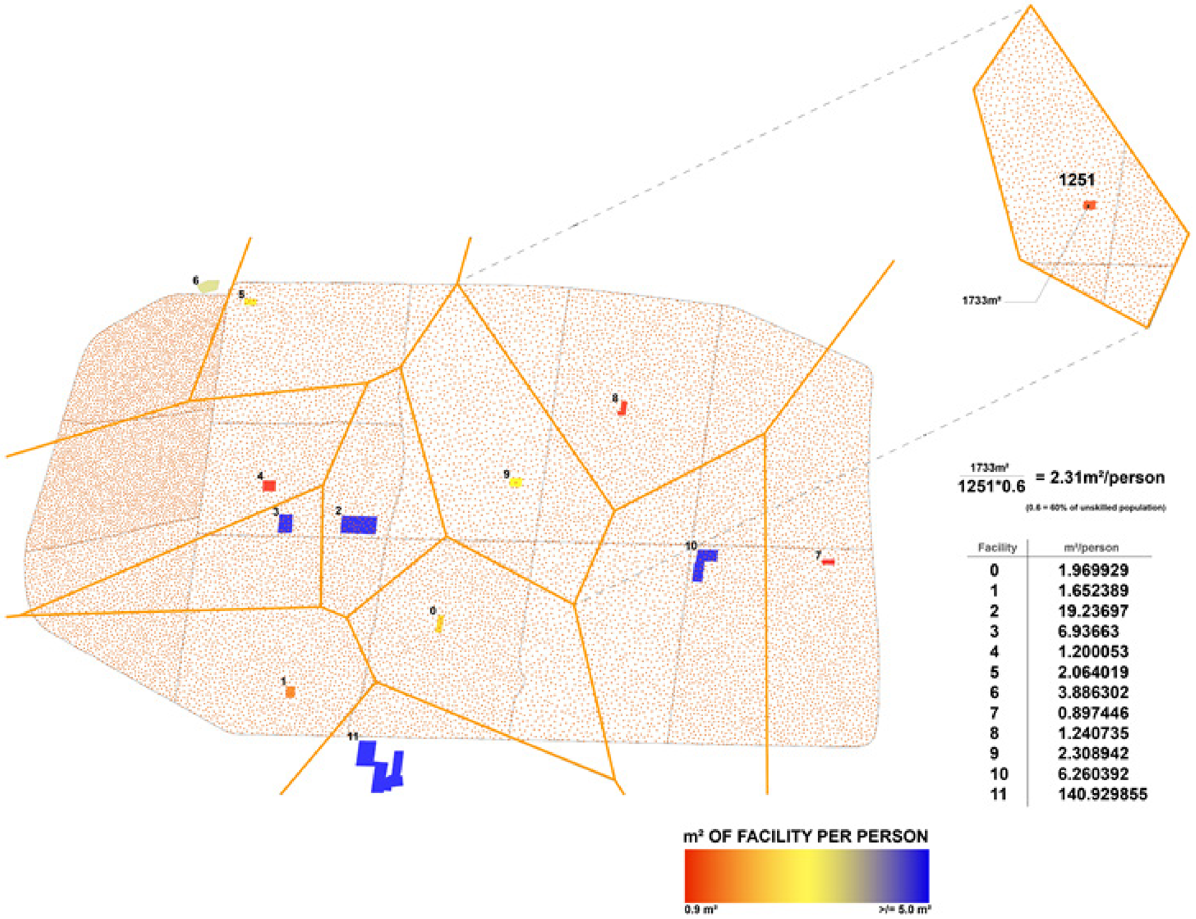


Figure 2.4: Existing Stress Map. Source: Authors.

Among these different locations, the final site (3900 m²) for the new Skill Based Community Centre is selected in the middle-south part of the camp due to its proximity to several facilities, such as a school, a clinic, a playground, several mosques, and the main road. The plot is located in a low-density area, where possible new houses will be built in future. For this reason, teaching construction techniques in the centre suits the location.

2.2.6 Synthesis

The urban analysis led to the creation of camp development guidelines.

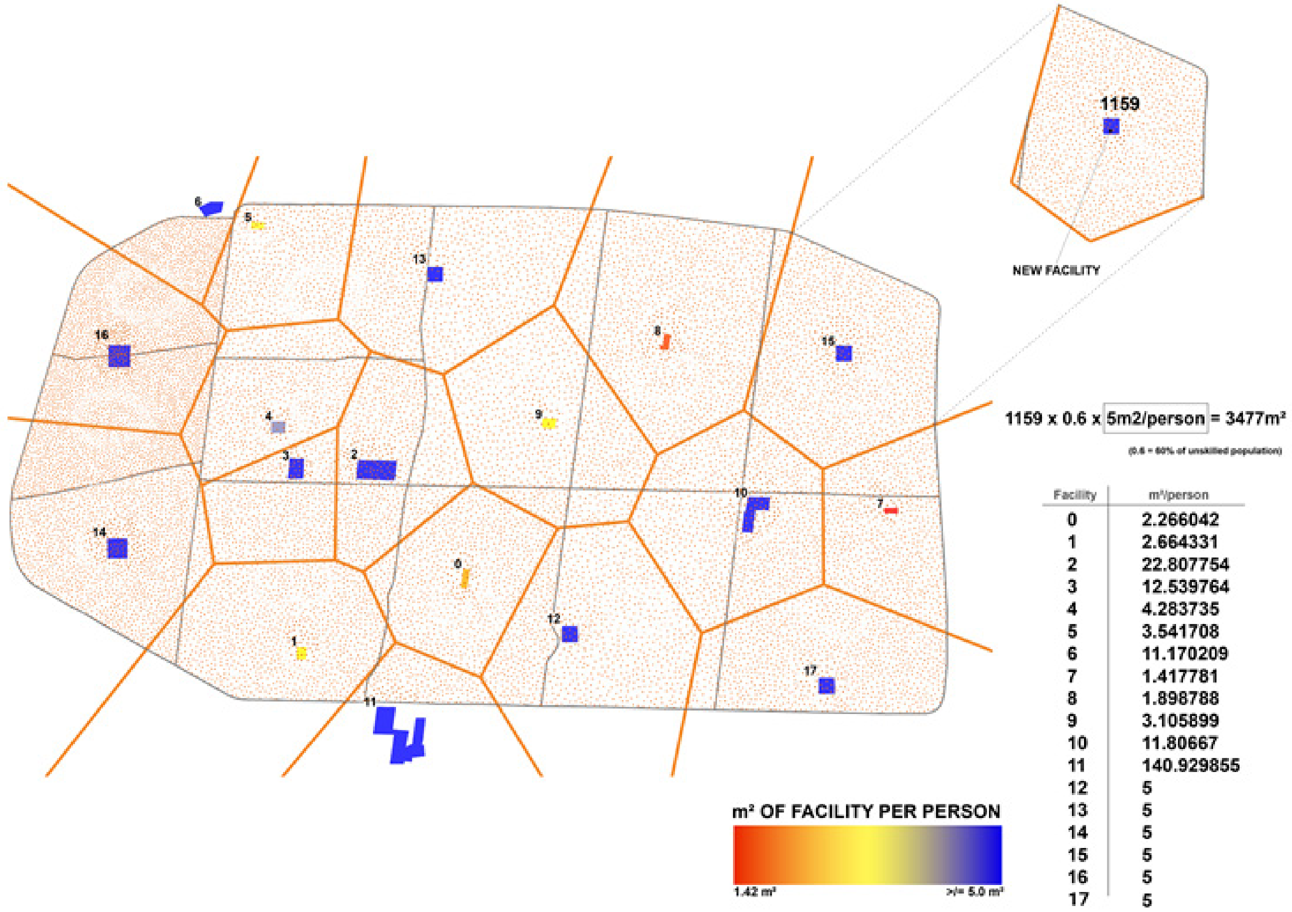
For overcrowded facilities (Figure 2.10 in red), where the population in the sphere of influence is higher than the capacity of the facility, 2 possible solutions are proposed:

- expand current facility
- introduce time slots for use of the facility

For uncrowded facilities (Figure 2.10 in blu), where the population in the sphere of influence is significantly smaller than the capacity of the facility, 2 possible solutions are proposed:

- densify sphere of influence with the youth population
- introduce more functions to the

Figure 2.5.New Coverage Map. Source: Authors



Facility	m²/person
0	2.266042
1	2.664331
2	22.807754
3	12.539764
4	4.283735
5	3.541708
6	11.170209
7	1.417781
8	1.898788
9	3.105899
10	11.80667
11	140.929855
12	5
13	5
14	5
15	5
16	5
17	5

Figure 2.6.New Stress Map. Source: Authors.

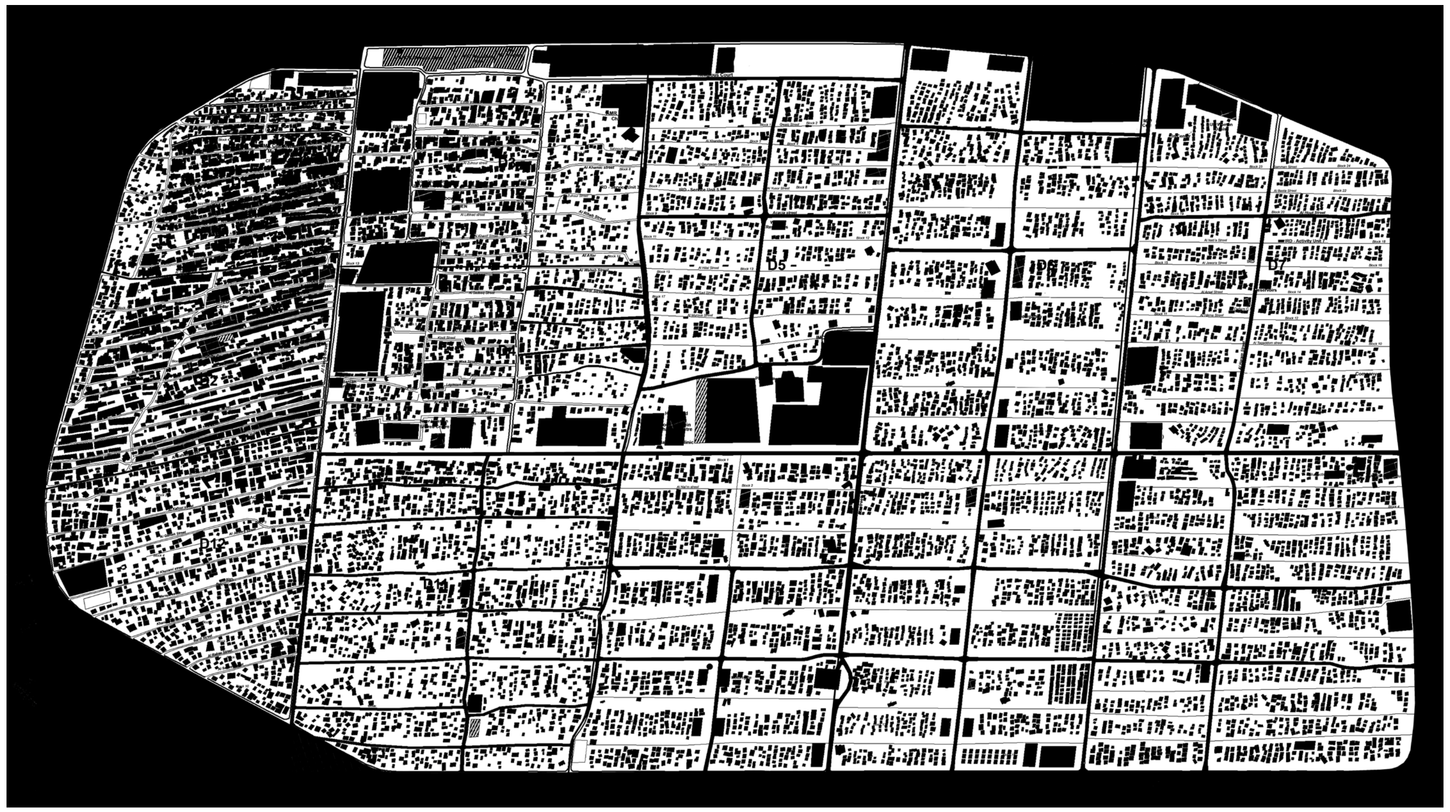


Figure 2.7: Image Sampler Map

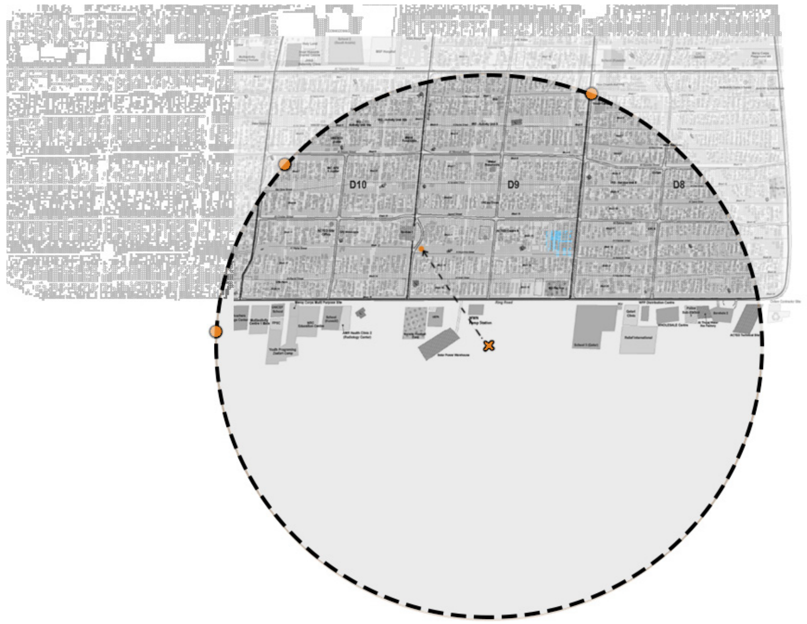


Figure 2.8: Circumcentre using Delaunay Triangulation method

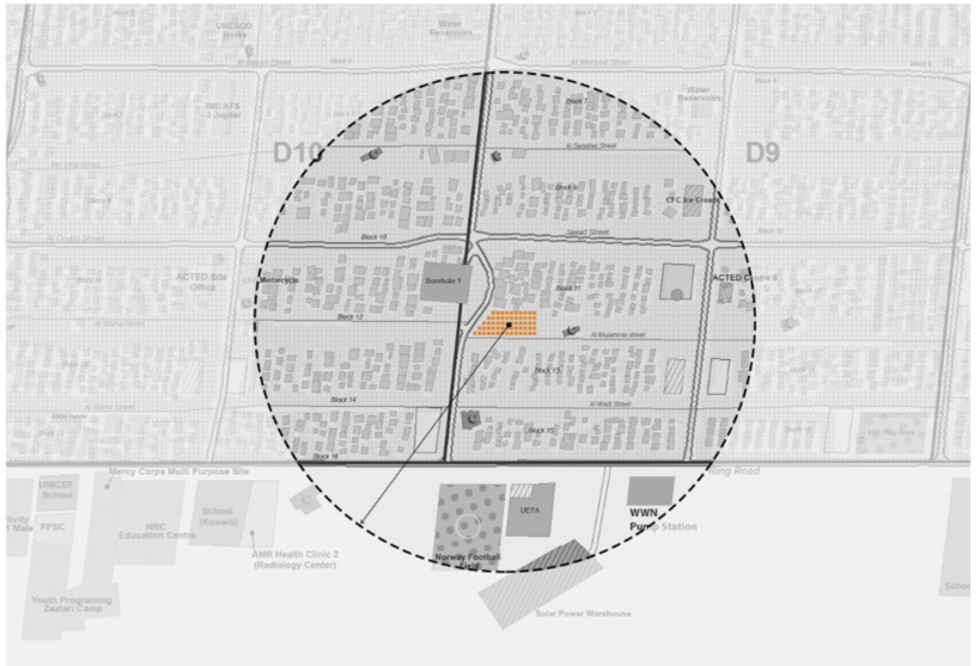


Figure 2.9:Final Location Map Source: Authors.

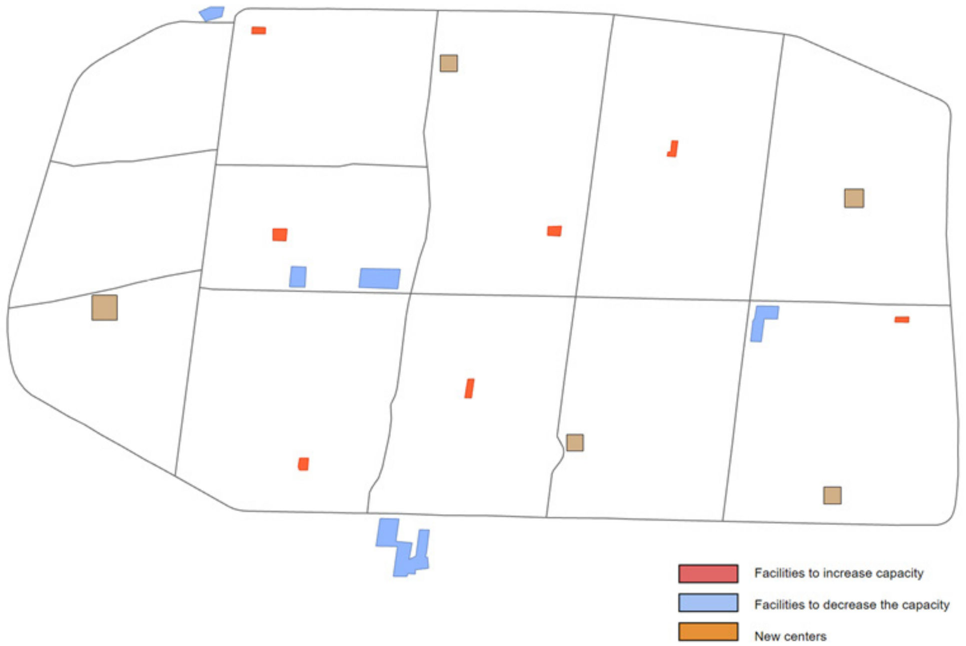


Figure 2.10.Camp Development Map. Source: Authors

2.3 Architectural analysis

2.3.1 Architectural Language

The Architecture language of the community centre can largely influence the connection of the building with its inhabitants. Therefore, it was necessary to replicate the same architecture language of Syria into the centre so that the users feel at home. The traditional Beehive architecture of Aleppo, Syria speaks a lot about the building language a community space must-have.

The presence of courtyard dictates the arrangement of spaces around. The courtyard planning is significant with regards to climatic aspects as well. The areas are grouped and kept adjacent to the courtyard. Through this, the analysis of the form and the adjacencies of the spaces were understood. This analysis was taken forward while configuring and forming of the user spaces.2.3.2

Figure 2.11 Traditional Beehive Architecture of Syria. Source: Syria NewsDaily, 2019

2.3.2 Site Analysis

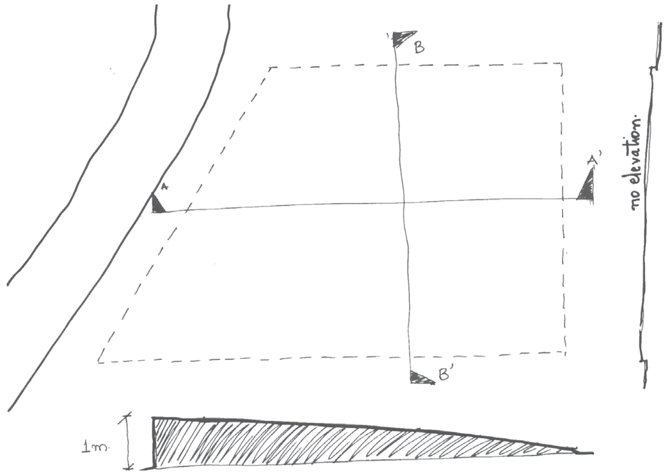
On the preliminary stage of design, the chosen site was analysed based factors to understand the nearby context, climate, pedestrian access, node of access, so forth. The parameters are illustrated in figure 2.12.

2.3.3 Site Zoning

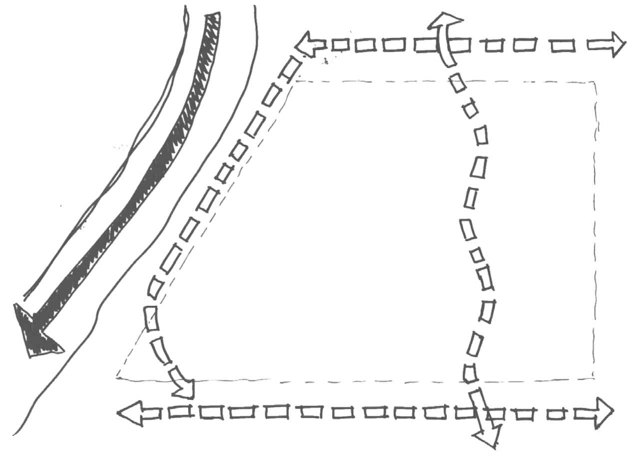
The site analysis helped in understanding the site planning of the project. From the architectural study discussed in section 2.3.1 Architectural Language, it was evident that the courtyards are the driving factor for the architectural layout of the buildings in such climatic condition. Therefore, the position and size of these courtyards were determined as the initial parameters which govern the architectural planning of the skill development centre (Figure 2.13). Figure 2.14 shows a schematic layout of different type of spaces based on the analysis of the site.

2.3.4 Programme of Requirements

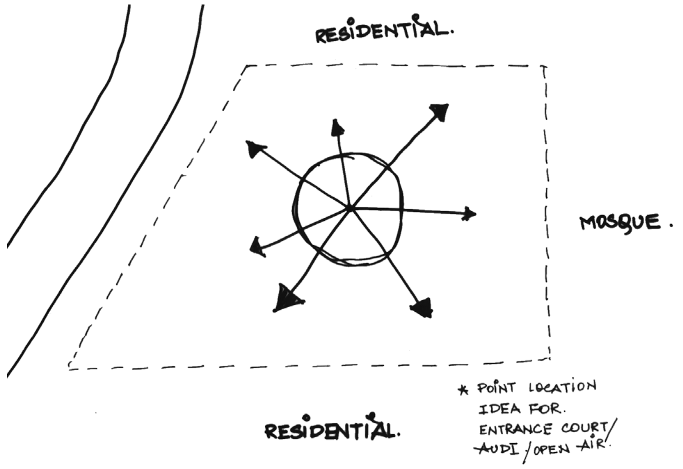
The architectural analysis of the site and initial review of the present conditions of the Youth in Zaatari camp it becomes evident to design a skill-based centre. However what type of activities



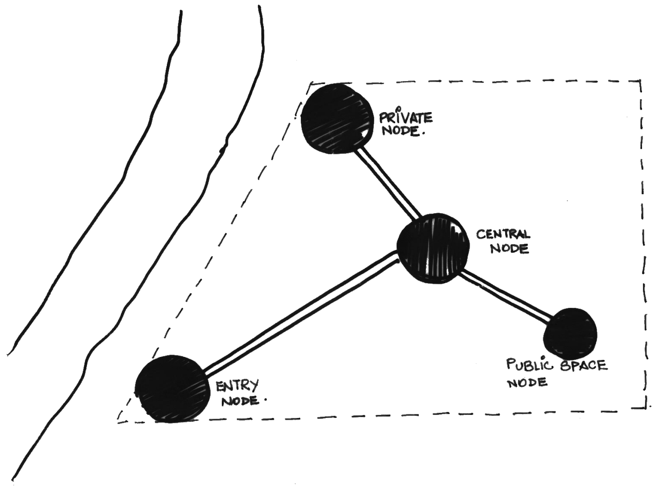
Contours



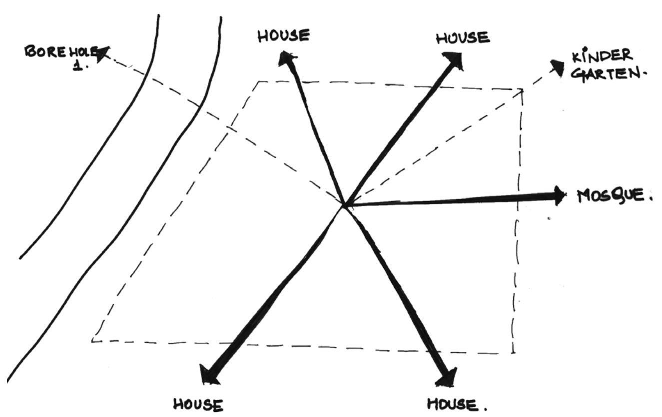
Existing Pedestrian Access



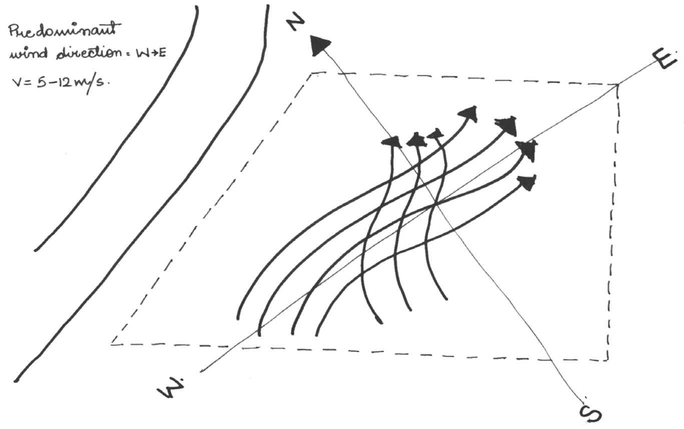
Centrality within the site



Possible Nodes on the site



Immediate Views from the site



Climate analysis

Figure 2.12 Parameters for site analysis. Source: Authors

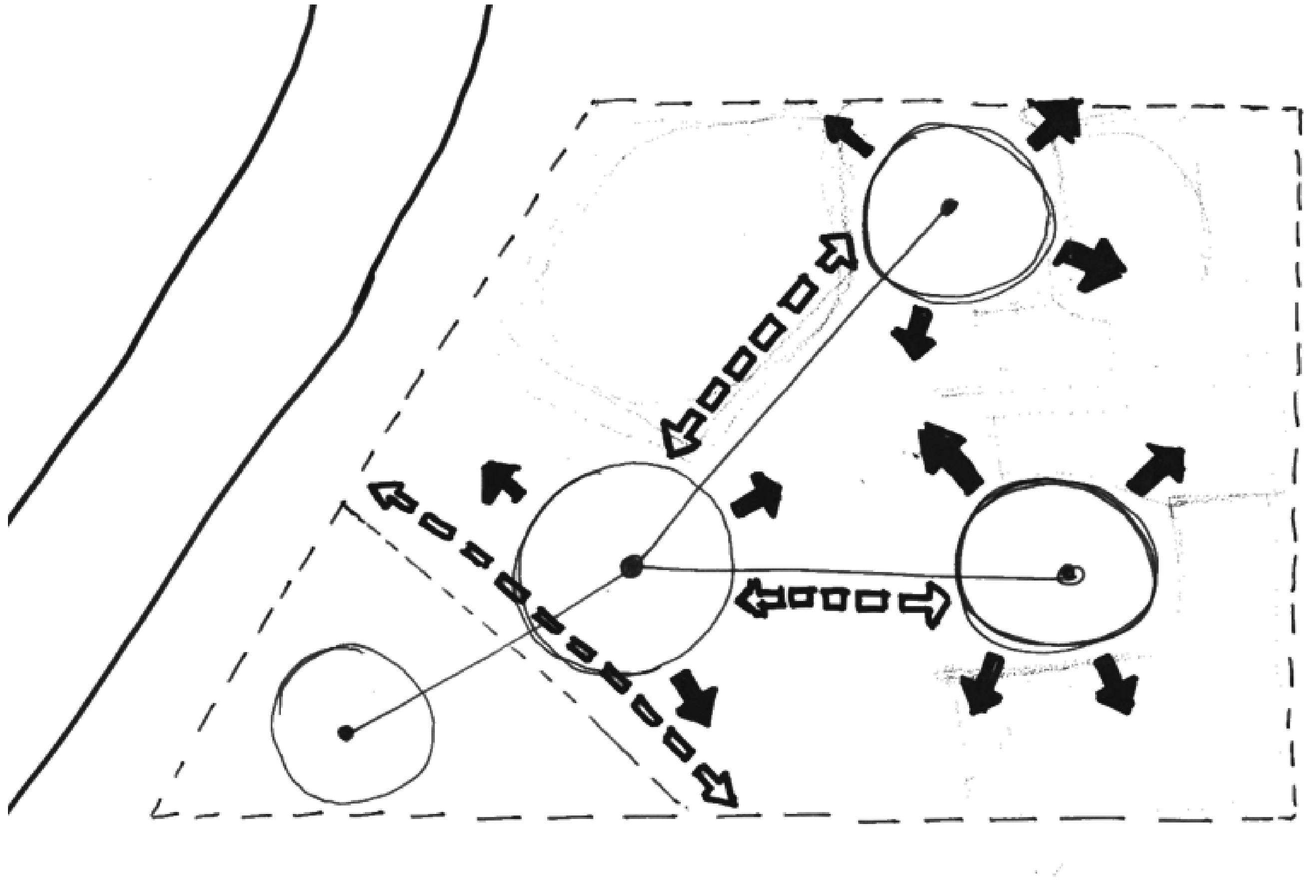


Figure 2.13 Size and location of the courtyard as layout generating factors. The position of courtyards can be estimated by the analysis of the nodes namely entry, public and private nodes over the site. Source: Authors

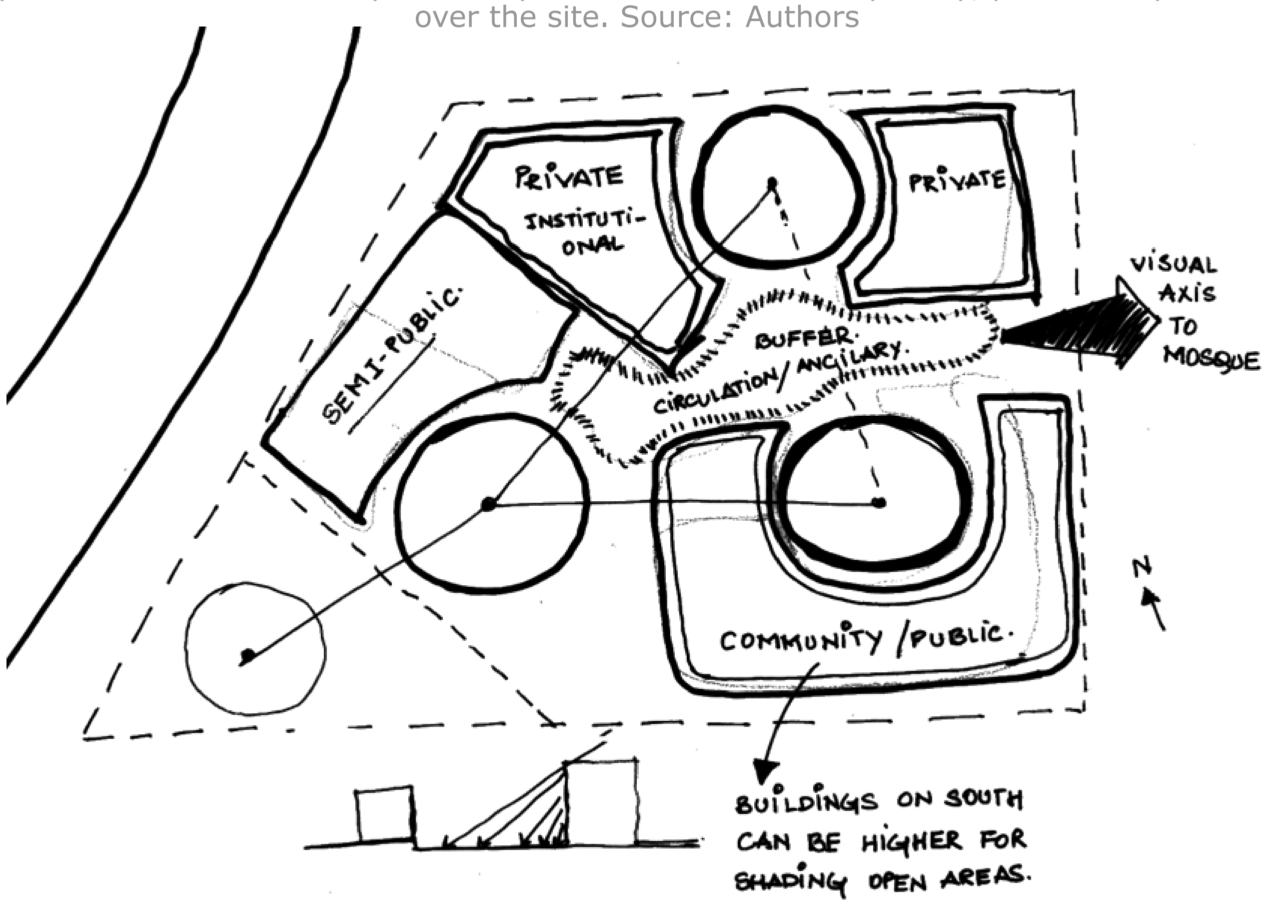


Figure 2.14 Site zoning showing connections between courtyards, adjacent type of areas and different nodes. Source: Author.

should be included into the programme was depended upon the location of the Skill development centre in the camp. The requirements of the skill development centre also should satisfy the vision of providing platform to climb two steps of Maslow's pyramid. Therefore, the values of physiological, safety and belongingness were converted to the activities which could support them. These activities were then converted to architectural spaces which can help learn the skills required to achieve these values. This process is well illustrated in Figure 2.15.

2.3.5 Area Analysis

Upon determining the POR, the area of each space was calculated based upon minimum space required per person and the capacity of that space. This helped us further in configuring exercise since the area becomes a parameter of determining the basic shapes of the spaces. Table 2.1 illustrates the area analysis, minimum height required and daylight orientation of different spaces

Space	Capacity	Area Required	Type of space	Min. Height Required	Daylight orientation
	[persons]	[m^2]	-	[m]	-
Classrooms					
Type A (masonry)	60.48	20	Closed	2.9	North East
Type B (language)	60.48	20	Closed	2.9	North and East
Type C (nursing)	43.243	20	Closed	2.9	North and East
Computer Room	43.2	20	Closed	2.9	North-east
Workshop Area	155.2	50	Semi-Open	-	South
Administration					
Office	25.92	5	Closed	2.9	west
Meeting Room	36	10	Closed	2.9	west
Counselling Room	12.96	4	Closed	2.5	west
Common Areas					
Library	324	100	Closed	2.7	North east
Multipurpose Hall	324	150	Closed	3	South or south west
Childcare / Creche	50.4	20	Closed	3	North east
Ancillary Spaces					
Storage	86.4	-	Closed	3.2	south
Cleaning Room	17.28	-	Closed	2.9	south
Toilets	69.12	-	Closed	2.4	east
Pantry	12.96	-	Semi-Open	2.4	east
Gross Area	**1718.08**				
30% circulation	**396.48**				
Net Area	**1321.6**				

Table 2.1: Programme of Requirements. Source: Authors

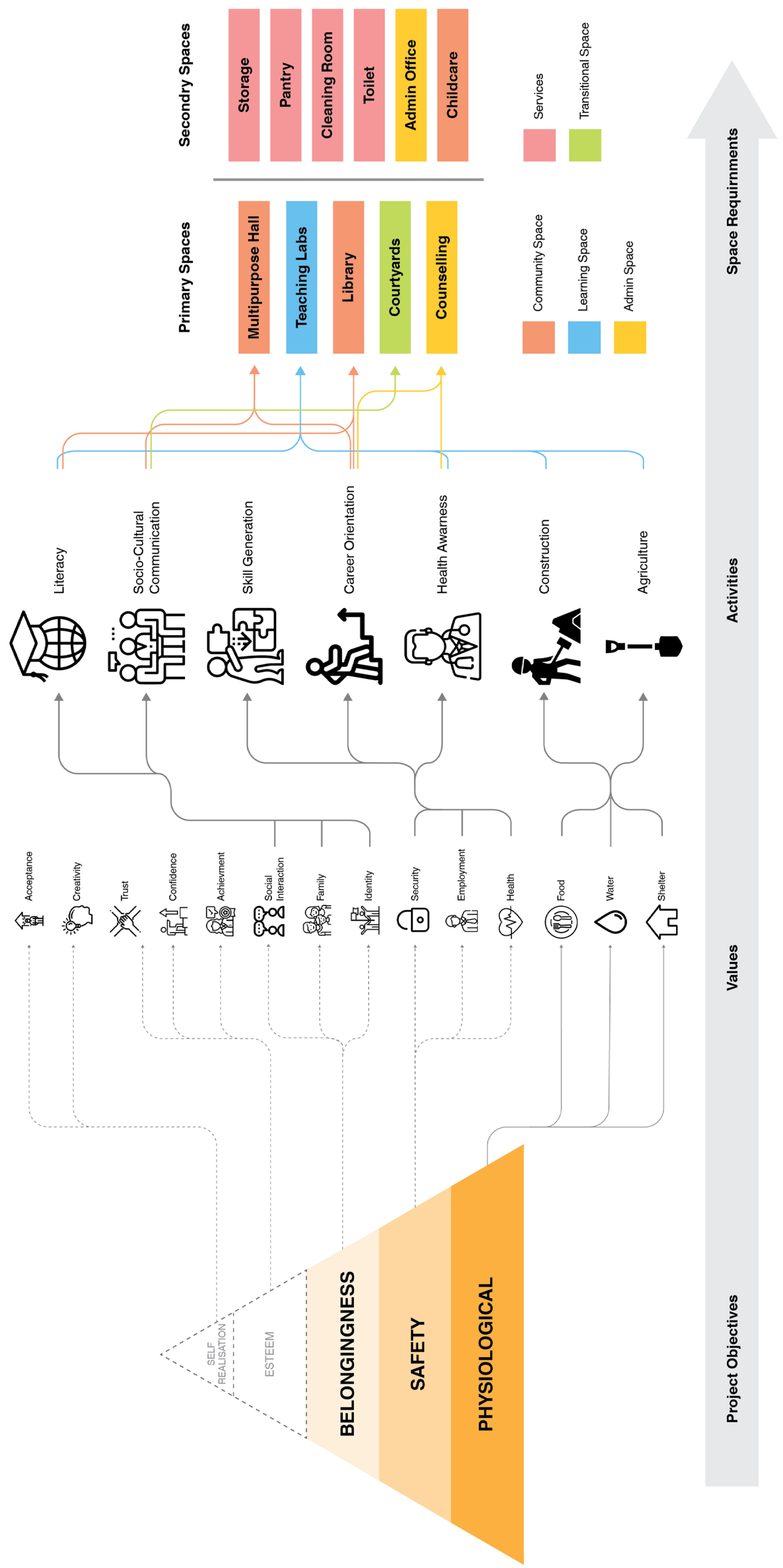


Figure 2.15 Determining the programme of Requirements from Maslow's Pyramid. Source: Authors

3 Configuration

For a project driven by strong architectural identity, the process of configuration was important. As defined, configurative process allows us to understand the relations between different type of spaces (Nourian, 2019). This spaces then can be analysed based on different parameters like Centrality, Marginality and Accessibility. Each of these parameters highlight the nuances unique to the space how it will interact in the later design phases.

3.1 Methodology

For the configurative process, the methodology adopted is shown in the flowchart (Figure 1.2). To understand the relation of spaces, bubble diagrams were made using the Synctactic plugin in Grasshopper. The inputs for the plugin were taken directly from the Program of Requirements and Rel Chart (Figure 9.1). Results of this bubble diagram were then analysed to propose changes in the connectivity and sizes of variable courtyards.

Upon the improvement in the POR, improved adjacency bubble diagram was created. This was then further fed into interactive configuration plugin based on Gradient Descent Optimization (Snyman & Wilke, 2018) which worked as shown in the flowchart to obtain the final layout.

3.2 Discussion

After the analysis phase, design objectives based on the adjacencies, orientation and connection with the courtyards were defined along with a Program of Requirements (POR) for various spaces of the building. This resulted in several bubble diagrams as shown in Figure 3.1.

Figure 3.1 Bubble diagrams obtained in Synctactic with initial POR settings. Source: Authors

It was observed that few spaces showed low centrality and accessibility. It was noted that few spaces like library and multipurpose hall can be moved to first floor for better functionality and accessibility. Thus, another iteration for bubble diagram Figure 3.2 with updated POR was performed with adjacency connections only to create better understanding of spaces. Since the spaces in bubble diagram were overlapping, it was concluded that courtyard area was too small for direct connection. Thus, the areas of courtyards were then made variable for the next step, but the ratio of courtyard dimensions were fixed based on the climatic reasons. A correlation model for was used to maintain the geometric proportions of the courtyard. This correlation model is illustrated in equation 3.1.

$$W = 1.8 + 0.65L$$

Equation 3.1:Correwlation Model used for maintain the geometric proportions of the courtyard. Where W=Width of the Courtyrad, L= Length of thr Courtyrad. Source: Soflaei, Shokouhian, & Soflaei, 2017.

Alongside this, an architectural analysis of the site on climatic and spatial aspects was conducted. This analysis lead to a general site zoning plan and the idea of formulating three types of nuclei on the site (fig 2.1.4).

For creating the layout of the different spaces of POR into the site a computational model based on Gradient Descent Optimization logic was created. Orientation (N,S,E,W), adjacencies and packing along the nuclei (courtyards) were defined as 'goals' as shown in Figure 3.3.

The optimization process showed the most relaxed state based on the goal conditions. Large spaces like Multipurpose Hall, Library were divided into small rooms to create efficient packing during the relaxation process. The whole process was achieved by using Kangaroo

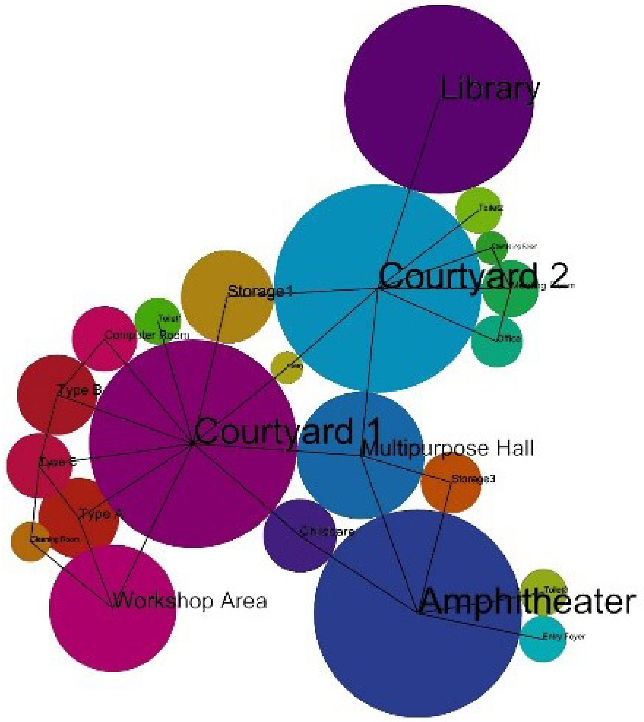


Figure 3.2 Updated bubble diagram for adjacencies. Source: Authors

Component with Python script in Grasshopper, which is depicted in the flowchart as shown in Figure 3.4.

By moving and resizing the courtyards several different layout options were generated computationally. From a preselection of 19 configurations as shown in Figure 3.5, one was chosen Figure 3.6 based on compactness, best orientation for spaces and satisfying adjacencies. The layout was then manually adjusted and improved to better fit in the predefined site grid and was given volumetric massing.

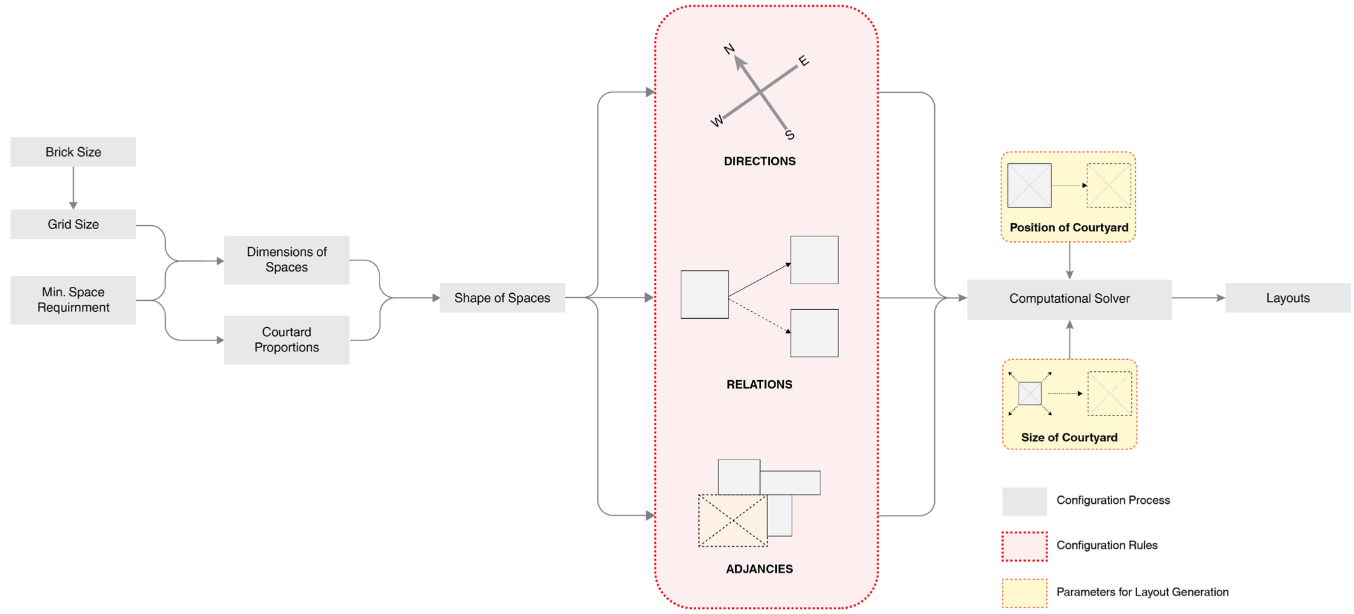


Figure 3.3 Conceptual flowchart of configurative process from bubble diagram onwards.

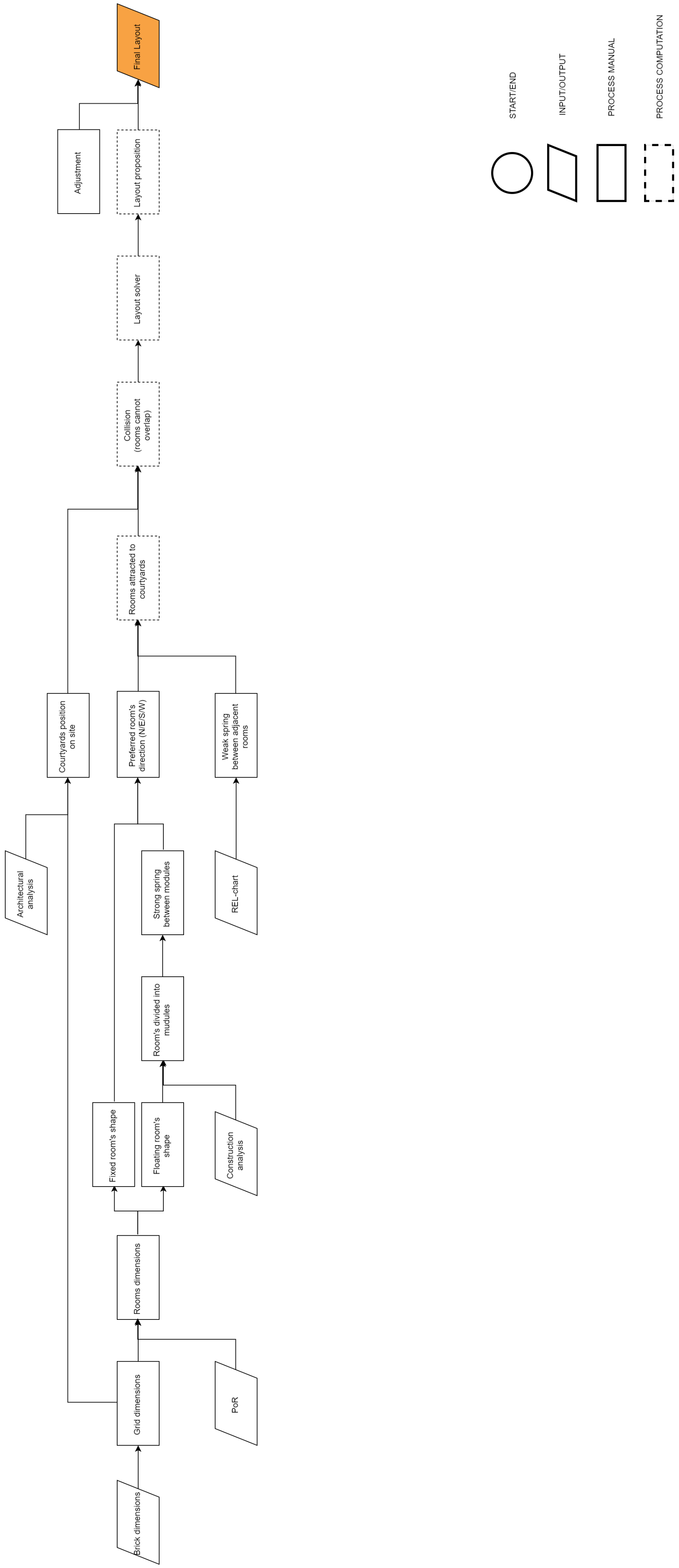


Figure 3.4 Detailed logical flowchart of Gradient Descent Optimization.
Source: Authors

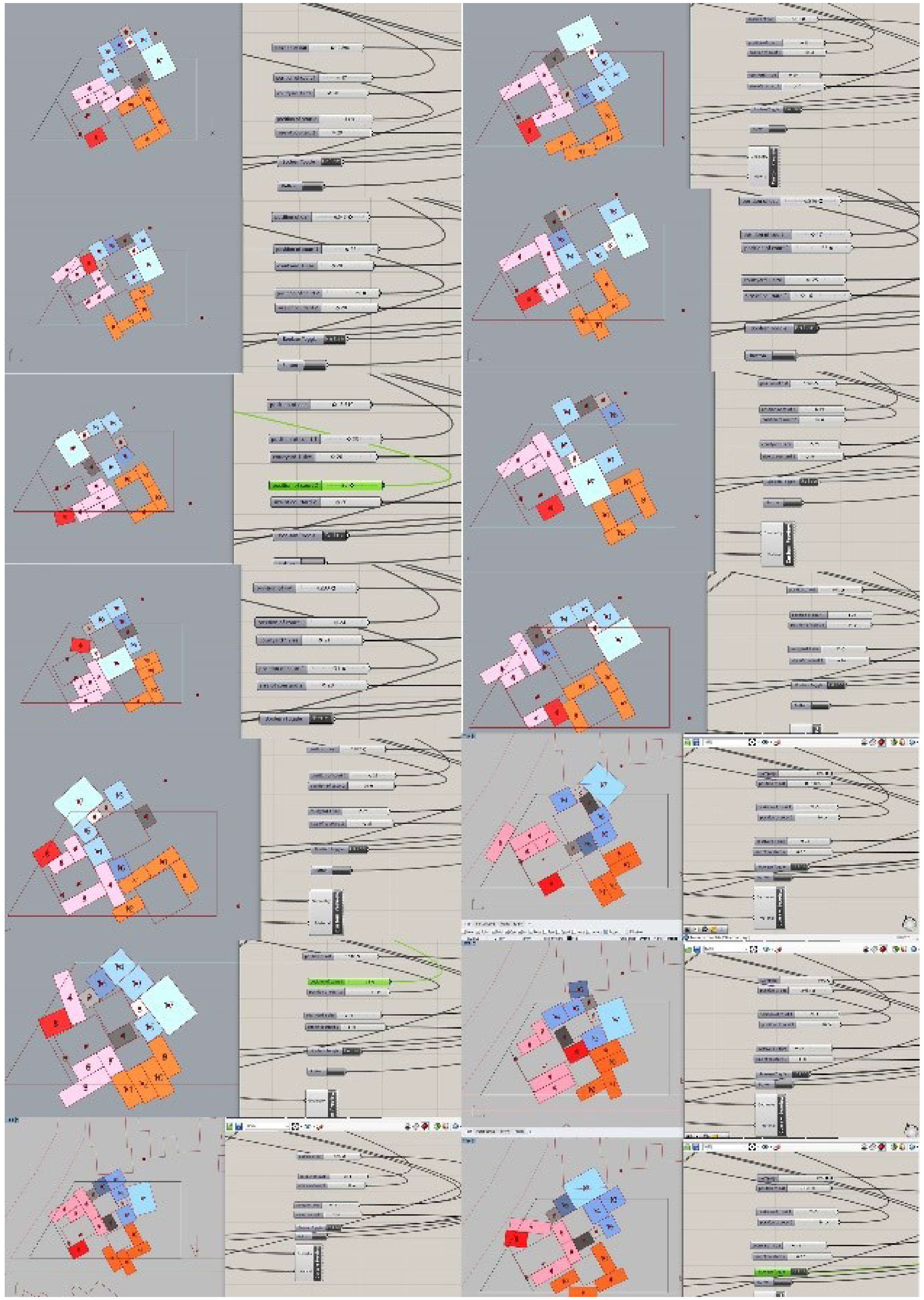


Figure 3.5 Configurative layouts obtained from the Gradient Descent Optimization.

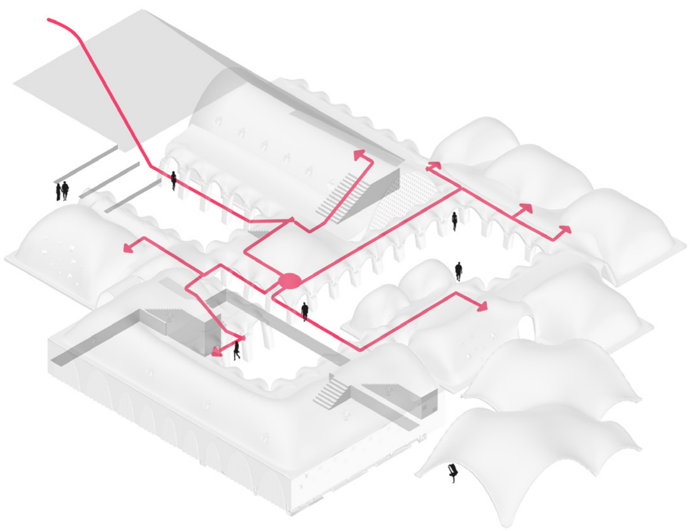


Figure 3.6 Circulation of user group. Source: Authors

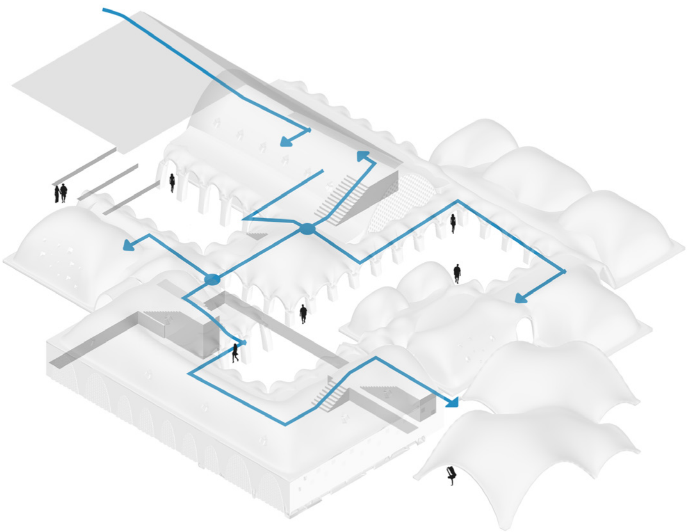


Figure 3.7 Circulation of staff. Source: Authors

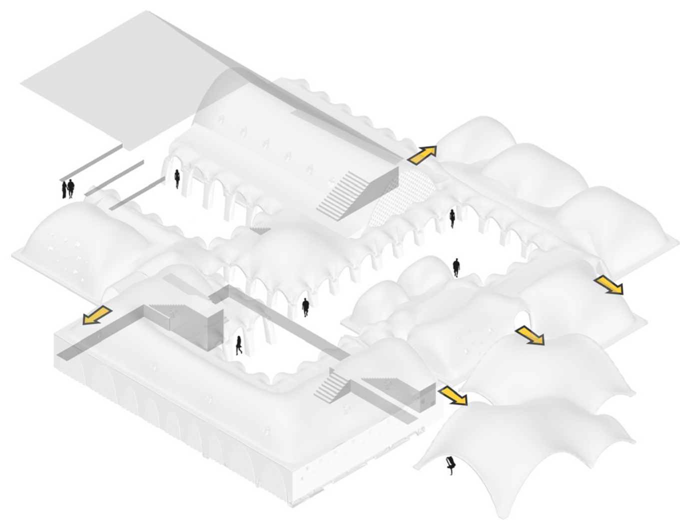


Figure 3.9 Fire Exit. Source: Authors

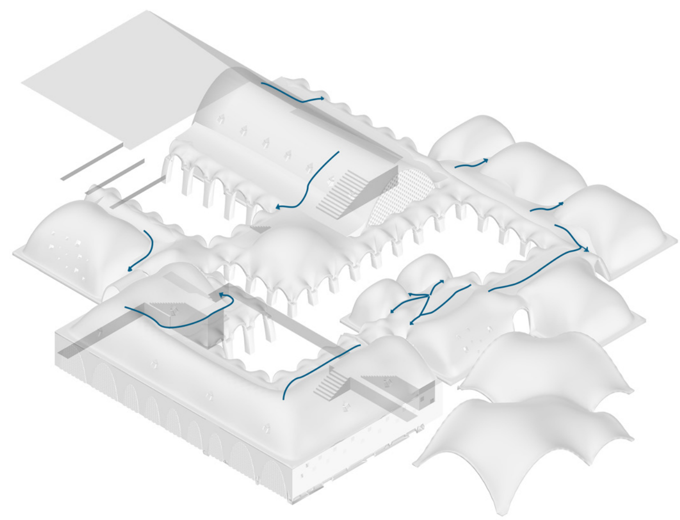


Figure 3.10 Drainage Pattern. Source: Authors

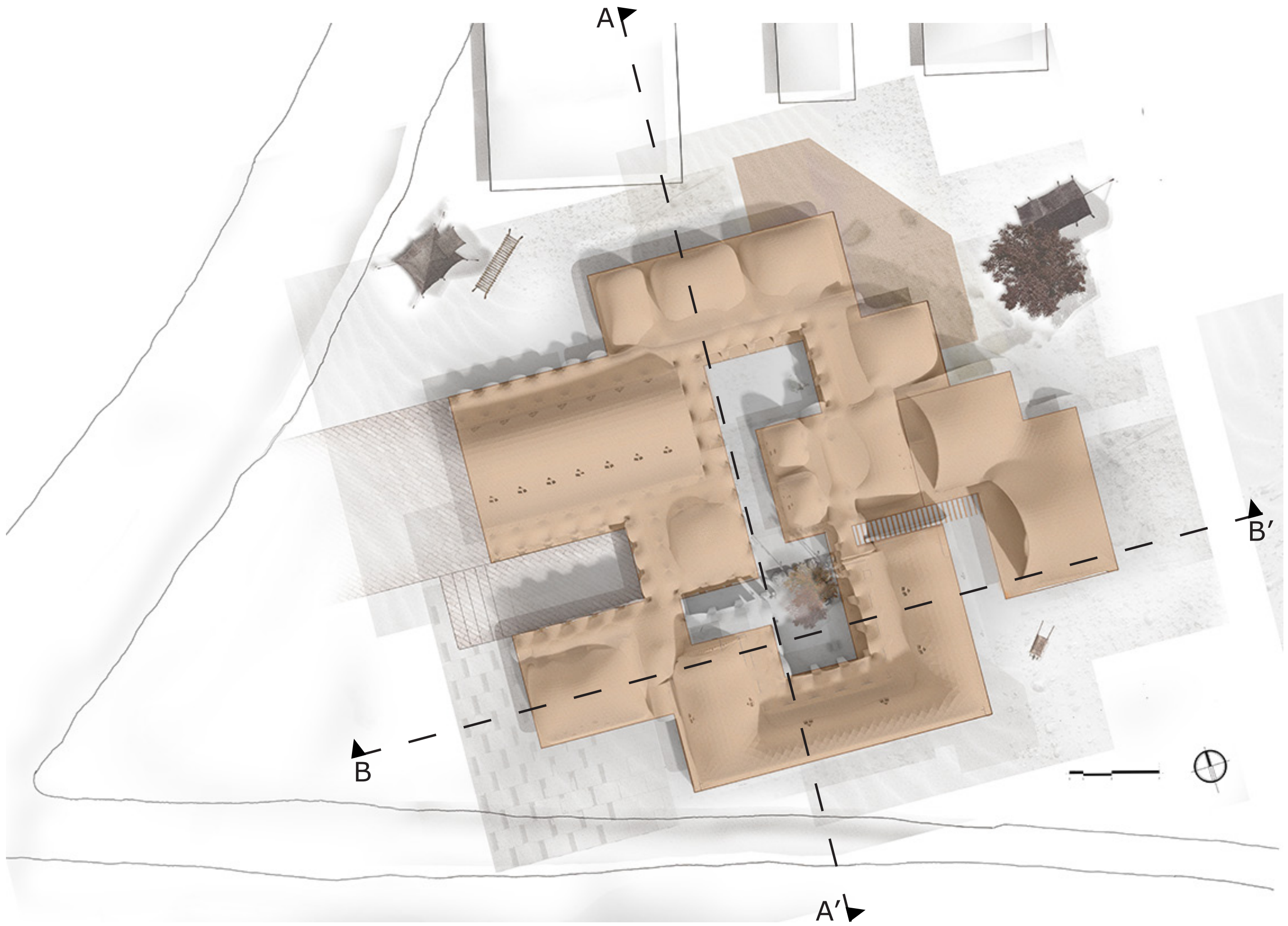


Figure 3.8 Site Plan. Source: Authors

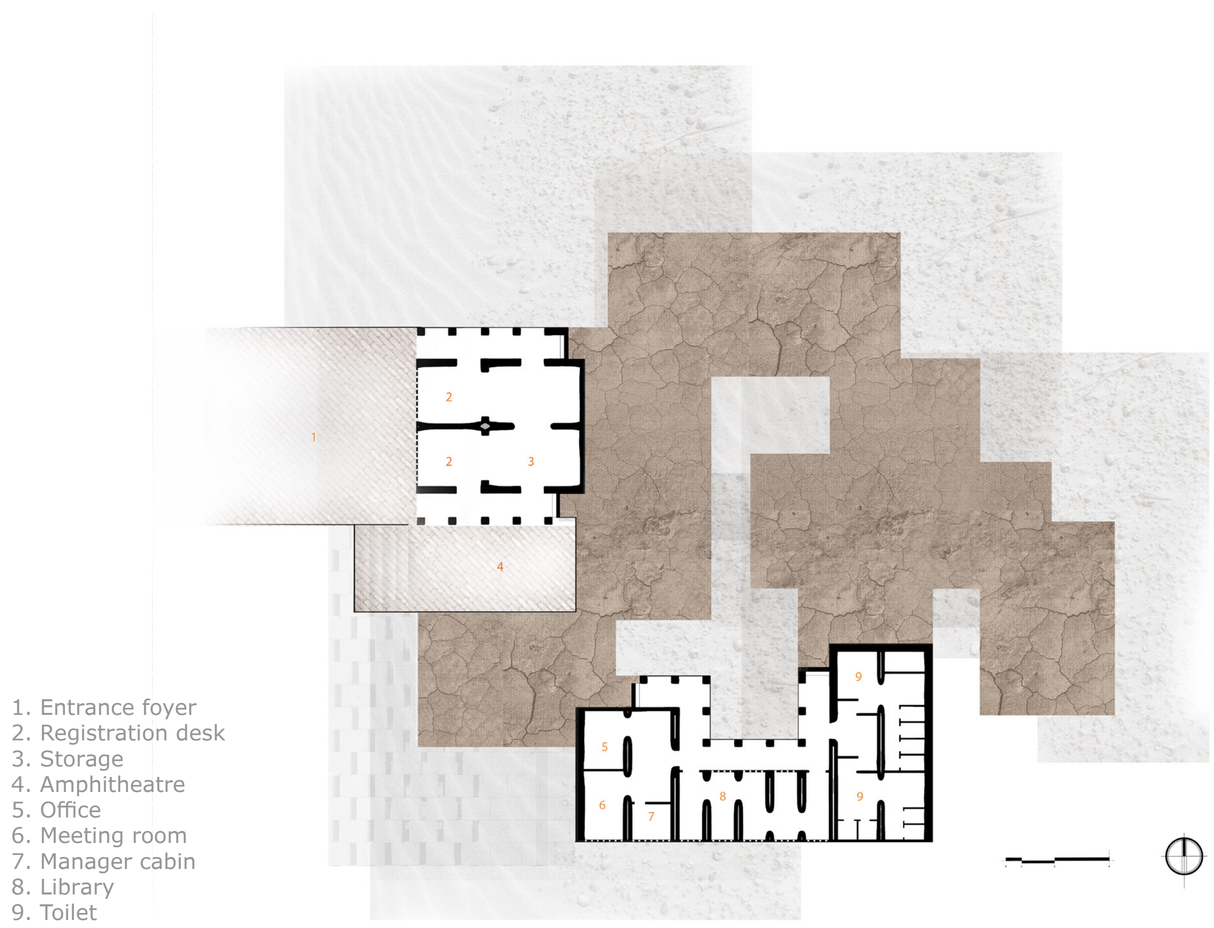


Figure 3.11 Lower Ground Floor Plan at -0.9 m . Source: Authors

1. Multipurpose hall
2. Pavilion hall
3. Childcare
4. Toilets
5. Storage
6. Pantry
7. Ict lab
8. Teaching lab
9. Courtyard
10. Workshop

Figure 3.12 Ground Floor Plan at .3 m . Source: Authors

1. Multipurpose hall
2. Library

Figure 3.13 First Floor Plan at 2.1 m . Source: Authors

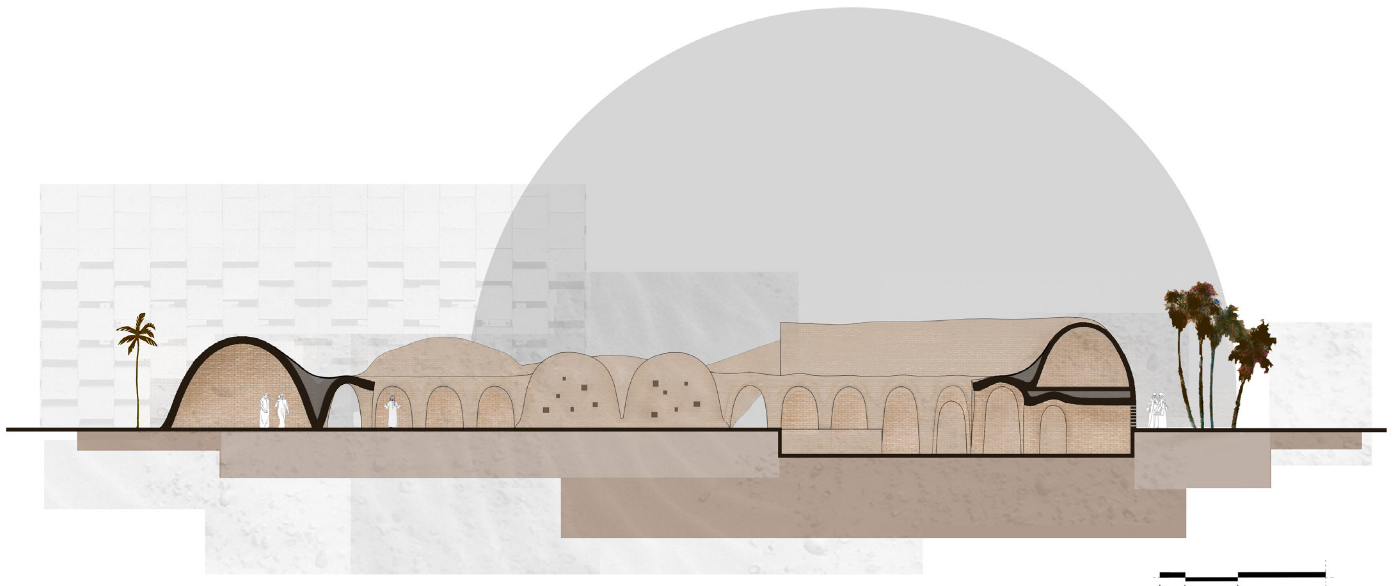


Figure 3.14 Section AA′. Source: Authors

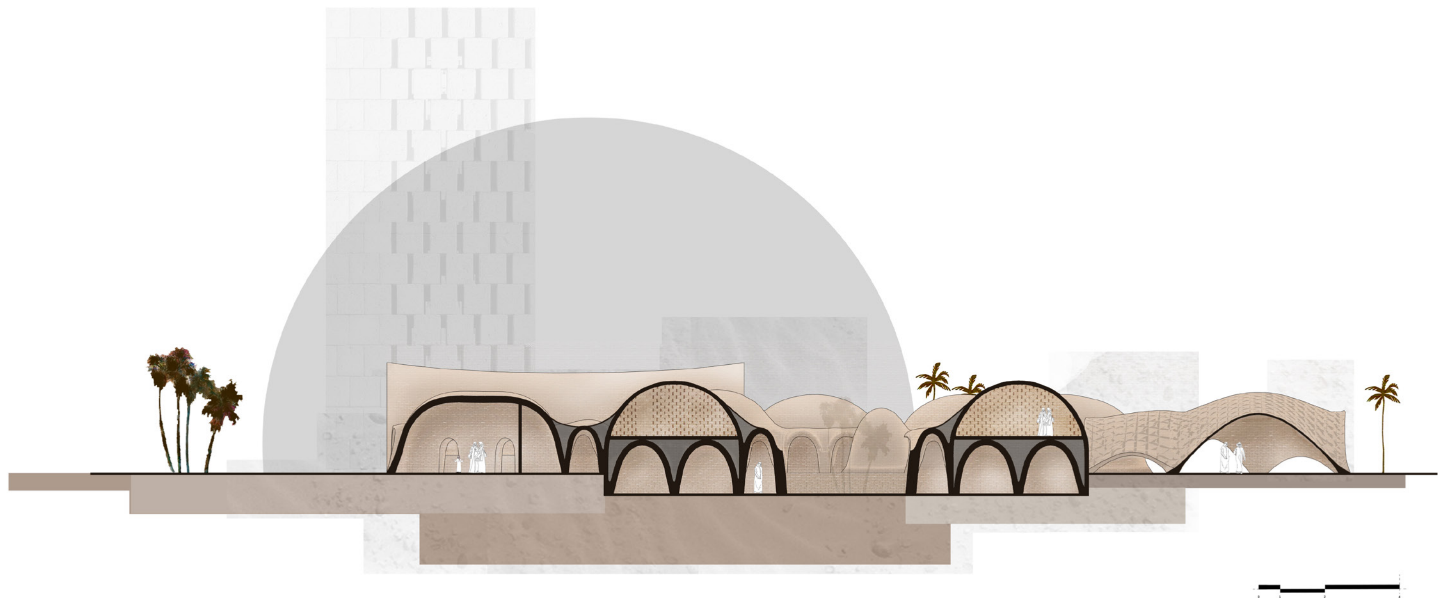


Figure 3.15 Section BB′. Source: Authors

4 Material Research

The Adobe bricks are proposed as the material for the construction of Skill Development Centre. The buildings are proposed to have compression only structures therefore an experiment was conducted involving making and breaking of the adobe bricks to determine the design values to propose a safe structure.

4.1 Methodology

The objective of this experiment is to discover the mechanical properties of various combinations of raw materials used to create adobe bricks. The mechanical properties to be considered are Young's Modulus and compressive strength. Although, mechanical properties like tensile strength, density values will rely on literature study. Insight into these mechanical properties of various mixtures of the adobe bricks will be used as inputs for the material properties in further structural analysis of the Skill Development Centre of Zaatari camp.

Since Adobe is a material that lacks certifications due to deviations in soil composition and the uncontrolled, natural drying process, we are not interested in the ultimate strengths of the material, but rather design values which can be used to create safe structures. The main research question is, what are the design values for compressive strength and Young's Modulus of the adobe bricks made during the brick-making workshop? To answer this primary research question, several sub-questions have been formulated:

1.How can mechanical properties be determined of these bricks?

2.How can the data found to be interpreted to find design values?

3.Which safety factors should be considered for these adobe brick structures?

Prerequisite of this experiment is the creation of the Adobe bricks with various raw materials. The goal is to find successful combinations and ratios of raw materials to create blocks that are as strong as possible. However, it is imperative to understand which raw materials can be used to develop stronger adobe bricks and why?

4.1.1 Limitations on Material availability

Since we are working in the context of Zaatari refugee camp in Jordan, there are several limitations on the availability of materials which can be used to create Adobe mixtures. Since many refugees flee to Zaatari without many personal belongings or money, many of the available objects and materials cannot be used for construction. UNHCR and other aid organisations bring in mainly the necessary artefacts and elements which need to be used for the specific reasons they are brought into the camp. This means the available materials should be found mainly from waste streams since these are the only materials that are not being used and are not wanted by anyone in the camp.

4.1.2 Research design

The research consists of two main parts, the first part is the making of the adobe bricks and the second part is the breaking of the adobe bricks. The making part of the research starts with literature research, followed by methodically making moulds and mixtures for the blocks. The breaking part consists of bricks undergoing a uniaxial compression test, which records the applied force and displacement on a computer. By interpreting the results of this experiment correctly, it is possible to find design values for various mixtures of the adobe bricks which will help in structural optimisation.

4.2 Brick Making: Material Research

Firstly, literature research is conducted to learn more about adobe brick creation. According to Christian Bock (2016), generally for stabilised earth blocks, cement is used as a binder, clay acts as fine aggregate and sand is used as the large aggregate. However, we do not have access to any cement in this case, so we will be considering the clay as the binder, fine sand as small aggregate and coarse sand as the large aggregate.

Adobe bricks have fair compressive mechanical properties, with inferior tensile mechanical properties. The compressive tests will be conducted to determine the compressive strength; however, the tensile strength can be considered as 10% of the compressive strength (Minke, 2006). Several types of research have been conducted to add fibrous materials to the adobe mixture to improve the compressive strength of the bricks further. Adding sugarcane bagasse, for example, has shown improving compressive strength of adobe bricks by 58.61% (Bock-hyeng et al., 2016). Sugarcane bagasse is the dry pulpy fibrous residue left over after crushing sugarcane to extract the juice. Mostly these are long dry fibres which are mixed into the adobe to make the brick stronger. Since sugarcane does not grow in the harsh climate of Zaatari, we can use dried straw, which is also a dry pulpy fibrous material.

After analysing a report presented by Oxfam discussion forum (2017), we have concluded that 40% of the waste produced in the Zaatari refugee camp is cardboard. Woodchips can also be found as a by-product of construction waste in the camp, while corn-starch is a cooking product in the camp. Corn-starch (maizena) is used as binder in cooking and baking, so we will use this in our mix as binder as well for the bricks.

To keep the building completely biodegradable and healthy, plastics or other non-organic materials will not be considered even though these are also available in the form of waste. This means straw, cardboard/paper, woodchips and corn-starch will be regarded as available materials to add to our adobe mixtures.

Figure 4.1:Mixing with industrial mixer. Source:Authors.

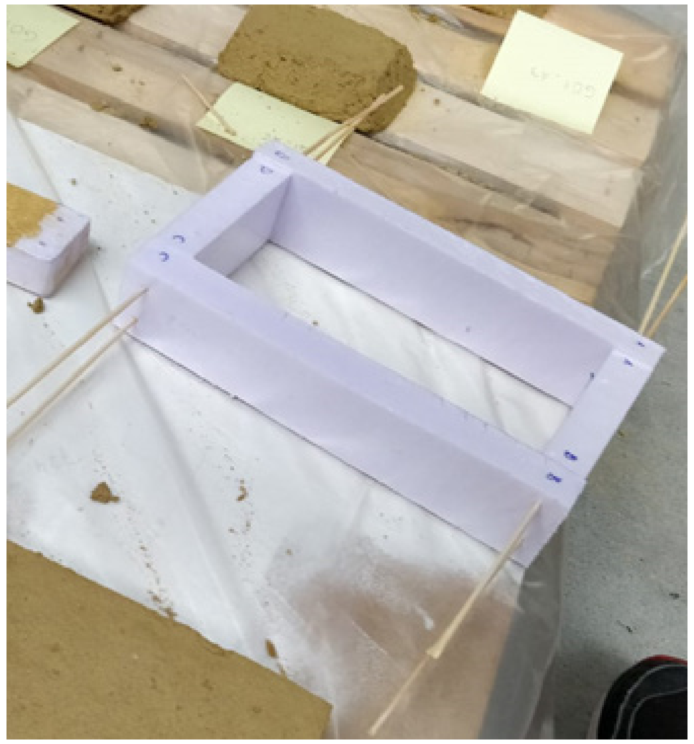


Figure 4.2:Polystyrene foam and skewer mould. Source: Authors.

4.3 Brick Making: Process

After choosing several materials to add to the combinations of the adobe bricks comes the step of making the mixtures. At least five specimens were made from each mix for data reliability. The overall sample count was 28. The main adobe recipe consisted of 30% clay, 30% fine sand and 40% course sand for the first ten specimens out of which 5 were small, and 5 were large bricks. About 10% water of the total weight of the dry mixture was added to this recipe. Next, the combination was mixed with a professional electric mixer (Figure 4.1) for several minutes.

Next, several moulds were created for shaping the bricks. Plastic Tupperware boxes with 95 x 70 x 30 mm3 dimensions were used to create the 'small' specimen, while a custom mould was created for the 'large' brick sample. This mould with aspects of 170 x 90 x 40 mm3 was created with Polystyrene foam pieces and wooden skewers (Figure 4.2).

The first five specimens were smaller and were created by using the Tupperware box. The mixture was put into the Tupperware mould and pressed/rammed by hand from the top to fill any gaps in the bottom of the box. Next, the head was cleared of any excess adobe, and the mixture was left into the mould for somewhere between 5 to 10 minutes before removing the Tupperware box.

After the first ten specimens made, other different mixtures were created. The different materials used, along with their composition, is tabulated in Table 4.1.

Brick Type	Code	Clay	Fine Sand	Coarse Sand	Additive		Water	Weight of mixture
		(%)	(%)	(%)	Type	%	(%)	(Kg)
Adobe	A1 – A-11	30%	30%	40%	-	-	10%	10.8
Adobe+Straw	S1-S4	30%	30%	40%	Straw	1% by volume	10%	11.3
Adobe + Woodchips	WD1-WD3	30%	30%	40%	Wood Chips	1% by volume	10%	4.17
Adobe + PaperPulp	PP_1-PP_5	25%	25%	-	Paper Pulp	50%	-	6
Adobe + Straw+Strach	SM_01-SM05	30%	30%	30%	Straw	1% by volume	10%	9

Table 4.1:Different mixtures used for making specimens. Source: Authors.

4.4 Brick Breaking: Process

After a week of drying, most specimens were dried up and hard enough to carry in a bucket without breaking or deforming, except for the few samples made with paper pulp. These last specimens were still very wet and deformed while transporting. Therefore, it was decided to exclude the five bricks made from paper-pulp from the testing procedure, resulting in the final 23 out of 28 samples made.

At the materials lab of 3mE, a setup was made to test the bricks. Zwick z100 machine was set up to perform the compression operation with a maximum loading capacity of 100KN. The tagged specimens were placed on a wooden plate underneath the compression machine one by one. The device outputs the amount of force it is pressing down with (in Mega Pascal) versus the vertical displacement (in millimetres) to a computer where these values were recorded in a table and graph. The machine kept pressing down with increasing force from 0 to maximum 10 tons of force. Usually this maximum limit would not be reached since the device would be stopped after it was evident the specimen had failed. The definition of failing, in this case, is when a sample stops linearly deforming and suddenly breaks and thus shows a further displacement with the same amount of force being exerted on the specimen. This process would be repeated for all 28 samples.

4.5 Results: Laboratory

The adobe bricks will be used for making compression-only structures for the displaced refugees in the camp of Al Zaatari, Jordon. For the same, laboratory test was performed for determining the mechanical properties of the adobe bricks. As mentioned in section 4.4, 23 out of 28 samples of different composition were subjected to a uniaxial compression test, as shown in Figure 4.4.

The bricks were placed on a base with a flat plate over it for uniform distribution of load during the compression test. The load was exerted continuously over the brick blocks till the bricks failed in compression resulting in maximum force at failure and deflection in brick height at failure. The values observed from the tests were used for analytical calculation of compressive strength using Equation 4.1. The modulus of elasticity of the bricks was calculated using Equation 4.2.

Compressive Strength [N/mm²]= F_max/Area

Equation 4.1:Formula to calculate compressive strength

Modulus of Elasticity [MPa]= Stress/Strain

Equation 4.2:Formula to calculate Modulus of Elasticity

Figure 4.4:Uniaxial Compression Test. Source:Authors

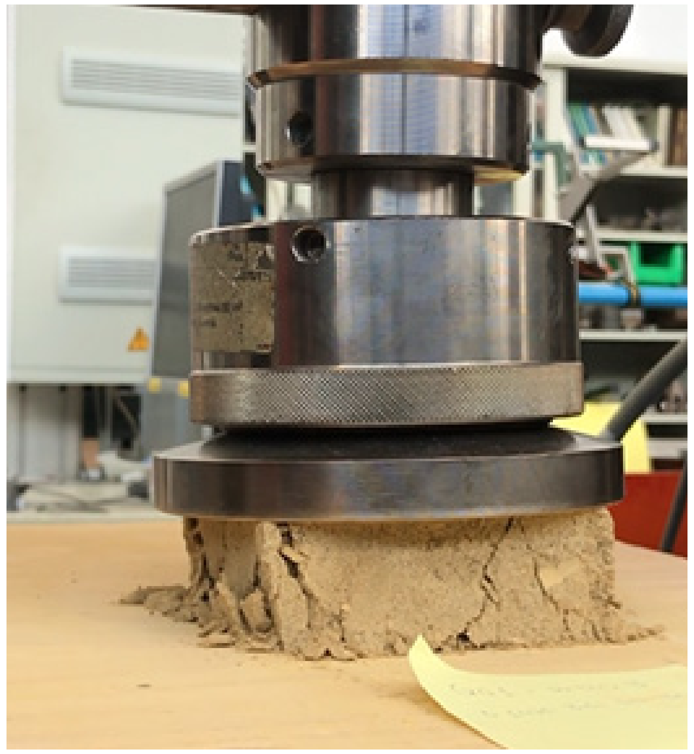


Figure 4.5:Diagonal Cracks at sides of Adobe Bricks. Source: Authors

4.5.1 Maximum force at Break

The failure of the bricks was observed as the development of diagonal cracks on the sides of the bricks (Figure 4.5). However, it was noted that the adobe bricks were subjected to disintegration when subjected to load, as shown in Figure 4.6.

The bricks with straw or wood were not entirely disintegrated as adobe bricks (Figure 4.7). It can be explained in a way that the straw fibres and wood chips hold the soil mixture together better then adobe which may also result in delayed failure of the brick blocks in compression. (Illampas, Ioannou, & Charmpis, 2011)

From Chart 4.1, we can observe that Bricks with Straw (S1-S4) and Straw+Strach (SM_01-SM_05) mixture resisted more force during the breaking test. The adobe bricks (A1-A11) and the adobe+wood chips bricks (WD_1-WD_3) resisted much less force comparatively. In the adobe bricks specimen A1-A6 were small bricks while A7-A11 were large bricks. Therefore, from the graphs it can be interpreted that the blocks with naturals fibres were able to hold the soil and clay matrix better than only adobe bricks.

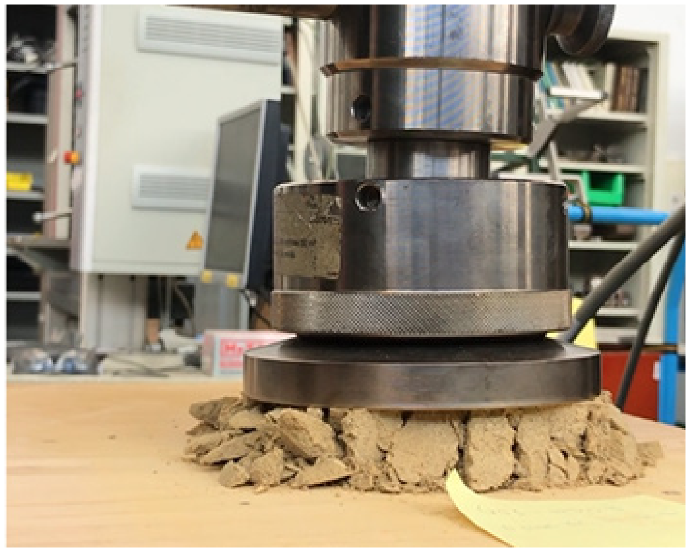


Figure 4.6: Disintegration of Adobe Bricks. Source: Authors

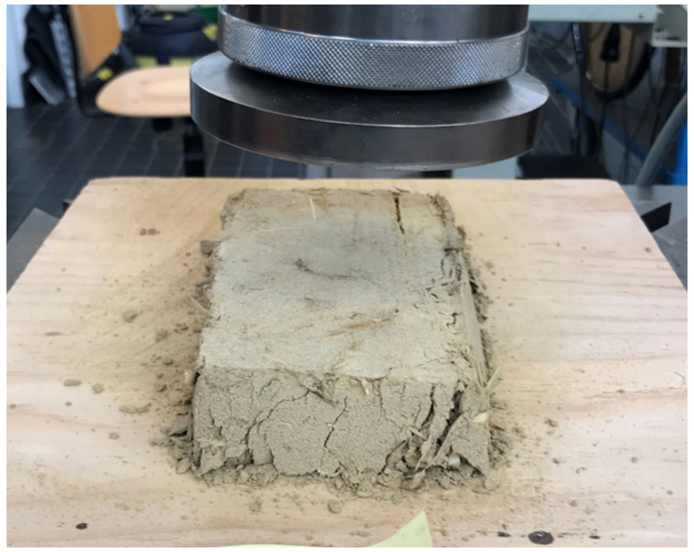


Figure 4.7: Adobe Straw Bricks less disintegrated as compared to Adobe Bricks. Source: Authors

4.5.2 Compressive Strength

The compressive strength of the adobe bricks is related to maximum force exerted divided by the area upon which the force was applied. Chart 4.2 shows the compressive strength of the specimen tested. From the graph, we can observe that the Adobe Bricks are low on compressive strength while Adobe with natural fibres that is straw, and Adobe with Straw and Starch are high on Compressive Strength.

However, to determine the design values, the data for adobe bricks, adobe+straw and adobe+wood chips from the entire class was considered. The data received from group 1 to group 7 (Appendix 2-7) was normalised using mean and standard deviation values. The outliers were removed then mean values were calculated again to identify the strength values for various compositions of bricks. Table 4.2 summarises the mean values from the normalised data. We will consider the range of the compressive strength between one standard deviation from the mean. The graphs can be refereed in appendix 2-7. However, the adobe bricks with straw and starch the data were synthesised from the five samples made.

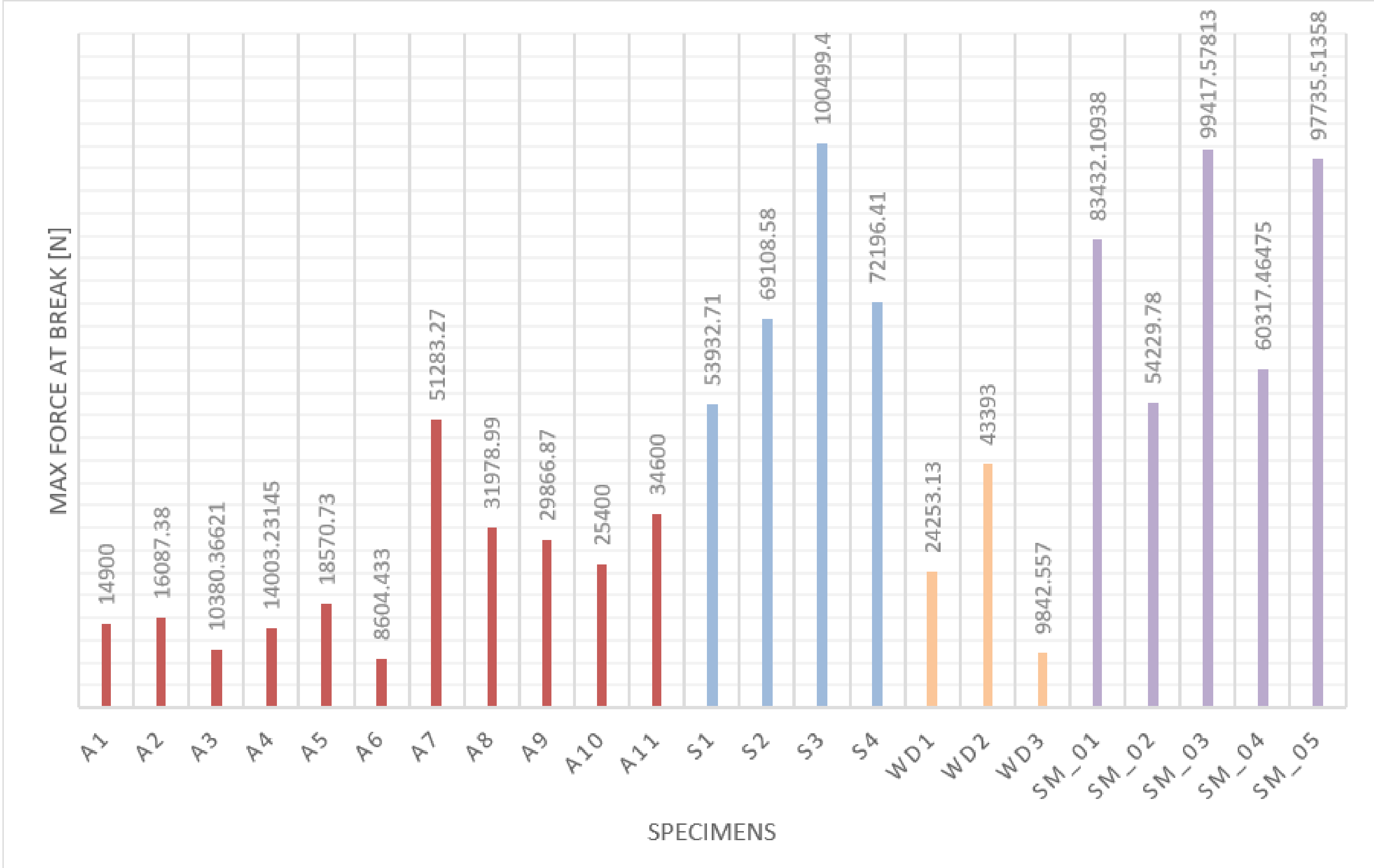


Chart 4.1:Comparison of Maximum Force at Break for Different Brick types.

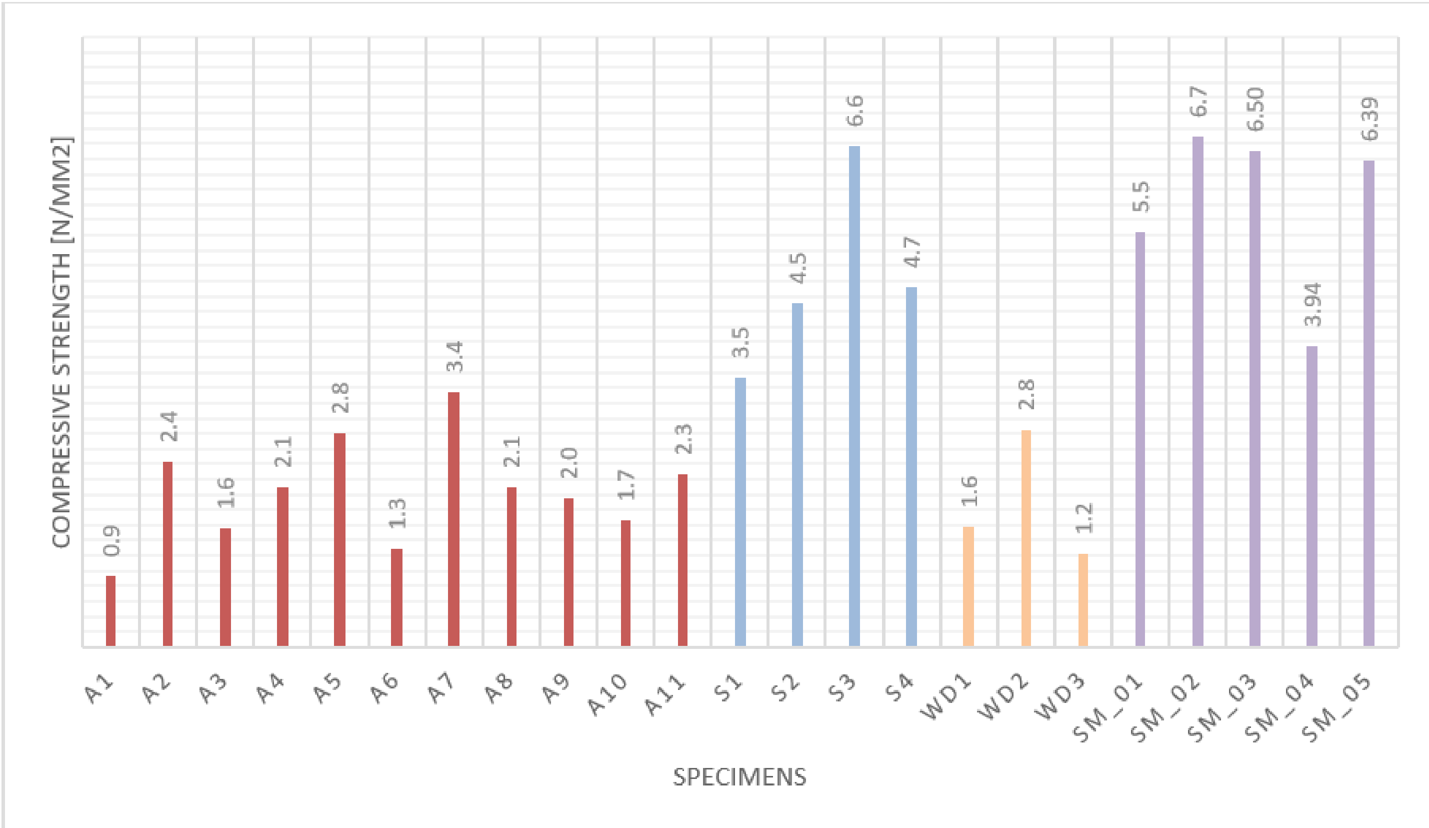


Chart 4.2: Comparison of compressive strength for Different Brick types. Source: Authors

The data mentioned in Table 4.2 represents the maximum compressive strength of the block at failure. However, according to literature it was noted that a compressive element made up of Adobe may achieve its maximum compressive stress at 10% of reduction in its height (Illampas et al., 2011).

This means that the brick would deform when the compressive stress induced due to self-weight, wind, etc reaches at 10% of deformation in height. This stress could be much lower than the maximum compressive strength of the brick at failure.

Therefore, the stress values were calculated for bricks made by group 1 – group 7 at 1.5%, 5% and 10% deformation in height. These stresses were calculated and compared for adobe bricks (group 1-7), Adobe+straw bricks (group 1-7), Adobe+Woodchips (group 1-7) and Adobe+Straw+Starch (group 1) respectively.

From table 4.3 we can observe that all the samples hold similar compressive stress at 1.5 % deformation. However, at 5% and 10% deformation the bricks with additives like woodchips or straw fibre exhibit better compressive strength. This could be explained as that the natural fibres binds the soil matrix better thus delaying the failure (Illampas et al., 2011)

Brick Type	Mean	Standard Deviation
	[N/mm2]	[N/mm2]
Adobe Bricks	1.33	0.61
Adobe + Straw	2.7	0.82
Adobe + Wood Chips	2.1	0.7
Adobe+Straw+Starch	5.8	1.02

Table 4.2:Mean compressive strength of different type of bricks. Source: Authors.

Brick Type	σ at 1.5% deform. In height	σ at 5% deform. In height
	[MPa]	[MPa]
Adobe Bricks	0.13	0.13
Adobe + Straw	0.12	0.3
Adobe + Wood Chips	0.13	0.4
Adobe+Straw+Starch	0.1	0.5

Table 4.3:Compressive strength at various deformation in height. Source: Authors.

4.5.3 Young's Modulus

The young's modulus or modulus of elasticity is determined by Equation 4.2. The maximum stress and deflection attained at break were considered for the calculation. The data was again taken from group 1-7, normalised and mean values were taken. Table 4.4 summarises the E calculated from the brick testing. However, the adobe bricks with straw and starch the data were synthesised from the five samples made.

Brick Type	Mean E [MPa]
Adobe Bricks	10.63
Adobe + Straw	12.37
Adobe + Wood Chips	11.3
Adobe+Straw+Starch	17.5

Table 4.4: Young's Modulus for different brick types. Source: Authors.

4.6 Discussion of Results

4.6.1 Compressive Strength

Upon comparing the mean compressive values from various literature studies and the data analysed from the brick making tests. It can be concluded that the compressive strength achieved by the blocks are valid enough to be used for further calculations. Chart 4.3 also summarise this comparison. The graph also shows that brick with straw and starch can significantly improve the compressive strength of the blocks.

However, if the compressive strength at 10% deformation is considered we can observe that the above-mentioned values in chart 4.2 cannot be used since they are much higher than the stress developed at maximum allowable deformation of the bricks. Chart 4.4 compares these values and we can observe that the adobe with straw and starch are comparatively better. Hence, these values could be utilised into the construction depending upon the type of use. For instance, the adobe bricks could be used for flooring; the blocks with straw could be used for partition walls while the bricks with straw and starch can be used for the main structure.

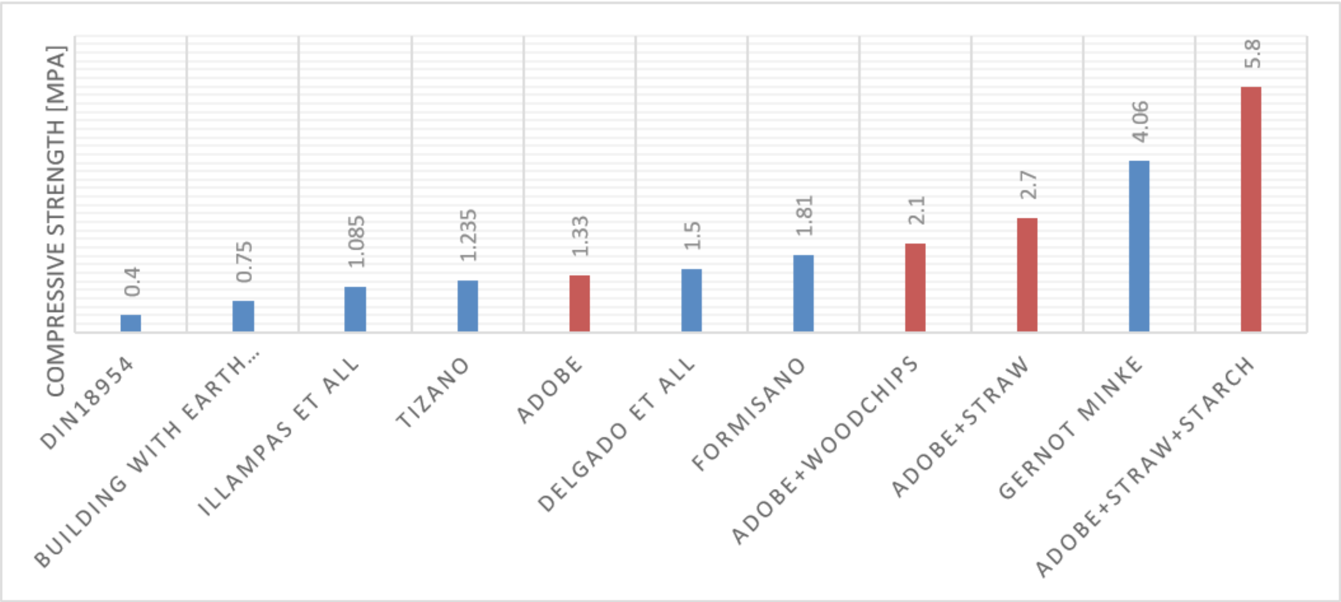


Chart 4.3:Comparison of compressive strength from literature and test results. Source: Authors.

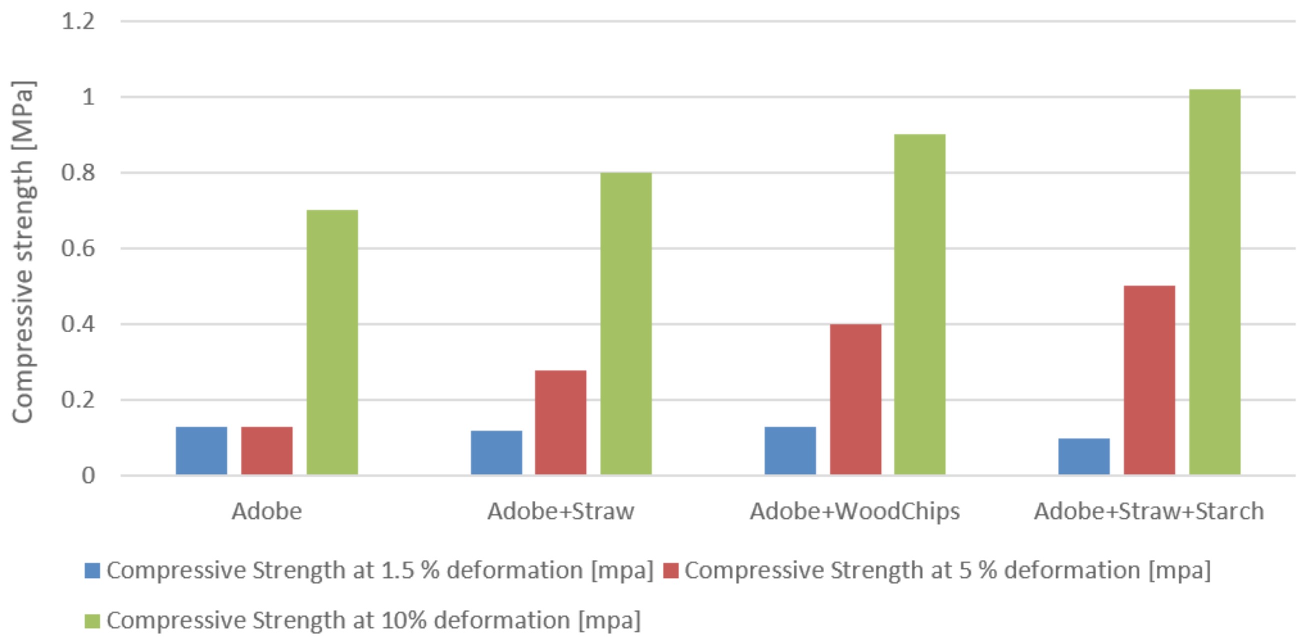


Chart 4.4:Comparison of compressive strength from literature and test results. Source: Authors

4.6.2 Young's Modulus

To determine the young's modulus, a comparison was made from the literature data and the data obtained from the group 1-7. However, it can be observed from Chart 4.5 that the young's modulus of the tested specimen is very low as compared to different literature studies. This could be because of the short curing time. As well as the the outdoor conditions within which the bricks were cured. Considering the bricks would be better cured in the high temperatures of Jordon. The bricks can receive higher Young's Modulus.

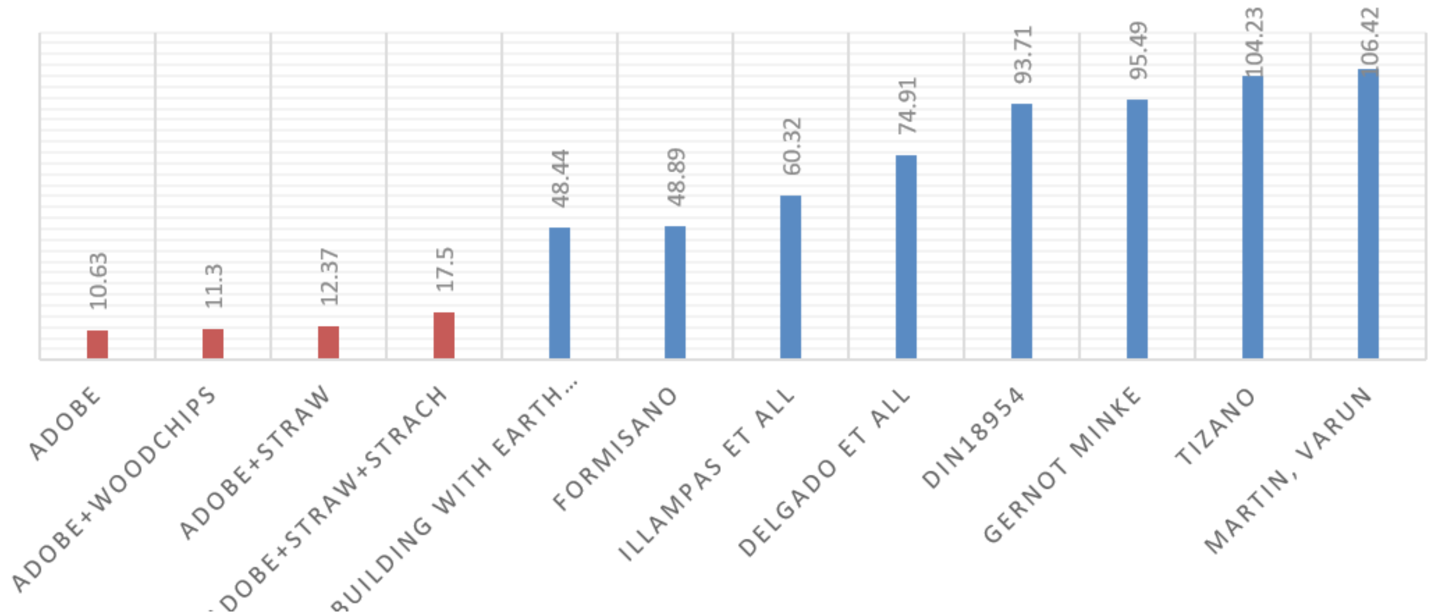


Chart 4.5:Youngs modulus comparison. Source: Authors

4.7 Conclusion

The primary objective of the research experiment was to determine the design values of the adobe bricks and the mixture which exhibits best properties in comparison to the literature studies. From the data collected from the experiment the mechanical properties like Compressive Strength, Young's Modulus can be calculated. These were calculated by the formula mention in section 4.5 of this report. The data collected from all the groups was analysed to determine the compressive strength and young's modulus.

From this synthesis it can be concluded that the bricks with additive materials like natural fibres(straw) and starch as binding agent increase the mechanical properties of the blocks. Therefore, the sample SM_01-SM_05 which exhibited a higher compressive value and Youngs Modulus will be considered for structural calculations.

For the compressive strength the design values were taken of the adobe, straw, starch mix which exhibited the greatest compressive strength at 10% deformation in the brick which is 1 MPa. It could be understood that considering this value also incorporate a safety factor since this value is quite low as compared to the compressive strength achieved at break which is 5.8 MPa.

The young's Modulus of this mix was calculated at 17 MPa . However, this value is quite low as compared to literature. The reason is depended upon the curing time and the temperature at which the bricks was cured. Therefore, a higher value of 80MPa will be taken considering that a higher Young's Modulus is possible to achieve in the high temperatures of Jordon. The final design values are tabulated in table 4.5.

Design Values		
Brick Type	Adobe + Straw + Starch	
Compressive Strength	1 MPa	Experiment
Young's Modulus	80 MPa	Literature
Tensile strength (1/10 Compressive Strength)	0.1 MPa	Literature

Table 4.5: Final Design Values. Source: Authors

5 Forming & Structuring

5.1 Methodology

The form finding process for the whole project was driven by strong architectural identity. The overall process for form finding was divided into two phases– experimenting and adapting. The first phase focussed on understanding how mesh played an important role in giving shape to the floor layout obtained in the previous process. While in the second phase of adaptation, desired form was generated using adopted technique and analysed using Finite Element analysis for its performance. This phase was a result of many iterative loops to obtain a safe and secure design. In the both the phases, Kangaroo Physics Engine was used to dynamically relax the form to attain the required height. Further, for the structural analysis, Karamba 3D FEA was used in grasshopper to understand the principal stresses and deflection.

5.2 Phase 1

5.2.1 Experimenting with the Shape using different approaches

To start the process and understand how different shapes interact, mathematical equations were used to generate the form for various functions. The first approach, Shaping v1 was as stated in the below steps -

1. Adobe structures literature research.

2. Categorize spaces in three spatial categories according to functional requirements as shown in Figure 5.1.

3. Define three construction modules and put the spaces into these three categories according to spatial requirements.

But during this process, it was noted that Geometry is not achieved through dynamic relaxation thus resulting in tension forces in the form. Additionally, the form obtained was a collection of different small forms and was not acting in totality.

Then, another approach, Shaping v2 was used as shown in the Figure 5.3 below:

After this process, it was learned that predefining the catenary vault shape gives severe limitations on spatial use and connections between spaces because of span-to-height ratios.

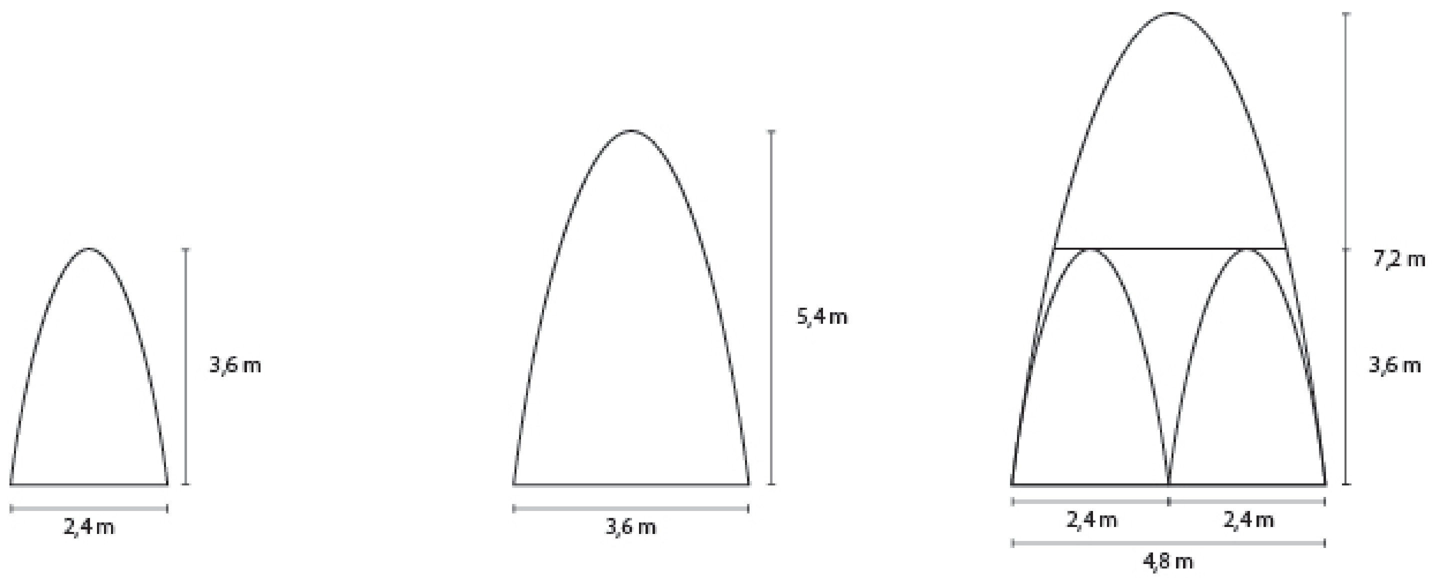


Figure 5.1:Catenary dimension for various space modules

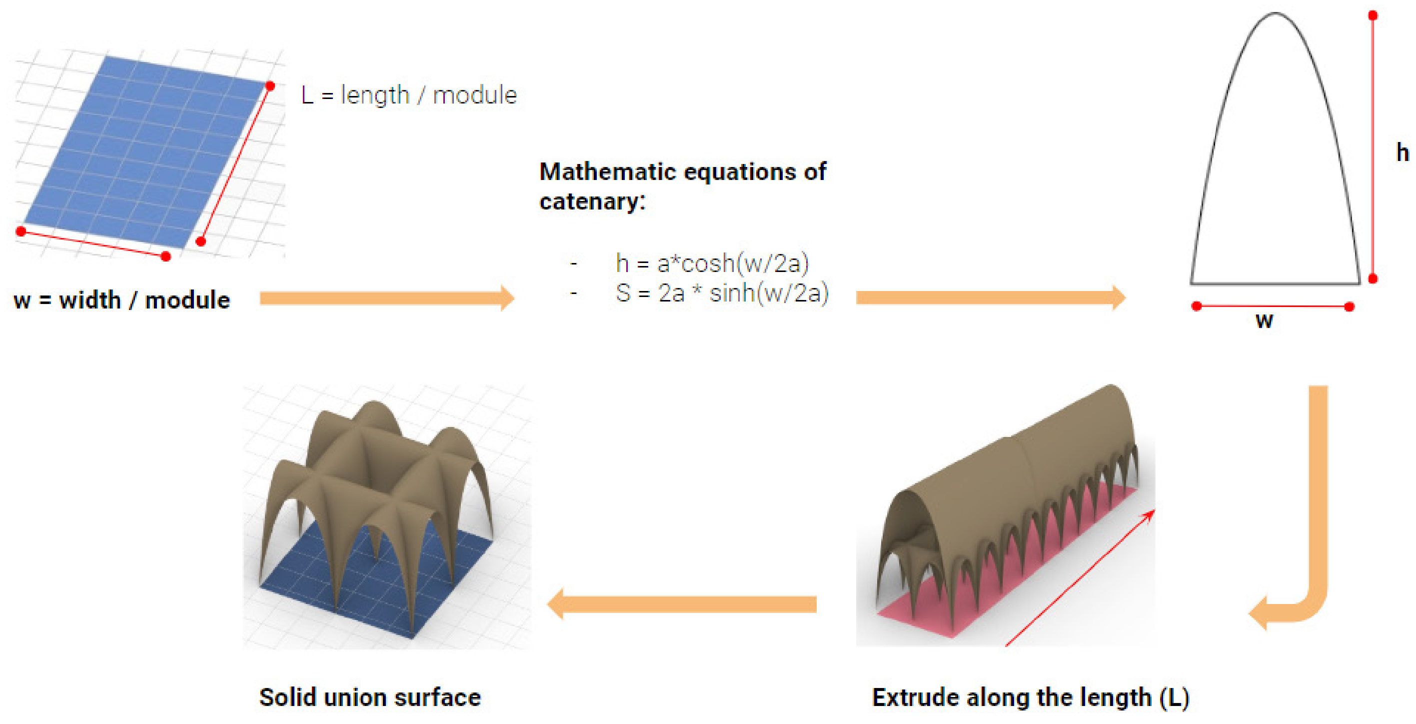


Figure 5.2. Process of catenary shape finding

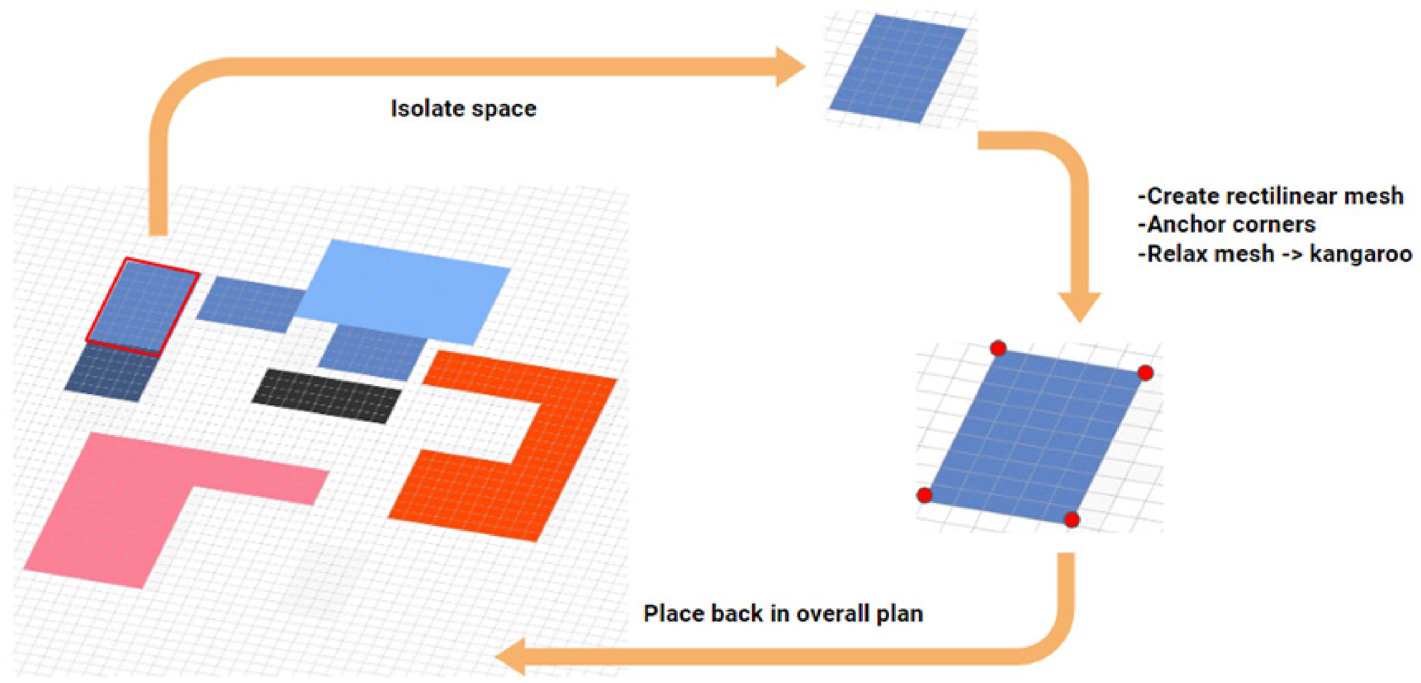


Figure 5.3 Process of creating regular grid mesh for spaces

Also, incorporating modularity on a space level results in issues of force dissipation in the connection between adjacent spaces.

5.2.2 Experimenting with the Mesh

A thorough literature research was then conducted into understanding different meshing algorithms. During this phase, an ambiguous form/plan was first taken into consideration to understand the different shapes it can obtain when dynamically relaxed as shown in the Figure 5.4. Since the configuration was overall composed of rectangular elements, the part of it was taken to study various meshing algorithms. It was noted that different algorithms resulted in different heights with same spring strength as shown in Figure 5.5.

It was then concluded that Catmull Clark and Regular Quad meshing algorithms were the best suited for our application as these resulted in more uniform distribution of loads and had desired shape of our architectural language.

Figure 5.4 Exploration of various meshing techniques.

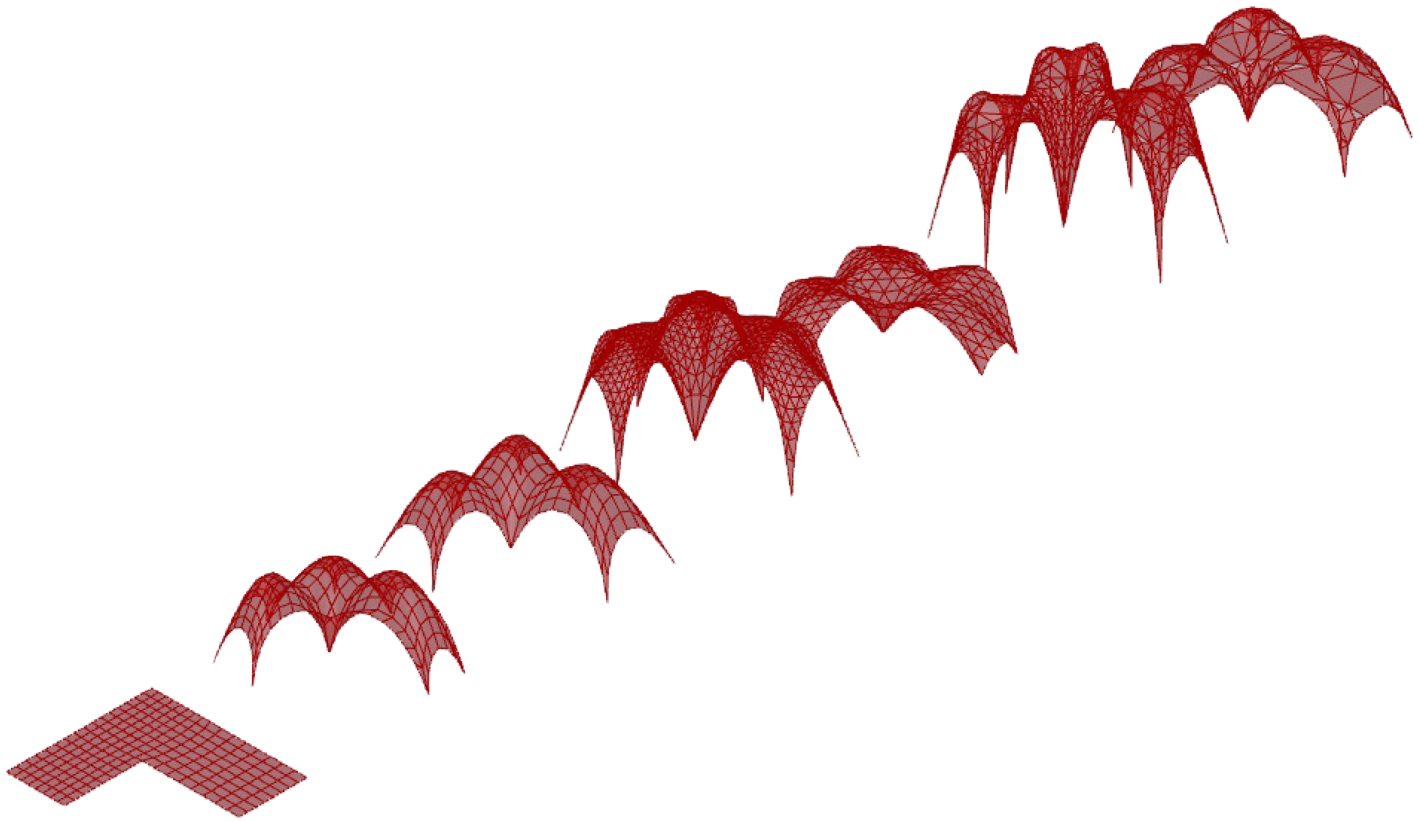


Figure 5.5 Understanding the relation of heights of different meshing algorithms

5.3 Phase 2

5.3.1 Adoption of meshing techniques

Since, the program of the whole building was large and composed of different functions and load conditions, it was decided to opt for different structural techniques for various spaces as listed below :

1. Regular Quad Mesh for Nubian Vault
2. Free Form Domes
3. Free Form Vaults
4. Shell Structure

This meant each structural scheme had to be evolved from different meshing technique. Thus, different methods were adopted to generate form for different structural scheme.

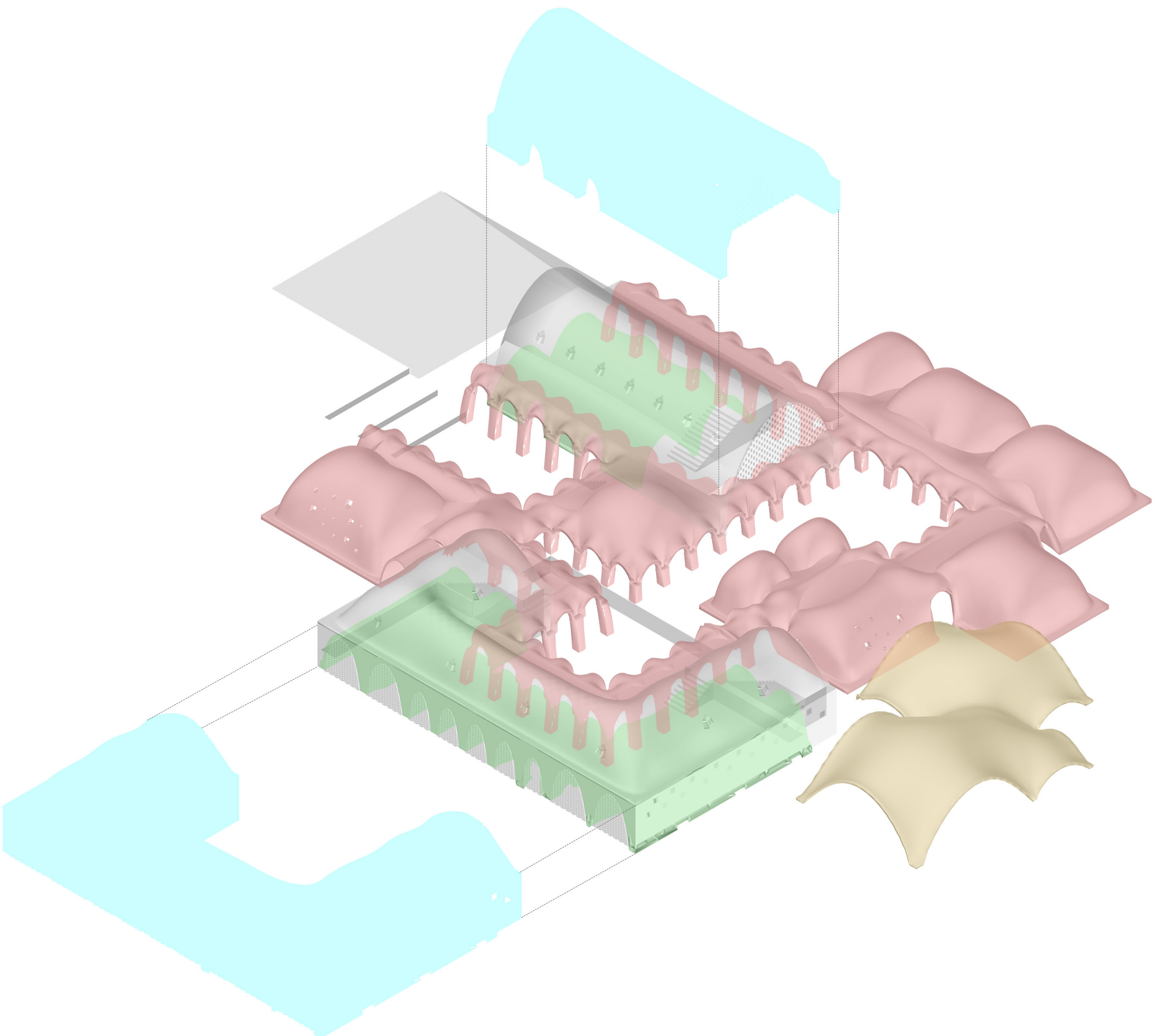


Figure 5.6 Structural classification of the entire building.

5.3.2 Nubian Vaults

The Nubian vault construction was proposed on the ground floor of double story parts (Figure 5.7) of the building. This was done for two reasons – first to create a uniform height structure so that first floor slab doesn't have slope and second was to uniformly distribute load to the edges using Nubian Vault technique. For these reasons, the regular grid of 0.15m was used as it was the most suitable meshing process that we learned from the previous phase.

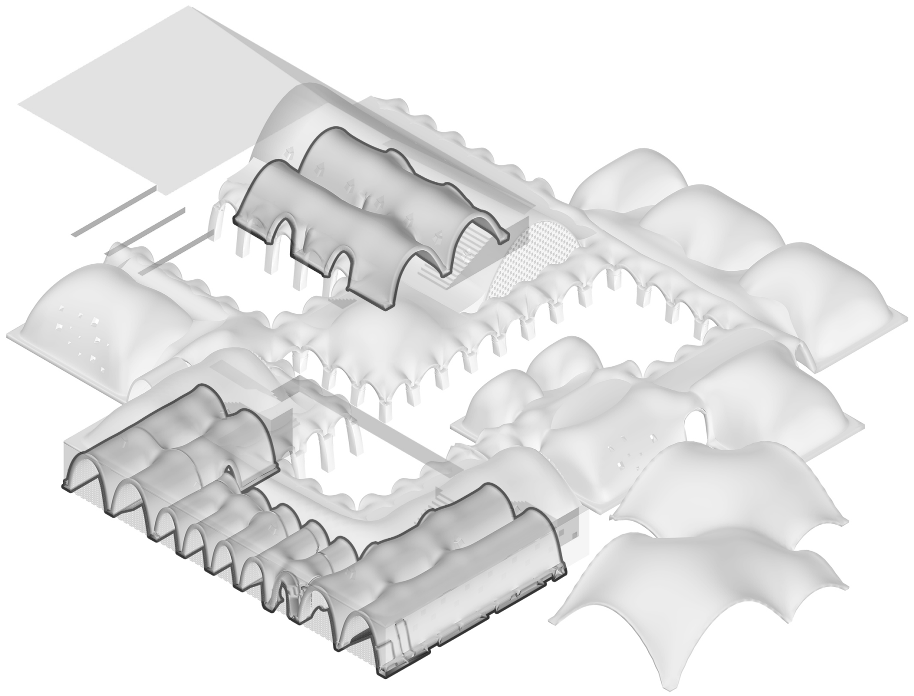


Figure 5.7 Area of Nubian Vault in entire building program

To generate Nubian vault, room boundary was offset by 0.6m to obtain wall boundaries, followed by extrusion to 1.5m to maintain clear height of the space. The support meshes, opening mesh and wall mesh were then dynamically relaxed in Kangaroo Solver to obtain required height and form. The whole process of mesh generation is also shown in the Figure 5.8.

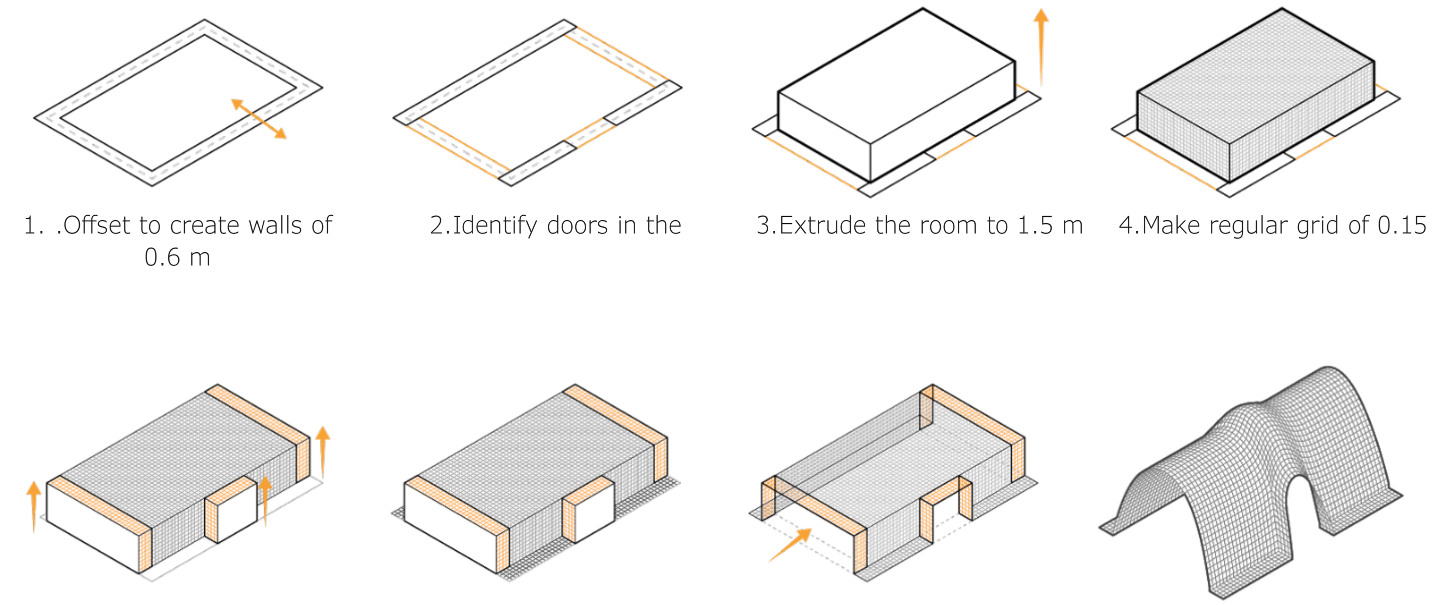


Figure 5.8 Meshing steps for Nubian Vault

After the generation of mesh, it was tested in Karamba 3D using Finite Element Analysis. The below text will show the analysis in the case of library building. The load case for this part of the building is shown in the Figure 5.9, where live load of first floor was considered as 4kN/m2 (Malakatas, 2008), the slab load and filling load were taken as 1kN/m2 and 150Kg/m3 respectively. Additional sand load of 2kN/m2 was also considered for storm conditions. The non vertical load was applied using mesh loads in Karamba 3D. The self-weight of the structure and the design values were taken from the material research as discussed in the Section before.

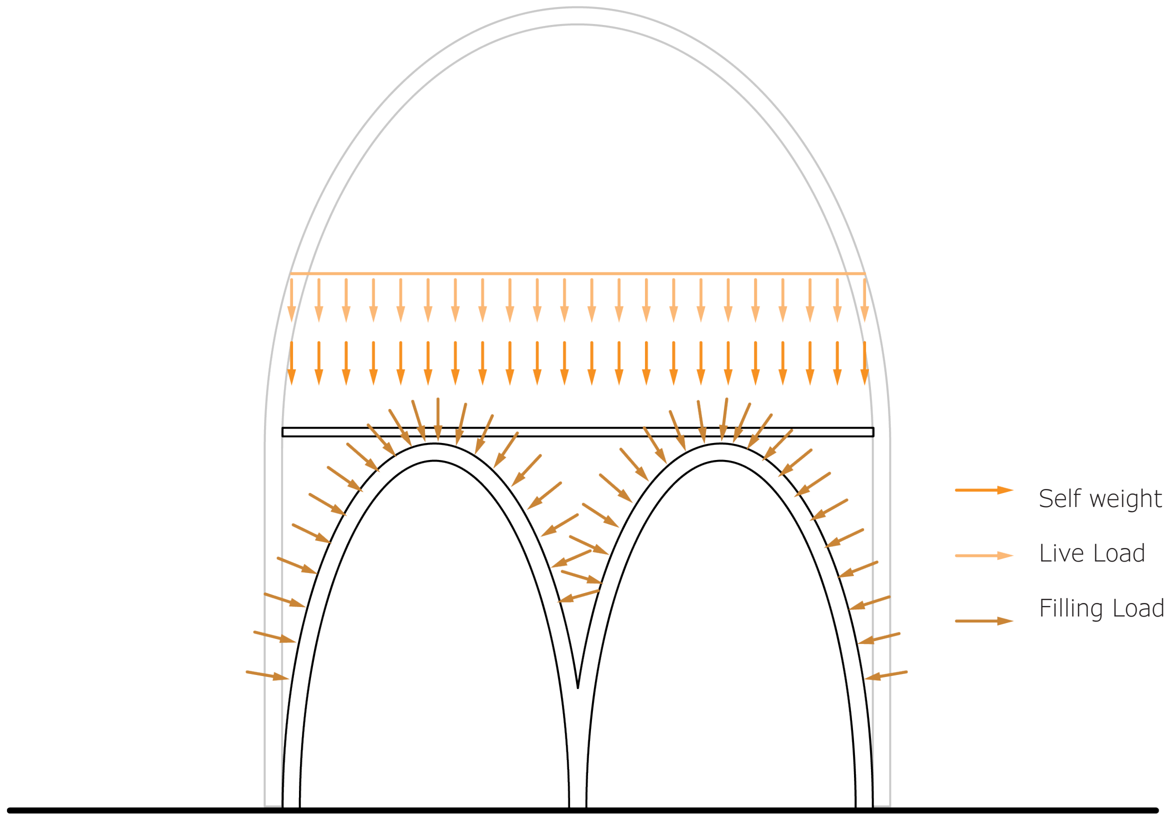


Figure 5.9 Structural load scheme for Nubian vault

Design Values

After the material analysis, design values for the structural analysis were takes as follows:

- **Allowable compressive Stres**s – 1 MPa [at 10% deformation] (This value considers safety factor of 6)
- **Allowable Tensile Stress** – 1/10 Compressive Stress – 0.1 MPa [at 10% deformation]
- **Deflection** – Span/400 – L/400 - 3000/400 – 7.5mm
- **Young's Modulus** - 80 MPa

The results from Karamba 3D were then checked for various thicknesses. The thicknesses were considered in the modules of the brick size thus 15cm, 30cm, 37.5cm, 45cm and 60 cm. The results for various thicknesses were tabulated in Table 5.1 and 30cm was the least thickness which was performing safe in crucial areas.

Thickness	m	0,15	0,3	0,375	0,45	0,6
Peak Compressive Stress	MPa	0,414	0,209	0,186	0,172	0,153
Peak Tensile Stress	MPa	0,168	0,0643	0,0495	0,0412	0,034
Max Displacement	cm	1,67	0,522	0,42	0,362	0,298
Total Height	m	3,17	3,32	3,395	3,47	3,62

Table 5.1: Results of FEA for different thicknesses of Nubian Vault

Upon analysis, 30cm thickness of the mesh showed peak deflection of 5.2mm (unity check 7.5 /5.2 = 1.44) on the top areas (Figure 5.10) which was less than allowable limit of 7.5mm. Since the Young's Modulus of 80MPa considered was lower than the literature values, the unity check of greater than 1 was more than enough for the structure to be safe.

While the principal stress analysis (Figure 5.11) showed development of tensile stresses on the top of side library bays, the peak tensile stresses of 0.06 MPa were well below the maximum allowable 0.1 MPa. This tensile stress was observed due to the asymmetrical filling load on the side bays of the library building. The peak compressive stress 0.2 MPa was observed on the side walls of the mesh but it was well below the design value of 1 MPa, thus 30cm thickness for this part of the building was considered safe.

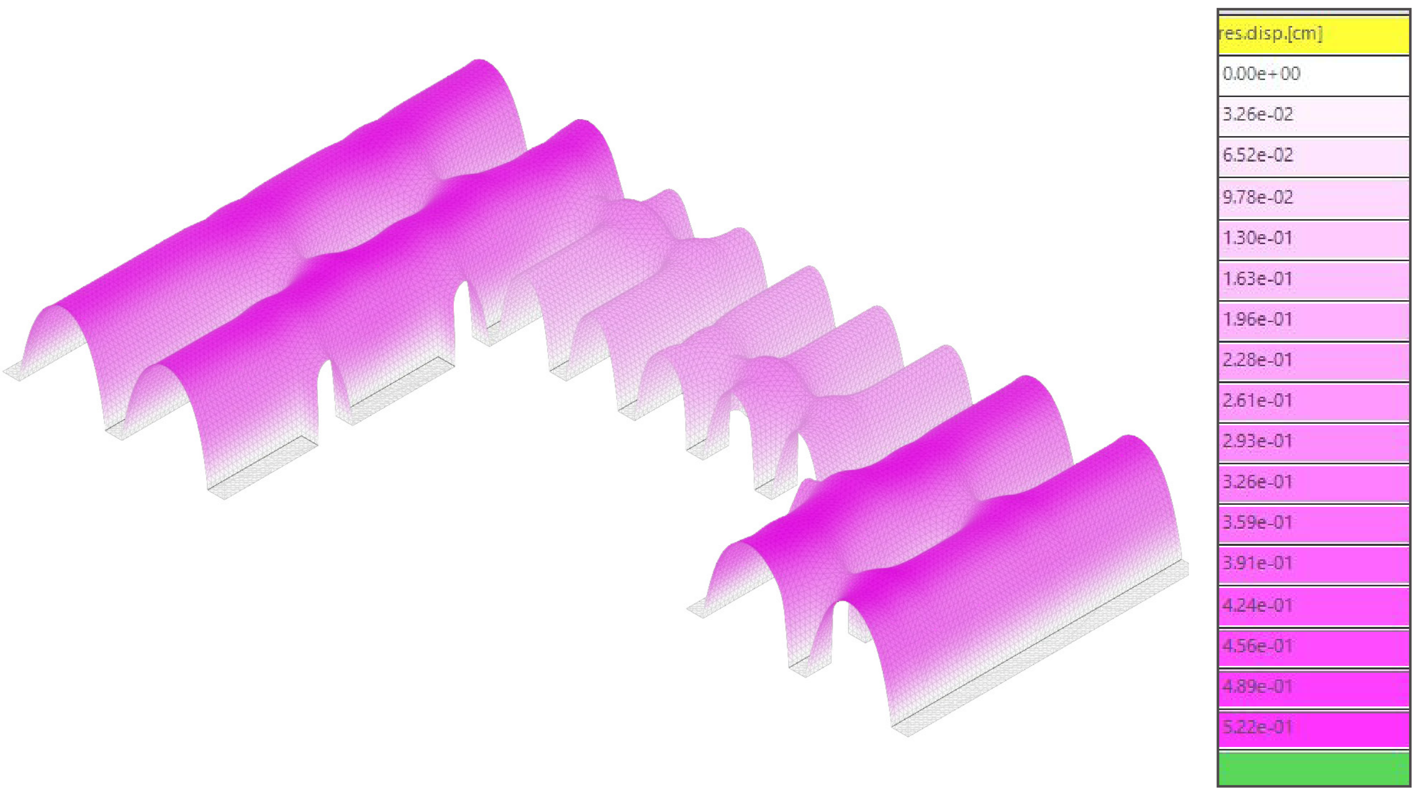


Figure 5.10 Deflection in Nubian Vault

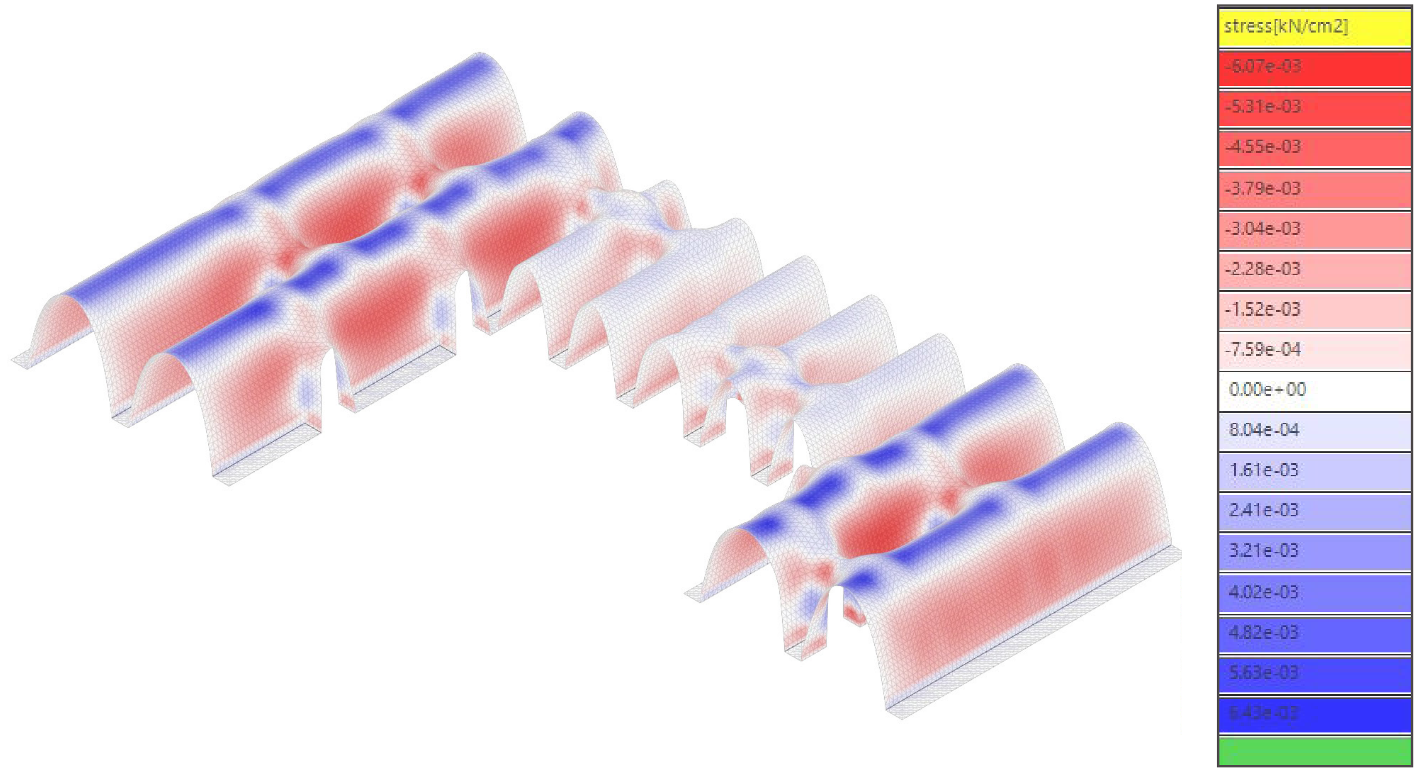


Figure 5.11 Principal Stress 1 in Nubian Vault

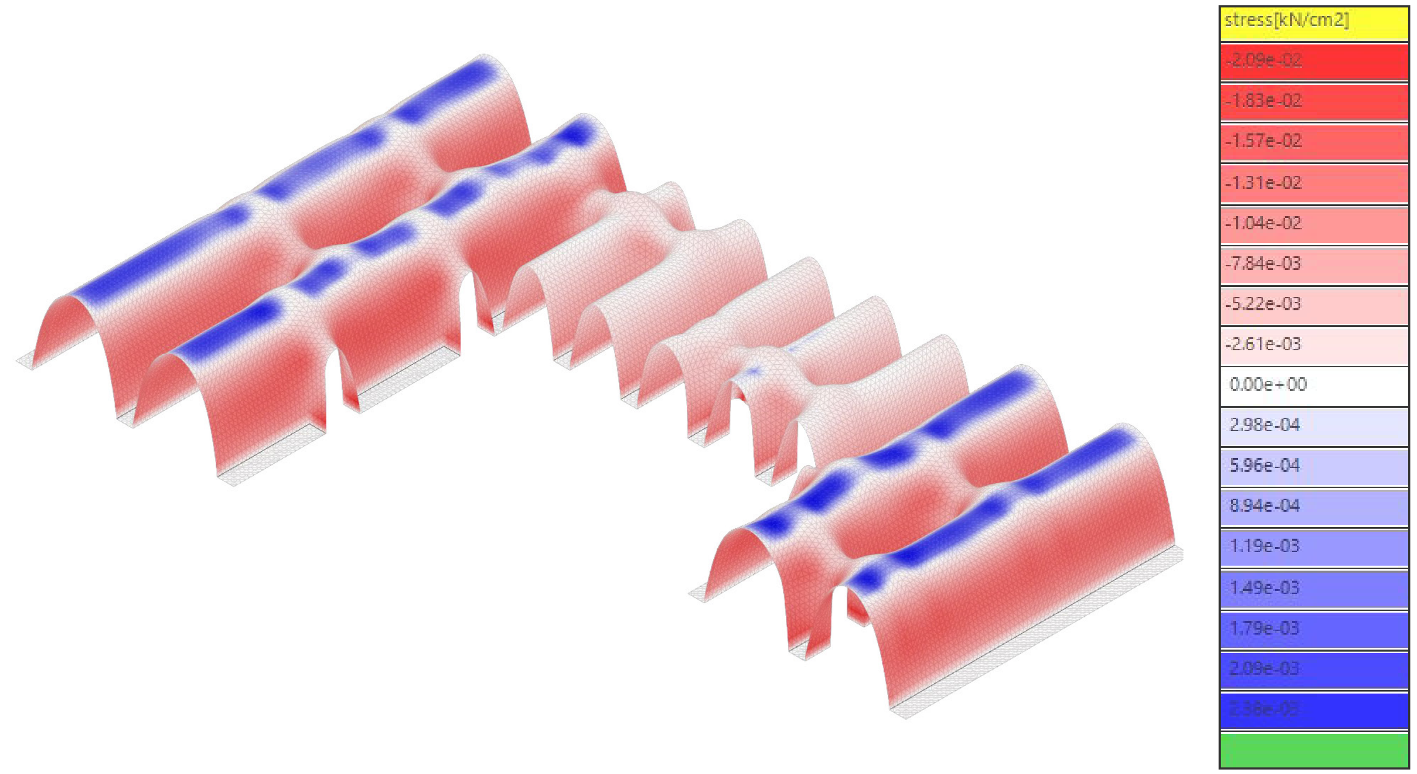


Figure 5.12 Principal Stress 2 in Nubian Vault

5.3.3 Free Form Domes

Free form dome structure was proposed for the single-story structure (Figure 5.13). This was done to create a challenging dynamic form through an exploratory approach. The aim was to create a structurally optimized form which uses less material and examines the structure from the topological point of view.

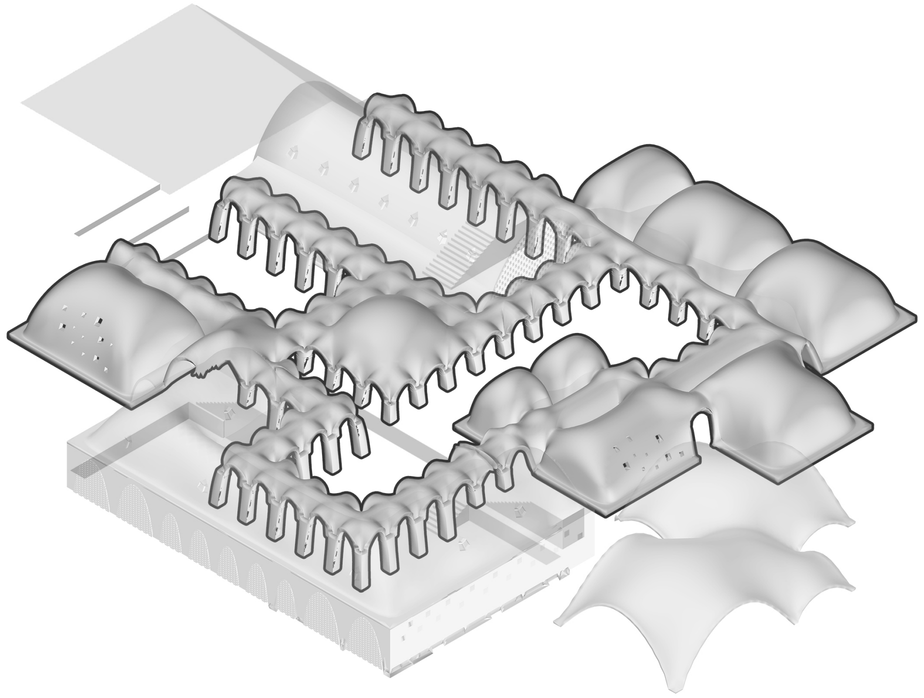


Figure 5.13 Free form dome area highlighted in the building scheme

To optimize the structure for free form domes, the approach of exploration of 'Topology as structural patterns' was adopted ((Robin Oval, 2018). For this, the procedure adopted is shown in the flowchart in the Figure 5.14: Flowchart for form finding processFigure 5.14. Due to computational and time limitations, the iterative loop was performed in the complicated part of the building as highlighted in the Figure 5.15 so that it can be replicated in the simple parts of the mesh. After the selection of the final mesh rule, the final rule was applied for the overall ground floor.

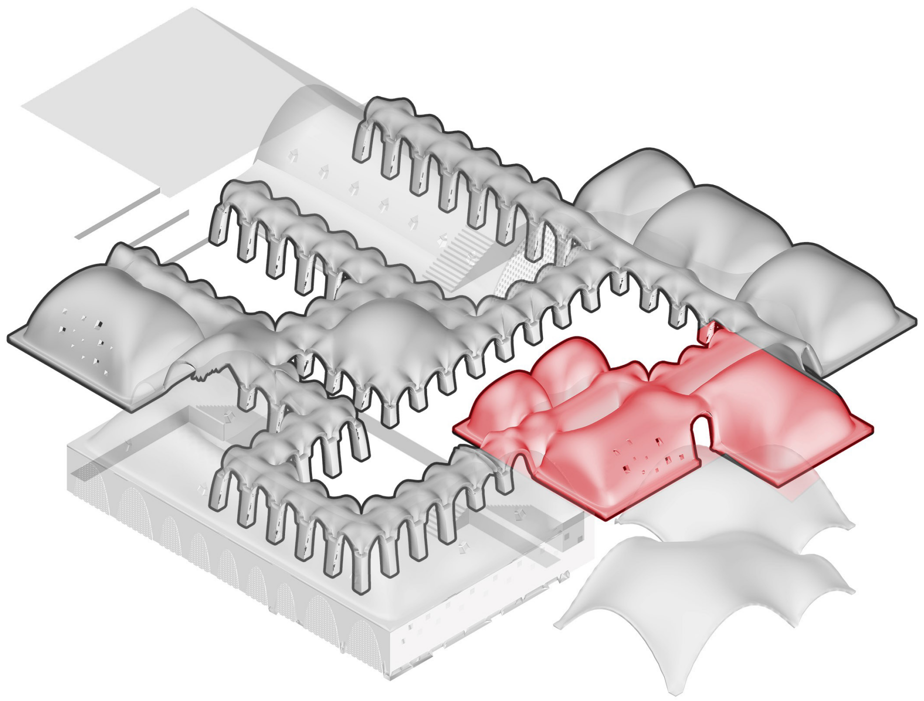


Figure 5.13 Free form dome area highlighted in the building scheme

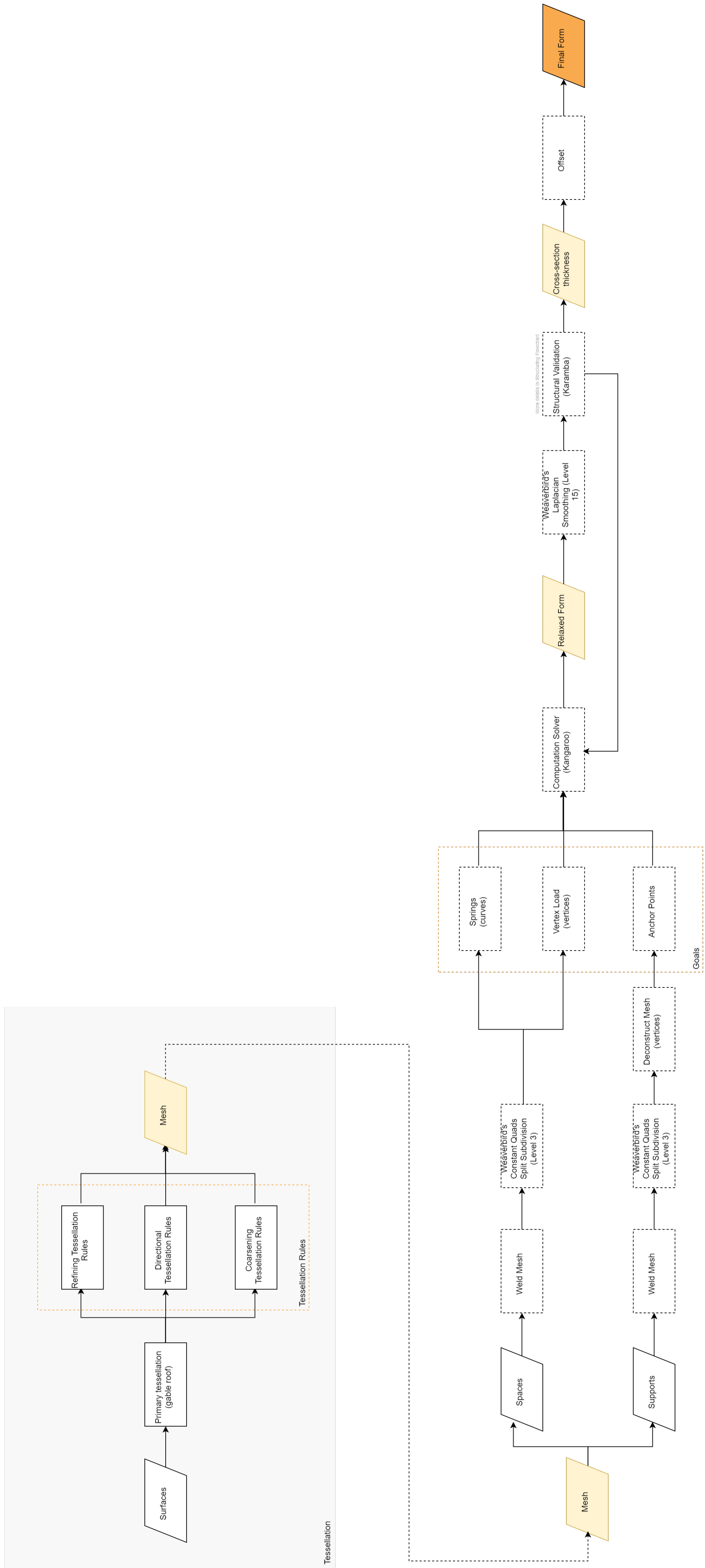


Figure 5.14: Flowchart for form finding process

The first tessellation for selected space was generated manually using medial axis algorithm as shown in Figure 5.17.Later the tessellation rules (Figure 5.16) were applied in the clockwise logic starting from the left bottom corner of the room, to the different rooms as shown in Figure 5.17. Some rules upon suggestion from mentors due to limited time were borrowed from the research (Robin Oval, 2018) while few rules were made by the authors which were required due to project complexity. These mesh rules were made keeping in mind all the possible operations of refining, coarsening and changing direction of mesh edges (Figure 5.16). Additionally, soft criteria of symmetrical, scalable and topologically uniform mesh were also considered. By applying different sequences of tessellation rules, several mesh configurations were obtained, dynamic relaxed and then structurally analysed (Figure 5.18).

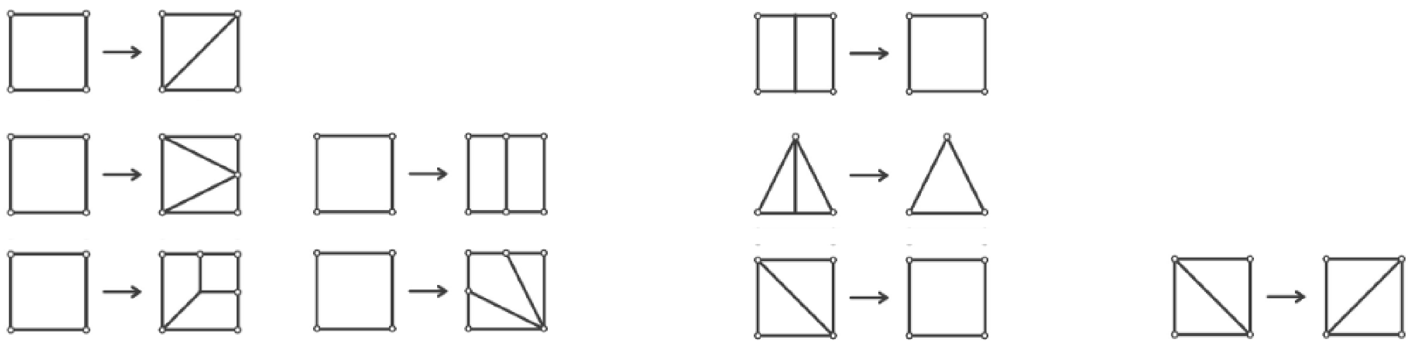


Figure 5.16 Tessellation rules (refining, coarsening and directional)

Each mesh was analysed in Karamba 3D with same parameters for peak compressive stresses. Since, the structure was majorly designed for compression, other structural performances were ignored for this step. After few iterations, it was observed that the multiple steps of refining of the mesh corners caused increase in the peak stresses. Thus, the final tessellation 4A was selected after a uniform distribution of load was achieved. This tessellation performed the best in the performed iterations as shown in the Table 5.2. The Karamba analysis has been compiled in the Appendix for further understanding

Mesh	1	2	2A	3	4	4A
Peak Compressive Stress	MPa	0.081	0.080	0.083	0.083	0.069

Table 5.2 Comparative results of different tessellations

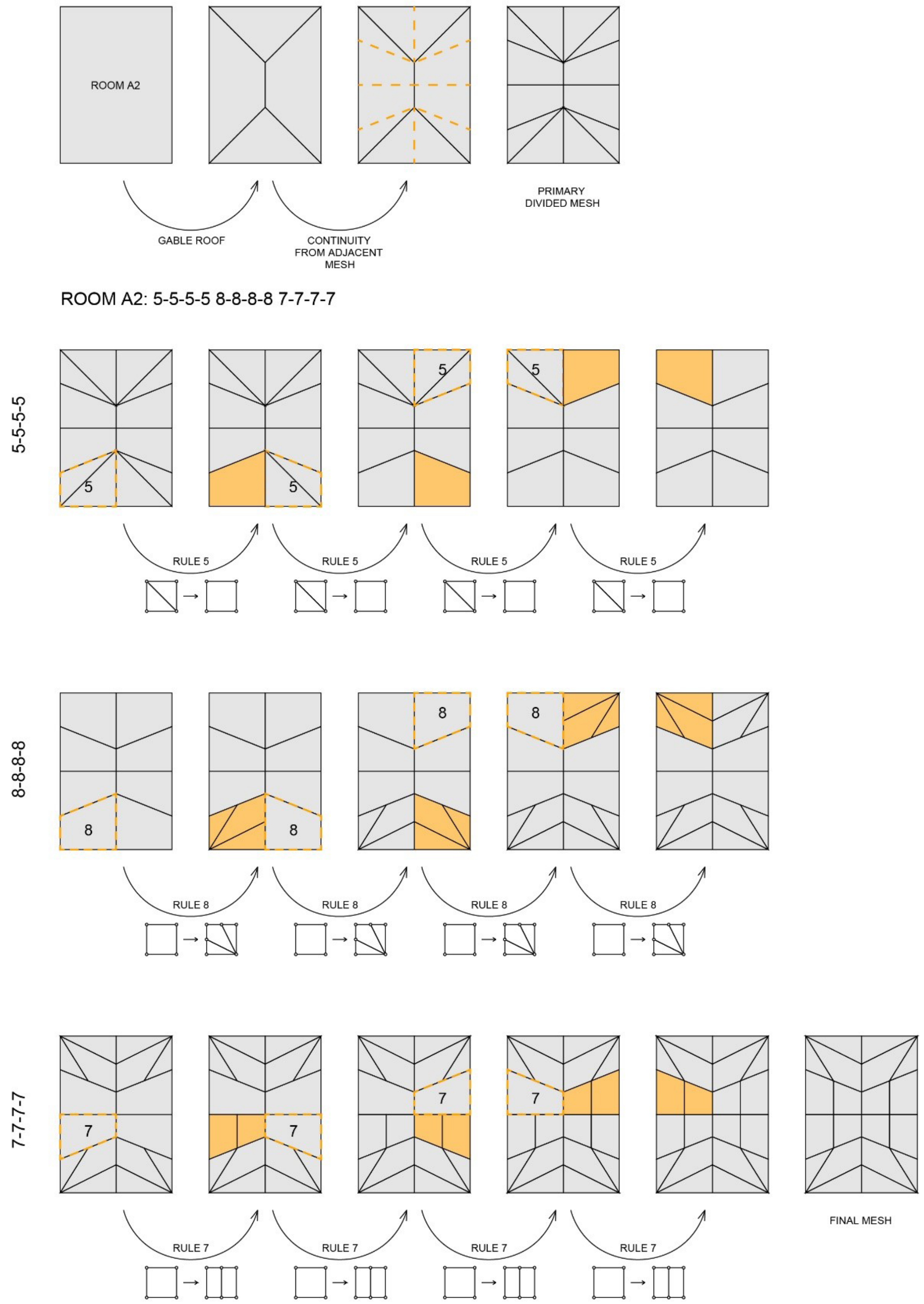


Figure 5.17 Application of tessellation rules on the selected mesh.

The final tessellation pattern was then replicated by adding door openings to the mesh. Two options were considered – cutting opening in the relaxed mesh or considering opening during the dynamic relaxation process, as shown in the Figure 5.19. Since, the building was designed for imparting masonry skills to the youth, the approach to select connected opening tessellation was chosen.

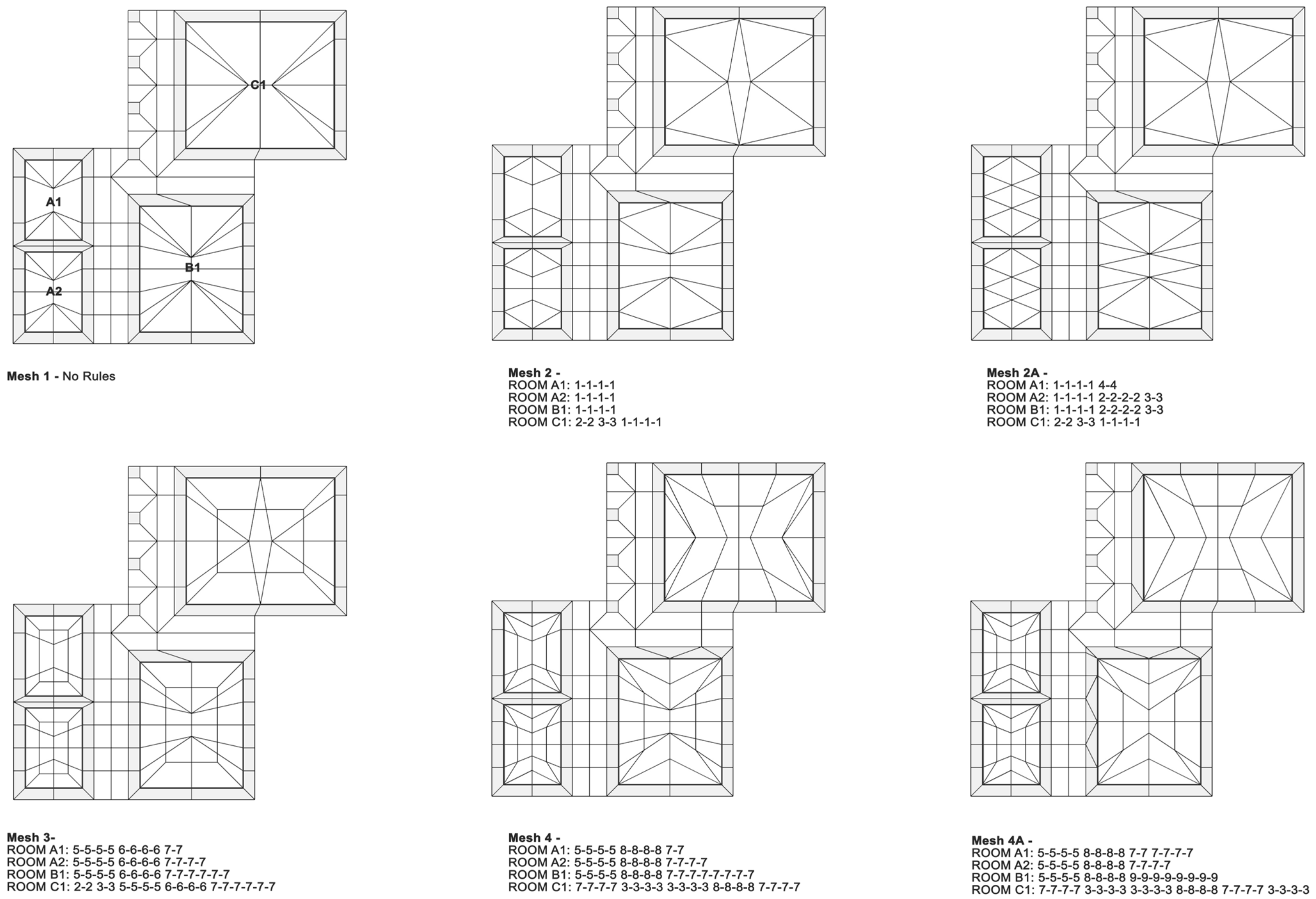


Figure 5.18 Tessellation options generated through various iterations

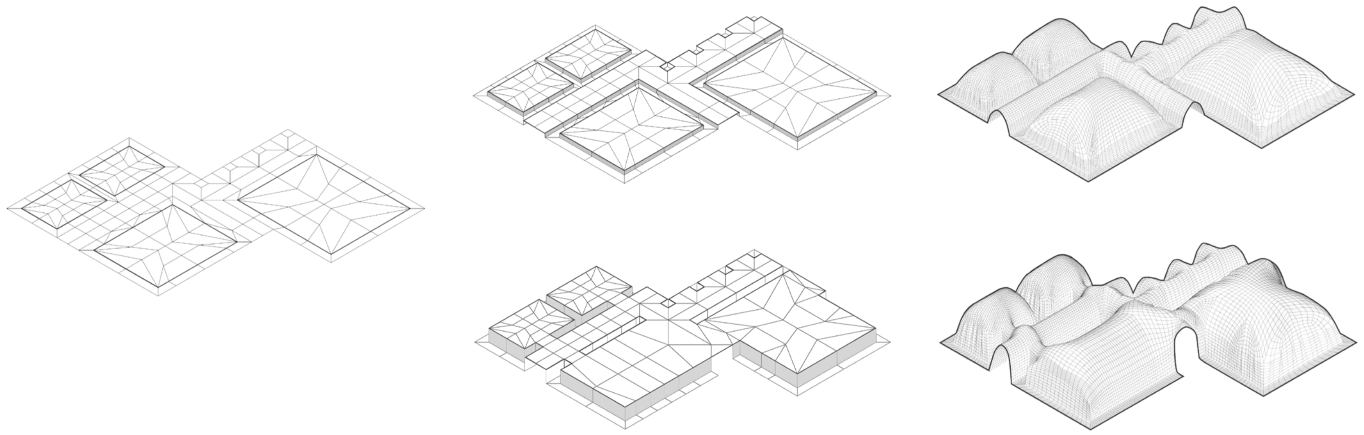


Figure 5.19 Dynamic relaxation of mesh with openings

After generating the final mesh, it was taken into Karamba 3D for final structural analysis. For the analysis, the structural scheme adopted is shown in the Figure 5.20. For the analysis, wind load of 0.2 kN/m2 was used (Habali, 1987), while self weight was taken as per the material research. Since the filling load was less as compared to overall vertical loads, the filling load was ignored but design strength values were considered with safety factor of 6 to overcome variable and additional loads.

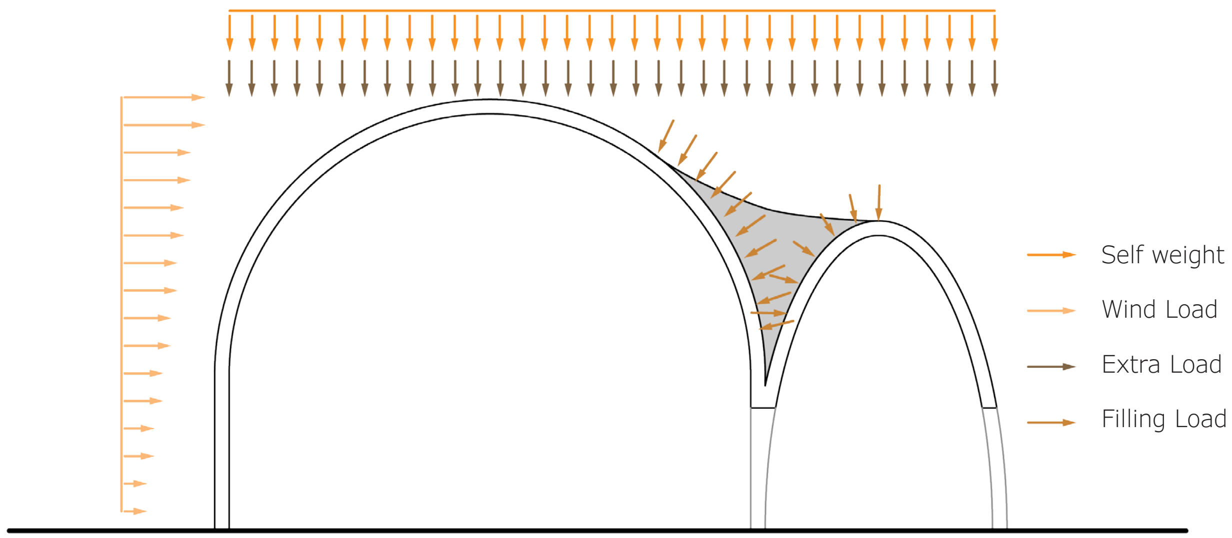


Figure 5.20 Structural Scheme of Free form dome

Design Values

After the material analysis, design values for the structural analysis were takes as follows –

Allowable compressive Stress – 1 MPa [at 10% deformation] (This value considers safety factor of 6)

Allowable Tensile Stress – 1/10 Compressive Stress – 0.1 MPa [at 10% deformation]

Deflection – Span/400 – L/400 - 7200/400 – 18mm

Young's Modulus - 80 MPa

The finite element analysis showed that with the thickness of 30cm the structure was safe. The peak compressive stress of 0.14 MPa was observed on the edge of door openings but was well under the safe limit. The maximum deflection observed was 7mm (Unity check 18/7 = 2.5) which was also safe for given load conditions. While peak tensile stresses were observed on the side walls as highlighted in Figure 5.22. Upon the successful structural analysis, the thickness of 30cm and tessellation pattern of 4A was used to generate the form for the whole ground floor, as highlighted in Figure 5.13.

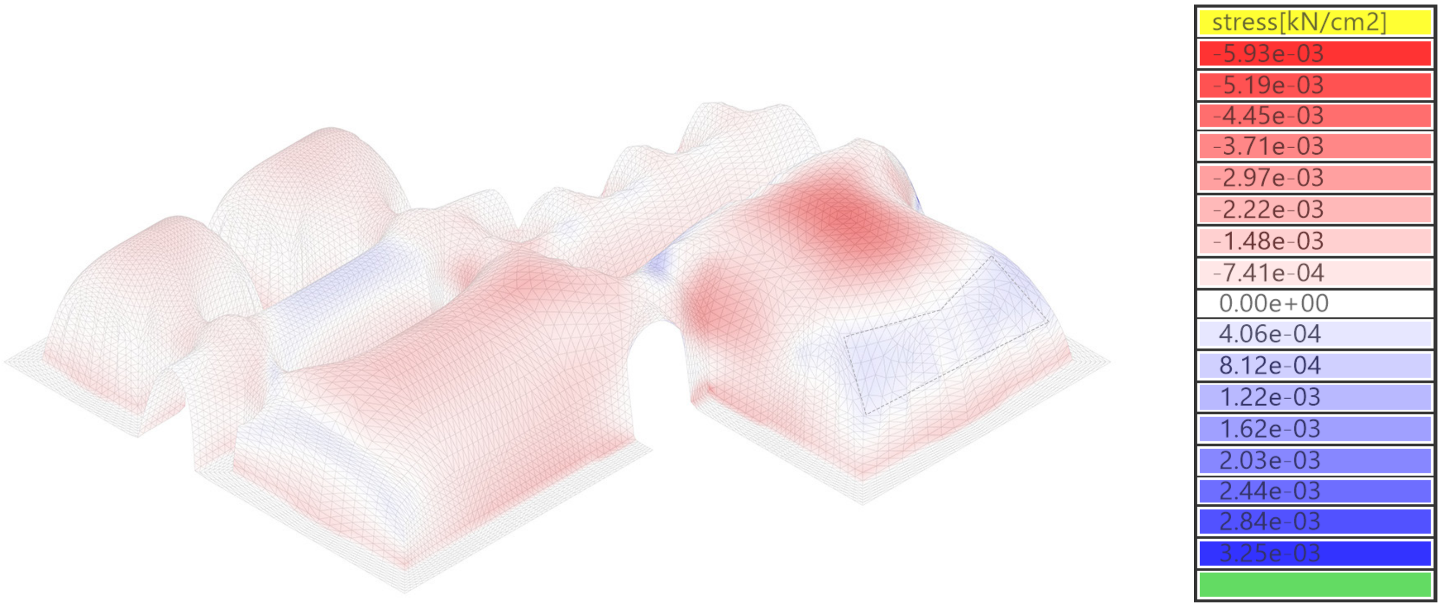


Figure 5.22 Principal Stress 1 for free form dome

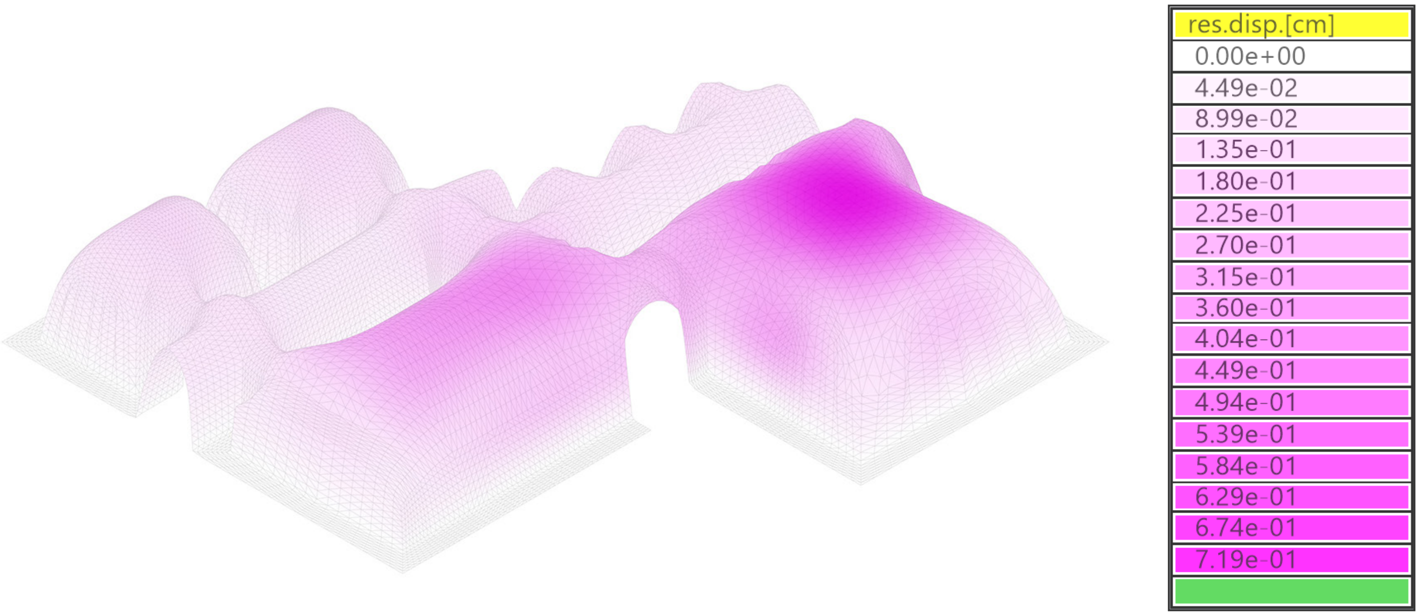


Figure 5.21 Deflection for free form dome

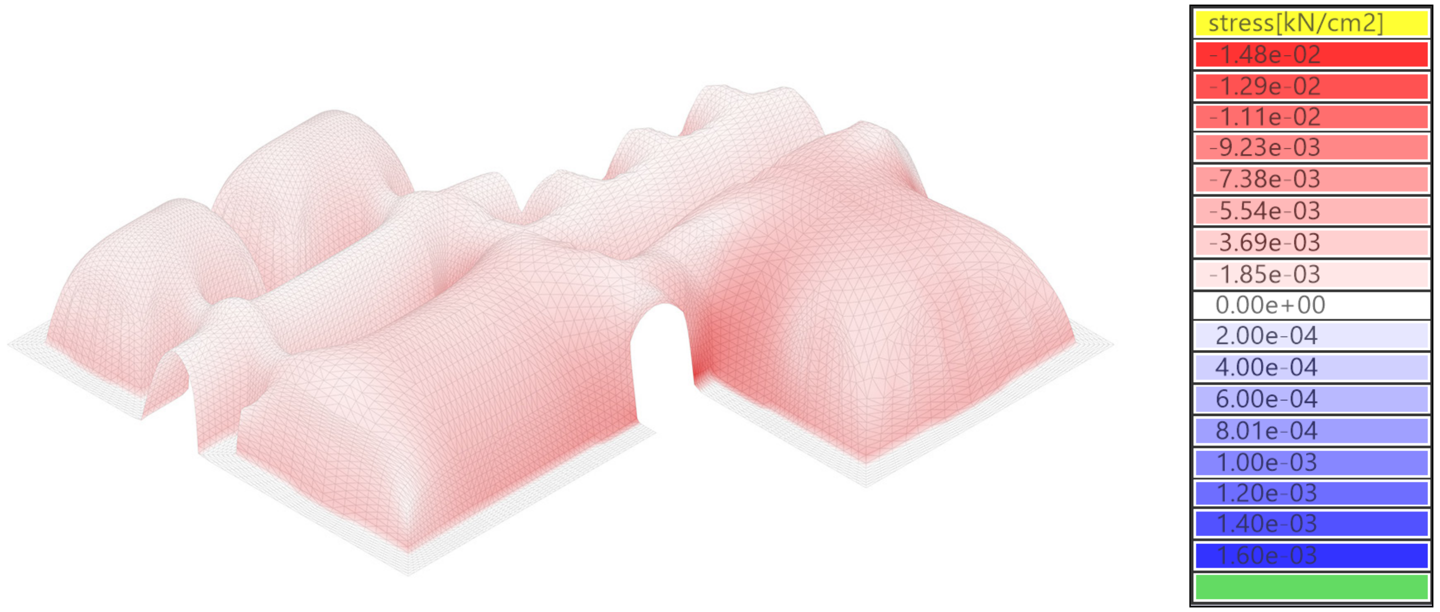


Figure 5.23 Principal Stress 2 for free form dome

5.3.4 Free Form Vaults

Free form vault structure was proposed for the first-floor ceiling structure (Figure 5.24). This was done to create space with large span with least structural load on the wall. It was learned during the literature studies that small openings can be efficiently cut in the vault structures.

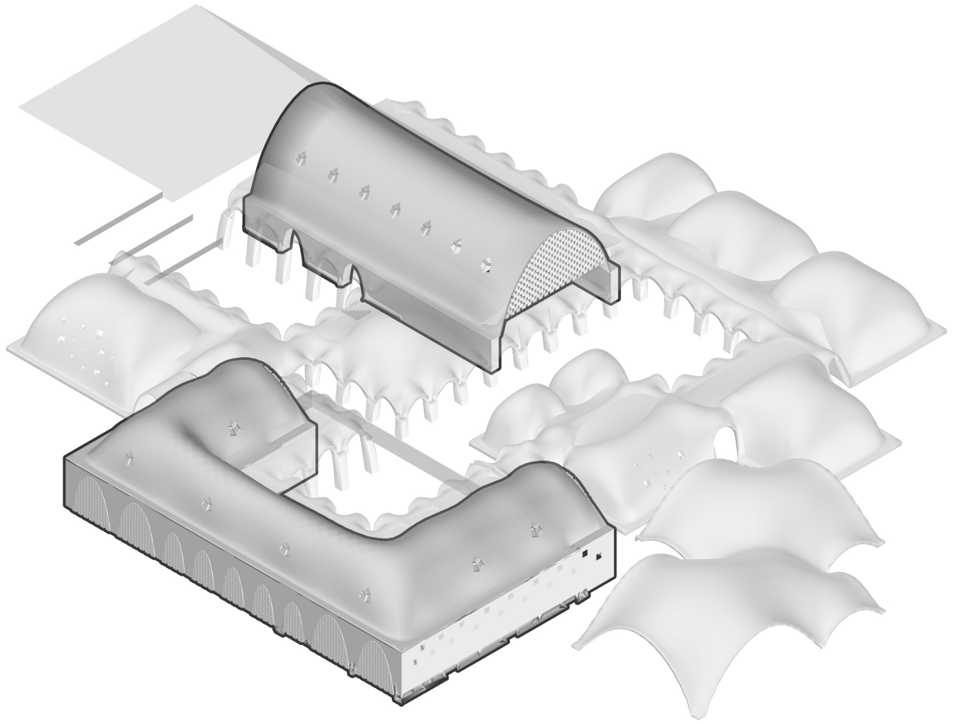


Figure 5.24 Free form vault area highlighted in the building scheme

For this part of the building, the tessellation was generated after an iterative loop to obtain the required shape according to the architectural vision. The steps of tessellation adoption are shown in the Figure 5.25. Since the architectural layout was not having the corridors on the outside of the library building, buttress structure was not used due to unsymmetrical structure.

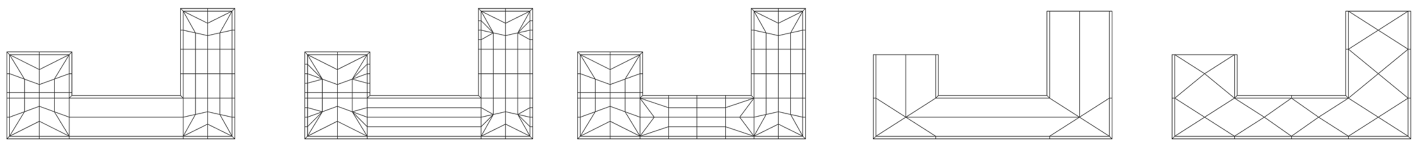


Figure 5.25 Different options explored for the library building in ordere

The structural scheme used for this part of the building is shown in the Figure 5.26. The loadcases and design values were same as for the earlier cases as follows:

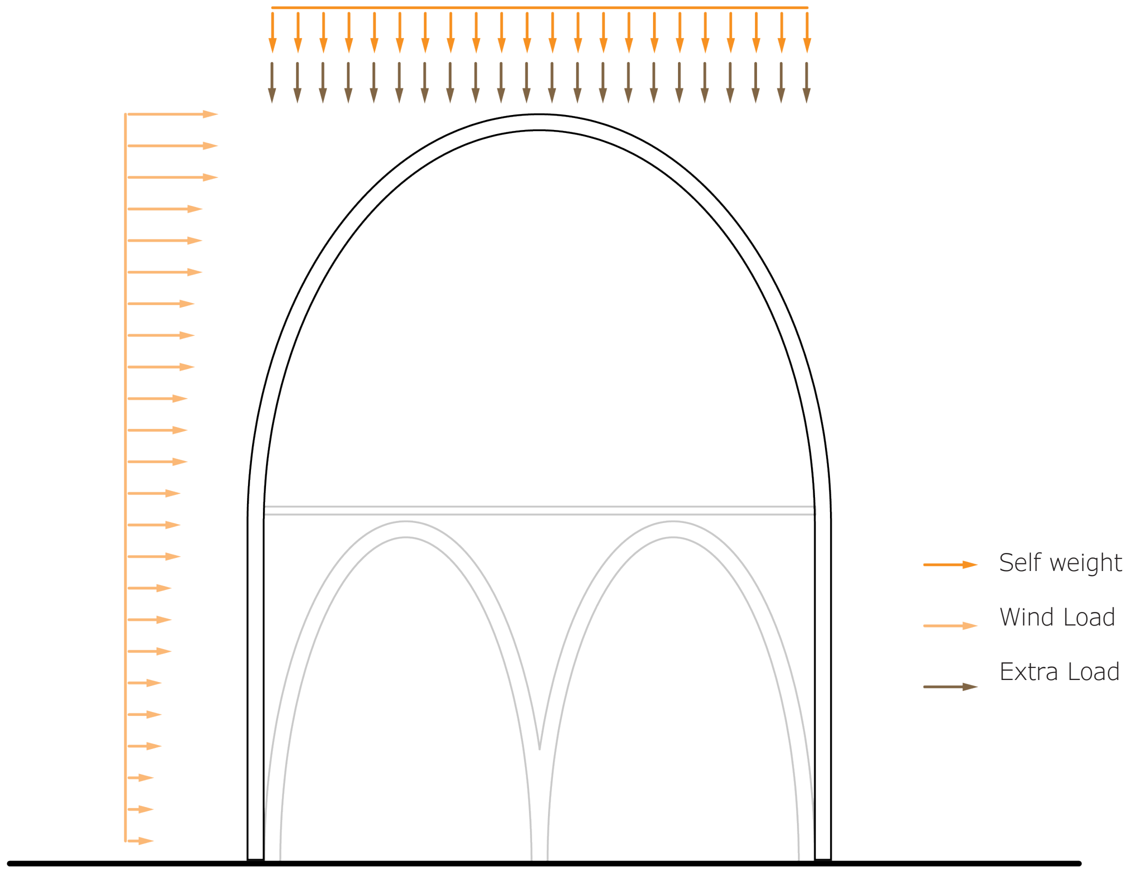


Figure 5.26 Structural scheme for free form vault

Design Values

- **Allowable compressive Stress** – 1 MPa [at 10% deformation] (This value considers safety factor of 6)
- **Allowable Tensile Stress** – 1/10 Compressive Stress – 0.1 MPa [at 10% deformation]
- **Deflection** – Span/400 – L/400 - 6800/400 – 16.5mm
- **Young's Modulus** - 80 MPa

The finite element in Karamba 3D showed that the peak compressive stress of 15cm thickness was 0.19 MPa while the peak tensile stress was 0.04 MPa as shown in Figure 5.27. This was above the safety limits, thus a test for creating openings on required locations was carried out. The location of openings was preferred according to the architectural understanding of daylight requirements. It was noted that there was tension in the areas where opening were preferred thus the finite element analysis was carried out again with the openings cut in the mesh as shown in the Figure 5.28.

It was observed that the peak compressive stress increased to 0.28 MPa while the peak tensile stress increased by small margin to 0.06 MPa (Unity Check 0.1/0.06 = 1.66), which was still well below the failure limit. The maximum deflection was 14 mm but it was deemed acceptable as it was the ceiling structure without any live load. Thus, this mesh was finally tested safe for 15cm thickness for the first-floor ceiling structure.

5.3.5 Mesh Smoothing

Following the structural analysis, the mesh was smoothened using Laplacian smoothing technique and the smoothed mesh was again tested for FEA. This process showed that the structure is safe, and the results does not change a lot from the primary structural analysis. Followed by this, the gaps for the proper drainage were filled using smoothing technique in Rhino replicating the process of how it would be done on the site.

5.3.6 Shell structure

Since, the building proposed is a skill-based training center, it was assumed that the residents will learn the masonry skills and the workshop structure will be built after that. Thus, the workshop structure proposed is a shell structure. The structural analysis for this structure was out of the scope due to time and course restrictions but preliminary analysis is done as shown in the Appendix.

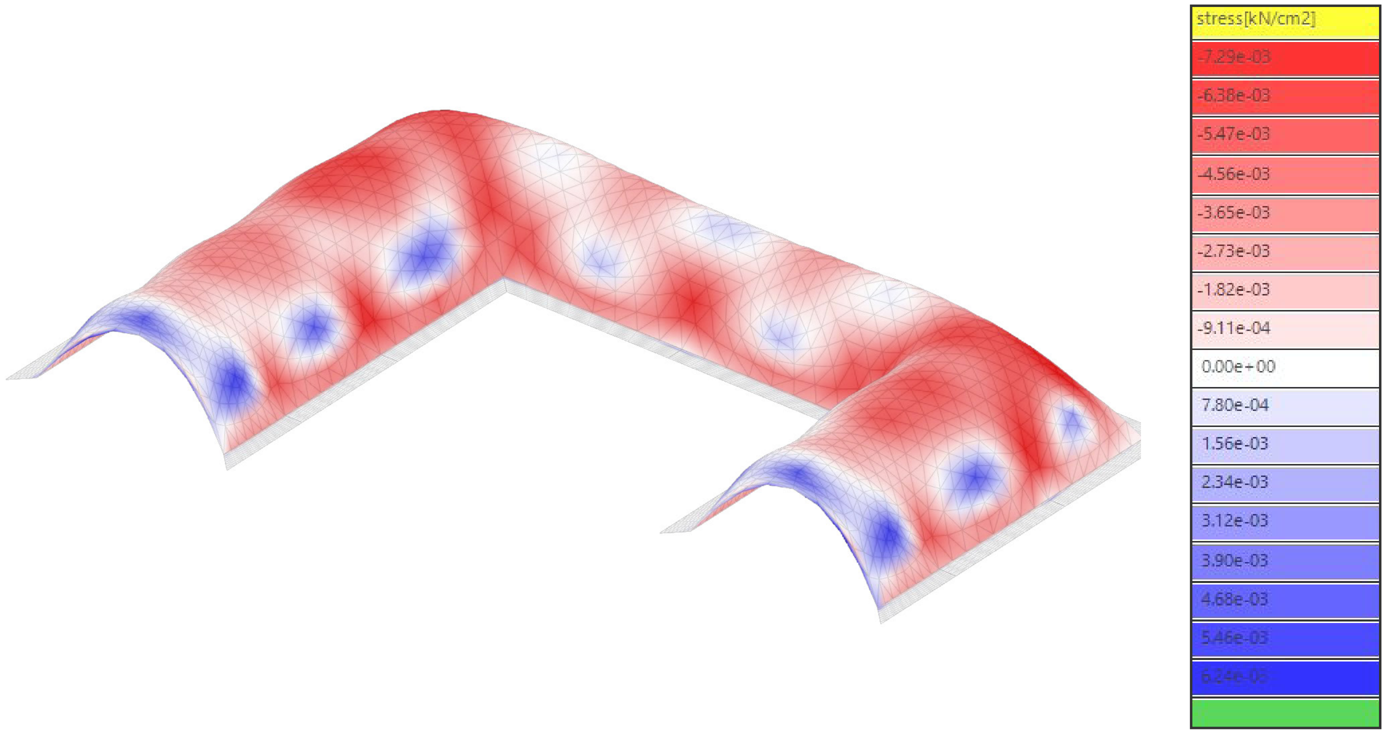


Figure 5.27 Principal Stress 1 for library first floor ceiling structure.

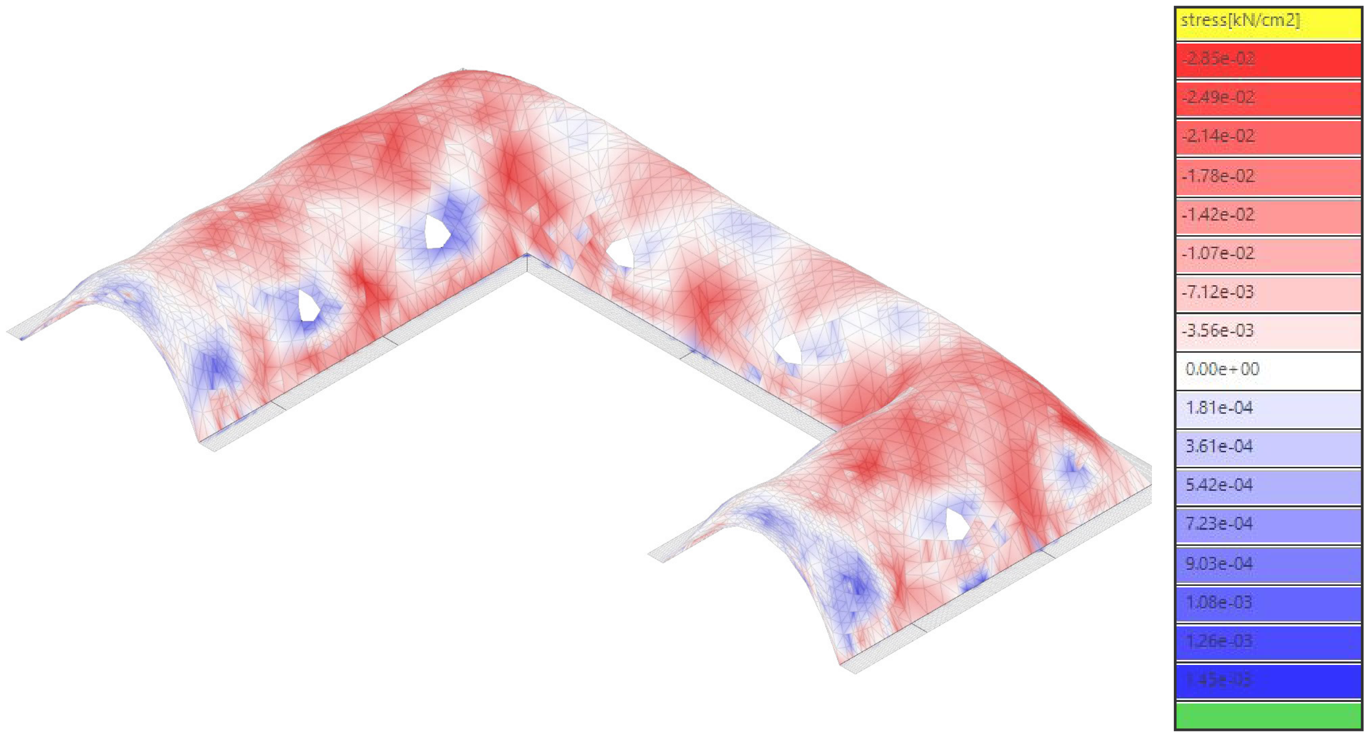


Figure 5.28 Principal Stress 1 for library first floor ceiling structure (openings)

6 Construction process

The context of the project provides several limitations in terms of recourses available for construction of any sort within the Al Zaatari camp. As mentioned before, construction of the skill centre should be done with minimal supporting materials and tools involving a skill-based technique that later becomes the part of taught curriculum. At the same time, construction of this building should not be perceived as a process for completely unskilled workers. The intention of the school is to teach the students construction skills, particularly masonry skills. It is therefore important that the construction of the school itself can contribute to this cause by developing not the simplest technique but one that can be modified and upgraded with improved skill and available resources.

6.1 Construction Manual

Since recourses are scarce in Al Zaatari, we must rely on one recourse which can never be in shortage; creativity. By combining available materials with familiar techniques of construction, the construction process is streamlined into detailed steps to make a self-explanatory construction manual as seen in Figure 6.1 Construction Manual. This will ensure efficient construction of the skill development centre while imparting the necessary skills involved in the process. The construction manual will divide the whole process into smaller chapters.

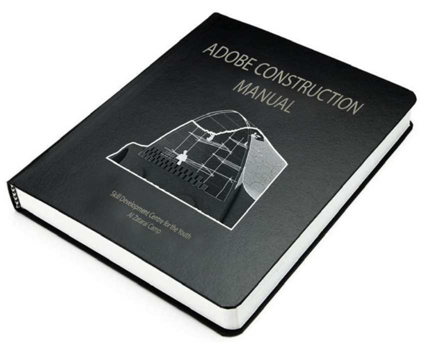


Figure 6.1 Construction Manual

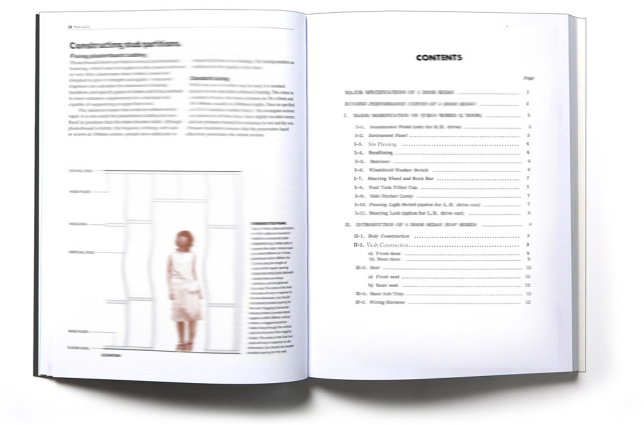
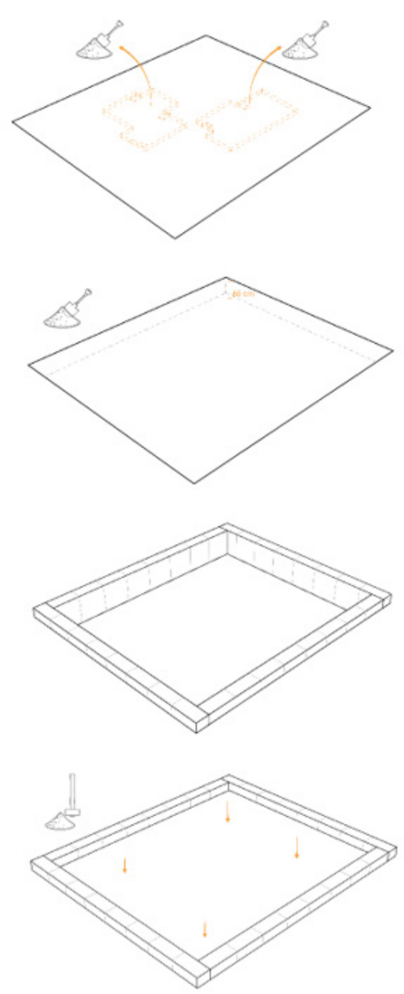


Figure 6.2: Construction Manual Contents

As seen in Figure 6.2, the order of contents will govern the construction order as well. Two such chapters are elaborated below, and the remaining chapters will have a similar explanation methodology.

6.2 Site Preparation

The site preparation and its planning is a chapter in itself as it is a broad task for excavating the material to prepare bricks and prepping the site before starting the construction. Figure 6.3 explains the main steps involved in this process.



Firstly, the site must be prepared to build upon. The site is excavated in relation to the given contour drawings. It must be noted that all the earth that is dug up is used as the primary material to build the adobe bricks with.

The perimeter of the floorplan should be chalked out on the ground for individual spaces based on the measurements given in the drawings. The spaces should have a simple rectangle as the perimeter for the ease of construction. Next, this footprint will then be further excavated for 60cm.

Next, stones will be placed along the chalked border of the space which will protrude for about 30cm from the ground. The stones prevent the building from water which can come up from the ground (capillary action). It also ensures a strong footing for the structure.

After this, the inner cavity is filled back with earth and the floor is rammed with a hand rammer to perfectly compress the soil. This will create a stiff and flat base for the floor.

Figure 6.3: Site Preparation Process

Several tools and materials are required to build the Skill development centre. The advantage of the school is, that all the tools which are used to build the school, are also needed after construction of the school for teaching purpose. That means that the tools will be used extensively before and after construction for a long time to come. Tools needed to make the Adobe bricks are listed in the table below. Their application, sourcing and re-usability are also mentioned in Table 6.1.

	Showel	Handmixer	Bucket	Scrapwood	Rope
Application	Digging site Moving earth	Mixing soil mixture	Container for mixture	To make brick moulds	Measuring
Sourcing	Hardware store UNHCR	Hardware store UNHCR	From Camp	Waste in camp	From camp
Re-usablility	Used for construction workshops	Used for construction workshops	Used for construction workshops	Used for construction workshops	Used for construction workshops

Table 6.1: Tools for brick making

To build the vault structures, some supports, and formwork must be utilized. To do this, use of steel rebar rods of diameter 20mm in various lengths and plumbing T-connections which can be found in the camp is made as explained in Table 6.2.

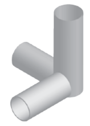
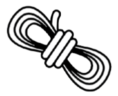
	 Plumbing connection	 Rebar rods	 Bolts	 Nails	 Rope
Application	Holding guiding rods	Act as guiding rod	Attache guiding rod to plumbing connection	Act as guide to shape guiding rod	Attach both ends of guiding rods. Support for bricks
Sourcing	Hardware store UNHCR	From camp UNHCR	Hardware store From camp	Hardware store From camp	From camp
Re-usablility	Used for construction workshops	Used for construction workshops	Used for construction workshops	Used for construction workshops	Used for construction workshops

Table 6.2: Formwork tools & equipment

6.3 INDIVIDUAL SPACE CONSTRUCTION

One of the chapters will focus on how to construct different kind of vaults and shapes. A summary for this process is explained in the steps below. The mesh created using tessellation method is used to extract the main catenary curves required for the construction.

This is achieved by creating catenary curves based on simple intersection and side ribs using NURBS curve of degree 2 (to create curve that is easy to construct). This NURBS curve of degree 2 represent the irrational Bezier curve for the side ribs as illustrated in Figure 6.4.

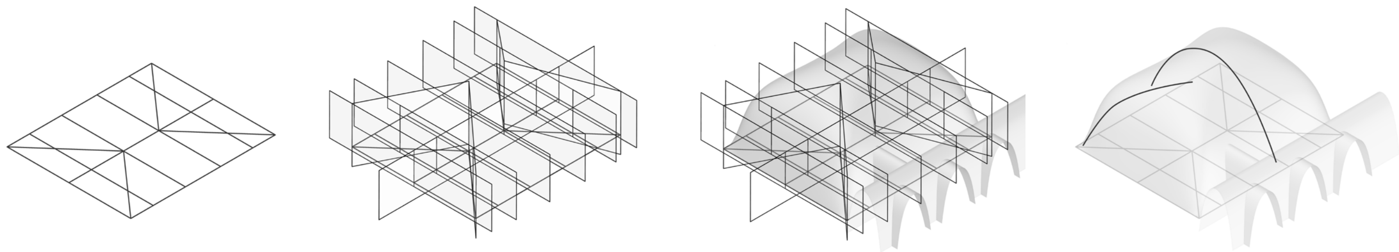


Figure 6.4 Extrusion of cutting planes to get catenary curves from tessellation mesh

After the main curves are retrieved from tessellation, it is important to achieve the exact same non-uniform Bezier curves for the structural accuracy of the vaults during construction. The construction curves are thus exported as lines to an application from which they can be projected on the ground using a smartphone with the help of Augmented Reality as explained in Figure 6.8: Curve Projection using AR.

After the main curves are retrieved from tessellation, it is important to achieve the exact same non-uniform Bezier curves for the structural accuracy of the vaults during construction. The construction curves are thus exported as lines to an application from which they can be projected on the ground using a smartphone with the help of Augmented Reality as explained in Figure 6.5: Curve Projection using AR.

After the curve is projected on the ground, the builders can chalk out the curves line on the ground. Several pairs of nails will be put at an optimum distance into the ground along this curve. This is used to bend the steel rebar in the desired shape for the required formwork. The rebar will be bend into shape by guiding it between the various pairs of nails. By doing so, the rebar will take the shape of the drawn curve. The ends of the rebar will then be inserted into one of the openings of the plumbing connections. The open ends of the plumbing connections that point to the other end of the rebar will then be connected by tying a rope between them. This will ensure that the rebar doesn't loses its form. The step is repeated to get two such bend rebars.

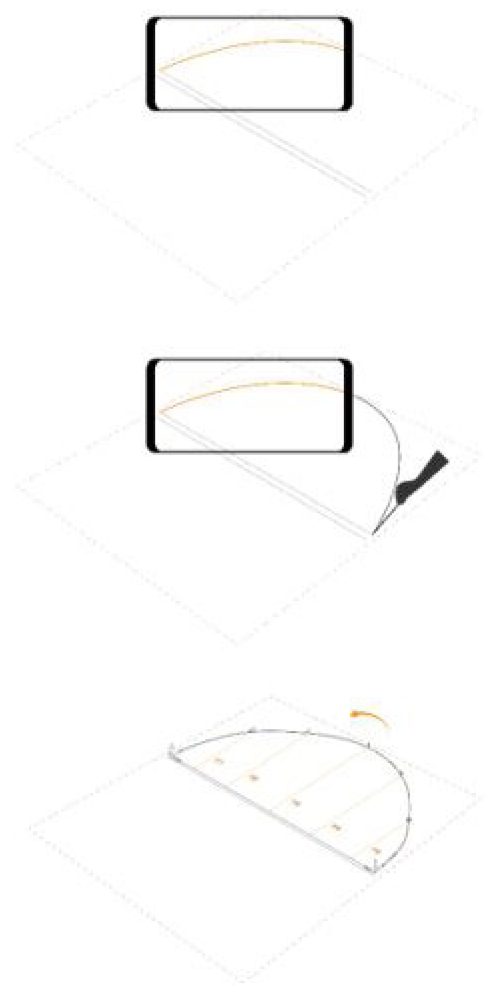


Figure 6.5 : Curve Projection using AR

The rebar formworks are then uplifted and placed next to each other with 200mm centre to centre distance. The two are then tied together using binding ropes in a weave pattern to create a supportive base for bricklaying. This method is widely used all over the world for practicing adobe construction. Shows some examples of similar formwork method used with positive end results.

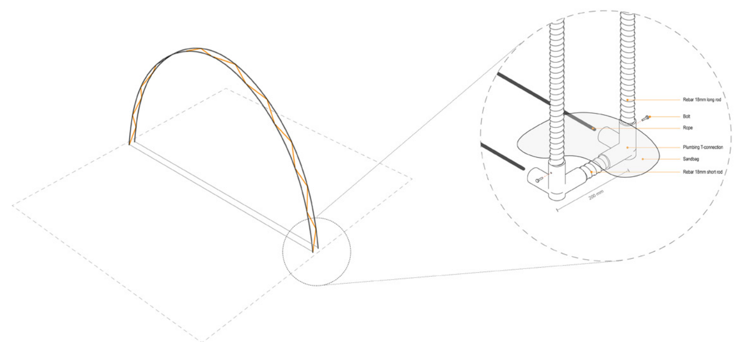


Figure 6.6 :Formwork Preparation

Figure 6.7: Arch Formwork, Auroville, India
(Source : earth-auroville.com)

Bamboo and timber scaffolding is built to provide support to the steel formwork and ropes on both sides hold the arch in place as seen in Figure 6.6. The intention is not to provide for a rigid formwork as to allow certain deformation with the drying up of the brick arch. Once it is stable, the bricks are stacked in an English bond pattern allowing formation of teeth which will help in insertion and interlocking of bricks for the vault later. The bricks are placed with their stretcher face towards the rebar. The course is repeated to achieve a shell thickness of 300mm.

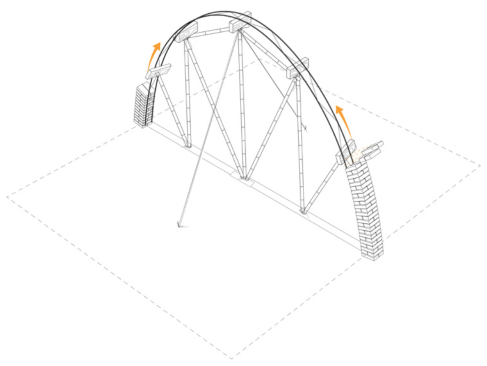


Figure 6.8: Formwork support structure for rib brick stacking

Figure 6.9: Forwork support structure, Auroville, India (Source : earth-auroville.com)

Once the rib is in place the formwork is untied and the two rebars are moved to the extreme ends of the longer span of the space. Ropes are pulled between them at frequent intervals along the arch to create guides for the catenary shape. These guides ensure the accuracy in the shape and the bricks are filled in following a gradual decent with more bricks on the rib side for support as seen in Figure 6.8.

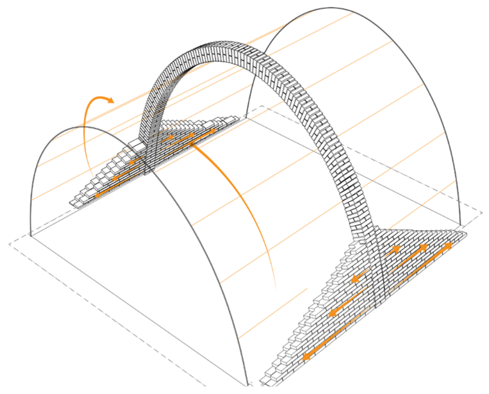


Figure 6.10: Catenary vault brick laying

Figure 6.11: Catenary vault construction, Auroville, India (Source : earth-auroville.com)

The openings are marked as per the drawing specifications. A similar technique but with a steeper curve is used to create the opening archway. This is for the connection between the rooms and corridors. This time a much shorter rebar rod is used, according to specification from the Augmented reality curve. Figure 6.10 illustrates how the bricks for this opening are laid in a similar fashion but oriented in the arch direction. The bigger vault and the opening bricks are constructed together to maximise the strength and bond between the two shapes.

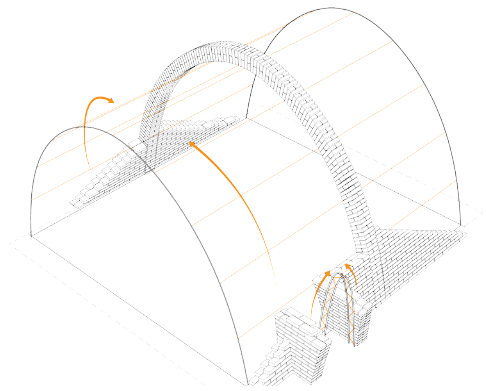


Figure 6.12 Opening insertion

Figure 6.13: Lunette construction, Auroville, India (Source : earth-auroville.com)

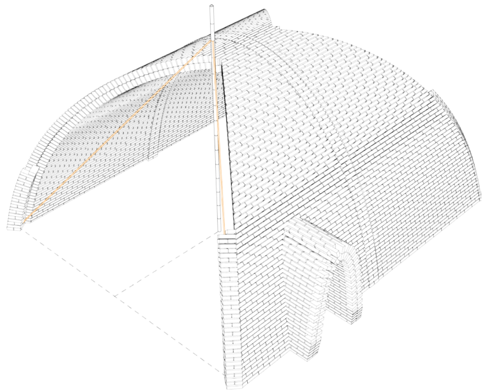


Figure 6.14: Termination markup

Place a bamboo pole on a specified spot in accordance with augmented reality image. This is the point where the catenary vault will terminate. Tie ropes between the top of the bamboo pole to the corners of the room. Continue to create the side walls till the rope guideline as seen in Figure 6.12.

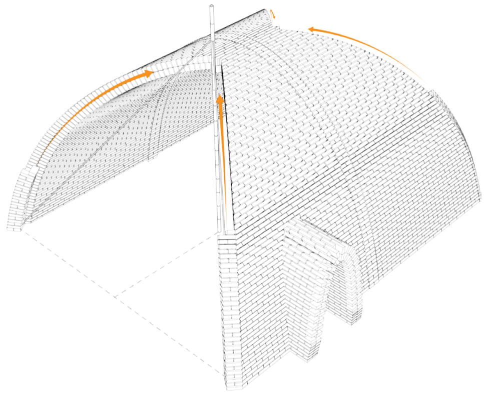


Figure 6.15: Termination rib detail

At the termination the direction bricks are oriented towards the bamboo to turn the vault angle and create a seamless interlocked termination for the catenary vault. Similar teeth are left to fill in the side walls of the space later. The corner ribs are a critical joinery point and should be layed with utmost precision. The smaller kinks and junctions should be simultaneously filled using mortar mix.

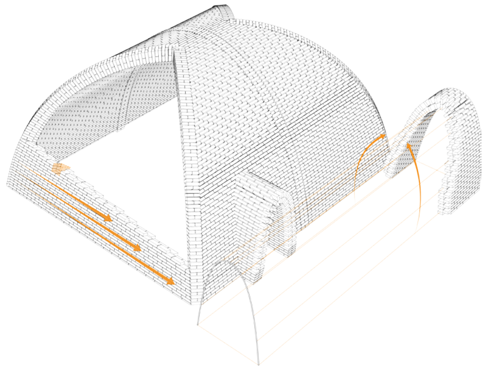


Figure 6.16: Adjacent space brick laying

As the defining shape for the side vault(pendentive shape) is already realized , no additional formwork is required and a the brick laying for this side can be done by interlocking bricks into the rib teeth. For light openings wherever desired, a gap of single brick can be left using some waste carboard boxes. Meanwhile, the brick laying for adjacent space can also start using the same steps as illustrated in Figure 6.14. It is advisable to end construction for a day with a staggered layering of bricks to prevent cracks.

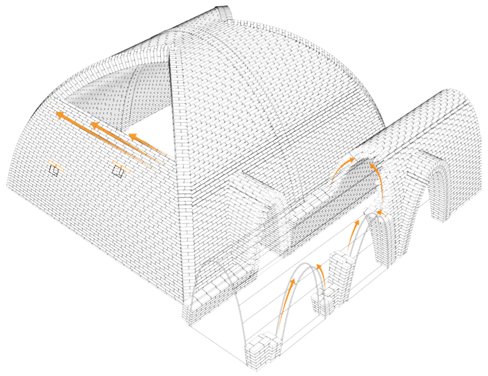


Figure 6.17: Lunette insertion

The openings should never have a full brick for lintel. Special sized lintel bricks an also be casted to achieve slightly bigger openings than the brick size. The corridors can be vaulted in a similar manner with leaving opening into the courtyards as specified in the drawings. The lunette type of openings in the long catenary vault provide support in counter direction and adds to the overall stability of the structure.

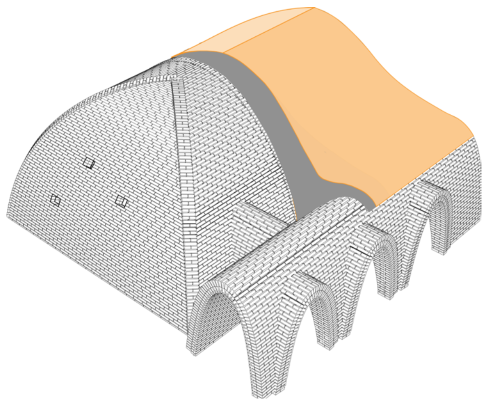


Figure 6.16: Hay-cob filling and plastering

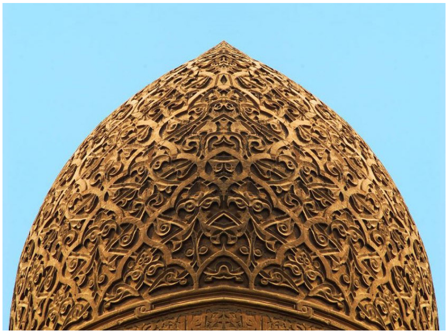


Figure 6.17: Shadow Relief pattern carving (Source: Emad Omar)

Figure 6.18: Reflective tile inlay (Source: emnpk)

6.4 Surface finish treatment

It is important to fill in the gaps between two structures to ensure water doesn't go in and helps in creating a unified space. These gaps can be filled in with a lightweight mix of cob (mixture of sand and compressed hay blocks). This is beneficial as it is a lighter mixture as compared to filling it up with soil. A desired slope can be achieved for the water to run off the building. A coating of water-resistant plaster mix of lime and clay is applied on the outer surface to ensure a sealed surface as illustrated in Figure 6.16. This step would require additional scaffolding formwork.

Some interesting carving patterns as seen in Figure 6.17 can be carved to add to the aesthetic appearance and shadow relief patterns. These will help in self shading of the exterior surfaces and thus improving the indoor temperature of the spaces. It is also intuitive to use locally available material to improve the aesthetic appearance of the skill centre. This can be inspired from the cultural backgrounds that the students come from. Broken mirror shards or bone china can be inlayed to improve the thermal properties of the space beneath as seen in Figure 6.18.

Figure 6.19 shows a section cut through the classroom and corridor in 3D. This emphasizes on the detail of how the different shapes unite into one seamless structure. The cob mix that is used for the gap between the two spaces creates a gradual slope for the water to trickle down into the courtyard spaces.

Figure 6.19 : Cut Section of a classroom

Both library and multipurpose hall are made with vault construction and thus have flat faces on two sides of the structure. These flat walls are easy to build, since they are straight and do not play any significant role in the structure. Therefore, these walls present the opportunity to infilter the dark earth domes with fresh light by creating 'Masharbia' openings with different patterns. These opening also allow for cross ventilation of these large vaulted spaces. As these spaces are for public gatherings the opening doesn't interfere with the privacy of these spaces. Two distinct jaali patterns are used in Library and Multipurpose hall as shown in Figure 6.20. This image also illustrates the construction vision for the first-floor spaces. The bamboo poles in combination with bamboo sleepers or corrugated metal sheets create the necessary scaffolding for the construction. It must be noted that when building the second floor of the library and multipurpose hall, temporary supports must be created on the floor underneath during construction of this second floor, since the scaffolding on the second floor will be temporary additional load.

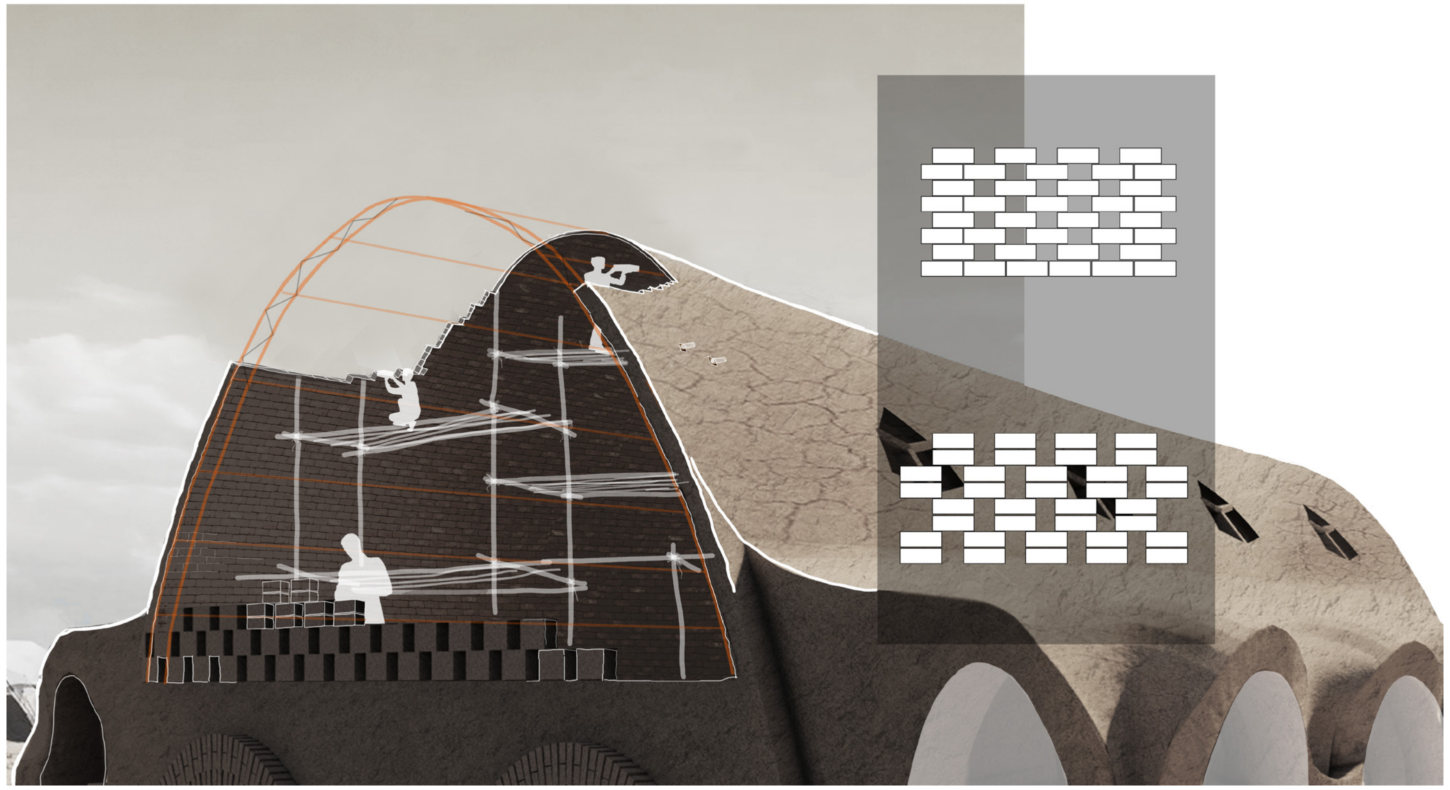


Figure 6.20: Construction Process with Jaali patterns

Earthy was a very interesting course for us. We all agree that this course has the steepest learning curve from all the courses given in Master track Building Technology. We feel like it touches upon many diverse aspects, from the social and political side of the humanitarian crisis of Al Zaatari camp, to the very abstract and technical aspects of Pirouz's lectures on geometry and linear algebra. It had very tangible aspects such as the Adobe brick making and breaking workshops, as well as tutoring about intangible concepts such as gradient descent optimization coding. Dealing with a material like adobe and having minimal recourses forces one to really find optimized solutions within the limitations set by the circumstances and to really think outside the box to find solutions. These are many ways to say the same thing, Earthy is a very complete course, we feel like we have learned a lot from it and have had a great time doing it. We believe this is evident from the result of our project too, which we are very proud of.

Following the lectures and discussing with our mentors and peers these last few months have lead to some very interesting discussions. We have experienced first hand the possibilities and limitations of computational methods. The fact that computational tools are not a magic box which give you the "optimal solution" for all your questions is very evident. At the same time, doing some exercises manually creates biases and can be very time consuming. For good design, a synergy between computational and human approaches are needed. We have seen that computational tools can generate many unbiased options based on predefined multi objective parameters. For humans it is hard to compute many dependant parameters at the same time, here a computer outperforms us by a large margin. Computational methods also help us to analyse datasets much faster than we could do manually and this saves time and boosts productivity. After computational tools have created multiple options based on our predefined criteria, it is up to us as designers to manually select the best option from the clutter. This step is likely going to be manual always. We as humans can feel empathy and can relate to the user since we are human ourselves. To teach a computer to 'feel' like a human or to 'feel' anything for that matter is an entirely different and interesting matter by itself.

But what does this mean for the future of the designer? Will the role of a designer shift towards someone who's biggest asset is to connect to the user or client and translate their wishes into inputs for computer scripts? This would depend on whether design is something that we can fully understand ourselves in the first place. How do we design? How do we make choices in a design process? Some steps are objectively done and are quantifiable, but other steps may be taken because of certain biases of the designer. Is it bad to have certain biases as a designer? If yes, then what distinguishes you as a designer? If it isn't, there would be many versions of a good design for any specific scenario. Would there be an objectively 'best' or 'optimal' design for any specific scenario? If there would, then feeding all the right parameters of this specific situation into a computer script might give the 'best' or 'optimal' solution for a specific situation. However, since human behaviour is not entirely predictable, the prospect of there being a 'best' or 'optimal' solution in architecture seems unlikely. There would always be imperfections in any 'perfect design', since we as humans are imperfect in a sense. Therefore, it might be that an imperfect human (designer) would always have to manually choose one of the imperfect solutions the computational scripts would generate. He or she, might have to manually 'perfect' this option, based on their own version of the perfect image.

Designer

/dɪ'zʌɪn□/

Noun

An empathetic person who understand the human challenges and translates those challenges into quantitative parameters and can attain suitable solutions in cooperation with Artificial Intelligence.

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Youth are the spirit of life, they determine how developed or underdeveloped a nations is !!!....

Syria will need this Youth Force to Build back their home.....

9 Appendix

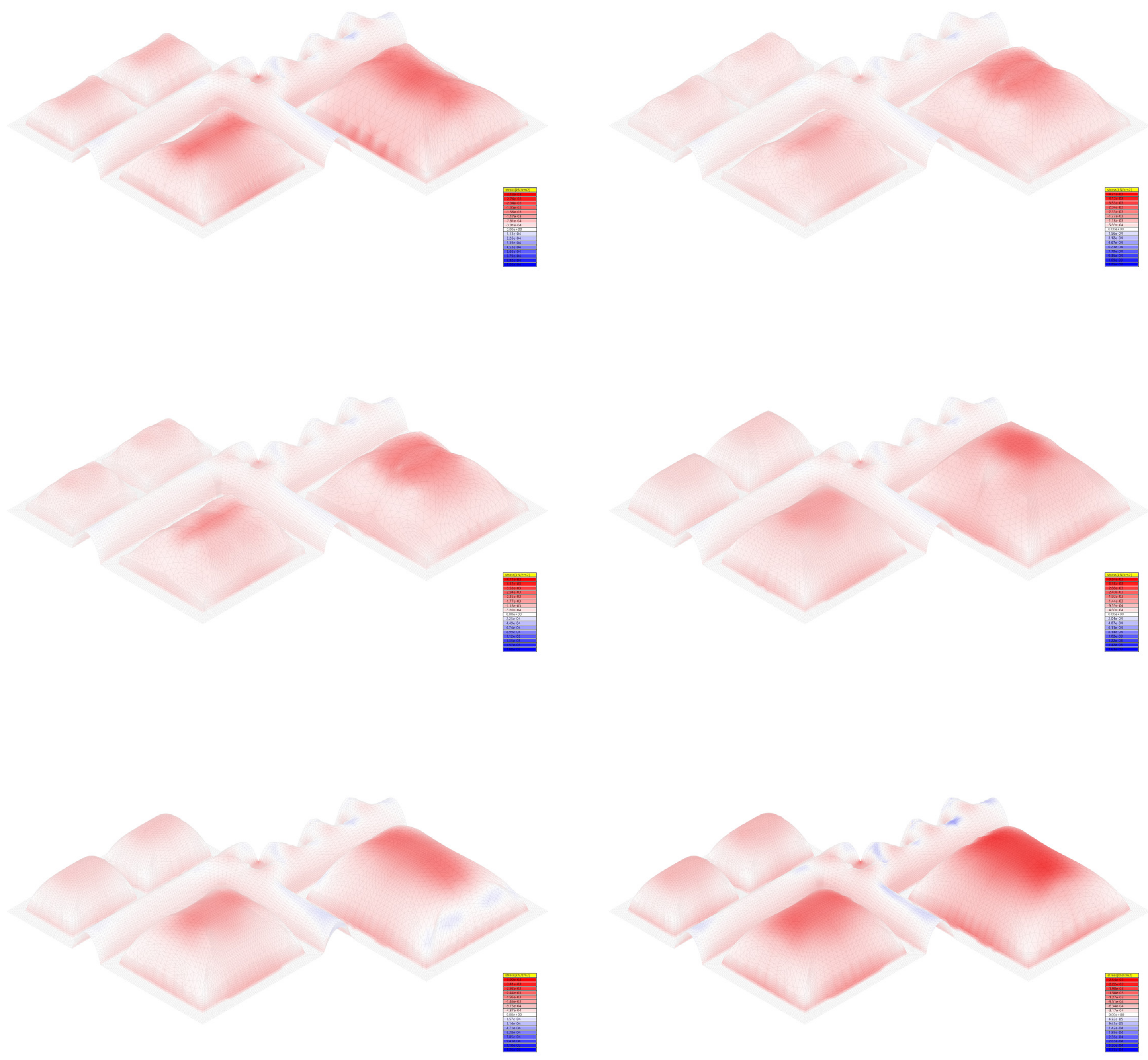
9.1 REL Chart

No Proximity	0
Proximity	1
Open Space	
Semi-Close Space	
Close Space	

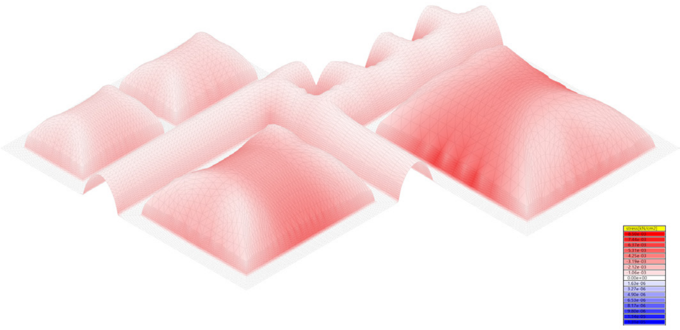
Index	Typology		Storage 1	Storage 3	Toilet 1	Toilet 2	Toilet 3	Cleaning Room	Pantry	Multipurpose Hall	Childcare	Library	Office	Meeting Room	Counseling Room	Teaching Lab A	Teaching Lab B	Teaching Lab C	Computer Room	Workshop	Amphitheatre	Courtyard 1	Courtyard 2
			services							community spaces			administration spaces			LEarning Spaces					Transition Spaces		
0	services	Storage 1																					
1		Storage 3	0																				
2		Toilet 1	1	0																			
3		Toilet 2	0	0	0																		
4		Toilet 3	0	0	0	0																	
5		Cleaning Room	0	0	0	0	0																
6	Community spaces	Pantry	0	0	0	0	0	0															
7		Multipurpose Hall	0	1	0	0	0	0	0														
8		Childcare	0	0	0	0	0	0	0	1													
9		Library	0	0	0	1	0	0	0	0	0												
10	Administration spaces	Office	0	0	0	0	0	0	0	0	0	0											
11		Meeting Room	0	0	0	0	0	0	0	0	0	1	0										
12		Counseling Room	0	0	0	1	0	0	0	0	0	0	0	1									
13	Learning spaces	Teaching Lab A	0	0	0	0	0	0	0	0	0	0	0	0	0								
14		Teaching Lab B	0	0	0	0	0	0	0	0	0	0	0	0	0	0							
15		Teaching Lab C	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1						
16		Computer Room	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0					
17		Workshop	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0				
18	Transition spaces	Amphitheatre	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0			
19		Courtyard 1	1	0	1	1	0	0	1	1	1	0	0	0	0	1	1	1	1	1	0		
20		Courtyard 2	1	0	0	0	0	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0	

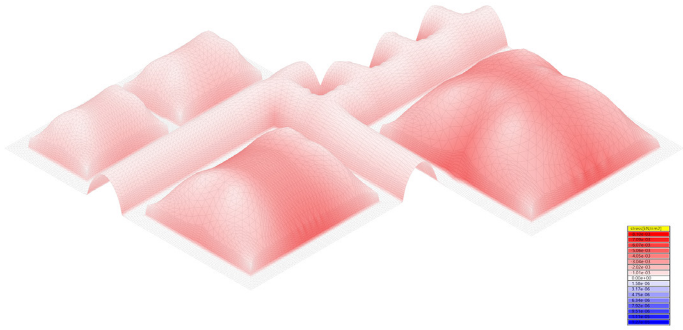
9.2 Tesselation

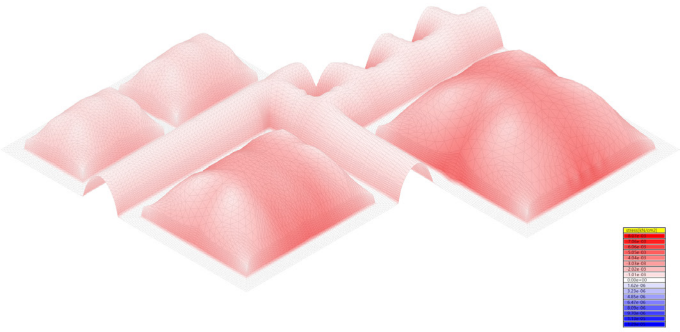
9.2.1 Principel 1 stresses

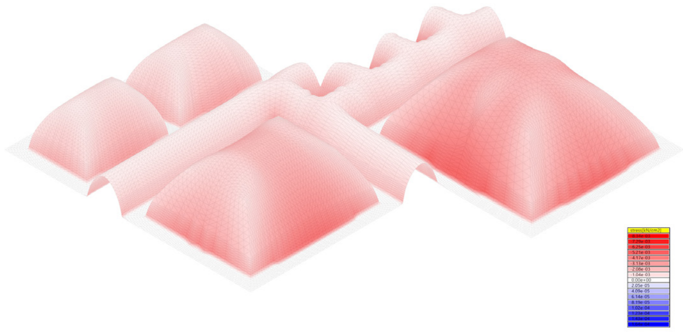


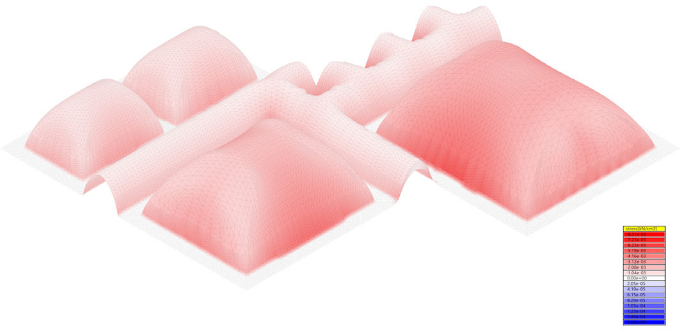
9.2.2 Principel 2 stresses

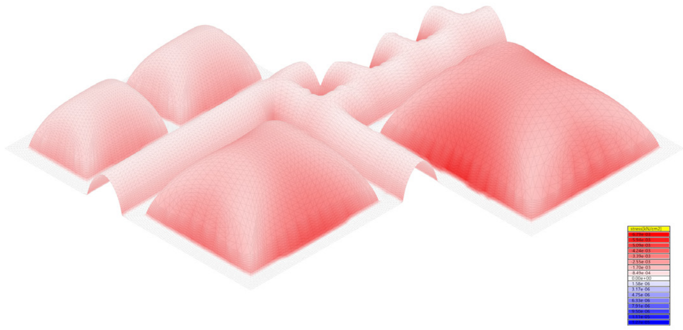




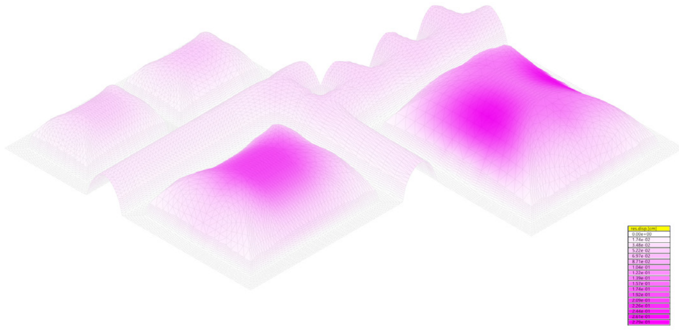


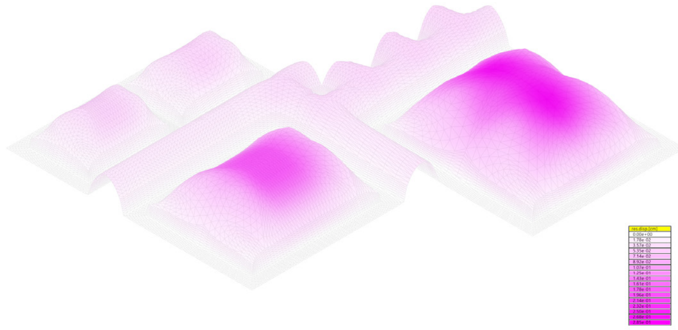


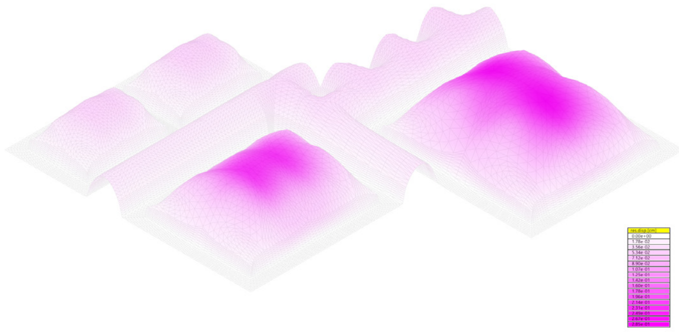


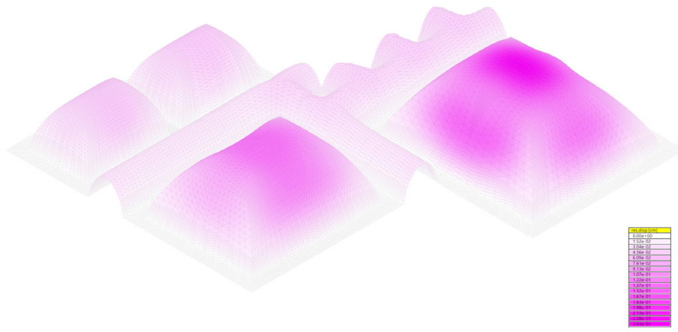


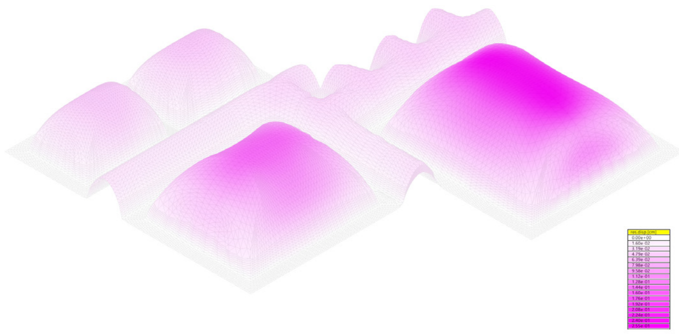
9.2.3 Deflections

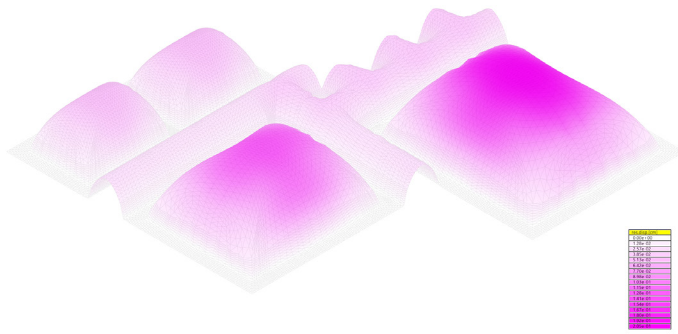




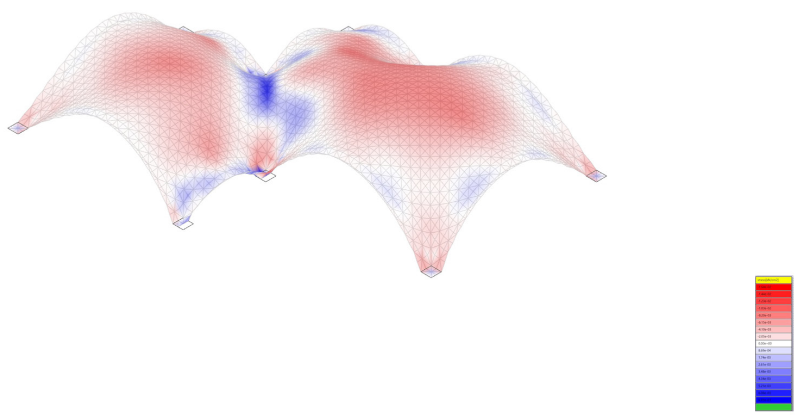




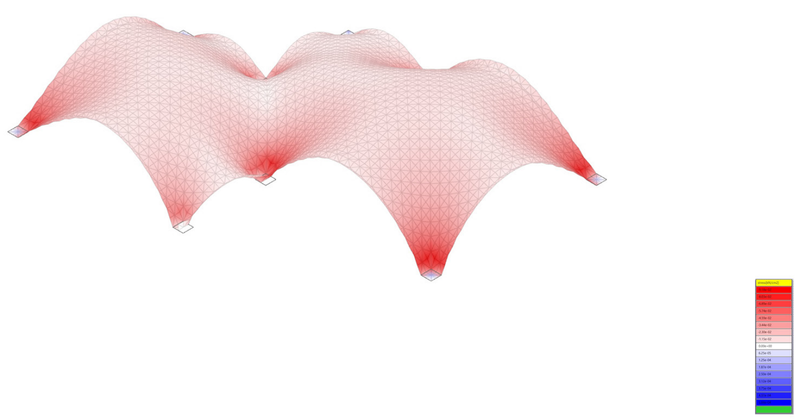




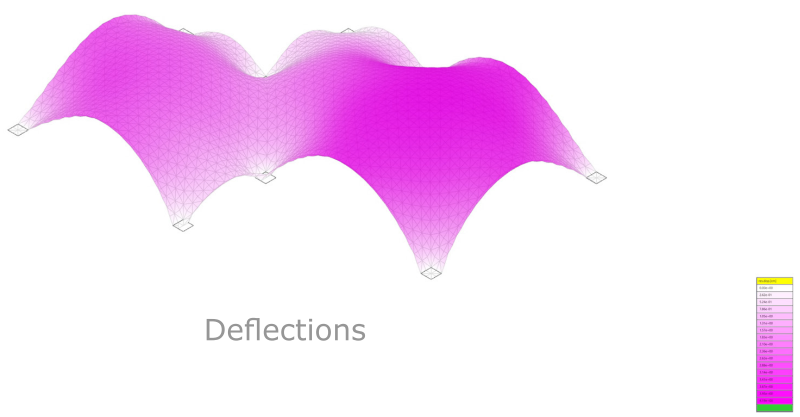
9.2.4 Workshop



Principel 1 stresses



Principel 2 stresses



Deflections

9.3 Tables

9.3.1 Programme Of Requirements

Space	Capacity	Area Required	Type of space	Min. Height Required	Daylight orientation
	[persons]	[m^2]	-	[m]	-
Classrooms					
Type A (masonry)	60.48	20	Closed	2.9	North East
Type B (language)	60.48	20	Closed	2.9	North and East
Type C (nursing)	43.243	20	Closed	2.9	North and East
Computer Room	43.2	20	Closed	2.9	North-east
Workshop Area	155.2	50	Semi-Open	-	South
Administration					
Office	25.92	5	Closed	2.9	west
Meeting Room	36	10	Closed	2.9	west
Counselling Room	12.96	4	Closed	2.5	west
Common Areas					
Library	324	100	Closed	2.7	North east
Multipurpose Hall	324	150	Closed	3	South or south west
Childcare / Creche	50.4	20	Closed	3	North east
Ancillary Spaces					
Storage	86.4	-	Closed	3.2	south
Cleaning Room	17.28	-	Closed	2.9	south
Toilets	69.12	-	Closed	2.4	east
Pantry	12.96	-	Semi-Open	2.4	east
Gross Area	**1718.08**				
30% circulation	**396.48**				
Net Area	**1321.6**				

9.3.2 Brick Making Recipes

Brick Type	Code	Clay	Fine Sand	Coarse Sand	Additive		Water	Weight of mixture
		(%)	(%)	(%)	Type	%	(%)	(Kg)
Adobe	A1 – A-11	30%	30%	40%	-	-	10%	10.8
Adobe+Straw	S1-S4	30%	30%	40%	Straw	1% by volume	10%	11.3
Adobe + Woodchips	WD1-WD3	30%	30%	40%	Wood Chips	1% by volume	10%	4.17
Adobe + PaperPulp	PP_1-PP_5	25%	25%	-	Paper Pulp	50%	-	6
Adobe + Straw+Strach	SM_01-SM05	30%	30%	30%	Straw	1% by volume	10%	9

9.3.3 Brick Testing Results

Brick Type	Mean	Standard Deviation
	[N/mm2]	[N/mm2]
Adobe Bricks	1.33	0.61
Adobe + Straw	2.7	0.82
Adobe + Wood Chips	2.1	0.7
Adobe+Straw+Starch	5.8	1.02

Brick Type	σ at 1.5% deform. In height	σ at 5% deform. In height
	[MPa]	[MPa]
Adobe Bricks	0.13	0.13
Adobe + Straw	0.12	0.3
Adobe + Wood Chips	0.13	0.4
Adobe+Straw+Starch	0.1	0.5

Brick Type	Mean E [MPa]
Adobe Bricks	10.63
Adobe + Straw	12.37
Adobe + Wood Chips	11.3
Adobe+Straw+Starch	17.5

Design Values		
Brick Type	Adobe + Straw + Starch	
Compressive Strength	1 MPa	Experiment
Young's Modulus	80 MPa	Literature
Tensile strength **(1/10 Compressive Strength)**	0.1 MPa	Literature

Mesh	1	2	2A	3	4	4A
Peak Compressive Stress	MPa	0.081	0.08	0.083	0.083	0.069

Appendix 1 : Maximum force at Break

Specimen	Max Force at Break [N]	Specimen	Max Force at Break [N]	Specimen	Max Force at Break [N]	Specimen	Max Force at Break [N]
A1	14900	S1	53932.71	WD_1	24253.13	SM_01	83432.10938
A2	16087.38	S2	69108.58	WD_2	43393	SM_02	54229.78
A3	10380.36621	S3	100499.4	WD_3	9842.557	SM_03	99417.57813
A4	14003.23145	S4	72196.41			SM_04	60317.46475
A5	18570.73					SM_05	97735.51358
A6	8604.433						
A7	51283.27						
A8	31978.99						
A9	29866.87						
A10	25400						
A11	34600						

Maximum Force At Break

Appendix 2 : Test data from Group 1-Group 7 for Adobe Only

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax
	L	W	H		
Group 1					
A1	160	100	60	14900	-
A2	95	70	30	16087.38	6.81
A3	95	70	30	10380.37	4.911062
A4	95	70	30	14003.23	5.904611
A5	95	70	30	18570.73	7.75
A6	95	70	30	8604.433	8.11
A7	170	90	40	51283.27	19.53
A8	170	90	40	31978.99	7.55
A9	170	90	40	29866.87	9.68
Group 2					
1A	164	121	71	8,319.96	11.76
1B	159	124	63	15,680.92	11.81
1C	155	124	67	10,478.11	11.19
1D	159	114	64	12,005.94	13.09
1E	159	128	68	8,844.50	12.41
2A	113	113	43	19,500.00	-
2B	109	111	40	93,036.24	24.98
2C	109	108	36	1,01,160.80	24.30
2D	116	109	42	20,700.00	-
2E	111	102	40	99,968.26	24.05
Group 3					
S1s	95	70	30	9216	-7,91
S2s	95	70	30	21900	-
S3s	95	70	30	17900	-
S4s	95	70	30	20200	-
S5s	95	70	30	16900	-

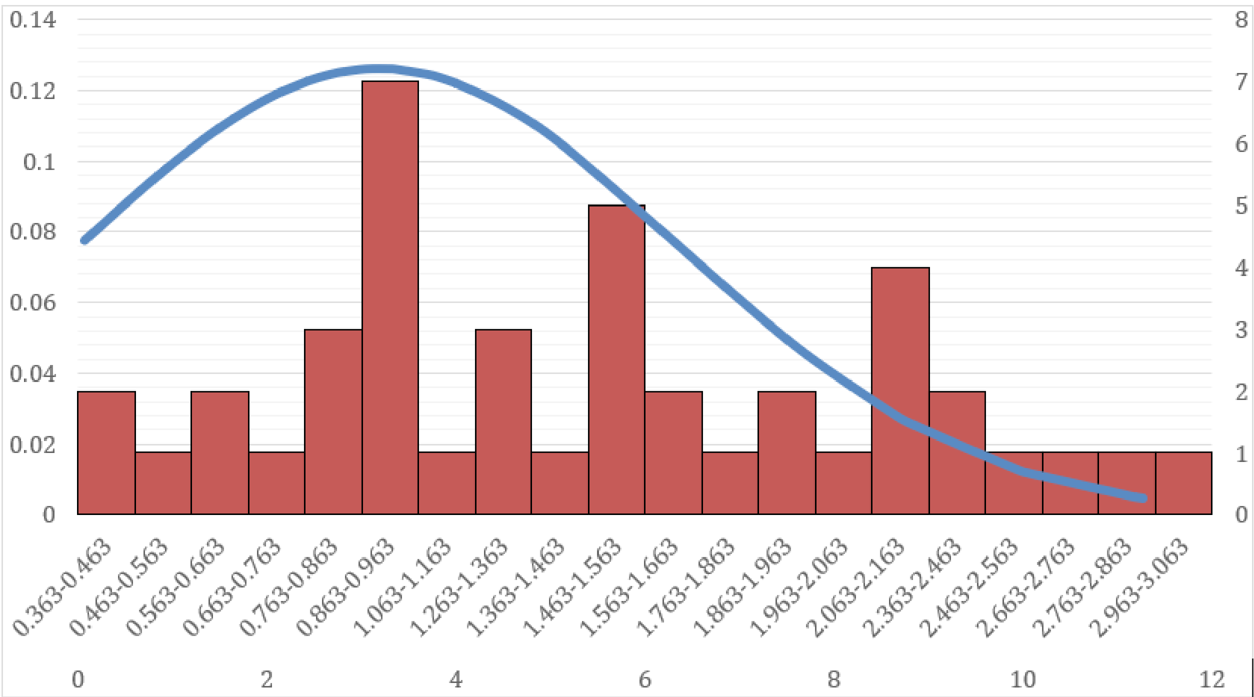
Group 4					
1	100	100	60	13310.3	9.126376
2	100	100	60	21595.4	9.896349
3	100	100	60	19246.79	12.69633
4	100	100	60	16456.54	14.32644
5	100	100	60	14791.9	8.94633
6	60	60	50	3360.184	2.726414
7	60	60	50	5351.55	12.53665
8	60	60	50	8721.683	3.744479
9	60	60	50	3059.625	3.816359
10	60	60	50	3241.821	6.386316
Group 5					
1	165	105	65	16122.84	8.98
2	165	105	65	1104.09	0.09
3	165	105	65	12435.69	9.60
4	165	105	65	15587.39	8.49
5	165	105	65	11456.90	9.67
6	110	80	30	98453.83	14.98
7	110	80	30	35100	9.97
8	110	80	30	59763.43	14.99
9	110	80	30	39892.43	9.97
10	110	80	30	35138.97	9.96

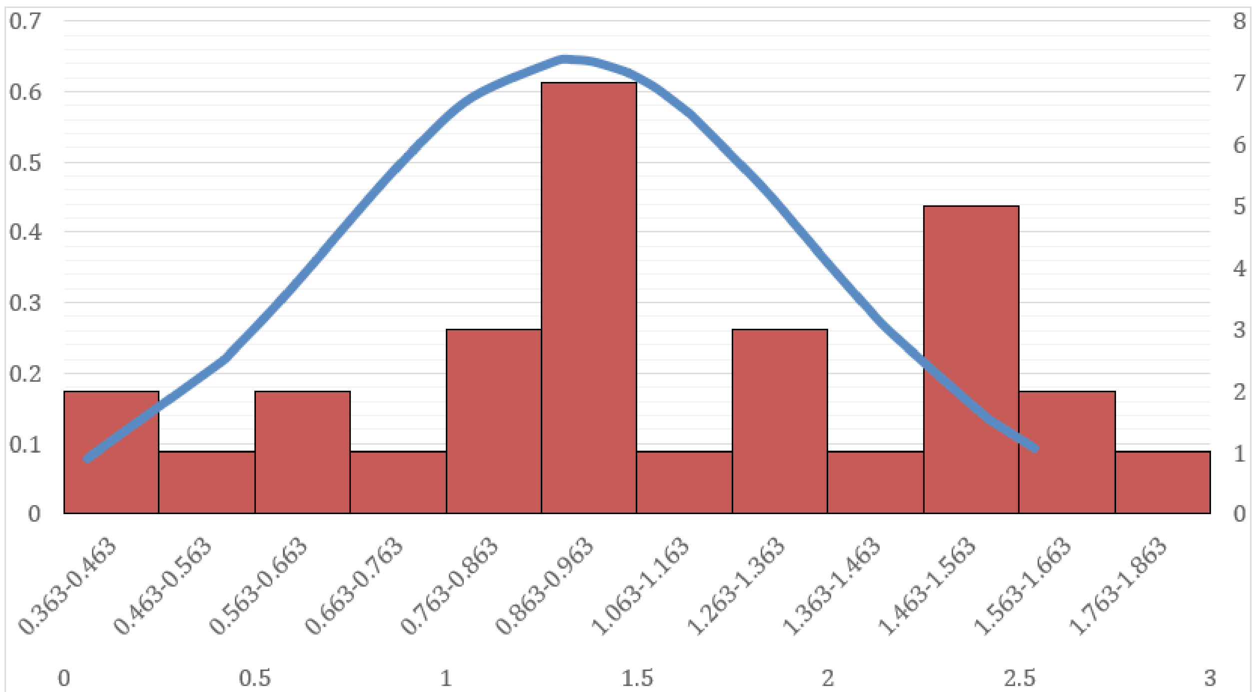
Test Data From Group-1 to Group-7 for Adobe Only

Group 6					
A1	175	85	40	12457.81	11.32
A2	175	85	40	13624.26	9.26
A3	175	85	40	13027.7	11.29
A4	175	85	40	15951.05	14.95
A5	175	85	40	19770.12	8.56
A6	175	85	40	21831.98	10.02
A7	105	75	30	78228.37	14.97
A8	105	75	30	88700	-------------
A9	105	75	30	29158.42	15
A10	105	75	30	87904.19	14.99
A11	105	75	30	30334.93	15
A12	105	75	30	79126.34	14.98

Group 7					
A1	100	75	30	38700	-
A2	100	75	30	83998.44	11.9737
A3	100	75	30	15700	-
A4	100	75	30	13672.56	9.4266
A5	100	75	30	52000	-
A6	100	75	30	14996.25	11.95588

Normalised Graph for Compressive Strength for Adobe Bricks only (Group-1 till Group-7)



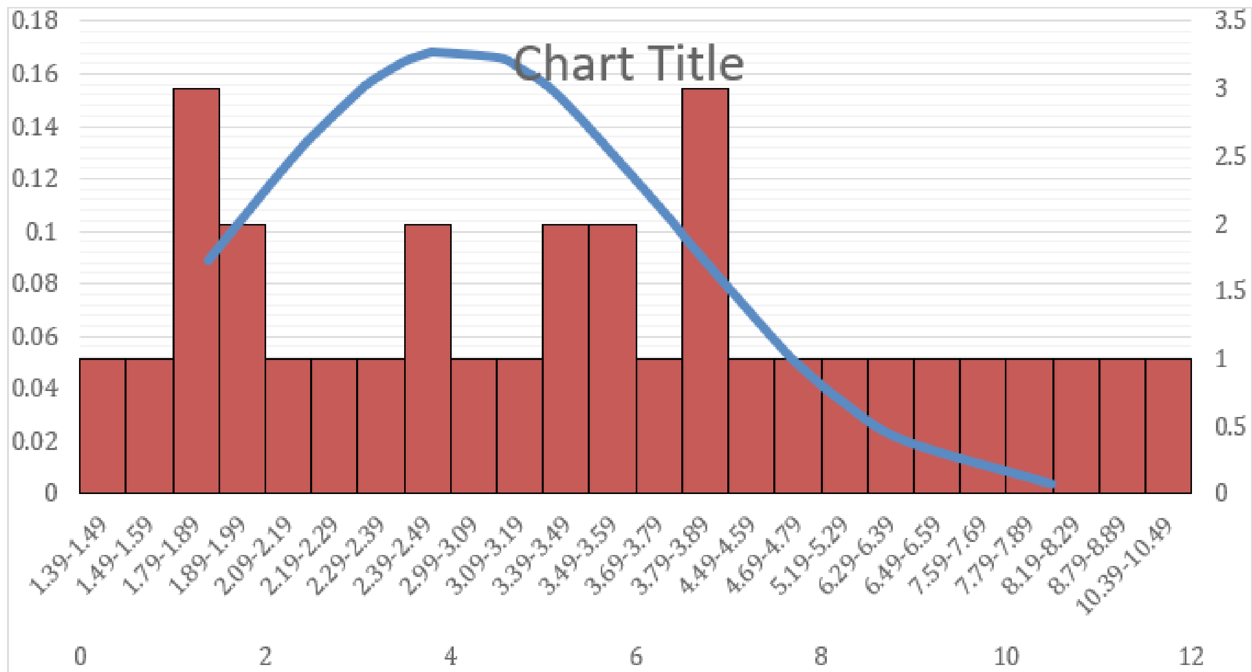


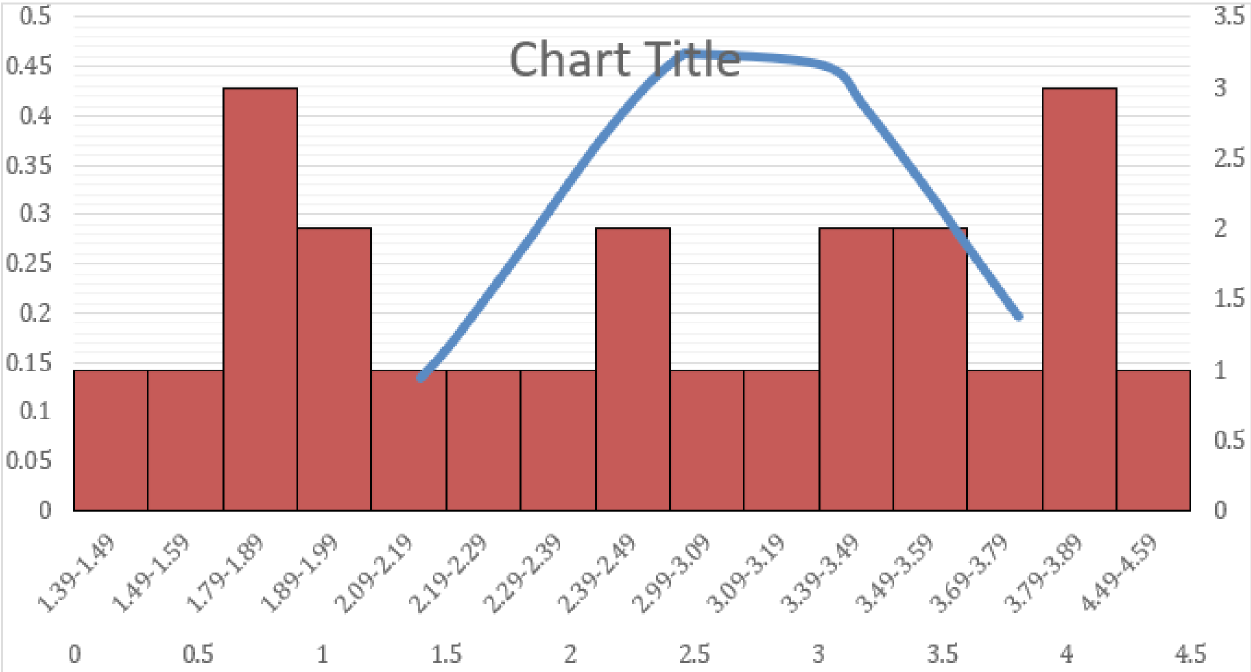
Test data for Group-1 till Group-7 for Adobe + Straw

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax
	L	W	H		
Group 1					
S1	170	90	40	53932.71	24.96
S2	170	90	40	69108.58	18.18
S3	170	90	40	100499.4	16.27
S4	170	90	40	72196.41	23.67
Group 2					
3A	115	111	40	100549.50	14.95
3B	116	114	41	100384.60	19.83
3C	111	110	41	100294.40	20.94
Group 3					
SS1b	175	85	40	35400	9,94
SS2b	175	85	40	28000	-
SS3b	175	85	40	29300	-
SS4b	175	85	40	31600	9,92
SS5b	175	85	40	44900	9,94
Group 4					
26	60	60	50	5483.833	4.786423
27	60	60	50	6759.476	11.73645
28	60	60	50	6607.645	5.546422
29	60	60	50	6904.746	11.15651
30	60	60	50	5017.566	6.716426
Group 5					
11	135	90	40	46286.38	14.94
12	135	90	40	29810.99	8.86
13	135	90	40	63061.82	14.95
14	135	90	40	46270.21	14.94
15	135	90	40	43370.08	13.16
16	135	90	40	38756.87	14.94

Group 6					
S1	175	85	40	36592.63	14.94
S2	175	85	40	33957.98	14.79
S3	175	85	40	56105.79	14.94
S4	175	85	40	51784.55	14.93
S5	175	85	40	56502.25	14.94
S6	105	75	30	27459.32	9.97
Group 7					
S1	100	75	30	78581.86	11.98106
S2	100	75	30	47607.38	11.965
S3	100	75	30	66655.61	11.96496

Normalised Graph for Compressive Strength for Adobe + Straw (Group-1 till Group-7)



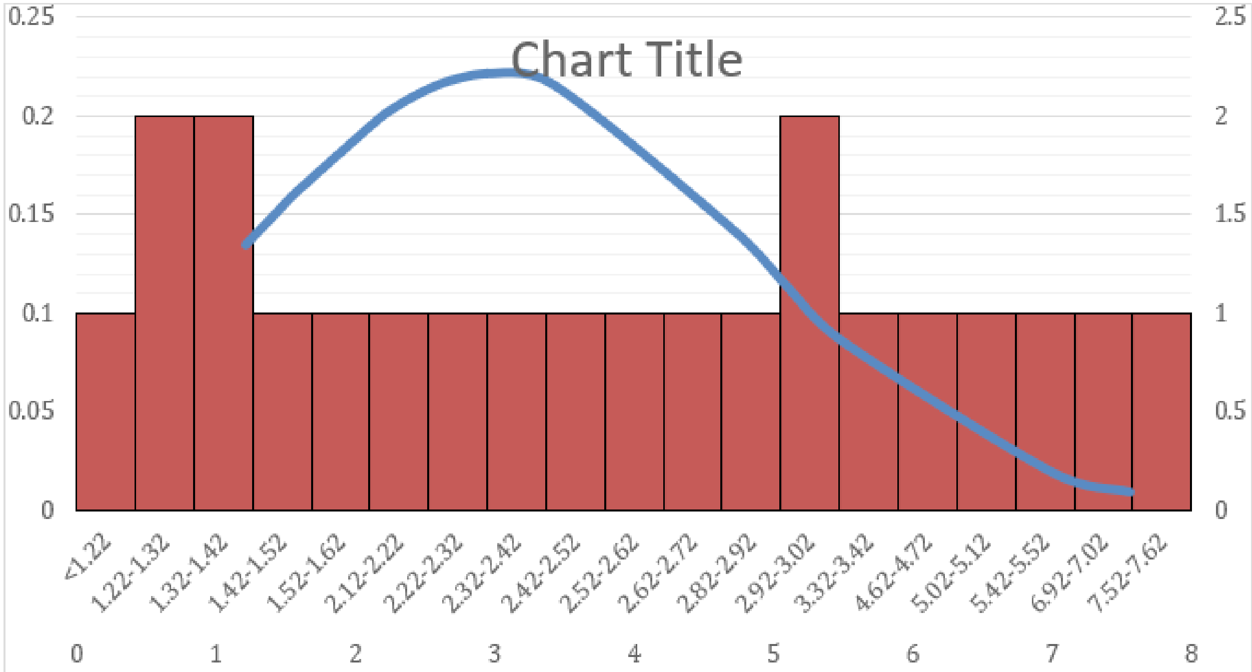


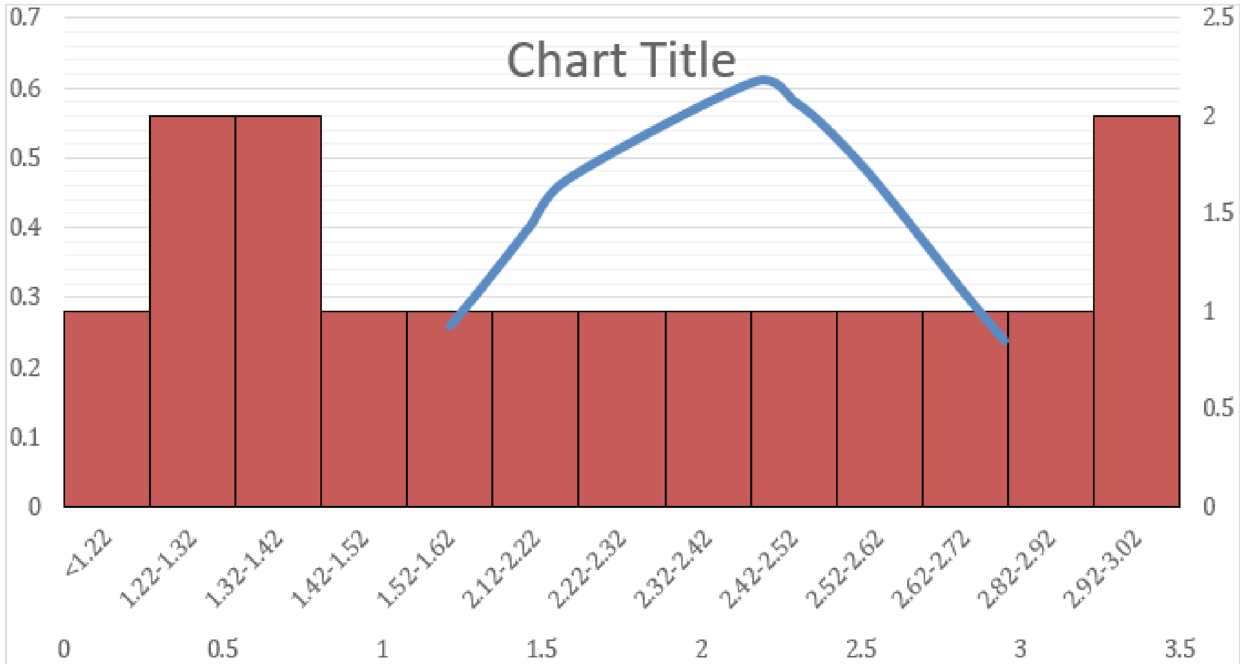
Test data from Group-1 till Group-7 for Adobe + Woodchips

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax
	L	W	H		
Group 1					
WD1	170	90	40	24253.13	6.72
WD2	170	90	40	43393	16.73
WD3	90	90	40	9842.557	7.28
Group 2					
4A	125	118	50	38373.860	19.958
4B	122	115	52	65934.380	24.965
Group 3					
SW1s	95	70	30	15900	-
Sw2s	95	70	30	22700	-
Sw3s	95	70	30	16700	-
Group 4					
21	60	60	50	5277,722	4,866442
22	60	60	50	4646,697	6,486415
23	60	60	50	5063,669	4,01638
24	60	60	50	4873,333	5,03645
25	60	60	50	4665,315	4,4643

Group 5					
17	135	90	40	32480.30	9.24
18	135	90	40	35830.86	9.97
19	135	90	40	27850.94	14.94
20	135	90	40	26408.52	9.44
21	135	90	40	35840.77	14.69
Group 6					
W1	105	75	30	43293,21	11,96
Group 7					
WD1	100	75	30	56650.17	11.96532
WD2	100	75	30	38300	-
WD3	100	75	30	52495.67	11.98119

Normalised Graph for Compressive Strength for Adobe + Woodchips (Group-1 till Group-7)





9.4 Pseudocodes

1. Urban analysis

- Start of the process “Urban analysis”
- Demographic and urban research (target group 15-29 years old = youths) - output: number of youths per district; youth facilities
- Randomly populate a number of points in each district. Each point represents one youth
- Manual input in Rhino: curves as camp and districts boundaries; surfaces representing youth facilities
- To analyze coverage:
- Draw a circle with a radius of 400m and circumcenter in the area centroid of each surface (youth center)
- Identify the number of points inside the union region of circles (point in curves), and subtract it from the overall number of youths - output: youths with a distance >400m to the closest facility
- To analyze the capacity of each facility:
- **Create a stress map with use of the Voronoi diagram:**

1. Manually specify boundary around the camp
2. Use centroids of facilities as points for diagram
3. The radius of the cell should be bigger than diagonal of the specified boundary (to be sure that cells will fully cover the whole boundary area)

- Identify the number of points inside each cell (point in curves)
- Divide the area of the facility (from corresponding Voronoi cell) by the number of youths (belonging to this cell) multiplied by 0.6 (40% of youths in the camp are skilled already and will not use skill development center) - output: m2 of the facility per person
- To improve coverage:
- Define new circumcenter (new facility) for a circle (radius 400m) using of closest 3 points (3 closest facilities centroids)
- Identify the number of points inside the new union region of circles (point in curves), and subtract it from the overall number of youths - output: youths with a distance >400m to the closest facility
- To improve capacity:
- **Create a new stress map with use of the Voronoi diagram:**

1. Use specified earlier boundary around the camp
2. Use centroids of facilities and new circumcenters as points for diagram
3. The radius of the cell should be bigger than diagonal of the specified boundary (to be sure that cells will fully cover the whole boundary area)

- Identify the number of points inside each cell (point in curves)
- For existing facilities: divide the area of the facility (from corresponding Voronoi cell) by the number of youths (belonging to this cell) multiplied by 0.6 (40% of youths in the camp are skilled already and will not use skill development center) - output: m2 of the facility per person
- For new facilities: multiply the number of youths (from corresponding Voronoi cell) by 0.6 (40% of youths in the camp are skilled already and will not use skill development center) and by 5 (parameter 5m2/person) - output: expected area of the new facility
- Increase the area of the existing facility to pass criterium of 5m2/person.
- End of the process “Urban analysis”

2. Building Layout

- Start of the process “Building Layout”
- Read excel file:
- Room names
- Room width and length
- Room preferred orientation
- Create room rectangles (room width * room length)
- Courtyard position (based on architectural research); courtyard can move along a defined vector using a slider
- Courtyard size (ratio of width and length based on architectural research); courtyard size can be changed using a slider
- Create direction (N/E/S/W) regions around the plot
- Create a rectangle on plane with the center as plot centroid
- Move rectangle in four directions (N/E/S/W)
- **Note:** direction region should be relatively big and far away from the site (to give rooms a possibility of moving between each other)
- Move rooms rectangles to preferred direction regions
- Count number of rooms per direction
- Randomly populate points in direction region (number of points in region is a number of rooms per region)
- Move room to corresponding direction region (centroid of the rectangle to one of the populated points)
- Define strong spring force between room’s modules (magnetic snap kangaroo component)

- **Note:** some bigger rooms are divided into smaller modules; modules have to be adjacent
- Define weak spring force between rooms meant to be close to each other (magnetic snap kangaroo component)
- **Note:** magnet force should be smaller than the force between modules of one room
- Attract rooms rectangles to courtyards curves (points on curve kangaroo component)
- All rooms rectangles centroids should be attracted to the assigned courtyard curve
- Prevent curves collision (rooms overlapping) (curve collide kangaroo component)
- Select all rooms as collide curves
- Select courtyards as passive curves
- Run solver
- Manually adjust the position and size of courtyards on site (interactive design)
- **Note:** for direction reason, courtyards should be relatively far from the designated position, furthermore, rooms need to have enough space to 'attach' to the courtyard
- Use sliders to move courtyards toward final position - it will increase packing on the plot
- Bake proposed layout
- Choose final layout (designer decision based on architectural research and experience)
- Manually adjust the position of rooms for maximal packing and grid alignment
- End of the process "Building Layout"

3. Shaping – grid

- Start of the process "Shaping"
- Select the surfaces of the rooms
- Obtain the boundaries lines of the rooms as curves
- **To create the walls:**
- Offset the curves of 0.3 m both inward and outward, define them as WALLS LINES
- Identify the connections between the rooms as openings in the walls (doors, arches...)
- Create perpendicular lines to indicate where the openings start and end along the boundaries of the rooms, define them as OPENINGS LINES
- Trim the WALLS LINES with the OPENINGS LINES
- Create close polylines/rectangles for the walls, defined as WALLS REGION
- **To tessellate the rooms:**
- Divide the rooms' spaces into smaller quads, following the grid
- Create a quadrangular mesh within the smaller quads
- Keep fix the corners in option
- Join the mesh into a single mesh, defined as MESH
- **To dynamic relax the mesh:**
- Select all the lines of the mesh, define them as SPRINGS
- Apply a strength to the SPRINGS
- Select all vertexes of the mesh, define them as PARTICLES
- Apply a vertical load on all PARTICLES
- Identify the PARTICLES that are enclosed in the WALLS REGION, define them as SUPPORTS
- Plug SPRINGS, PARTICLES and SUPPORTS into Kangaroo solver
- Let Kangaroo solver run to find the new relaxed mesh, defined as 3D MESH
- **Check if the 3D MESH meets the spatial requirements:**

1. If no, re-tessellate the mesh and re-run the dynamic relaxation process
2. If yes, the output needs to be verified structurally and further improved

- **End of the process "Shaping"**

9.5 Model Photos

9.5.1 Scale 1:100 Model of Whole Skill Development Center in context

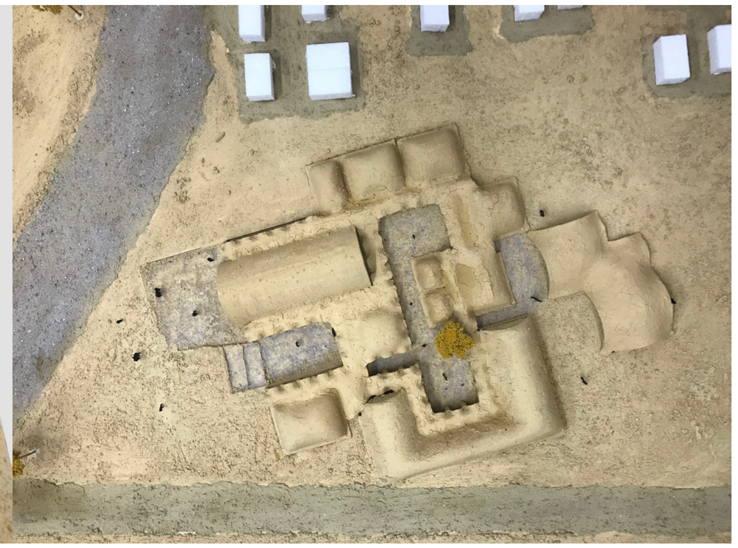




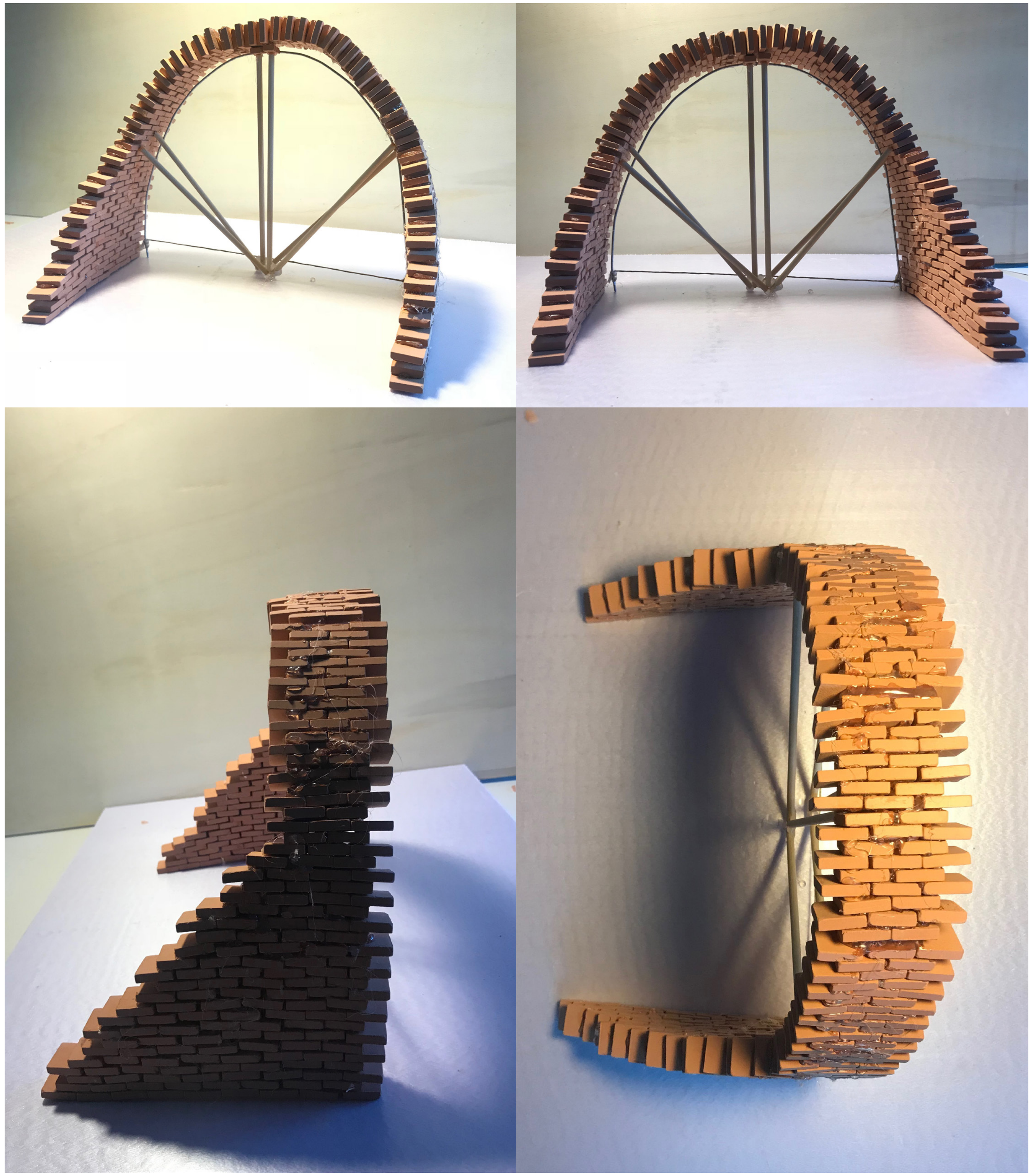


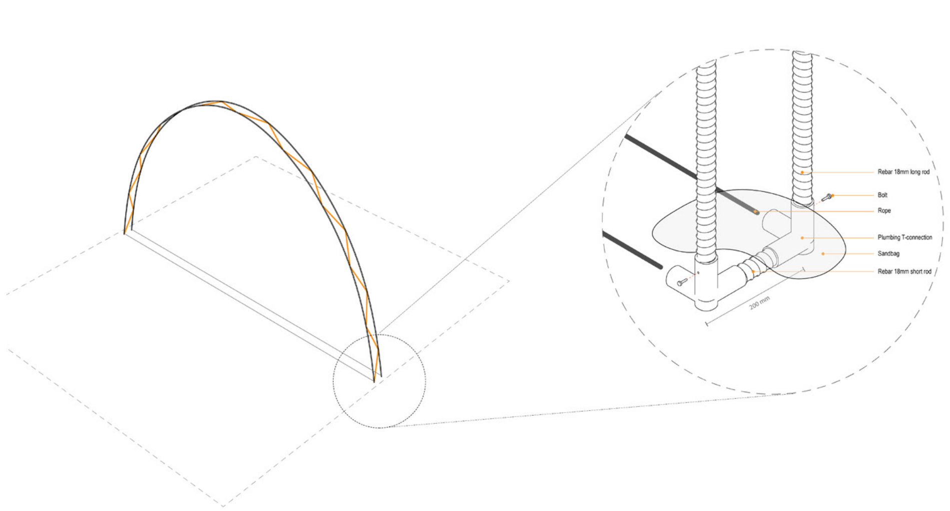




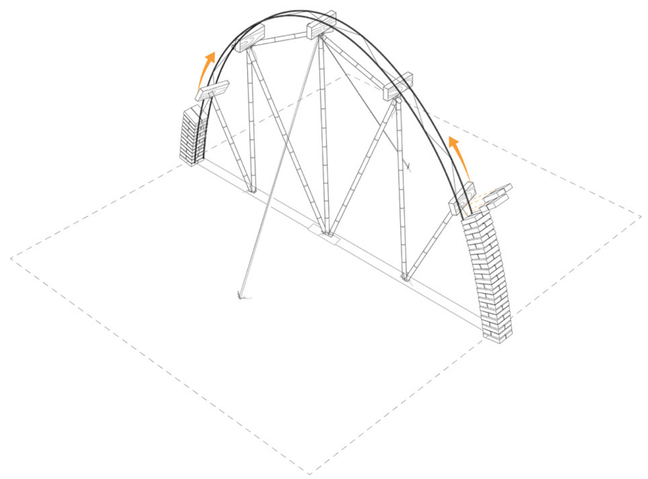



9.5.2 Scale 1:20 Model of Construction Process of Classroom

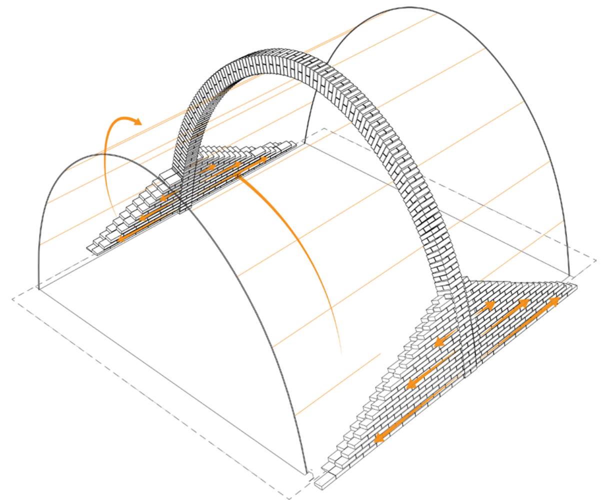




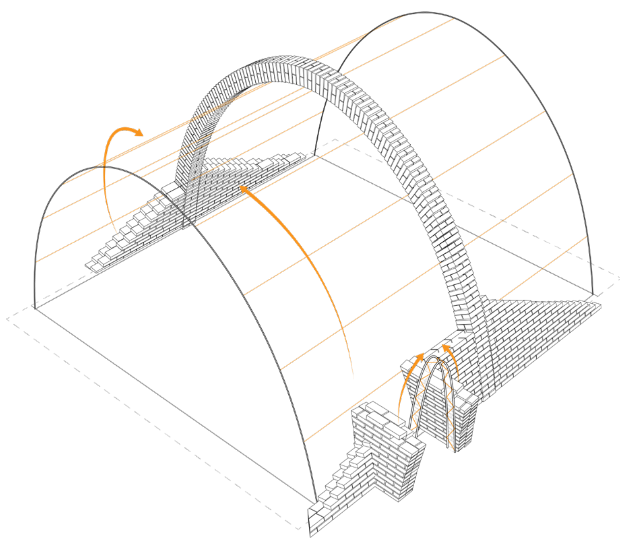
1. Formwork Preparation



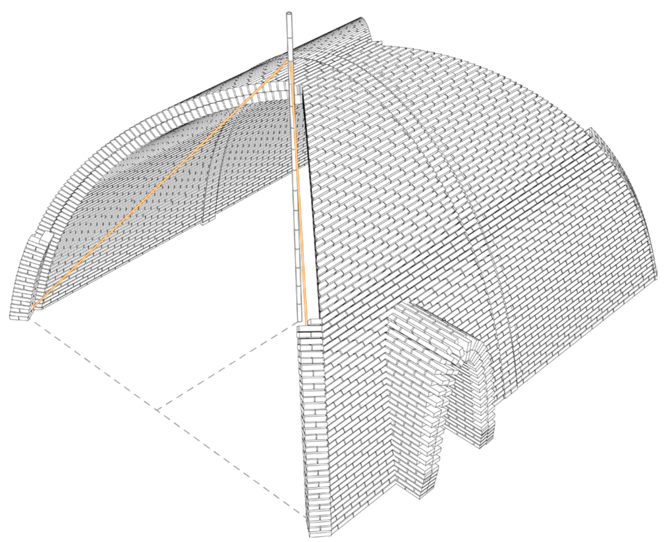
2. Formwork support structure for rib brick stacking



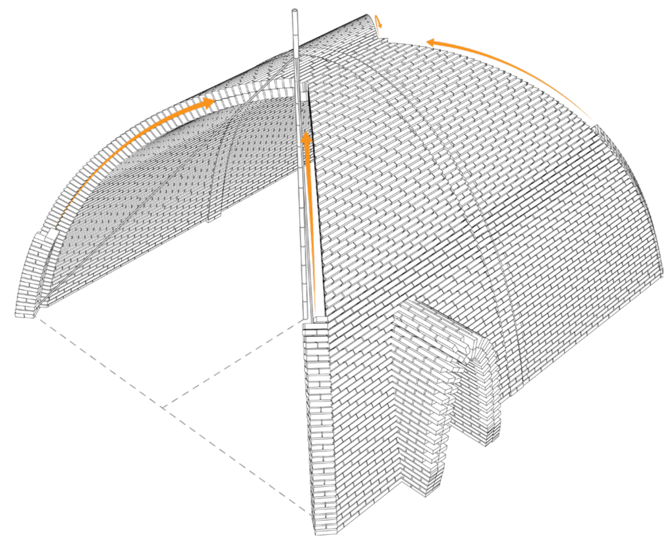
3. Catenary vault brick laying



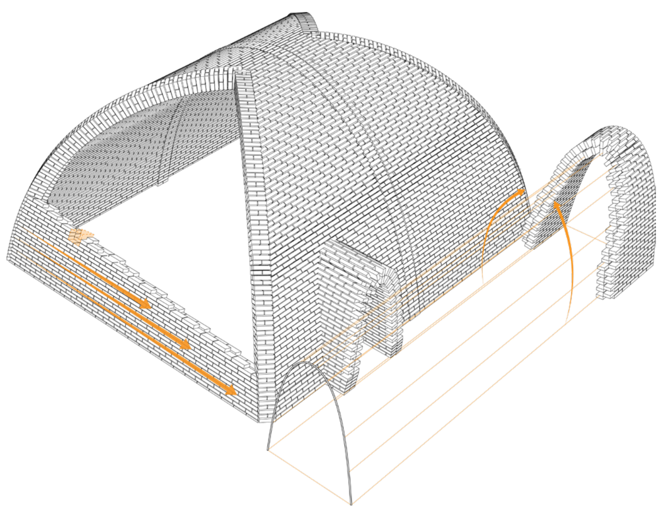
4. Opening insertion



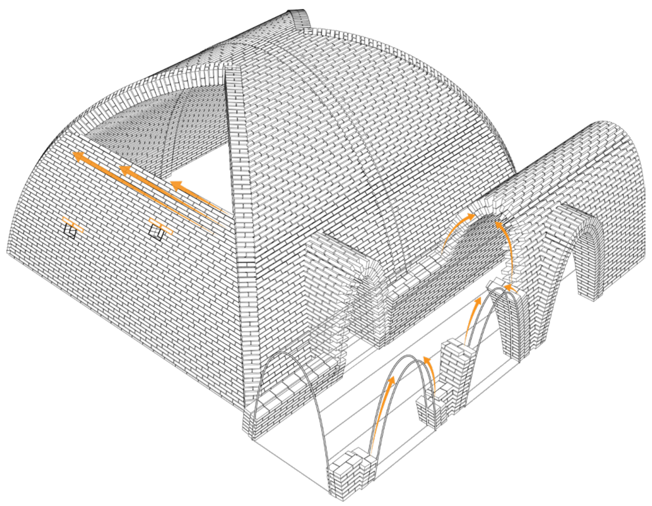
5. Termination mark-up



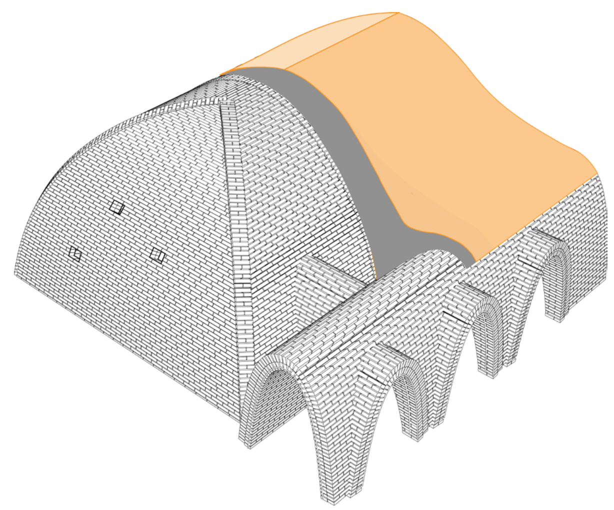
6. Termination rib detail



7. Adjacent space brick laying



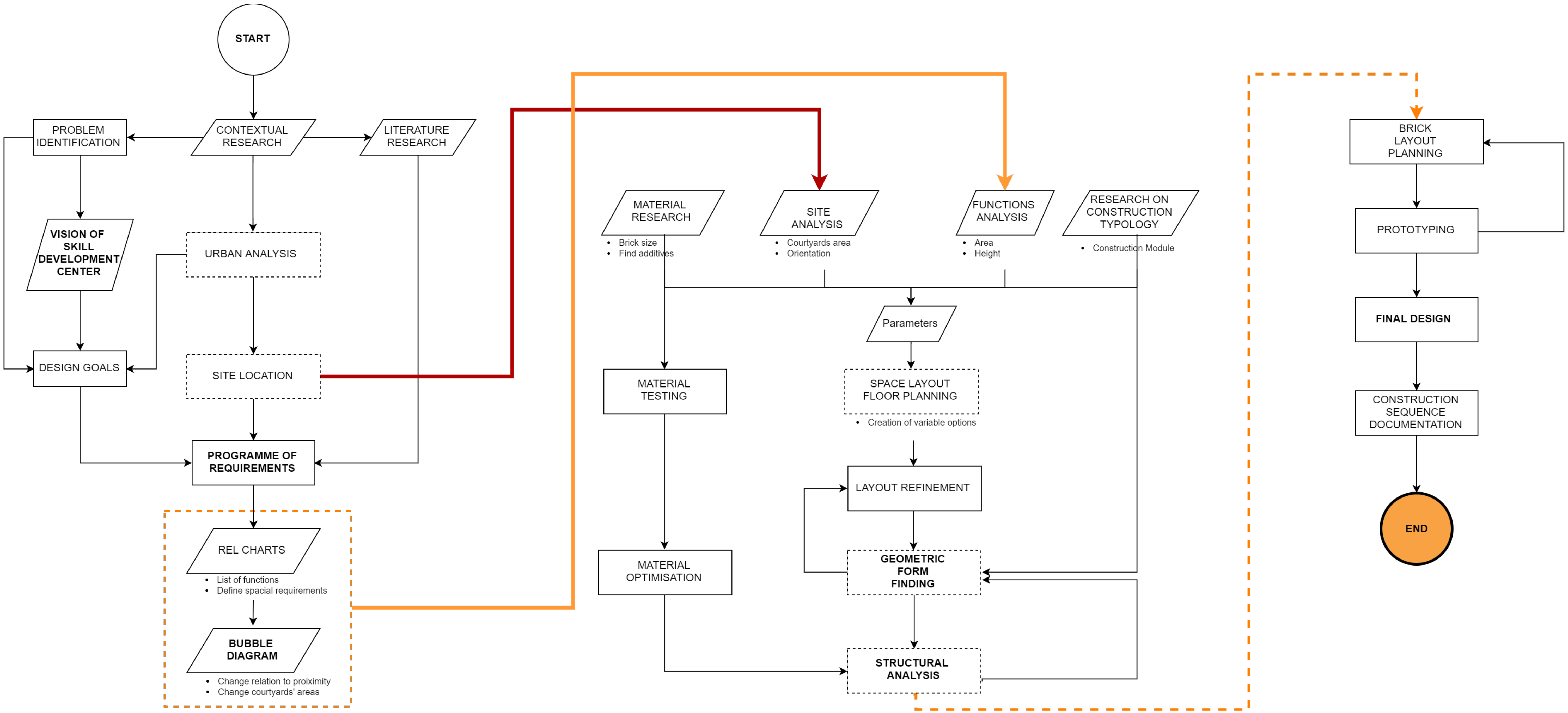
8. Lunette openings insertion

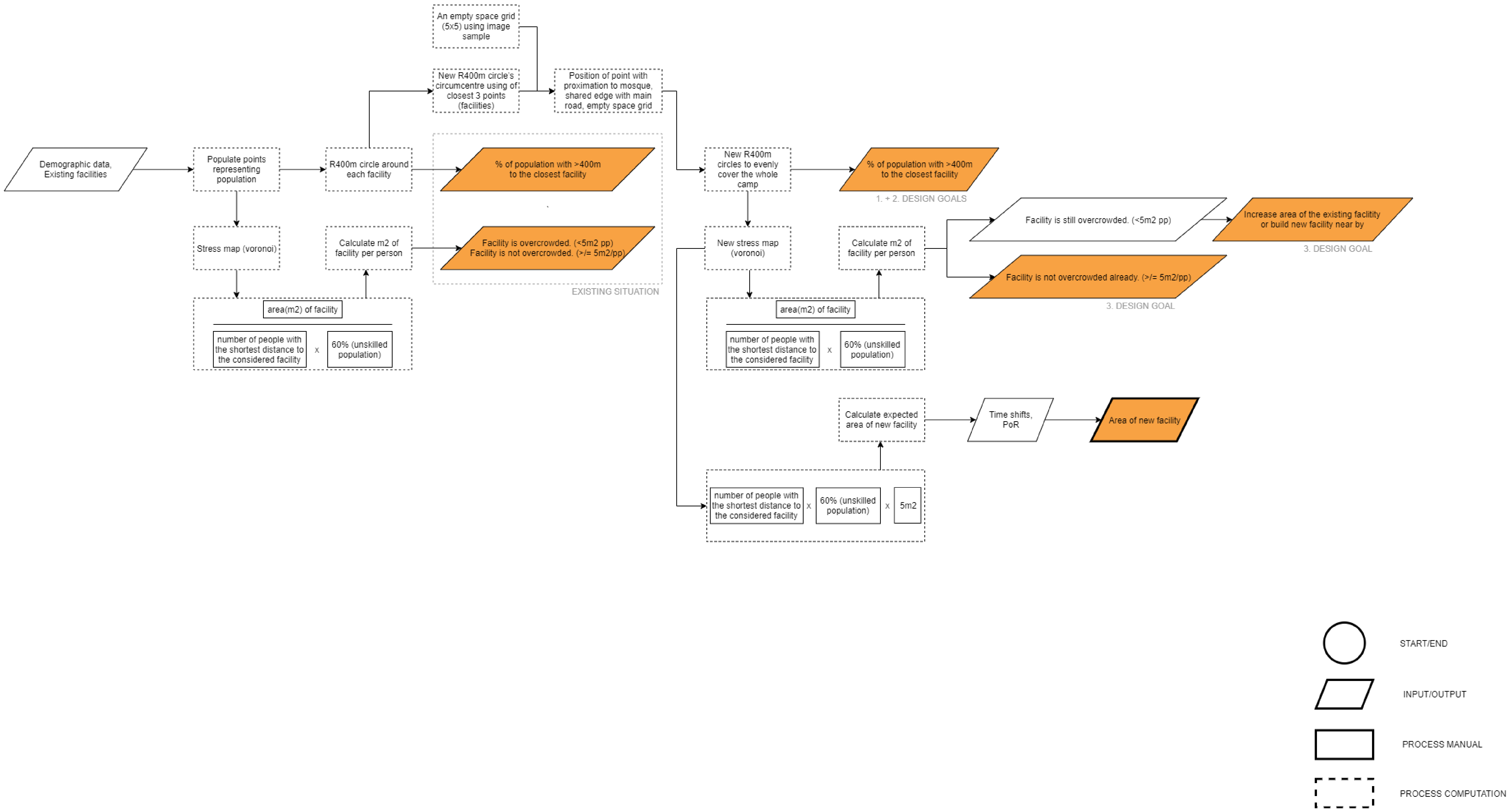


9. Hay-cob filling and plastering

9.7 Flowcharts

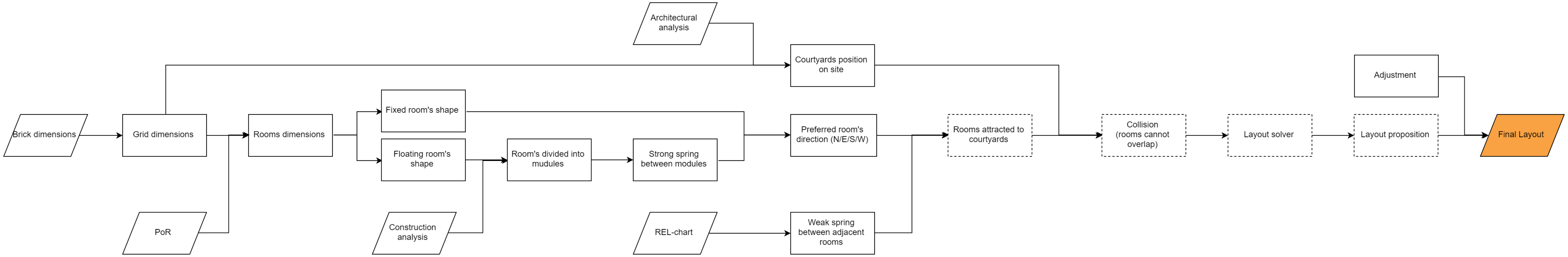
9.7.1 Overall Process

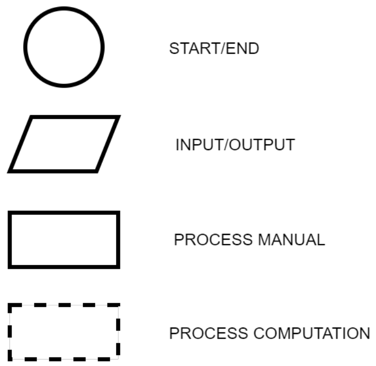


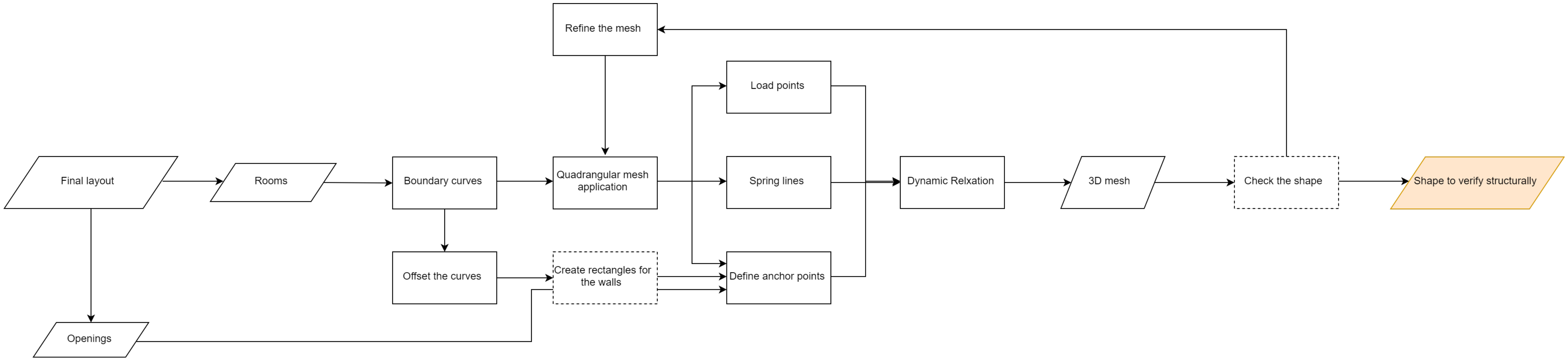


Demographic data, Existing facilities
Populate points representing population
R400m circle around each facility
An empty space grid (5x5) using image sample
New R400m circle's circumcentre using of closest 3 points (facilities)
Position of point with proximation to mosque, shared edge with main road, empty space grid
% of population with >400m to the closest facility
Stress map (voronoi)
Calculate m2 of facility per person
Facility is overcrowded. (<5m2 pp) Facility is not overcrowded. (>/= 5m2/pp)
area(m2) of facility
number of people with the shortest distance to the considered facility
x
60% (unskilled population)
EXISTING SITUATION
New R400m circles to evenly cover the whole camp
% of population with >400m to the closest facility
1. + 2. DESIGN GOALS
New stress map (voronoi)
Calculate m2 of facility per person
Facility is still overcrowded. (<5m2 pp)
Increase area of the existing facitlity or build new facility near by
3. DESIGN GOAL
Facility is not overcrowded already. (>/= 5m2/pp)
3. DESIGN GOAL
area(m2) of facility
number of people with the shortest distance to the considered facility
x
60% (unskilled population)
Calculate expected area of new facility
Time shifts, PoR
Area of new facility
number of people with the shortest distance to the considered facility
x
60% (unskilled population)
x
5m2
START/END
INPUT/OUTPUT
PROCESS MANUAL
PROCESS COMPUTATION

9.7.3 Building Layout






Refine the mesh
Load points
Final layout
Rooms
Boundary curves
Quadrangular mesh application
Spring lines
Dynamic Relxation
3D mesh
Check the shape
Shape to verify structurally
Offset the curves
Create rectangles for the walls
Define anchor points
Openings

9.7.5 Construction Process

Construction Process