Cloud Matrix

Report

Earthy 4.0

Group 8

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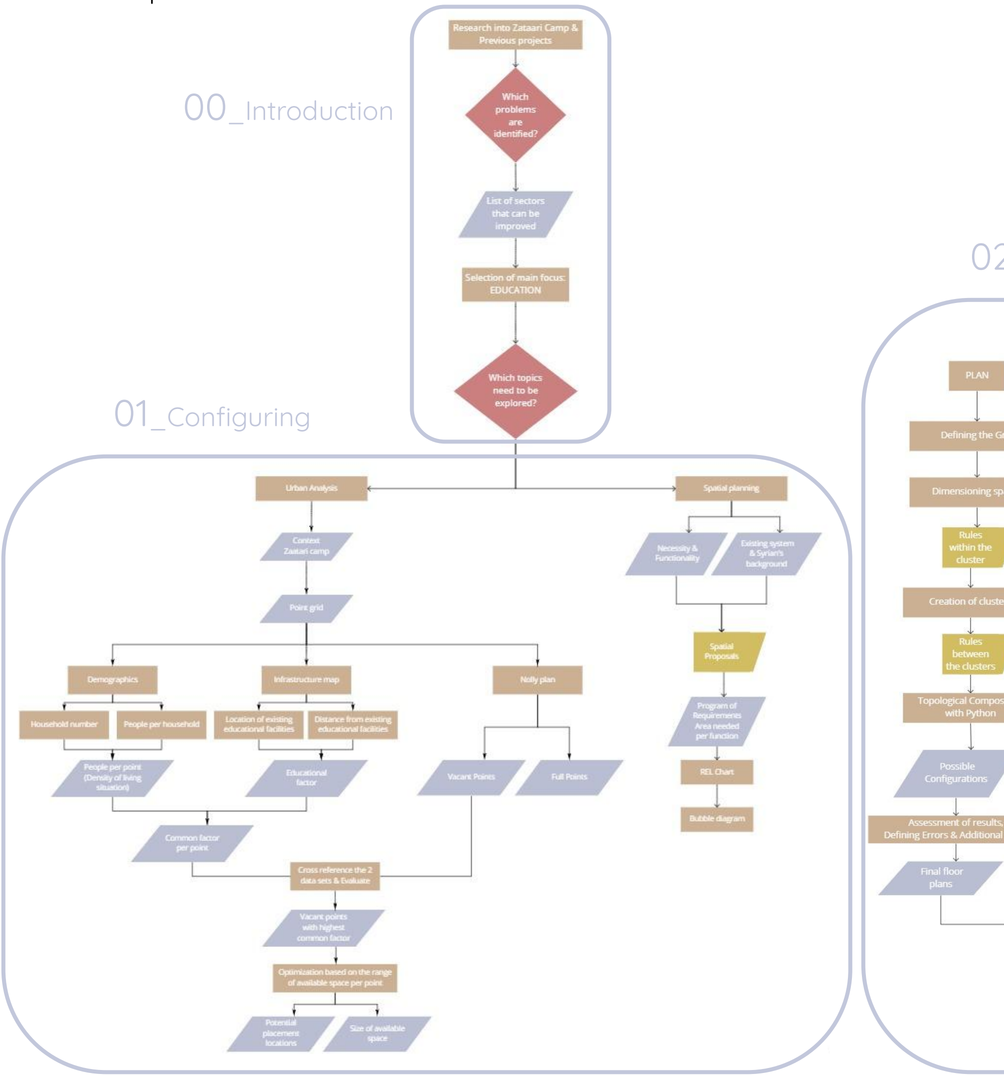
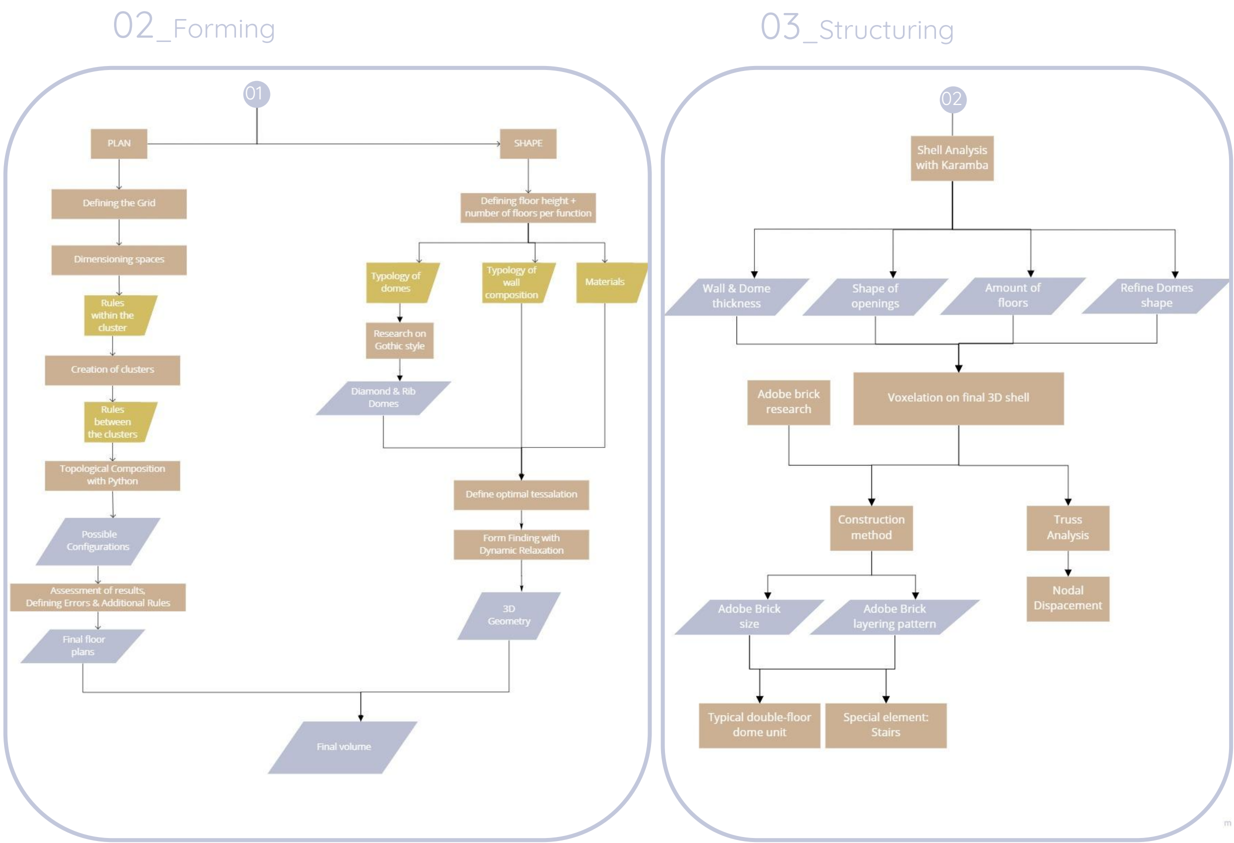
Abstract

The vision of the project is to create a community for the people of Zaatari camp where they will feel safe, learn and grow together, thus, the building program is related to the creation of an educational and skill learning centre. The urban configuration for the building placement is related to the educational demand and the population density in the camp.

Additionally, the forming of the plan is developed as a set of game rules and applied to python in order to investigate a range of different design variations and give the possibility to the local people to generate a different configuration each time according to their preferences and needs. The building is made out of adobe bricks and its construction process focuses on ease of construction in order to further facilitate the local workers. The shaping of vaults is achieved through experimenting with dynamic relaxation and its structural performance is evaluated through FEA analysis.





General flowchart of report structure

00_Introduction

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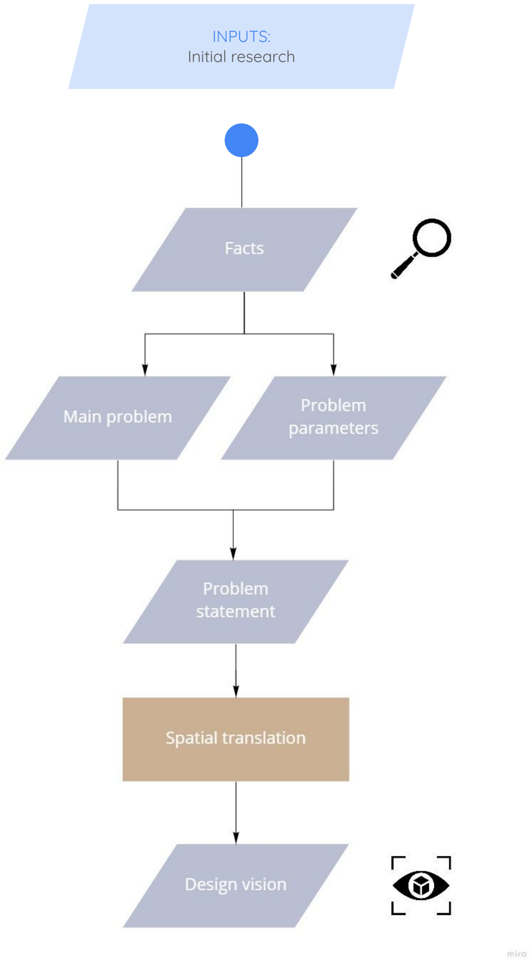
Flowchart



Facts

After conducting the first research for the prevailing conditions in Zaatari camp, it was pinpointed that the biggest part of the community faces problems regarding education and employment.

Specifically, according to data from the Refugee Agency (UNHCR,2020), in Zaatari camp more than half of the population is underage. The percentage of kids that do not attend classes in school accounts for almost one quarter of the total children and youth population. The causes for this phenomenon underly in different aspects of the daily life in Zaatari and will be further investigated later.

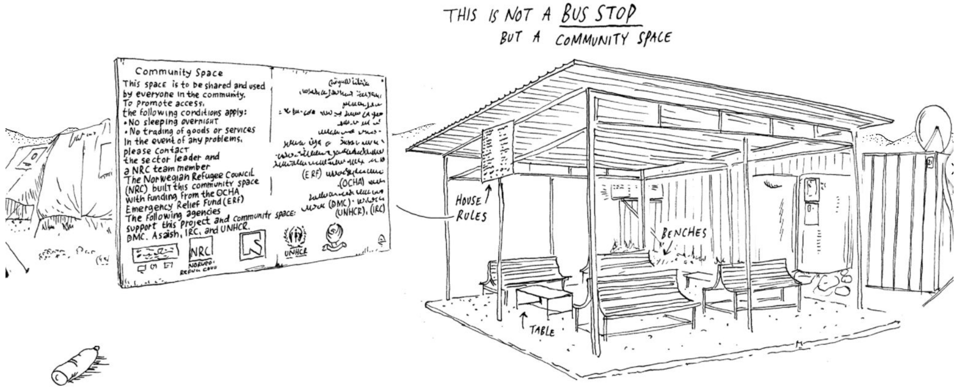
Additionally, an important problem of the adult community is the lack of the necessary skills that would provide them a secure job during their stay in the camp. In this regard, it cannot be ensured that they will have a stable source of income and this intensifies the feeling of unsafety there.

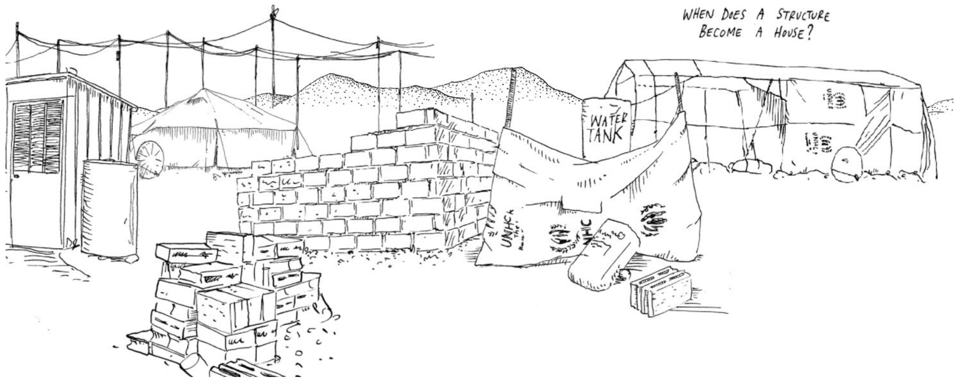
55% population < 18 years old

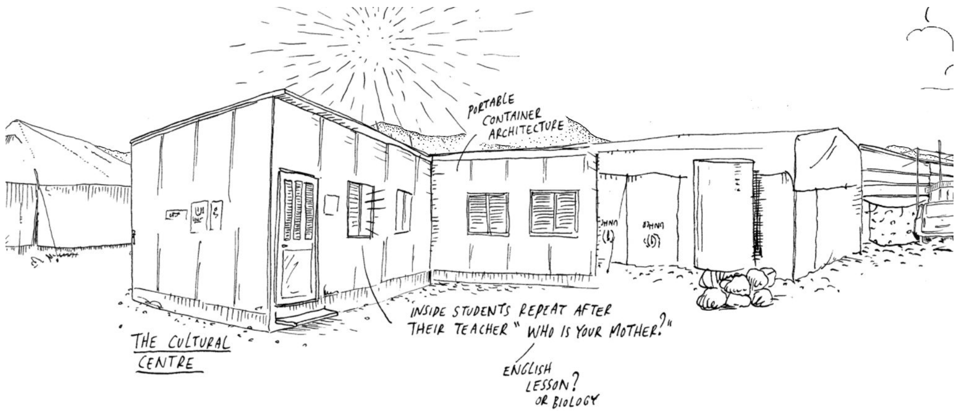
24% children out of school

insecure source of income

This mural painted by children, reads 'Let's go register for school'.
Source: UNHCR, Jared J.Kahler



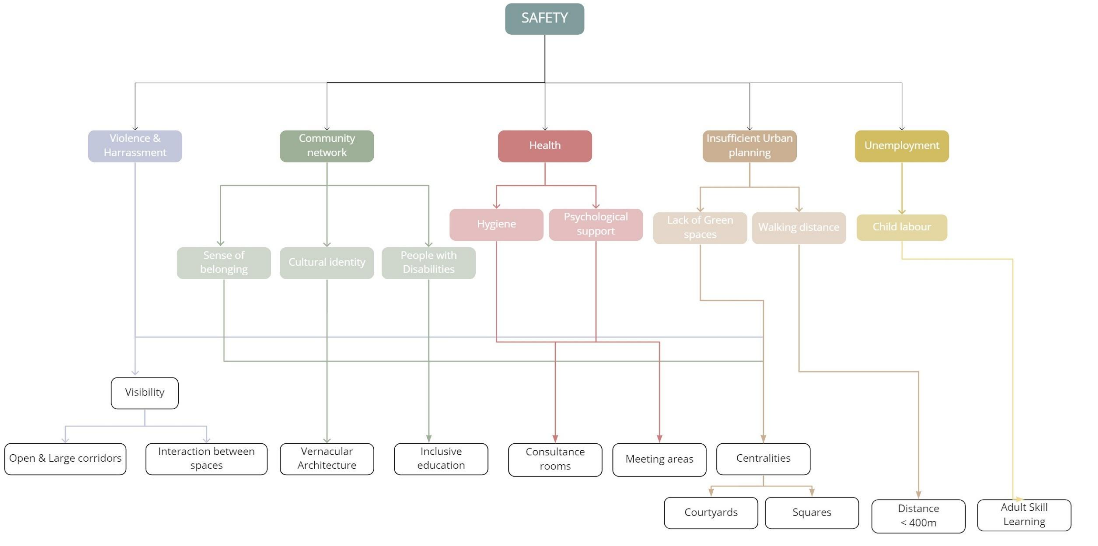




Source: https://refugeerepublic.submarinechannel.com/intro_en.php?o=o

Problem statement

The prevailing sense of unsafety in Zaatari camp is the main problem where this project focuses. Unsafety is mainly caused by the unstable social structure and can be analysed into five main aspects.
These are, firstly, violence and harassment, as well as insufficient community network and underdeveloped urban planning, which result into people being afraid and, thus, not being able to access basic facilities of the camp if these are not in close proximity to their houses. Moreover, the lack of sufficient health supply facilities and the high unemployment rate make people feel more insecure and uncertain about their future.
Each of the five main aspects is analysed into further subcategories and separate parameters. Afterwards, different design strategies were applied in the project in order to tackle them.



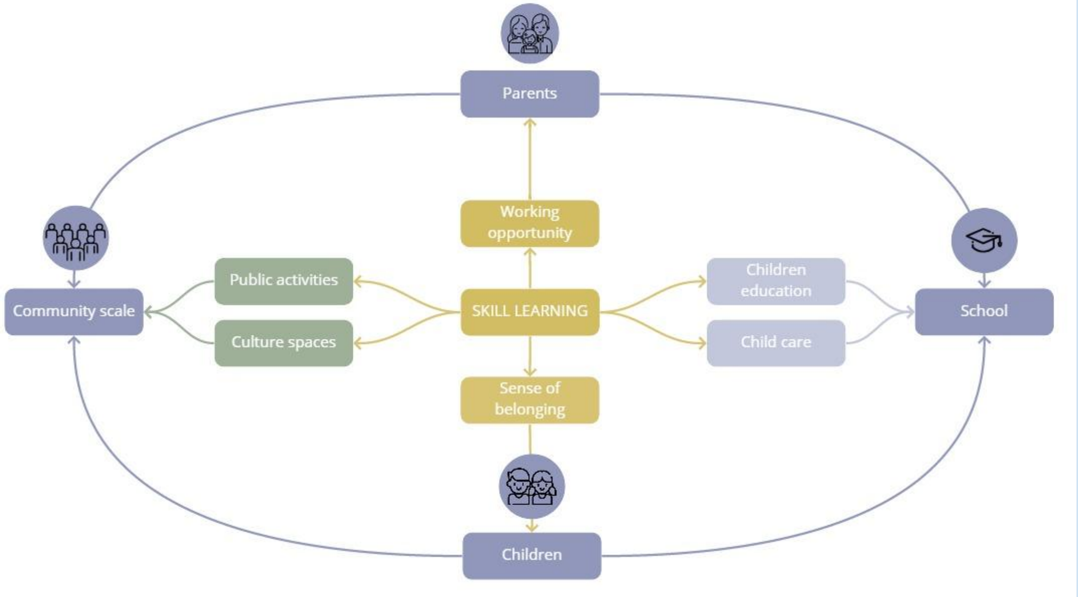
Problem Statement and Spatial proposition diagram

Spatial translation

As mentioned before, different design strategies were applied in order to tackle each problem parameter and, subsequently, tackle the overall insecurity feeling.
Through vocational education, adults and youth people can have better job opportunities. In order to decrease the incidents of violence, the program will be placed in close proximity to the houses. Moreover, it will include large spaces which are not secluded but connected to their neighbouring rooms so that the visibility is not blocked. Lastly, central public spaces are meant to enhance the feeling of community in each neighborhood.

Design vision

Taking all the aforementioned into account, the design vision of the project was established. The main goal is to create a community whose members can learn, earn, teach and grow together. They will feel safer by forming stronger connections between them, as well as they will develop the skills to improve their quality of life now and in the future.
The building program aims to create a bidirectional relation between the community and the educational center. Having skill learning at the center of attention, students and parents can meet and interact with each other. Cultural classes can result to public events inside the camp, while more practical courses can even feed the facilities of the school and create job opportunities for the parents.



Design vision diagram

01_Configuring

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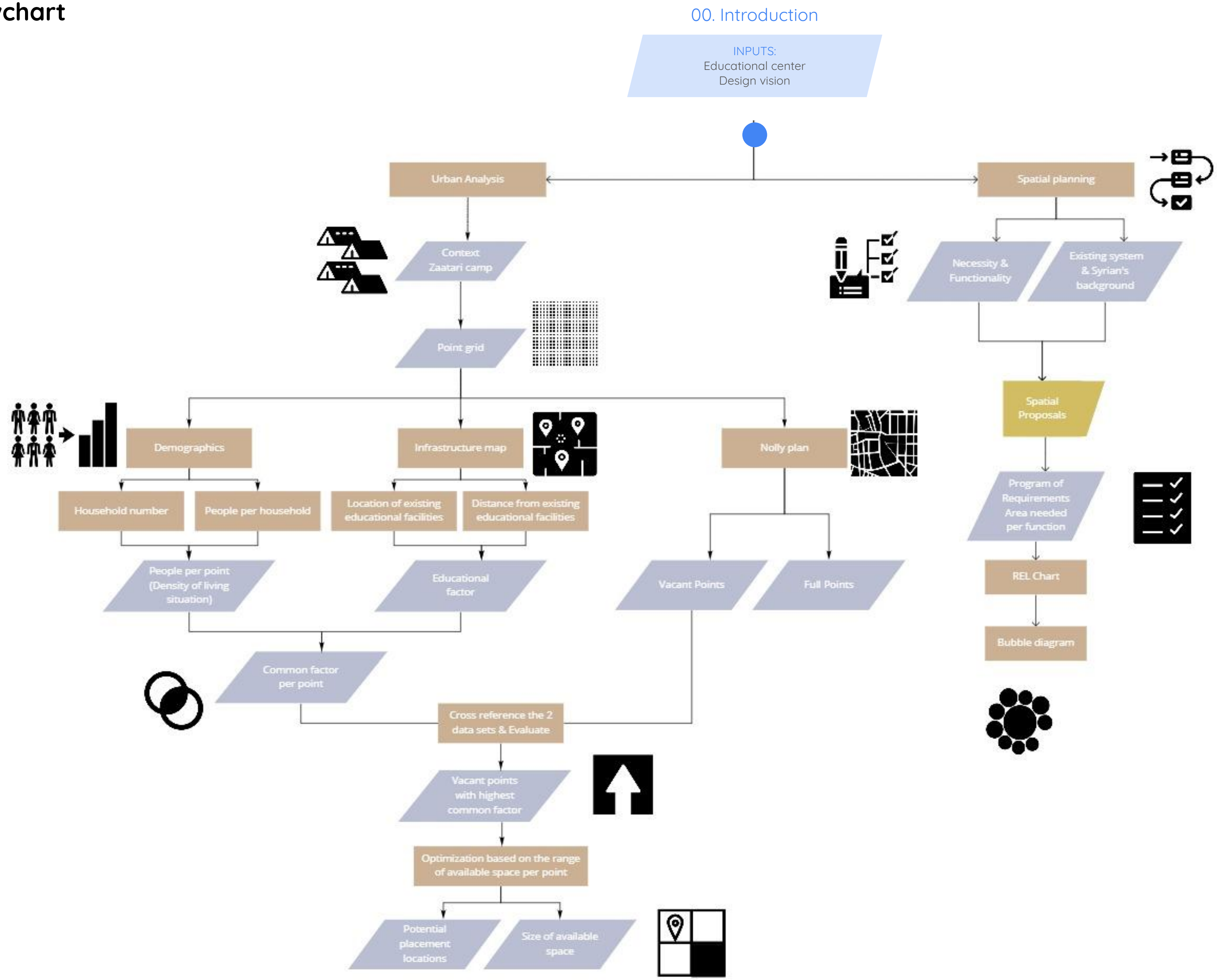
Flowchart

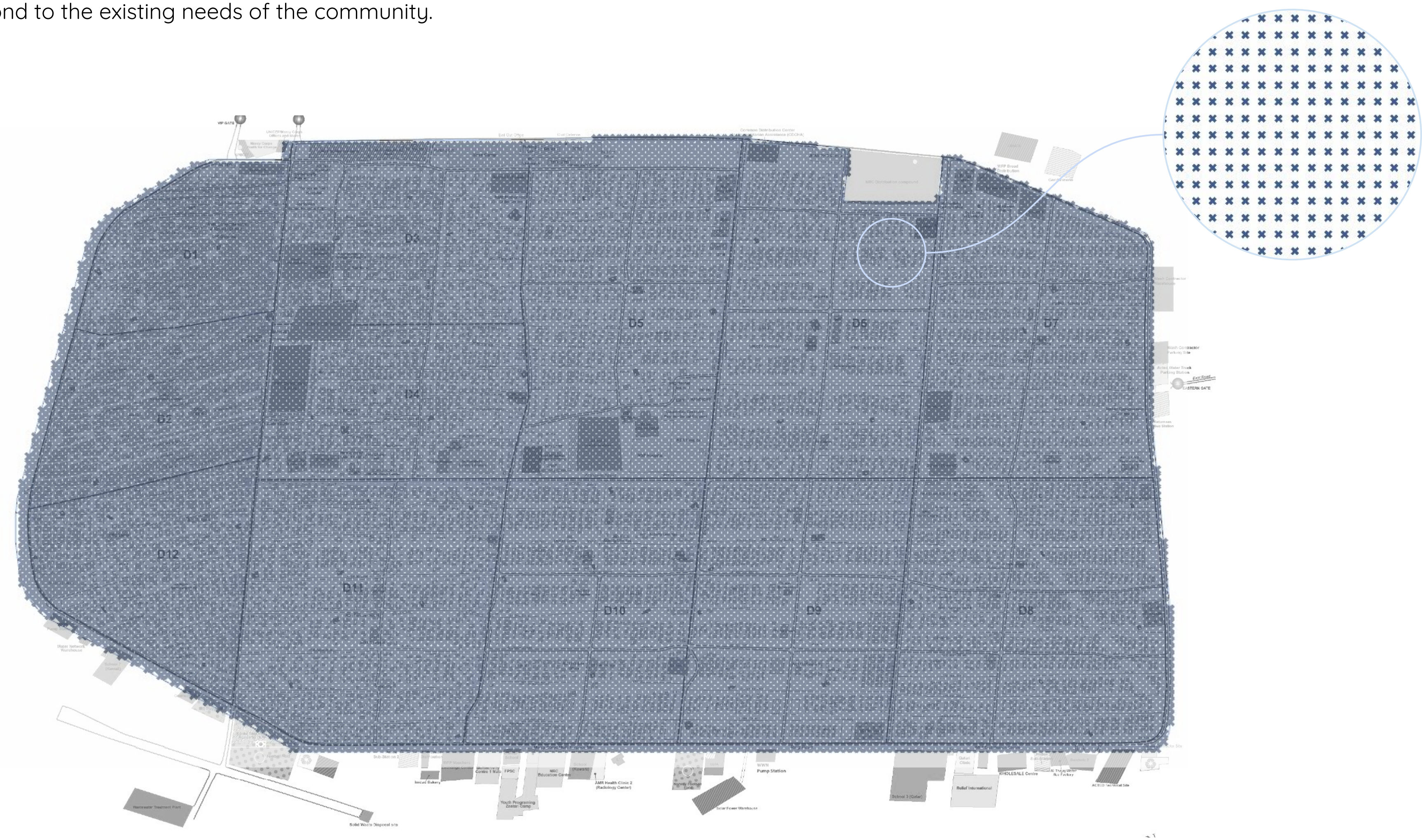


00. Introduction
INPUTS:
Educational center
Design vision
Urban Analysis
Spatial planning
Context
Zaatari camp
Necessity & Functionality
Existing system & Syrian's background
Point grid
Spatial Proposals
Demographics
Infrastructure map
Nolly plan
Program of Requirements Area needed per function
Household number
People per household
Location of existing educational facilities
Distance from existing educational facilities
People per point (Density of living situation)
Educational factor
Vacant Points
Full Points
REL Chart
Bubble diagram
Common factor per point
Cross reference the 2 data sets & Evaluate
Vacant points with highest common factor
Optimization based on the range of available space per point
Potential placement locations
Size of available space

Point matrix in camp

The urban analysis takes into consideration the demographic characteristics of the camp as well as the educational and community facilities that already exist there in order to locate the most influential place for the placement of the educational centre. Afterwards, these places are cross referenced with the available vacant space in the camp in order to conclude to a final position. This approach was selected since it provides an objective view to understand the camp, while the logic approaches for evaluating the levels of demand ensure that the final position will respond to the existing needs of the community.

The first part of the analysis refers to setting the common layout for the evaluation of the different factors. In this regard, the camp is divided into a point matrix of 2 by 2 meters. The point matrix can represent the area with a specific index, whilst at the same time values regarding the different factors can be assigned to it. Given that more than one value of data can be assigned to each point, the cross-reference data can be compared in the same place and generate the final optimized outcome regarding the highest demand/supply points.

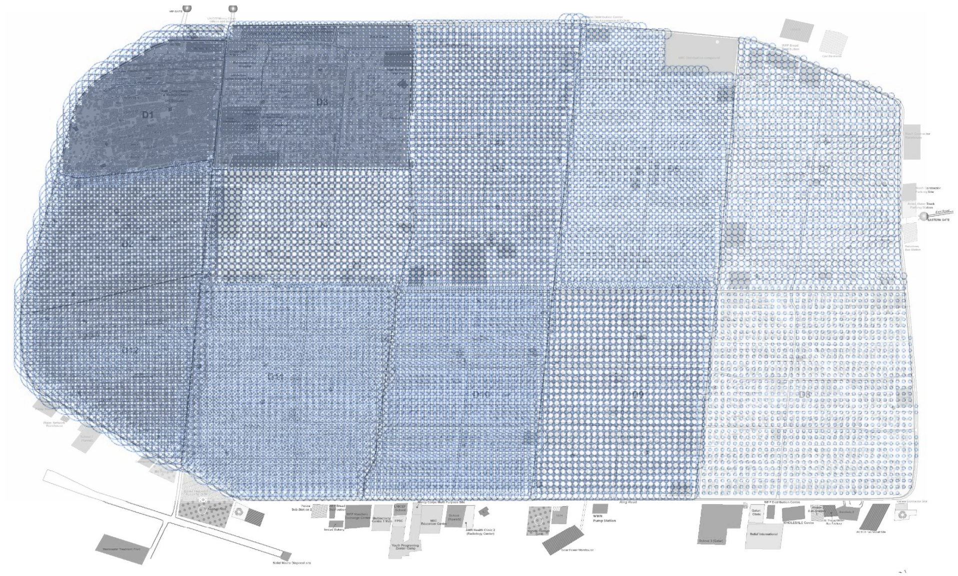


Population factor

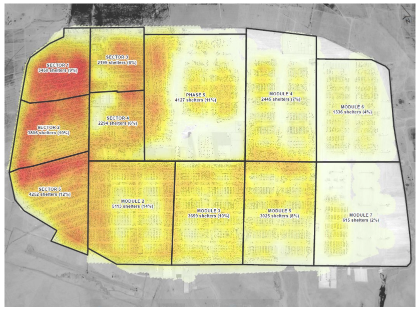
The age range of population is assumed to be equally distributed throughout the whole camp. Given this assumption, the population factor can represent the number of people in different age ranges.

The information regarding the population needs to be combined with the number of households that exist in each district and the number of people that live in each household respectively. In the Grasshopper script, the data is converted in a scale of 1-5, where the higher level means the higher population number. For better understanding of the data, the values are illustrated as circles with radius corresponding to the population values.

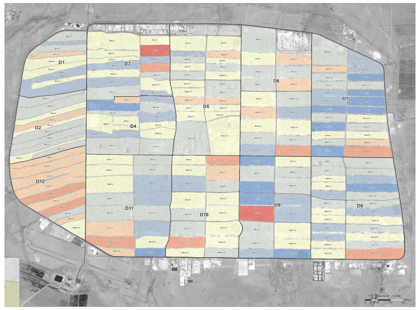
It is worth mentioning that the data is calculated manually in advance, to ensure the outcome of digitalization is more accurate.



Household number on point matrix



Household number (Unicef, 2017)

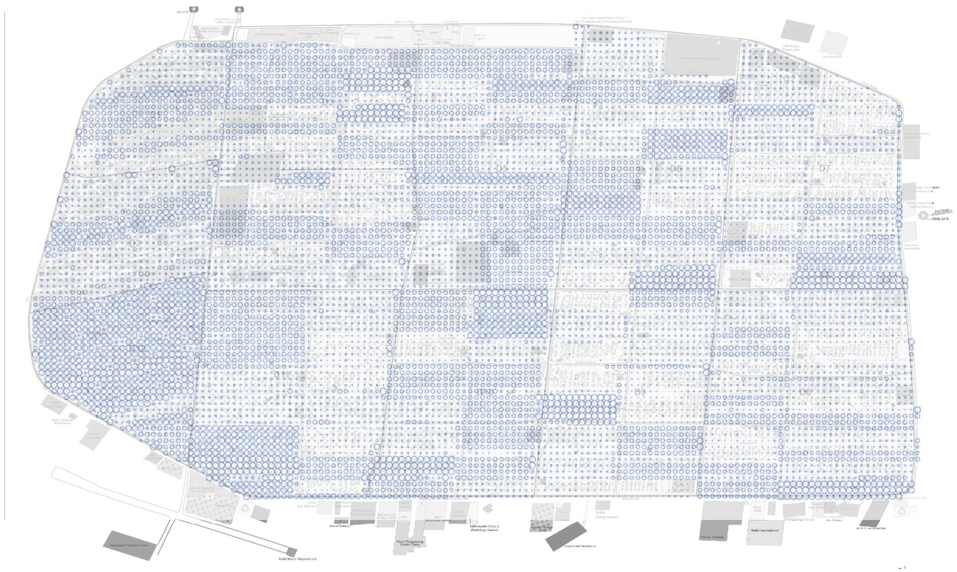


People number per house (Unicef, 2017)

Sector	household	population	age range	people number
1	3450	18113	0 to 4	3568
			5 to 11	3894
			12 to 17	2608
			18 to 59	7426
			60-	489
2	3806	21276	0 to 4	4191
			5 to 11	4574
			12 to 17	3064
			18 to 59	8723
			60-	574
3	2199	12456	0 to 4	2454
			5 to 11	2678
			12 to 17	1794
			18 to 59	5107
			60-	336
4	2294	12407	0 to 4	2444
			5 to 11	2667
			12 to 17	1787
			18 to 59	5087
			60-	335
5	4127	23362	0 to 4	4602
			5 to 11	5023
			12 to 17	3364
			18 to 59	9579
			60-	631
6	2445	13643	0 to 4	2688
			5 to 11	2933
			12 to 17	1965
			18 to 59	5594
			60-	368

Sector	household	population	age range	people number
7	1336	7114	0 to 4	1401
			5 to 11	1530
			12 to 17	1024
			18 to 59	2917
			60-	192
8	615	3375	0 to 4	665
			5 to 11	726
			12 to 17	486
			18 to 59	1384
			60-	91
9	3025	16275	0 to 4	3206
			5 to 11	3499
			12 to 17	2344
			18 to 59	6673
			60-	439
10	3659	20971	0 to 4	4131
			5 to 11	4509
			12 to 17	3020
			18 to 59	8598
			60-	566
11	5113	28409	0 to 4	5597
			5 to 11	6108
			12 to 17	4091
			18 to 59	11648
			60-	767
12	4252	25767	0 to 4	5076
			5 to 11	5540
			12 to 17	3710
			18 to 59	10565
			60-	696

Hand calculation of demography

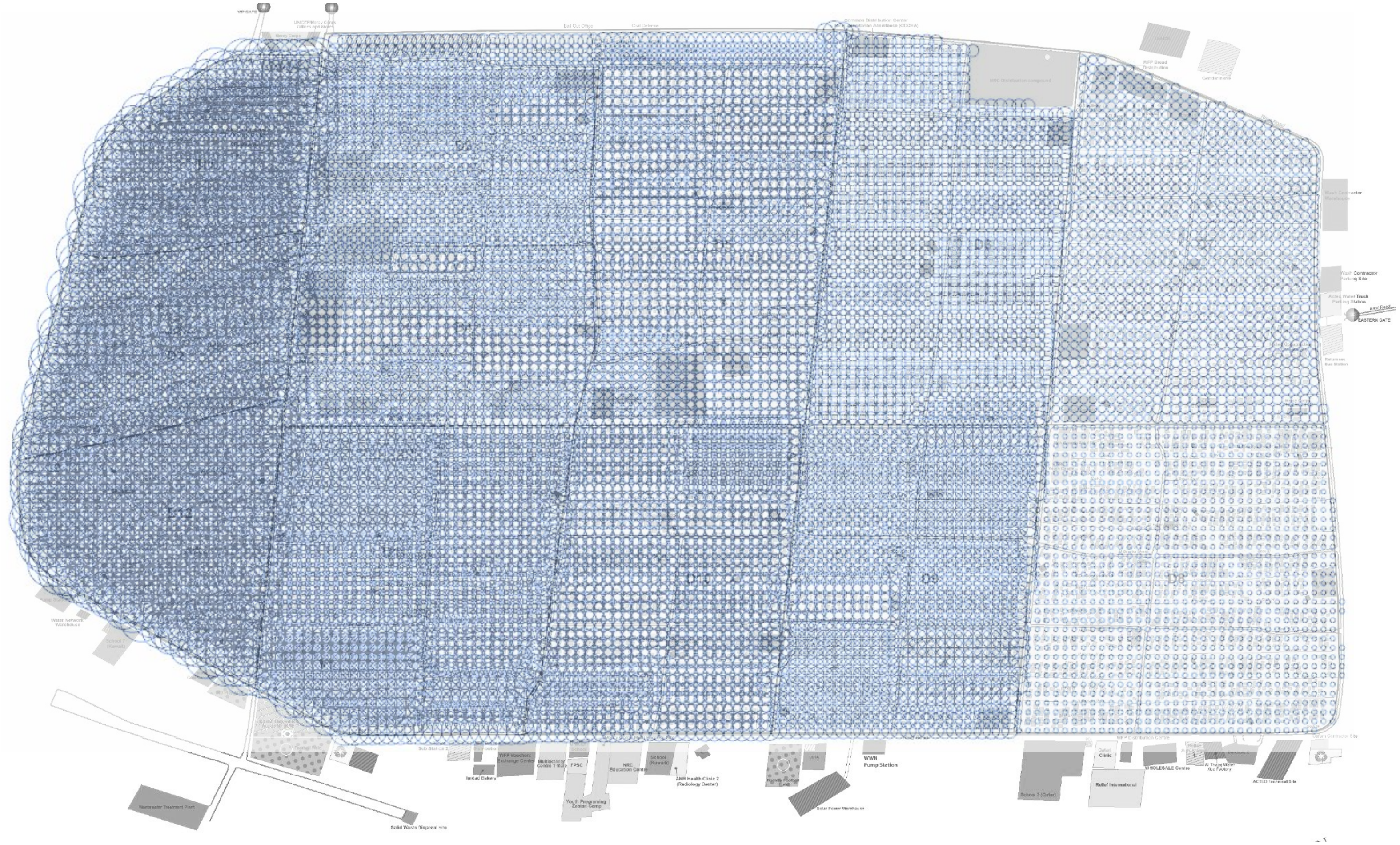


People number per house on point matrix

Population factor

By multiplying the aforementioned two sets of data together, the population density level on each point is identified. The population density is the first of the factors that are assigned to the point matrix of the site location. In the process, we find out the range of population density is quite big, ranging from 0.8 people to 4 people per 4 m2.

In the graphic, it is evident that the neighborhoods with highest density of living space are located on the left part of the camp. Subsequently, the demand of education would be higher in these areas given the larger number of people living there.

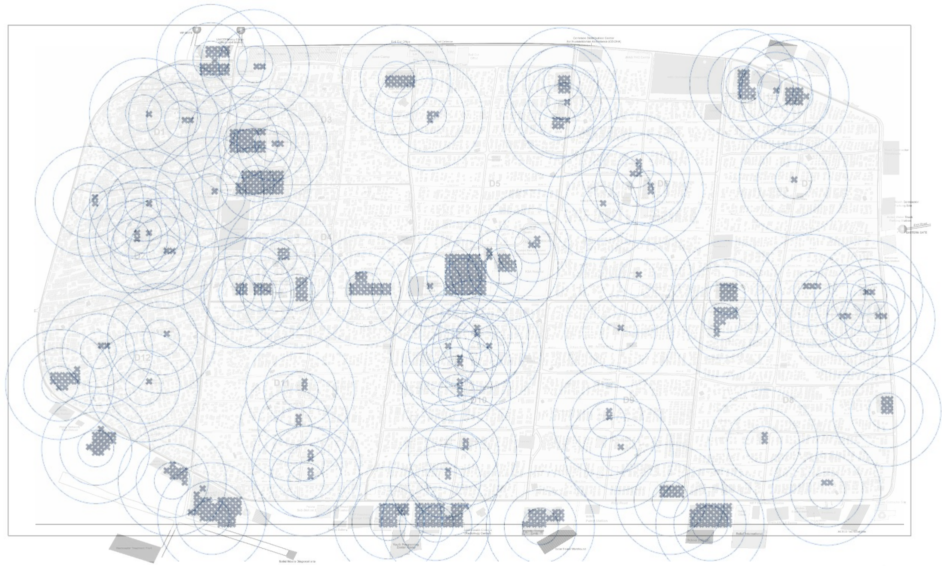


Population density

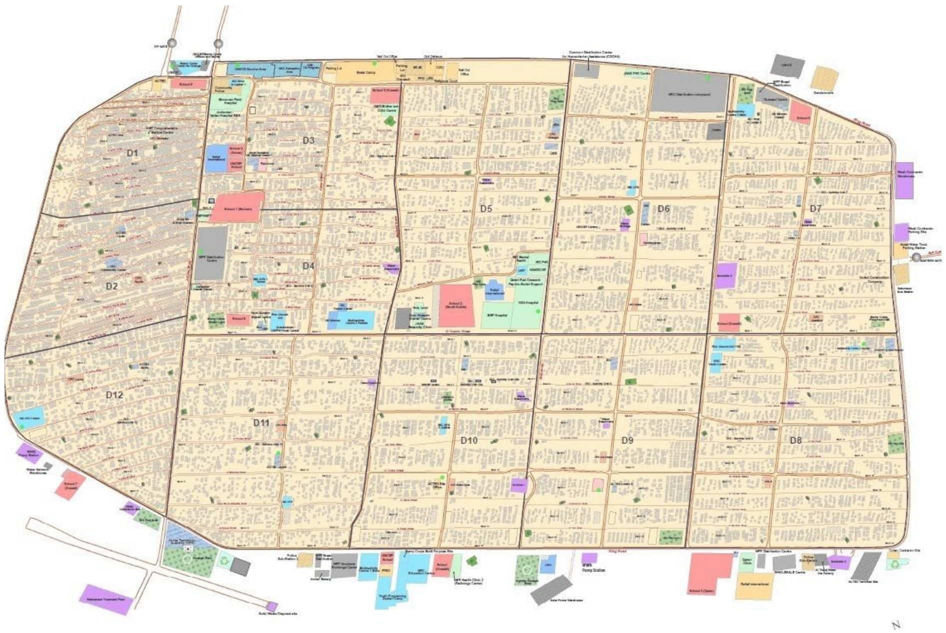
Educational factor

The second factor taken into consideration is the educational factor. Through this analysis, the lack of accessibility to education facilities in each place in the camp will be evaluated. From the function map of Zaatari camp, we can locate the existing facilities which are related to education, like schools, skill learning centres, and childcare.

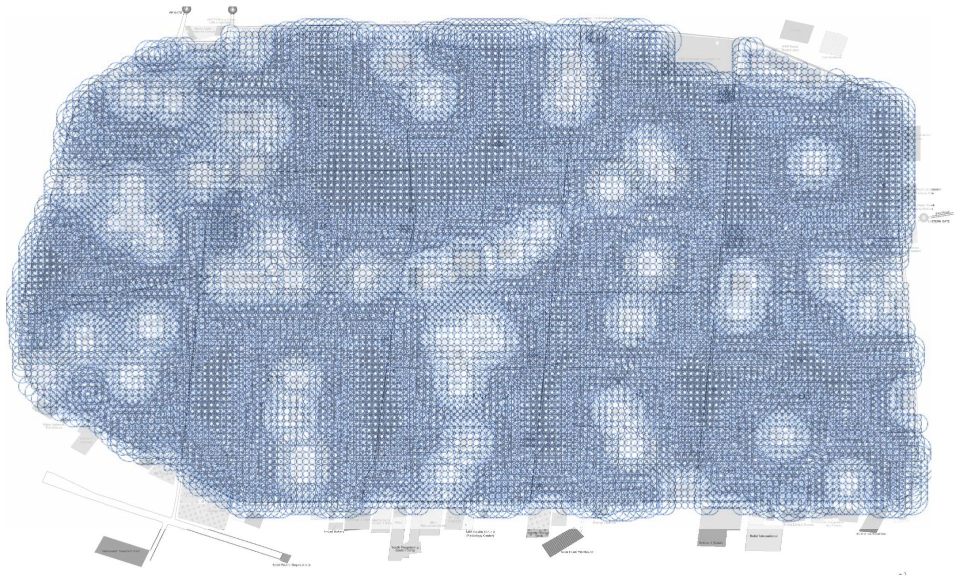
The inaccessibility is evaluated based on the distance from the facilities. The educational factor increases as the distance from the center of each facility becomes longer. The factor has the lowest value (1) near the facilities, while as the distance increases, the factor ascends until 5. The dark blue part In the graphic has the highest inaccessibility educational factor representing the places where the educational sources are harder to be reached.



Distance from facilities



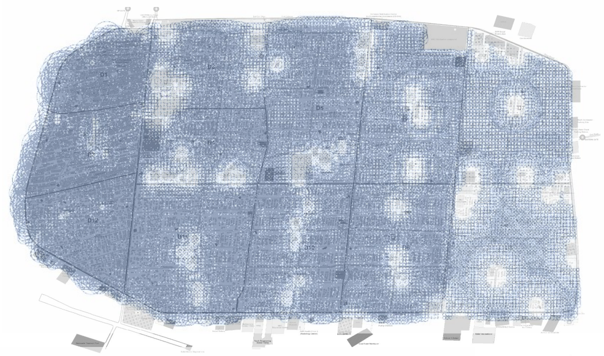
Function map (UNHCR, 2006)



Accessibility of educational places

Educational demand

The two aforementioned data sets are combined by multiplying two factors of population and inaccessibility of education. In this way, the educational demand on each point is pinpointed. The graphic on the right hand side represents the degree of the demand. The 2000 points with the highest common factor are isolated in one new data det, in order to run the optimization simulation regarding the vacant space and finalize the location of the school within this area.



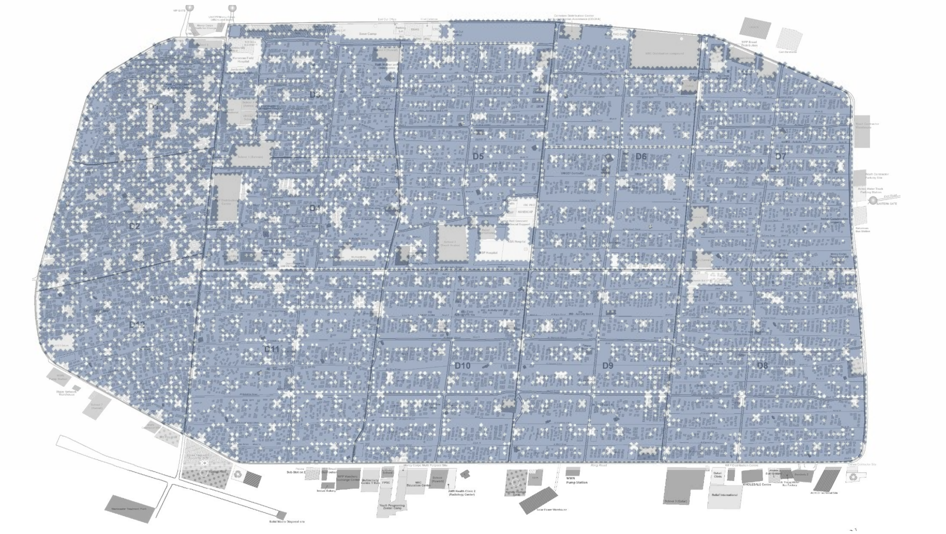
Intersection of population factor and Educational factor

Highest educational demand areas

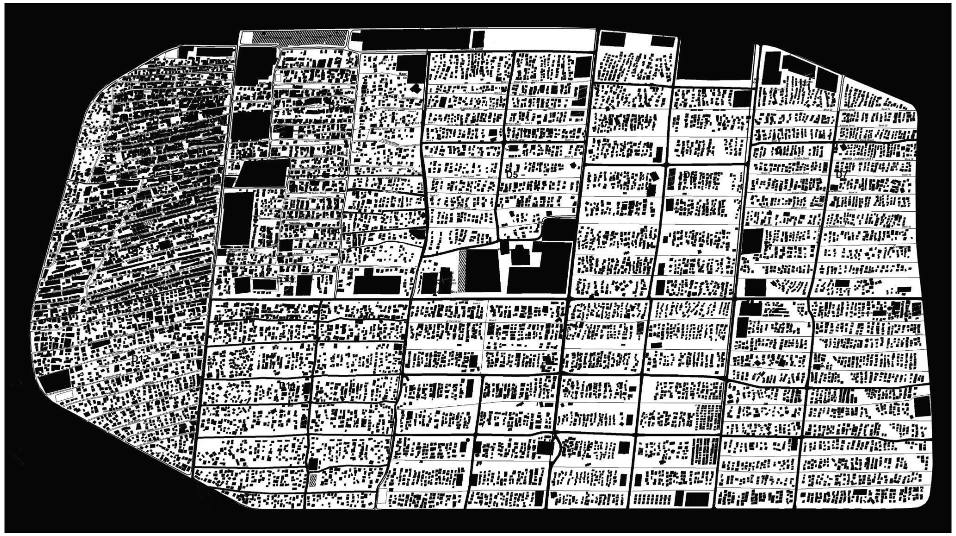
Vacant factor

To place the new educational center, the sufficient vacant place needs to be determined as well. Nolli plan is a simplified graph showing the vacancy and occupied places. In this plan, the black part is the occupied places and the white part is the vacant places. Through Grasshopper's Image sampler, Nolly plan can be transferred as 0 and 1 with the point matrix.

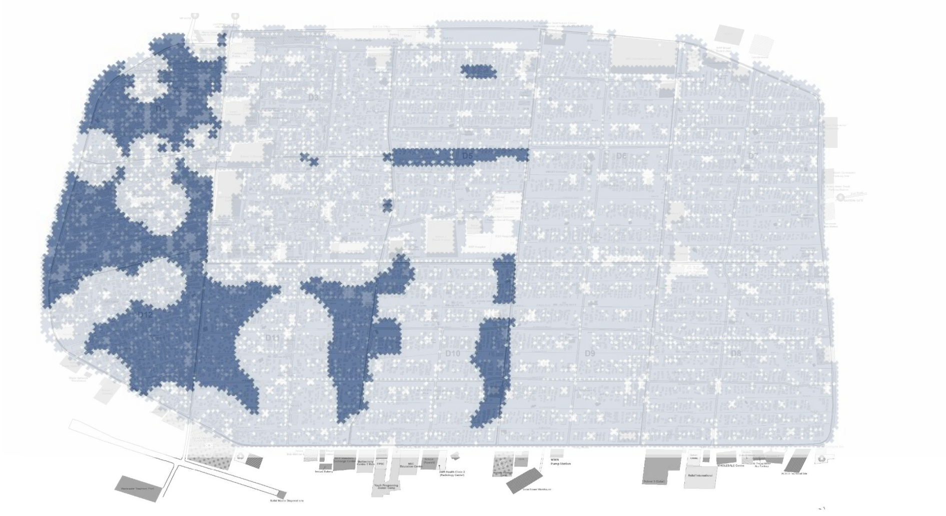
Overlapping the vacant factor with educational demand, we can find all the possible places. However, in this stage, the vacant area around the generated points is not necessarily continuous which means some of the places would not have in reality sufficient space to place the educational center..



Vacant factor diagram



Nolli plan

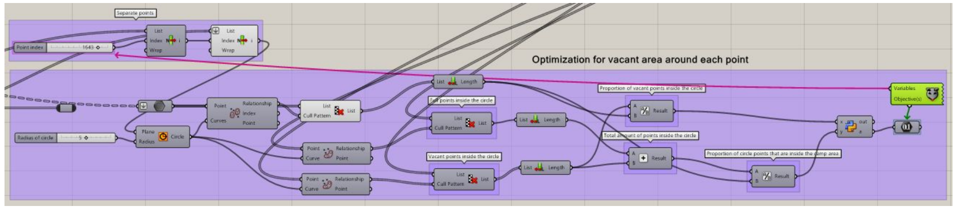


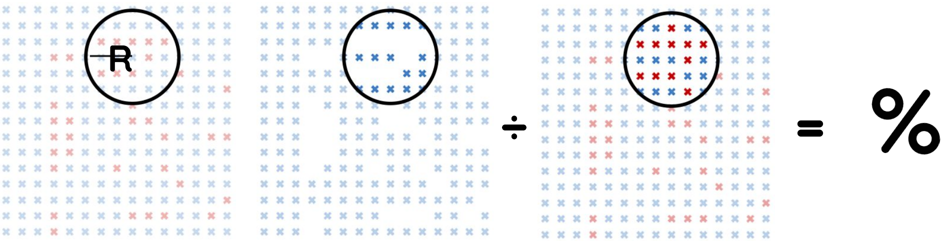
Overlapping vacant places with educational demand

Potential placement locations

In order to tackle the problem mentioned previously, a Grasshopper script was developed in order to identify if there is enough vacant space around the points which were indicated as the points with the higher educational demand, as well as if this vacant space is continuous or scattered.

The methodology which was followed involved the use of a circle with radius respective to the amount of space needed for the functions of the building program each time. The script calculated the proportion of vacant points inside the circle and optimized for the maximization of this factor using the Opossum plugin. At the same time, another constraint was set in order to ensure that the majority of circle points are inside the camp area.





Step1:

Define the surface based on a radius

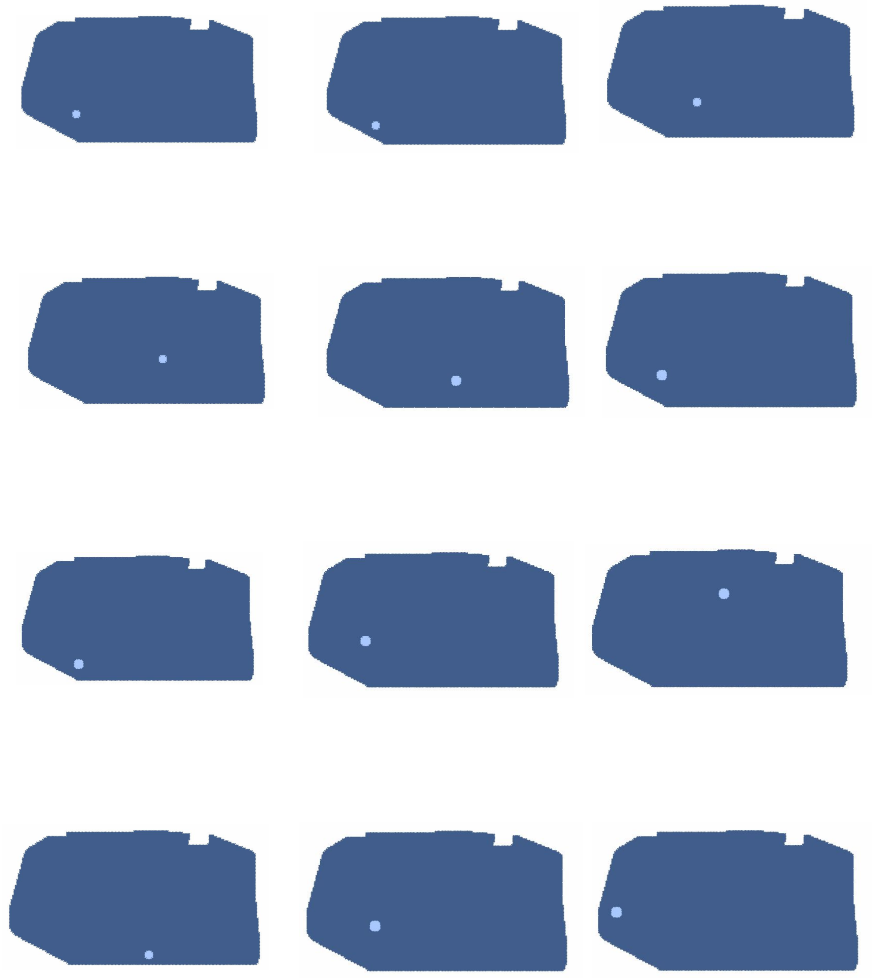
Step2:

Number of vacant points in the circle / Total points in the circle

Step3:

Vacant space factor

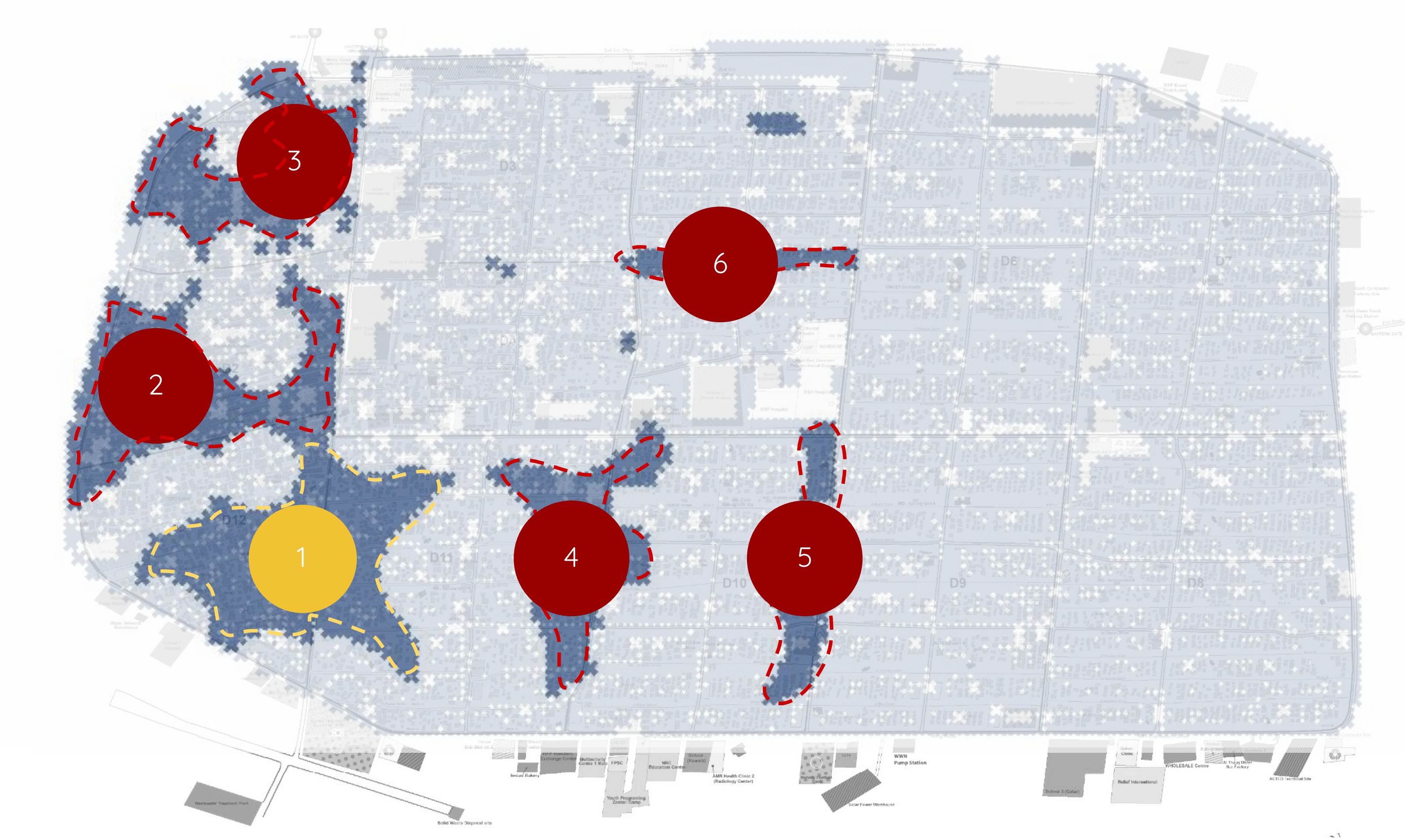
Vacant factor methodology



Optimization results

Placement areas

With the methodology stated before, the potential locations with the highest education demand and the most continuous vacant spaces are located. Combining those locations together in the map underneath, we set a hierarchy on each area. The area with label 1 has the most accessible vacant places for constructing an educational center.



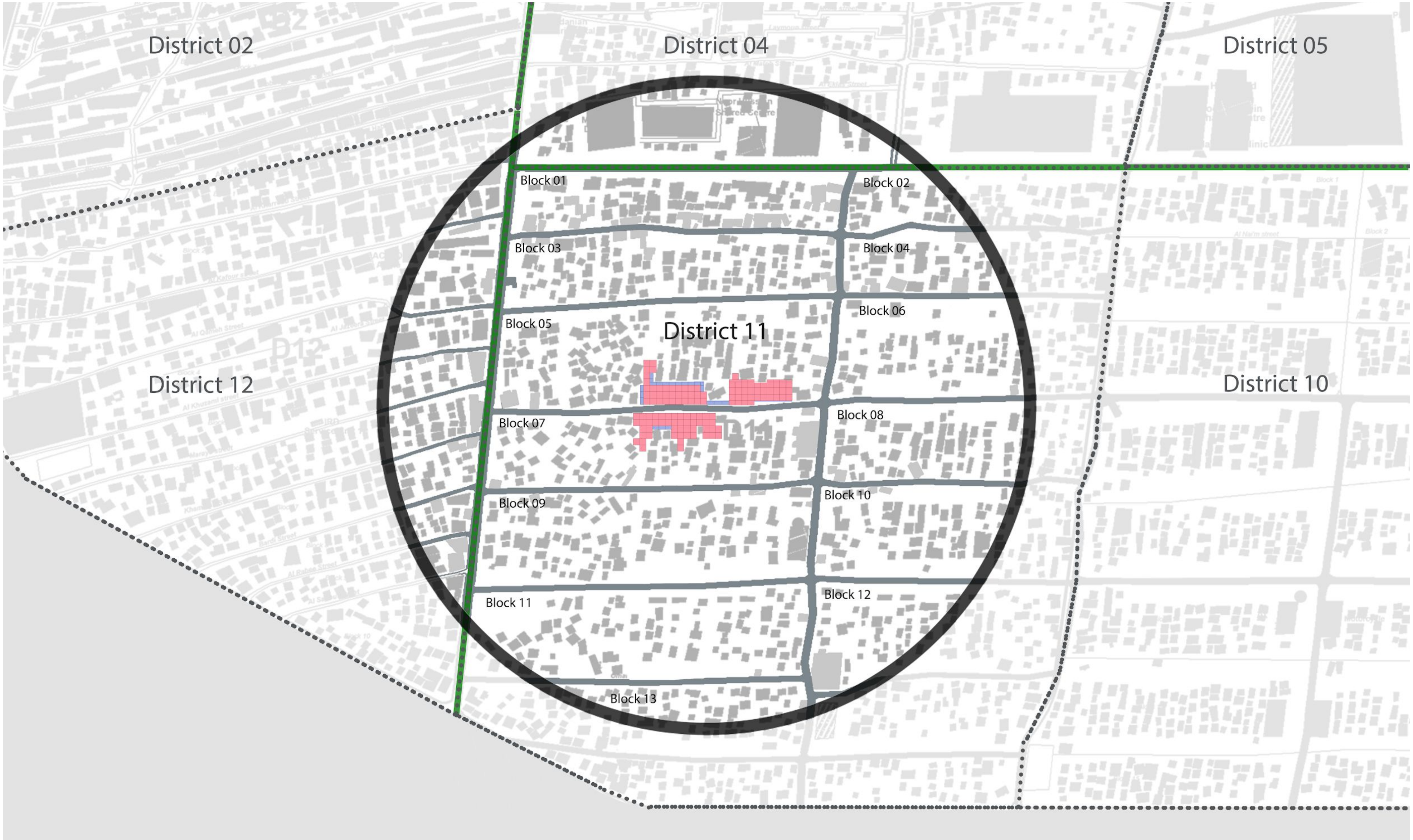
Chosen site area

Final site selection

The final site is based on the criteria of:

1. Size of vacant space
2. Shape of vacant space
3. Possibility of having extension in the future

The final location is the pink area in Block 05 on the left side. This place has is more square with bigger size and has potential to have extension space across the street or in the same block.



Skill Learning Opportunities

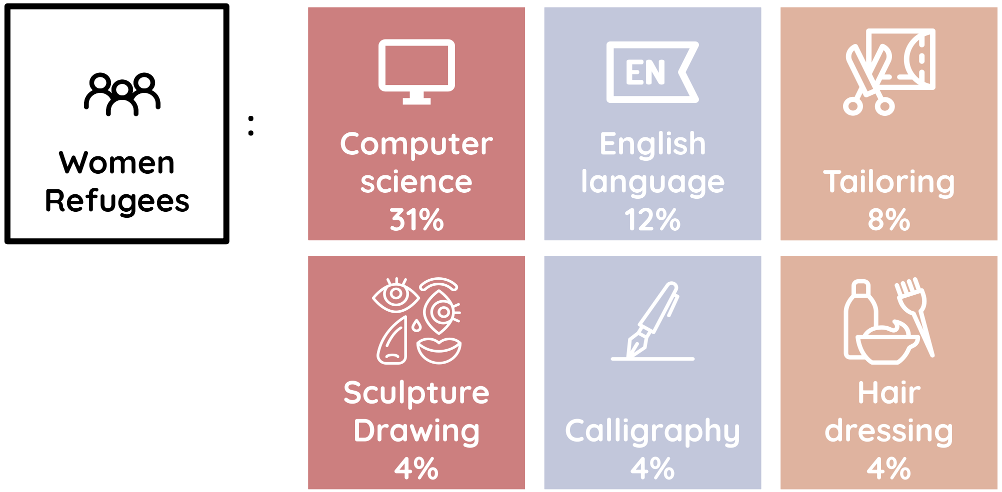
In order to form the program of requirements for our building, the preferences of the local population regarding the skills that they want to acquire as well as the syrian traditions were taken into consideration.

Questionnaires:
It is important to mention that, according to a questionnaire (Sinaria Abdel Jabbar & Haidar Ibrahim Zaza, 2016) conducted in 2016 among women refugees in Zaatari camp that took part in the ‘Women and Girls Oasis’ vocational training program, approximately one third of them wanted to acquire computer science skills, while 12% mentioned english language skills.

Table 4. Skills which the women refugees wished to acquire for free.

Skill	Percentage of women refugees
Computer	31
English language	12
Sculpture and drawing	4
Tailoring	8
Calligraphy	4
Hairdressing	4
None	4
No answer	35

Source: Sinaria Abdel Jabbar & Haidar Ibrahim Zaza (2016) Evaluating a vocational training programme for women refugees at the Zaatari camp in Jordan: women empowerment: a journey and not an output



Syrian Traditions:
Considering Syrian’s background, skill learning is related to wood painting, textiles and knitting. This variety of traditional skills are much appreciated and our ultimate goal is to integrate them in the skill learning classes of our program.

Program of Requirements

FUNCTION	LEVEL OF PRIVACY	INDOOR - OUTDOORS	AREA (m2)	NUMBER OF PEOPLE	HEIGHT REQUIREMENT	QUANTITY OF ROOMS	DAYLIGHT (LUX)
Main Court Yard	PUBLIC	OUTDOORS	128m2	-	-	1	-
Sport Field	PUBLIC	OUTDOORS	Football= (5p/team)= 36,5*27,5m (7p/team)= 55*36,5m (11p/team)= 105*68,5m Basketball= 28*15m	-	7,5 m	1	-
Library	PUBLIC	INDOORS	min. of 149 m2 and a max. of 372 m2	-	2,7 m	1	200 (book area) / 500 (reading area)
Farm	PUBLIC	INDOORS	-	-	-	1	-
Multifunctional hall	PUBLIC	INDOORS	one multipurpose space of 93 m2	for each 150 students	4,0 m	1	300
Shop/ Exhibition hall	PUBLIC	INDOORS	minimum 32m2	-	4,0 m	1	200
Court Yard	SEMI-PRIVATE	OUTDOORS	64m2 per 3 classrooms	-	-	1 - 2	-
Corridor	SEMI-PRIVATE	IN BETWEEN	4m2 per module	-	2,7 m	1 - 2	
Cantine	SEMI-PRIVATE	IN BETWEEN	32m2 per school	-	2,7 m	1 - 2	200
Kitchen	PRIVATE	INDOORS	64m2 per school	-	2,7 m	1	
CLASSROOMS: Childcare	PRIVATE	INDOORS	48m2 per classroom	30 pupils each	2,7 m	-	300-500
CLASSROOMS: Elementary or High school	PRIVATE	INDOORS	48m2 per classroom	30 pupils each	2,7 m	-	300-500
CLASSROOMS: Skill learning center	PRIVATE	INDOORS	48m2 per classroom	30 pupils each	2,7 m	-	300-500
Storage	PRIVATE	INDOORS	24 m2	-	2,7 m	2 - 4	-
Toilets (M & F)	PRIVATE	INDOORS	24 m2	1 for every 20 pupils 1 for every 25 staff	2,7 m	2 - 4	150
Teachers Office	PRIVATE	INDOORS	32 m2 per 6 classrooms	min. of 1.4 m2 of space per adult	2,7 m	1 - 2	500
Administration	PRIVATE	INDOORS	32 m2 per 6 classrooms	-	2,7 m	1	500
First Aid	PRIVATE	INDOORS	64 m2 per school	-	2,7 m	1 - 2	200
Changing rooms (M & F)	PRIVATE	INDOORS	32 m2 per school	-	2,7 m	1 - 2	150

Connections between functions

The following chart provides information about the various types of relationships between the different functions of the program of requirements which can be potentially accommodated each time in the automated generated sets of configurations. This step is crucial before the gamification procedure begins because this chart in combination with the bubble diagrams and the sets of rules are the conditions that should be validated each time in order to finalize the configuration.

Types of connections
In our case, three categories of space connections are defined:

a.Desired Connections:
This type of connection is wanted but not mandatory.

E.g. First Aid module would be desired to be connected with the secondary courtyard but it is not mandatory.

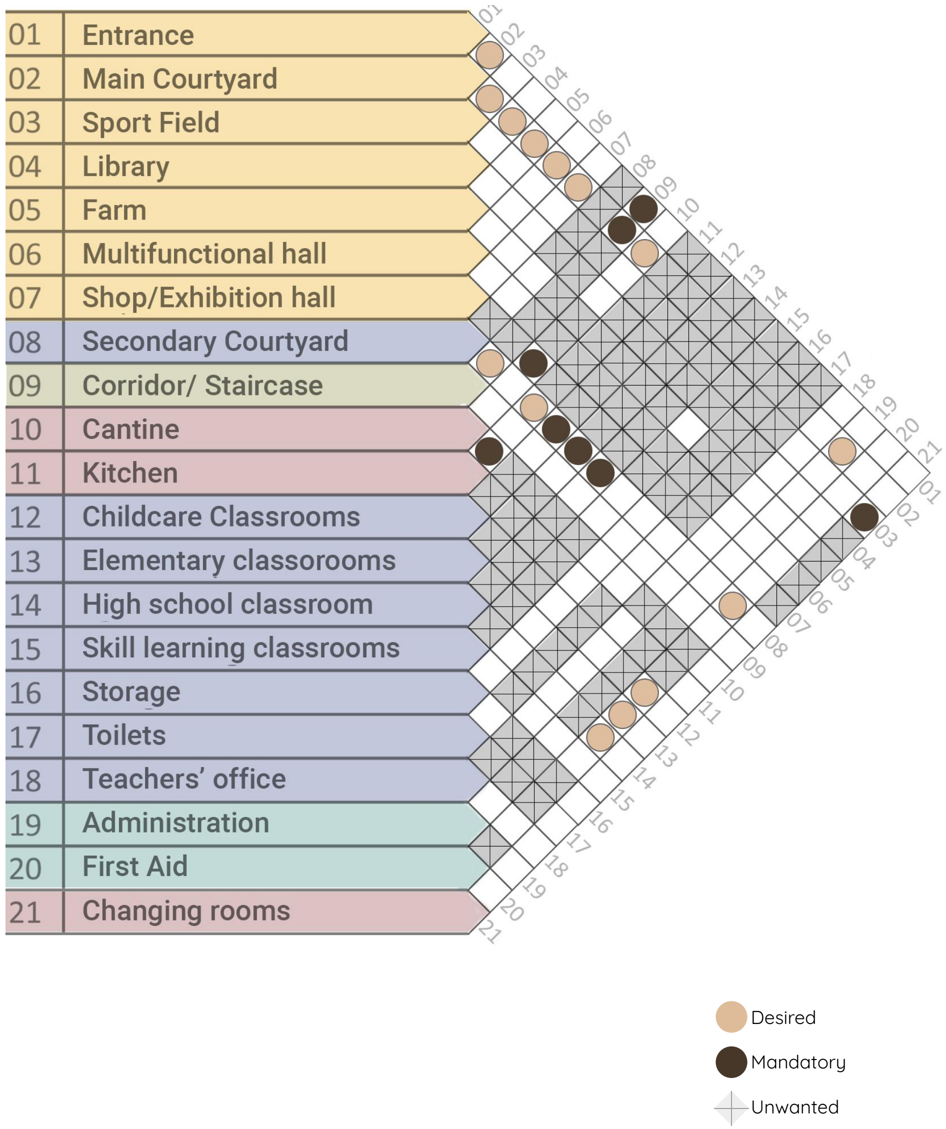
b.Mandatory Connections:
This type of connection is compulsory.

E.g. Cantine and Kitchen should always be connected.

c.Unwanted Connections:
This type of connection is rejected.

E.g. Toilets should not be directly connected with classrooms.

REL Chart

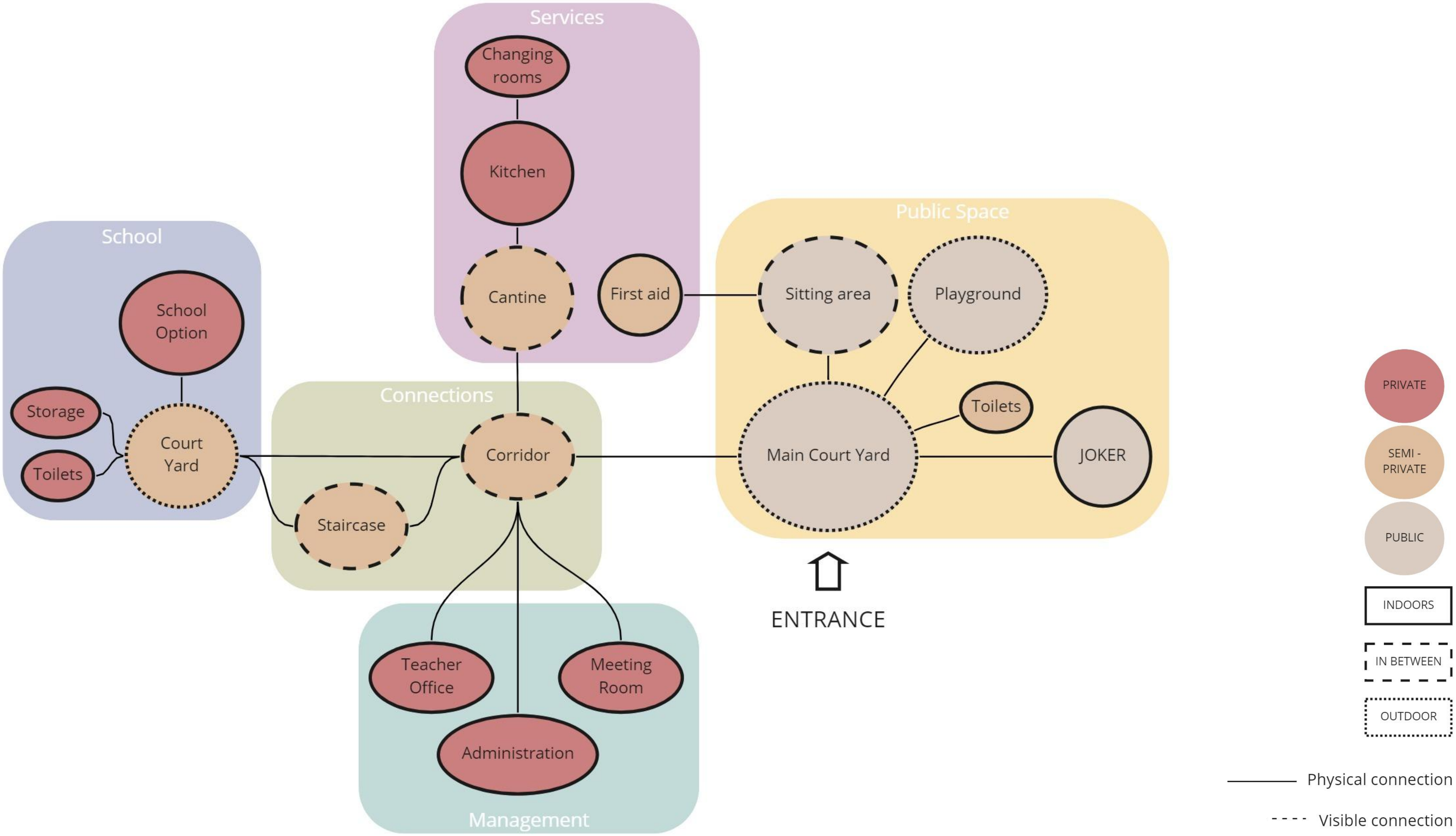


Bubble Diagram Logic

Spatial connections are visualized more clearly in the following bubble diagram. The ultimate intention is to create a game that is composed by at least 5 clusters (School, Management, Services, Public spaces and their connections). Spaces are categorized in public, private and semi-private areas, as well as. indoors, outdoors and semi-open spaces.

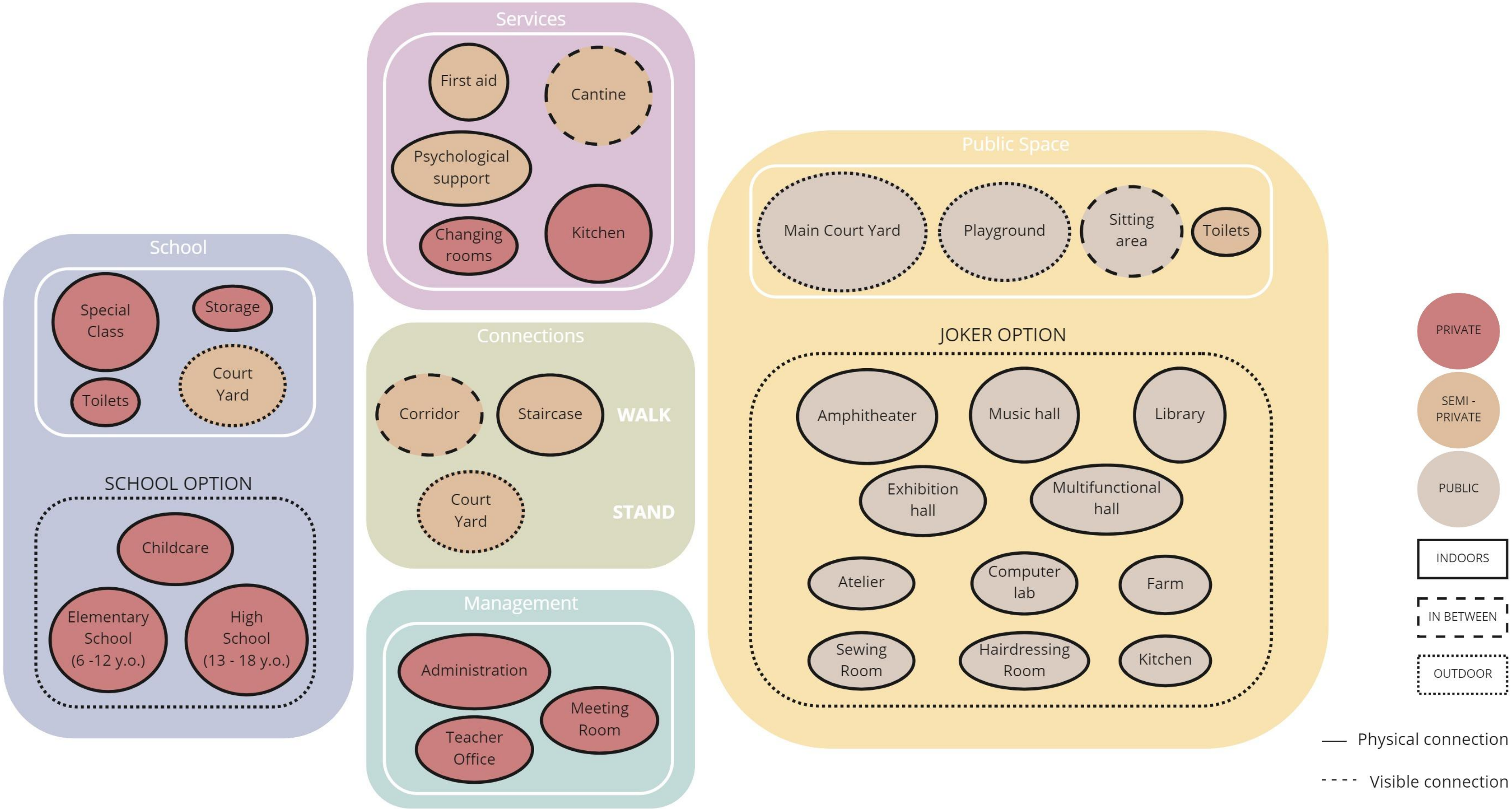
Minimum Composition Example

In the example below the minimum composition is introduced. This should always have one school option, either childcare, elementary or high school. Within the public clustin a Joker element related to skill learning should always be present. It represents possible spatial areas that we choose, considering population's preferences.



Main Clusters

An overview of these clusters is depicted below. The mandatory spaces within each cluster are enclosed within the white boxes, while from the rest of the function at least one is chosen each time, creating different possibilities of compositions. According to the aforementioned rules, each center should have at least one set of classrooms and at least one joker element.



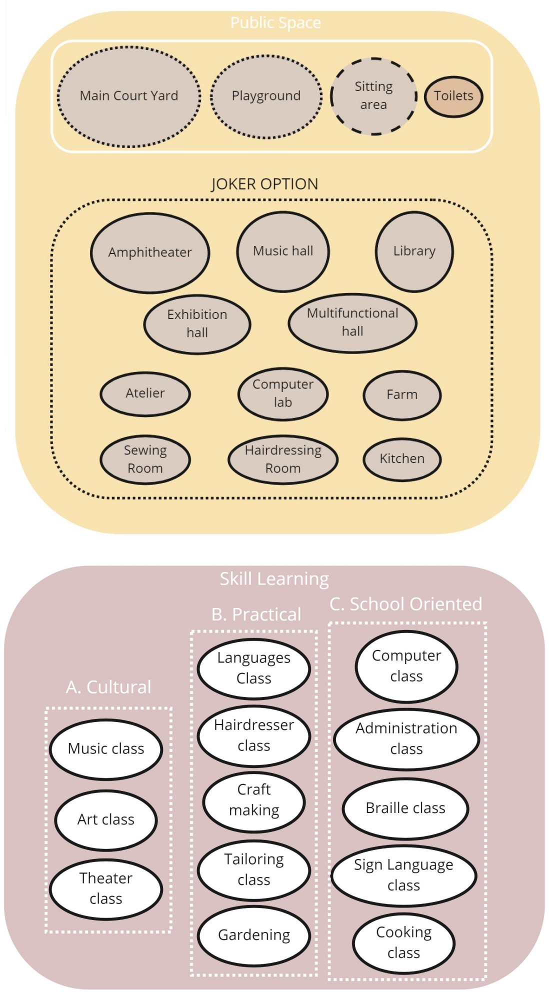
Joker Element

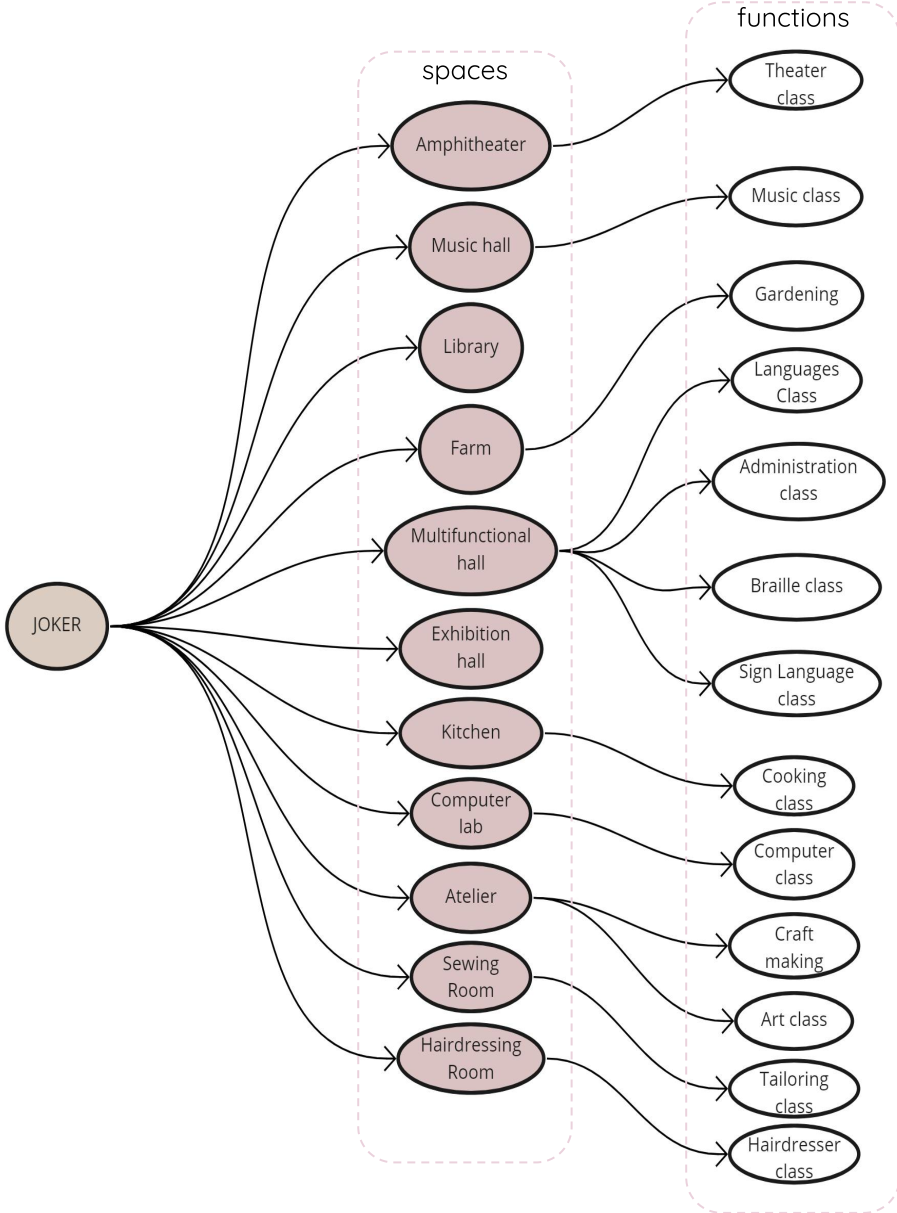
Skill Learning Classes

In the following cluster all the possible spatial areas that the joker can take are shown. In the white bubbles the type of classes that the education center could have are organized in 3 categories including cultural, practical and related to the school facilities.

Spatial interpretation of functions

On the right side of this page it is depicted the spatial interpretation of functions. It is clear that some spaces could potentially host one or more skill learning classes.





Classrooms' quantity methodology and example

Those steps will happen after the optimisation of finding the available area in the camp.

1.0.0) Find the sector of the camp where the available area was found.

e.g.: sector 11

2.0.0) Find how many schools and kids are in the particular sector.

e.g.: sector 11 has no schools

0-4 y: 1478

5-9 y: 1363

0-14y: 1009

15-19y: 810

2.1.0) If there is school, what is the ratio of classroom per kids?

e.g.: 50 kids per classroom

2.1.1) If the ratio is higher than the ideal (20 kids per classroom) then a school need to be added to lower the ratio.

2.1.2) If not, no school will be added.

2.2.0) If there is NO school, follow the same next step as if there were schools.

2.3.0) What are the educational stages available in that sector? Are they sufficient?

*REMINDER: all the sector must have all 3 educational stages: childcare, elementary and high school.

e.g.: Suppose that in sector 11 don't have any childcare, enough elementary school's classroom, but the high school has only 30 classroom.

2.2.1) How to check that they are sufficient?

(Amount of kids at the age to be in elementary or high school / 20) / 2 = ideal amount of classrooms

e.g.: Suppose that in sector 11 there is enough elementary school classroom, but the high school has only 30 classrooms

High school (13-18y): 2125 kids

(Amount of kids at the age to be in high school / 20)/2 = ideal amount of classrooms

(2125/20)/2 = 54 classrooms

REMINDER: High school and elementary school can have 2 shifts, morning and afternoon. Therefore the amount of classrooms will be divided by 2.

Amount of kids at the age to be in a childcare/ 20 = ideal amount of classrooms

e.g.: Suppose that in sector 11 don't have any childcare.

Childcare (0-4 y): 1478 kids

Amount of kids at the age to be in a childcare / 20 = ideal amount of classrooms

1478/20 = 74 classrooms

If the amount of classrooms in the sector are different from the ideal amount, then is insufficient / not sufficient:

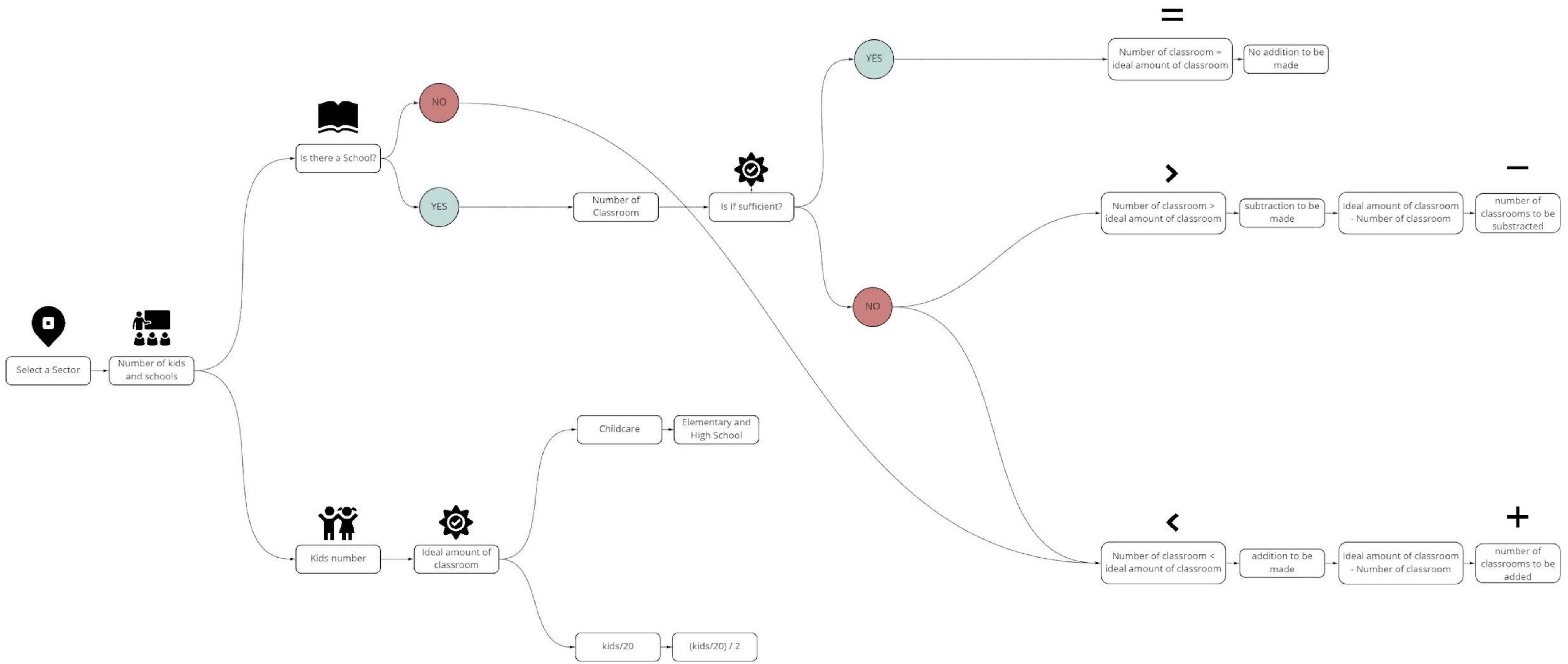
2.2.2) If sufficient, no classrooms need to be added.

2.2.3) If not sufficient, how many classrooms are needed for each educational stage?

ideal amount of classrooms - current amount of classrooms = number of classrooms to be added

e.g.: Suppose that in sector 11 don't have any childcare. But the ideal amount of classrooms would be 74. Ideal amount of classrooms - current amount of classrooms = number of classrooms to be added. (74 - 0 = 74)

Classrooms’ quantity methodology flowchart



02_Forming

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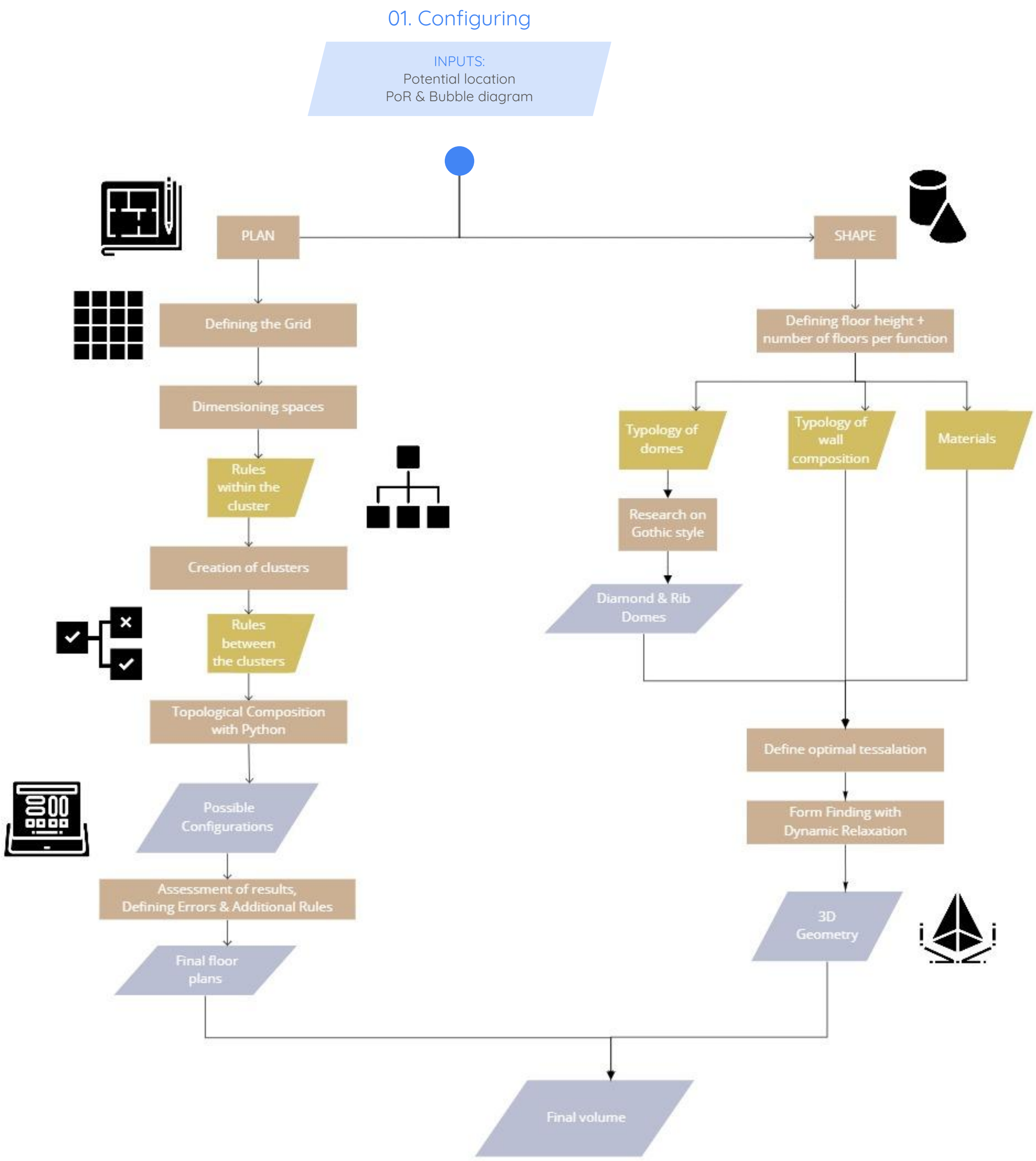
Flowchart


01. Configuring
INPUTS:
Potential location
PoR & Bubble diagram
PLAN
SHAPE
Defining the Grid
Dimensioning spaces
Rules within the cluster
Creation of clusters
Rules between the clusters
Topological Composition with Python
Possible Configurations
Assessment of results, Defining Errors & Additional Rules
Final floor plans
Defining floor height + number of floors per function
Typology of domes
Typology of wall composition
Materials
Research on Gothic style
Diamond & Rib Domes
Define optimal tessalation
Form Finding with Dynamic Relaxation
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Final volume

Rules of the game

The first step of the plan configuration is to define a grid. In our case a 2 by 2-meter grid is considered more suitable since the minimum space dimension is the 2-meter corridor.

Afterwards the rules of each function inside each cluster are set, considering their dimensions, space sequence and connectivity.

R U L E S

Public cluster

- Main Courtyard (128 m2): the main entrance to the school. It's placed first in the middle of the plan with the smallest edge next to the road, surrounded by corridors

- Playground (64m2) & Sitting area (64m2): they are placed second and the are connected to the corridor the surrounds the main courtyard

- Public Toilets (24m2): its smallest edge connected to the corridor that surrounds the main courtyard. Avoid sharing an edge with the road

- Joker (128 m2): smallest edge connected to the main courtyard, largest edge next to the road

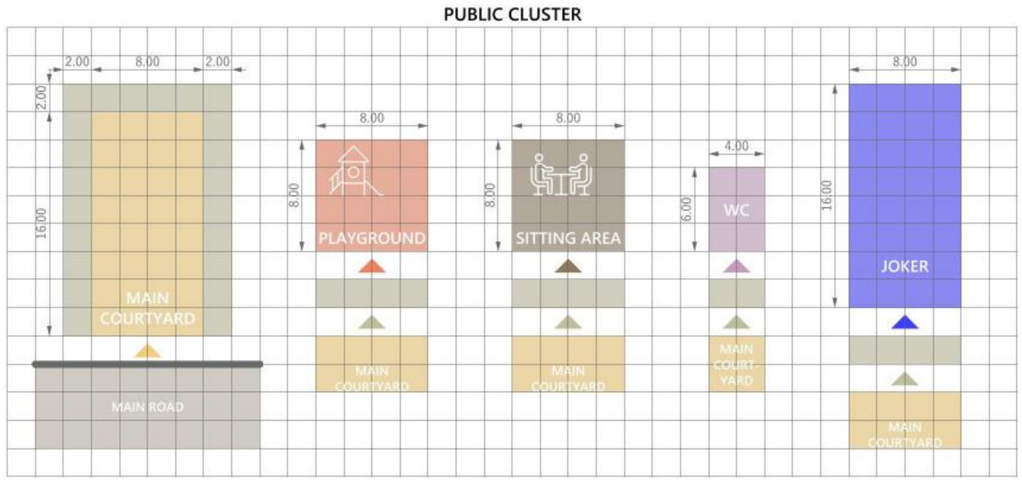
Services cluster

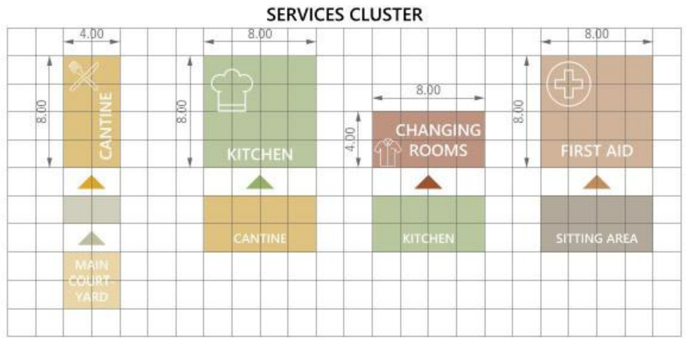
- Cantine (32 m2): 1 per school, connected with the smallest edge to the corridor that surrounds the main courtyard. Connected to its largest side to the road

- Kitchen (64m2): 1 per school, connected to the largest edge of the cantine

- Changing rooms (32 m2): 1 per school, connected with its largest edge to the kitchen

- First aid (64m2): 1 per school, connected to the sitting area





Rules of Public and Services Cluster

Rules of the game

Connections cluster

- Corridors: placed at the side of the remaining corridor, surrounding the main courtyard, leading to the classrooms. Their maximum length can reach 16 meters, while their width is 2 meters.

Management cluster

- Administration room (32 m2): Teacher's room (32 m2) & Meeting room (32 m2): between main and school courtyard, smallest edge connected to the corridor

- 1 Teacher's room (10 teachers) per 6 classrooms

- 1 Meeting room per school

- 1 Administration room per school (3 people)

School cluster

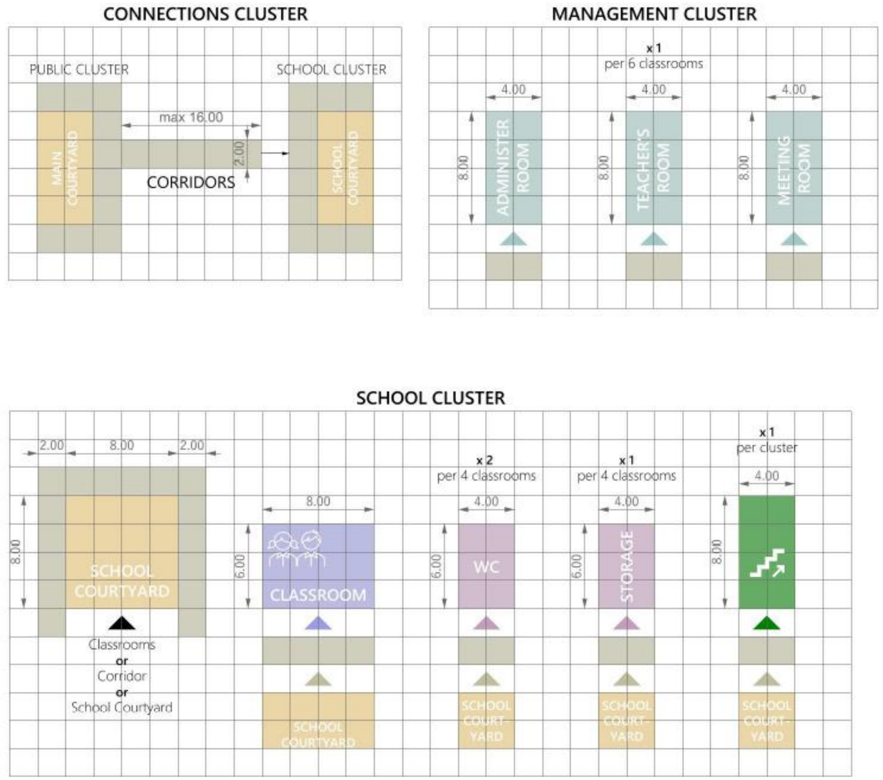
- School courtyard (64 m2): surrounded in all sides by private/semi-private space, 1 per at least 3 classrooms

- Classroom (48 m2): one edge connected to the school's courtyards

- Toilets (24 m2): 2 per 4 classrooms, connected to its smallest edge to corridor that surrounds the school courtyard

- Storage (24 m2): 1 per 4 classrooms, connected to its smallest edge to corridor that surrounds the school courtyard

- Staircase (32 m2): 1 per set of classrooms, connected to its smallest edge to the corridor that surrounds the school courtyard



Rules of the Connections, Management and School Cluster

Python programming

Python programming is implemented to generate the possible topological configurations inside the chosen location. The libraries that were imported for this code are **topogenesis, numpy, matplotlib** for plotting each step in a static 2D visualization and **pandas** to export the results in an excel file.

1. The coding starts with the creation of a 3D array of zeros that has the basic dimensions of the chosen site defined during the urban analysis. In this array each cell represents a cubic meter of 1 by 1 meter.

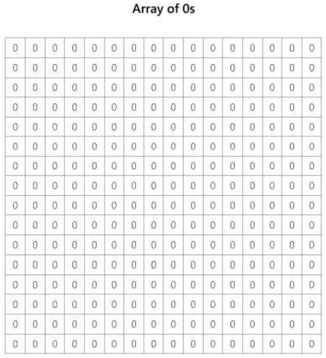
Assignment of functions strategy – array patterns

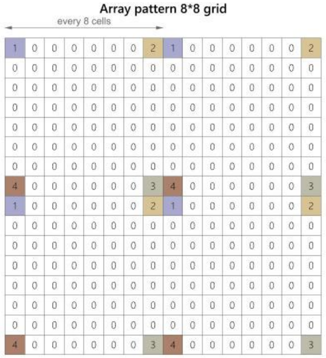
2. def grid(i):

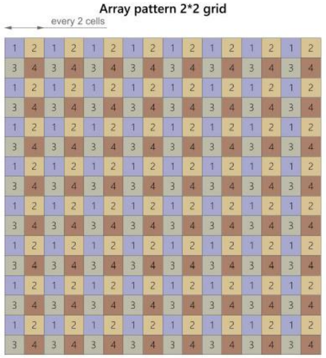
The next step is the generation of pattern arrays with the same dimensions as the first one.
Since the dimensions of the defined functions are vary from 2, 4, 6 and 8 meters, all even numbers, a creation of a pattern every 8 and every 2 cells is chosen. The aim is to apply the same number (one = 1) every 8 cells horizontally and vertically to track these cells in the general array and assign the functions. However, the placement of the function differs depending on the orientation they are on the array. To track and check the available space the neighbor cells of the 1s also receive a value of either 2, 3 or 4 depending on their position.

3. def plot(array_x):

Plot the array in a **matplotlip** diagram to visualize every step of the process







Plot representation

```python
import topogenesis as tg
import numpy as np
import matplotlib.pyplot as plt
import matplotlib
```

```python
# create an array of 0s
# dimensions are selected from the vacant area that was selected during
width = 98
length = 35
avail_array = np.zeros((width,length,1), dtype=int)
p_array = np.copy(avail_array)
```

```python
# create array every i cells
def grid(i):
    array = np.array(avail_array, copy=True)
    array[0::i,::i] = 1
    array[::i,i-1::i] = 2
    array[i-1::i,i-1::i] = 3
    array[i-1::i,::i] = 4
    return array
```

```python
# create 8 cell array
eight_array = grid(8)
# create 2 cell array
two_array = grid(2)
```

```python
def plot(array_x):
    fig, ax = plt.subplots()
    plt.imshow(array_x)
    for x in range(98):
        ax.axhline(x, lw=0.1, color='k', zorder=5)
    for x in range(35):
        ax.axvline(x, lw=0.1, color='k', zorder=5)
    plt.colorbar()
    plt.show()
```

Coding PYTHON

Python programming

Definition for each function category

On each function is being assigned a different index number in order to organize, visualize and ease the selection of neighbor cells on the next step.

4. def courtyard(point):

Creation of a tuple with courtyard's dimensions and position it to the possible starting point with an index number of 1

5. def public(point, i):

Creation of a tuple with 8*8 dimensions and position it to the possible starting point with an adjustable index number i

6. def services_v(point, i, h, v):

Creation of a tuple with either 8*4 dimensions or 4*8 dimensions. Since 4*8 spaces are placed with their smallest side next to the corridors, the horizontal and vertical position of spaces differs. For that reason, the values h and v are used to verify whether the space is placed on the horizontal or vertical direction. As before the index number is adjustable by the value i

7. def corrid_v(point,i):

Same as the above definition with either 16*2 or 2*16 dimensions

8. def classroom_v(point,i):

Same as the above definition with either 8*6 or 6*8 dimensions

9. def services_v(point,i):

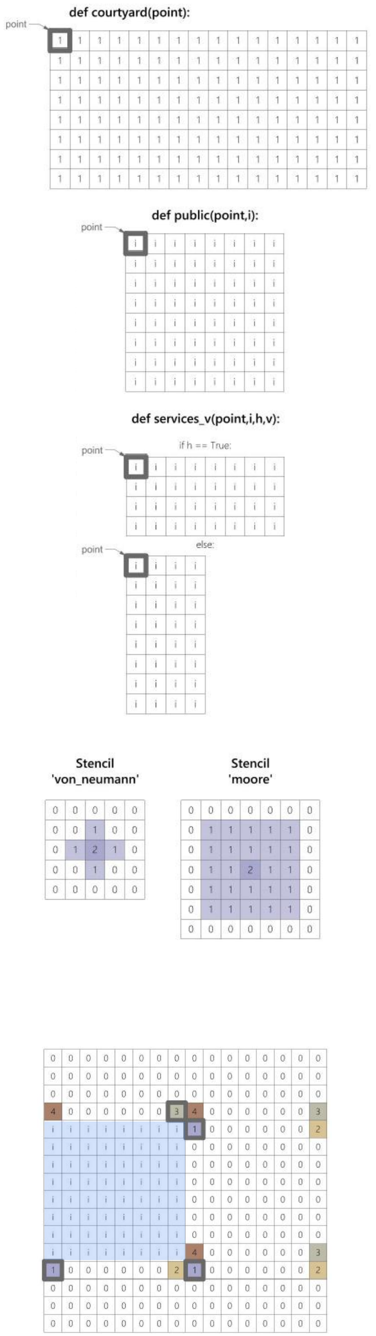
Same as the above definition with either 6*4 or 4*6 dimensions

Applied Stencils to select neighbour cells

10. Two different stencils are applied. By 'moore' to select each first and second neighbor of every cell and by 'von_neumann' to select each first neighbor. The former also contains the corner point, while the latter excludes them.

11. def find_possible_p(new_lattice, array, avail, i):

Select the possible points for positioning the function. These points need to be on the array of neighbor cells, that is defined by the available lattice (new_lattice) and they carry an index number (i), depending on the function's index that they surround. Additionally, the available array that contains all the configuration needs to be empty, which means contain 0s. To assign each function, the top left corner is always selected, and the function is placed underneath. Therefore, by using the array pattern (array) the possible points that contain 1s in the array pattern are the neighbors at the left and bottom of the function, while the 3s are the top neighbors. While separating the ones that are positioned on the top, the possible points are moved at the top of the function's starting point.



Plot representation

Coding PYTHON

```python
# definition of public spaces with 8*8 m2 (top starting point, index number)
def public(point,i):
    c = (8,8,1)
    avail_array[point[0]:point[0] + c[0], point[1]:point[1] + c[1]] = i
```

```python
# definition of secondary spaces with 8*4 m2 (top starting point, index number)
def services_v(point,i):
    c = (8,4,1)
    avail_array[point[0]:point[0] + c[0], point[1]:point[1] + c[1]] = i
def services_h(point,i):
    c = (4,8,1)
    avail_array[point[0]:point[0] + c[0], point[1]:point[1] + c[1]] = i
def services(point,i,h,v):
    if h == True:
        services_h(point,i)
    else:
        services_v(point,i)
```

```python
avail_lattice = tg.to_lattice(avail_array, minbound=[0,0,0])
```

```python
up_s = tg.create_stencil("moore", 2, 2)
up_s.function = tg.sfunc.sum
print(up_s)
```

```python
vn_stencil = tg.create_stencil("von_neumann", 1, 1)
vn_stencil[1, 1, 1] = 0
vn_stencil[1, 1, :] = 0
vn_stencil.function = tg.sfunc.sum
print(vn_stencil)
```

```
[[[0 0 0]
  [0 1 0]
  [0 0 0]]

 [[0 1 0]
  [0 0 0]
  [0 1 0]]

 [[0 0 0]
  [0 1 0]
  [0 0 0]]]
```

```python
neigh2_lattice = avail_lattice.apply_stencil(up_s)
```

```python
def find_possible_p(new_lattice, array, avail, i):
    # points where we have neighbours and number 1s (down and side cells)
    points_2 = np.argwhere(((new_lattice == i)*(array == 1)*(avail == 0)) == 1)

    # points where we have neighbours and number 3s (up cells) - find 1s to apply spaces
    points_3 = np.argwhere(((new_lattice == i)*(array == 3)*(avail == 0)) == 1)
    point_A = points_3[:][:]-[7,7,0]
    neg = np.where(point_A[:][:] < 0)
    point_A = np.delete(point_A, neg, axis=0)

    # all points together
    p = np.append(points_2, point_A, axis=0)
    return p
```

Coding PYTHON

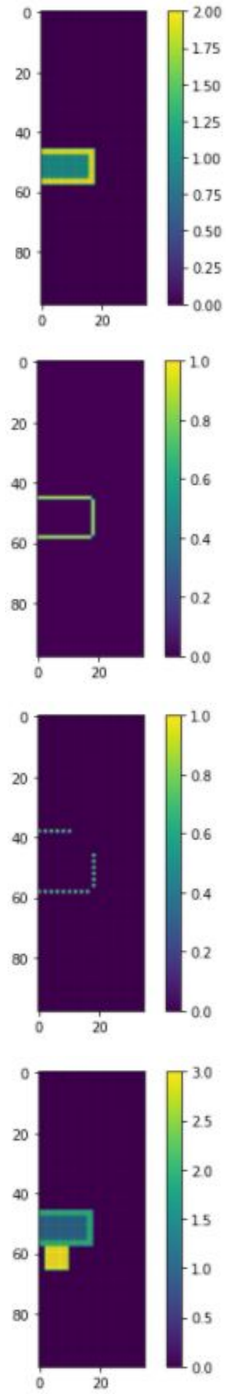
Python programming

Assign functions

12. The functions are assigned after we found the possible points for placing them. In this step a random selection of a point is set, to allow the creation of different alternatives it's time we run the code. In order to assign each function a number of parameters are being checked. First whether the selected point is at the top, bottom, or side of the function. After whether there is available space at the bottom and at the side of it. Then the function can be placed. While running the code sometimes the random selection can run infinite number of times without finding the appropriate result. Therefore, an addition is being implemented to stop the operation after 9000 times.

Export

13. The final configuration is exported to an excel sheet using **pandas.DataFrame.** These excel sheets are later imported to grasshopper and 3D shapes are assigned to generate the axonometric voxelation of the configuration.



Plot representation
Coding PYTHON

```python
# adding 4 classrooms 8*6 around corridors
i = 0
j = 0
while i <= 3:
    a = False
    while (a == False) and (j < 9000):
        si = pcl[np.random.choice(len(pcl), 1, replace=False)[0]]
        ar = np.sum(p_array[si[0]:si[0]+8, si[1]]==1) == 8
        ac = np.sum(p_array[si[0], si[1]:si[1]+8]==1) == 8
        a = ar or ac
        if (a==True) and (p_array[si[0],si[1]]==1):
            if ar == True:
                p_array[si[0]:si[0]+7, si[1]] = 0
                if avail_array[si[0],si[1]-1] == 0:
                    if avail_array[si[0], si[1]:si[1]-6] == 0:
                        si = si[:][:]-[0,5,0]
                    else:
                        a = False
                else:
                    if avail_array[si[0], si[1]:si[1]+6] == 0:
                        si = si[:][:]-[0,5,0]
                    else:
                        a = False
            else:
                p_array[si[0], si[1]:si[1]+7] = 0
                if avail_array[si[0]-1,si[1]] == 0:
                    if avail_array[si[0]:si[0]-6, si[1]] == 0:
                        si = si[:][:]-[5,0,0]
                    else:
                        a = False
                else:
                    if avail_array[si[0]:si[0]+6, si[1]] == 0:
                        si = si[:][:]-[0,5,0]
                    else:
                        a = False
            if a == True:
                classroom(si,14,ac,ar)
                i = i + 1
        else:
            a = False
            j = j + 1
    if j == 9000:
        i = i + 1
plot(avail_array)
```

Python

```python
newarr = np.reshape(avail_array, (98,35))
```

Python

```python
# export to an excel
df = pd.DataFrame(newarr)
df.to_csv(r'C:\Users\Mariana\Desktop\export_dataframe.csv', index = False)
```

Python

	A	B	C	D	E	F	G	H	I
1	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34								
2	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
3	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
4	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
5	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
6	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
7	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
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9	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
10	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
11	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
12	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
13	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
14	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
15	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
16	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
17	15,15,15,15,15,15,15,15,4,4,4,4,15,15,15,15,15,15,15,15,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
18	15,15,15,15,15,15,15,15,4,4,4,4,15,15,15,15,15,15,15,15,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
19	15,15,15,15,15,15,15,15,4,4,4,4,15,15,15,15,15,15,15,15,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
20	15,15,15,15,15,15,15,15,4,4,4,4,15,15,15,15,15,15,15,15,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
21	15,15,15,15,15,15,15,15,4,4,4,4,15,15,15,15,15,15,15,15,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
22	15,15,15,15,15,15,15,15,4,4,4,4,15,15,15,15,15,15,15,15,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0								
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24	13,13,13,13,13,13,13,13,13,13,13,13,13,13,13,13,13,13,13,13,4,4,4,4,4,4,0,0,0,0,0,0,0,0,0								
25	13,13,12,12,12,12,12,12,12,12,12,12,12,12,12,12,12,12,13,13,4,4,4,4,4,4,0,0,0,0,0,0,0,0,0								
26	13,13,12,12,12,12,12,12,12,12,12,12,12,12,12,12,12,12,13,13,4,4,4,4,4,4,0,0,0,0,0,0,0,0,0								
27	13,13,12,12,12,12,12,12,12,12,12,12,12,12,12,12,12,12,13,13,15,15,15,15,15,15,0,0,0,0,0,0,0,0,0								
28	13,13,12,12,12,12,12,12,12,12,12,12,12,12,12,12,12,12,13,13,15,15,15,15,15,15,0,0,0,0,0,0,0,0,0								
29	13,13,12,12,12,12,12,12,12,12,12,12,12,12,12,12,12,12,13,13,15,15,15,15,15,15,0,0,0,0,0,0,0,0,0								

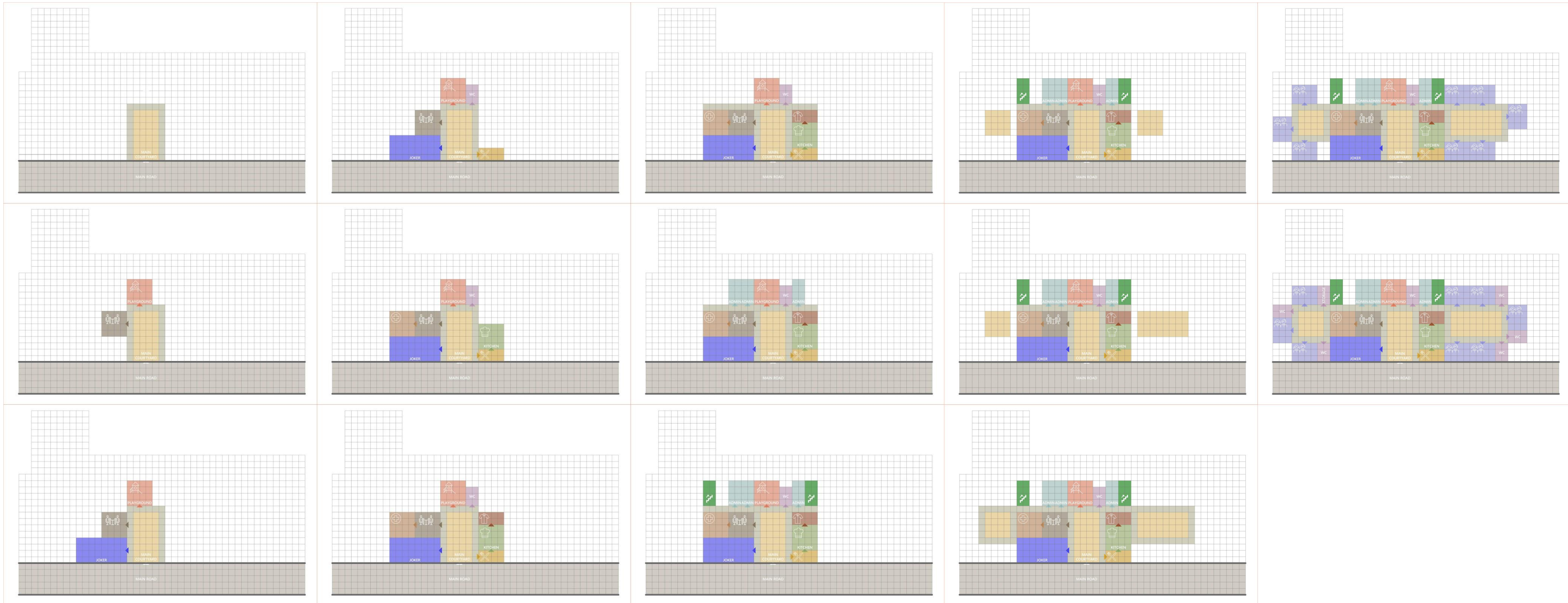
Export example EXCEL

Ground floor composition

The configuration starts with the position of the main courtyard at the middle of the site's grid. Around it a corridor of 2-meters is placed. Around the corridor the sitting area and the playground are positioned first and then the joker element, the public toilet and the cantine. Afterwards, the sequence of kitchen and changing rooms are placed next to the cantine and the first aid next to the sitting area. Then the two side corridors are placed, where the 3 rooms of the administration cluster and the staircases will be assigned. Next the first three courtyards are placed together with their surrounding corridors. Around the corridor's classrooms, toilets and storages are distributed and the configuration is finished.

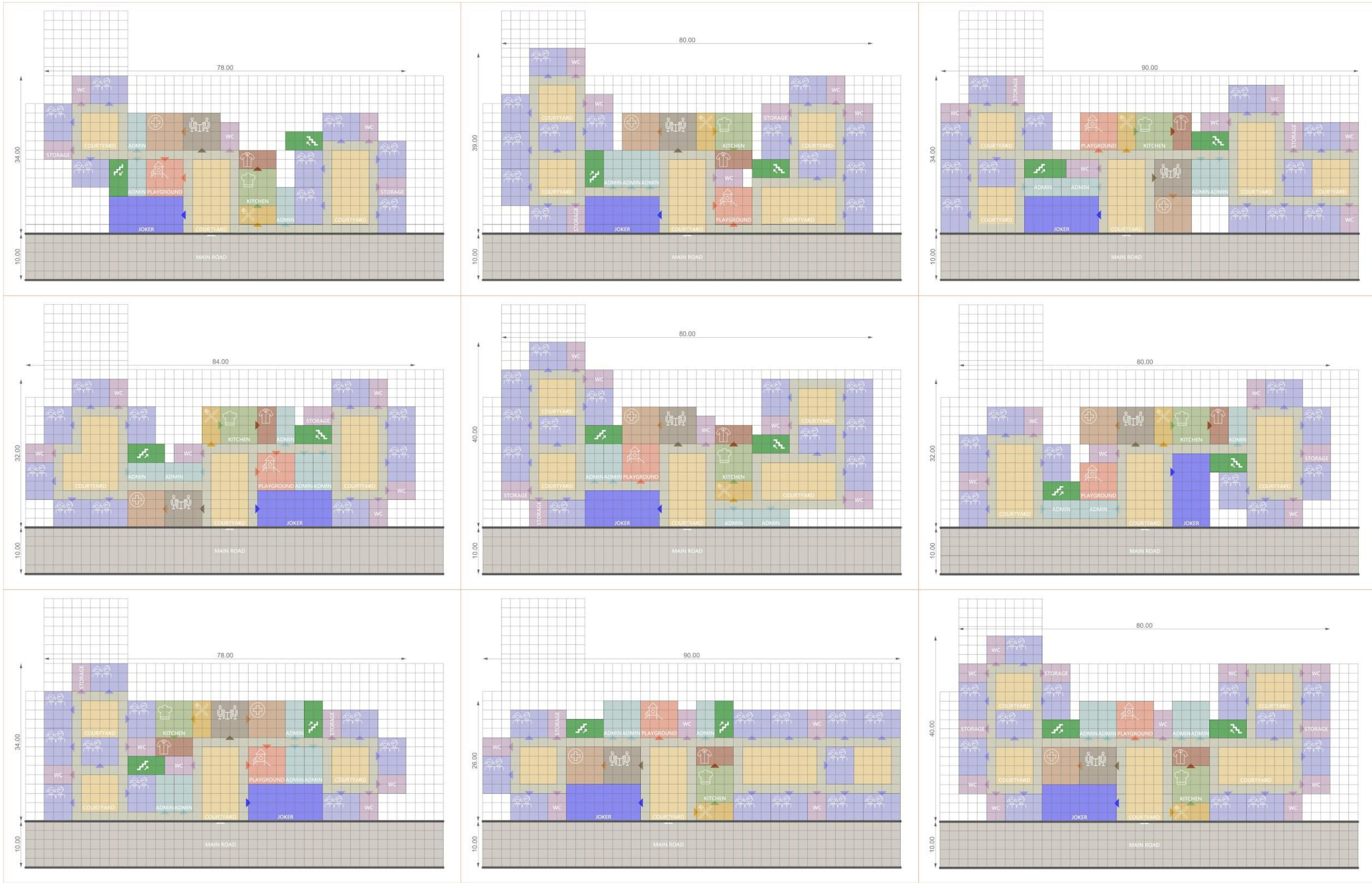
Ground floor composition - alternatives & evaluation

In the following two pages the different first floor configuration that were generated by python are presented as well as their evaluation process. The empty dead-end spaces in between the functions were considered an error, as well as the direct connection of the side corridors to the road. At the end the no error configuration with the maximum number of classrooms was selected.



Generation of one alternative configuration in steps

Ground floor composition - alternatives



Alternatives of first floor configuration PYTHON

Ground floor composition - evaluation

Identified errors for each alternative

Ground & First floor chosen composition

The chosen configuration contains 20 classrooms, 12 at the ground and 8 at the first floor and its general dimension are 80 * 40 meters.

Regarding the vertical growth of the educational center, it was considered important to reach the desired number of classrooms, presented at the end of the configuration stage. Additional rules were set for the expansion in the upper floors.

RULES

- Function without roofs: Courtyards and Playground

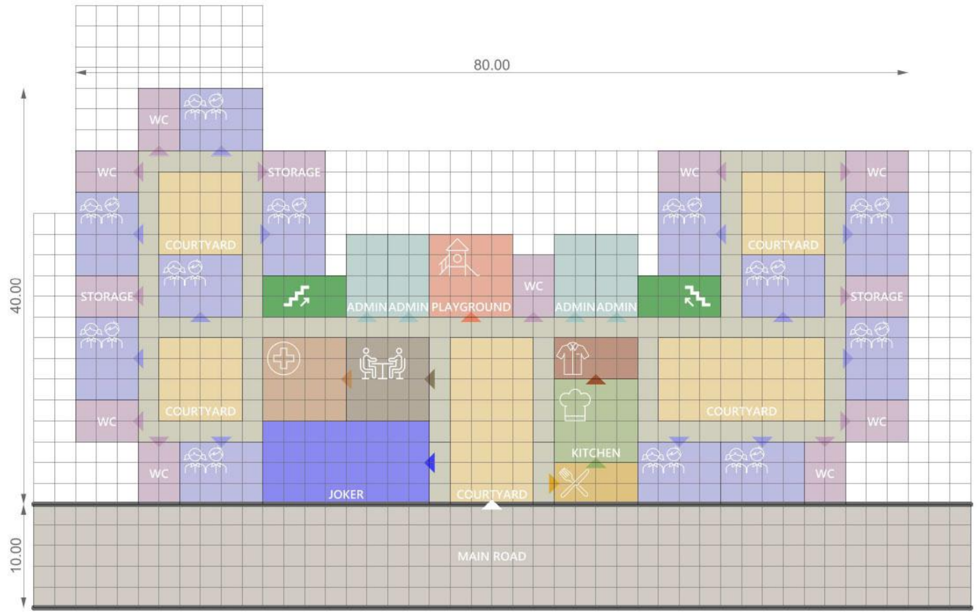
- Function positioned on the first floor: Classrooms, Toilets, Storage, Sitting area Teacher's room and Corridors

- Sitting area (48 m2): when a classroom is placed in between school courtyards on the ground floor, the same cells at the first floor become a sitting area.

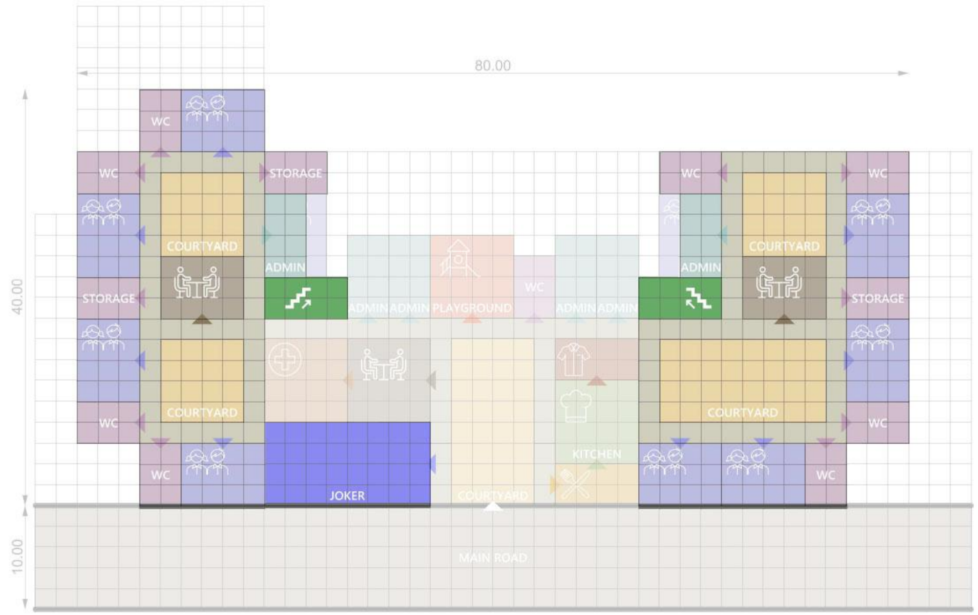
- Teacher's room (32 m2): for every group of classrooms on the first floor 1 teacher's room is added, connected with its largest dimension to the corridor, above a classroom. Teacher's room is preferred to be positioned next to the staircase unit.

- All function positioned to the ground floor should have the same height

- Height is assigned based on the importance of the space, therefore the Joker element should be higher than the rest of the functions

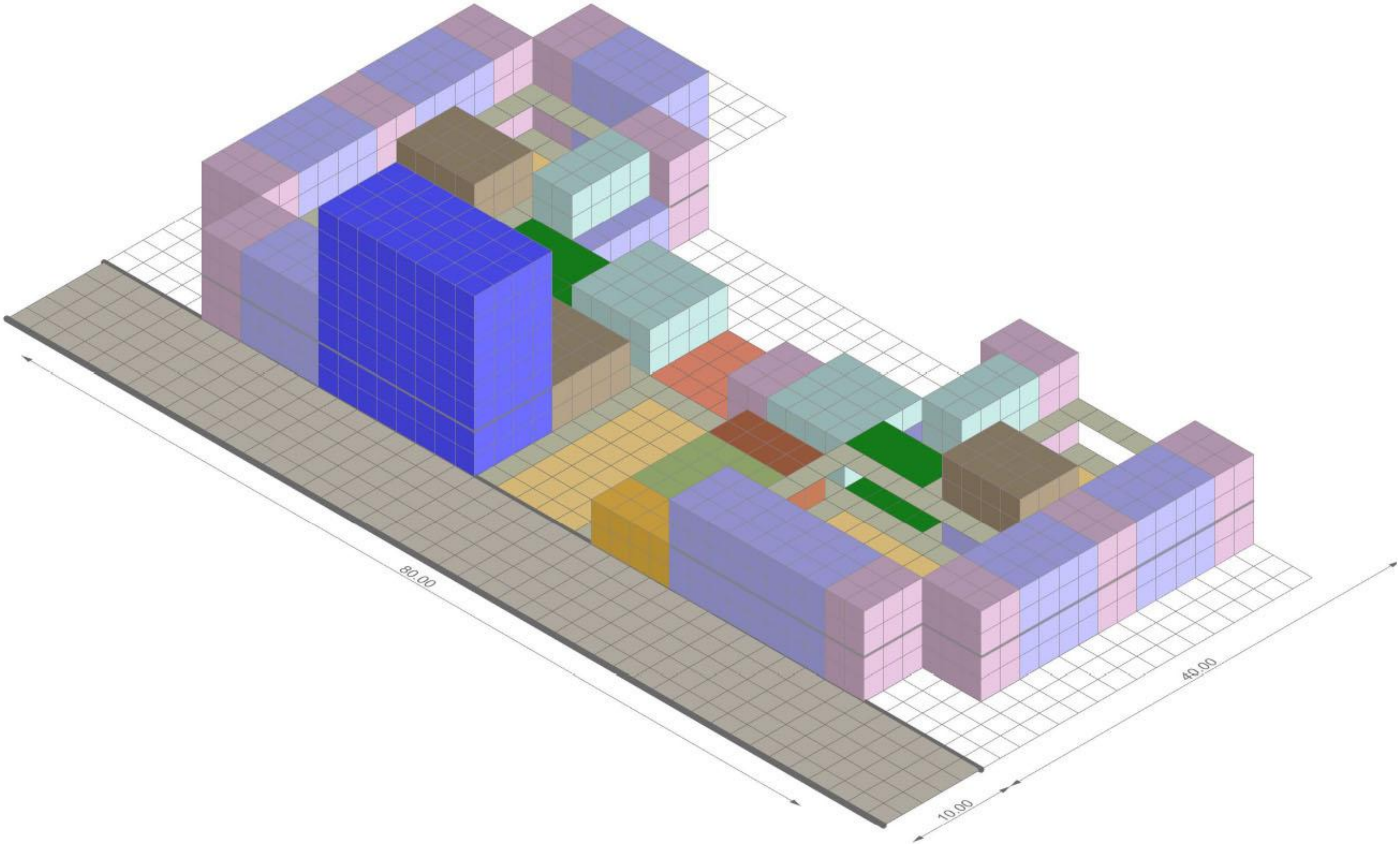


Ground floor - Final configuration



First floor - Final configuration

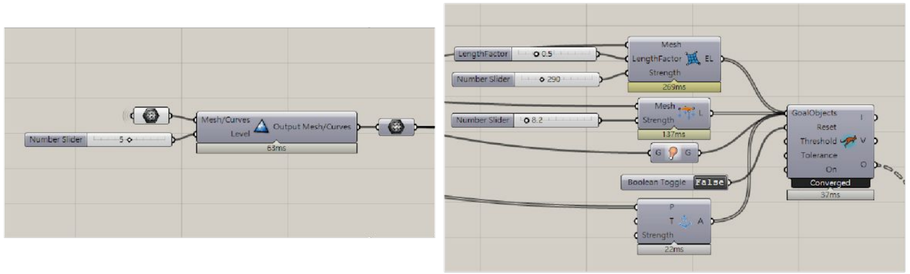
Isometric configuration diagram



Tessellation and from finding principle

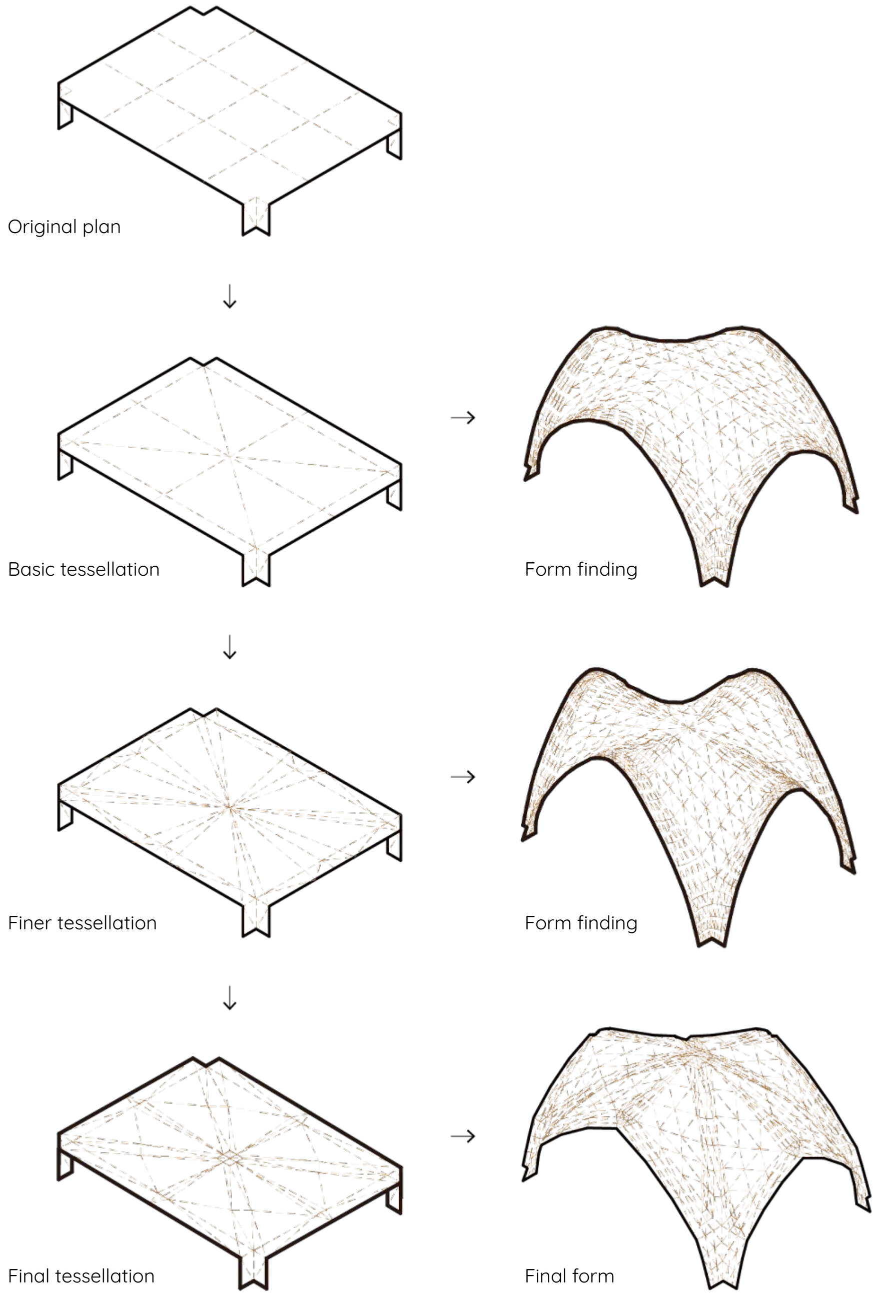
Tessellation is the first step to determining the form of spaces. With the area requirement from configuration, there are six types of domes/vaults that we need to define in this chapter.

By dividing the geometry of the room size of each function into simple triangles or quadrilaterals mesh, we have the basic tessellation mesh. We finalized in triangle mesh with our units as it is able to generate more pointing arch than quadrilateral ones. During the form finding process, after tessellating the surface, we used Kangaroo plugin in Grasshopper. By setting the "Length Factor", "Strength", and "Vertex Load", the shape of vaults can be adjusted and the shape is finalized by the best performance of on stress and displacement.



During the process, we noticed that due to the size of spaces have a long span, the vaults would be relevant high. Consequently, we decided to place vault on floor rather than on top of wall or column. So the ground level can be placed on the lowest height, 5 meters above the ground. To create a vault with vertical walls, the movement on the edge of the mesh is fixed into only 2 dimension.

On the next page, the result of form finding for roofs is displayed in 6 categories. It also shows the basic tessellations that we started in the beginning which did not give us the ideal performance. And all the shapes we selected pass the first round of stress analysis in Karamba with maximum of 5 MPa compression and 0.5 MPa tensile stress.



Form finding principle

Main part of form finding script in Grasshopper

Form finding result and programs

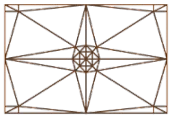
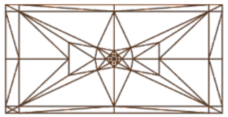
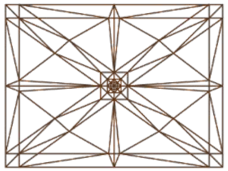
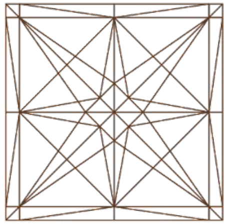
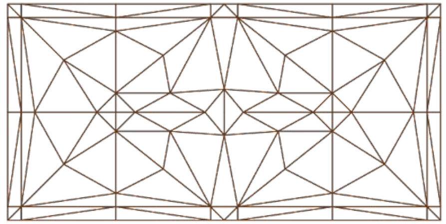
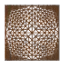
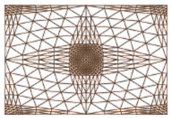
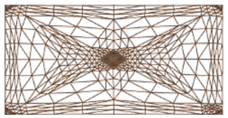
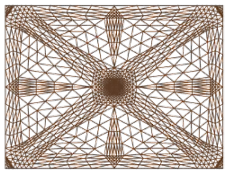
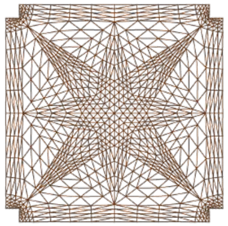
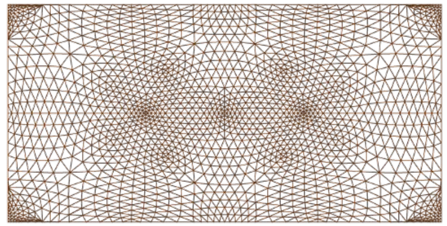
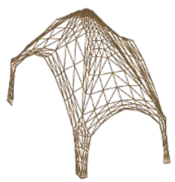
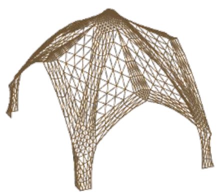
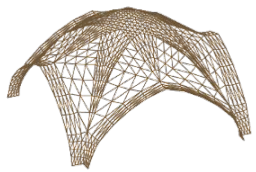
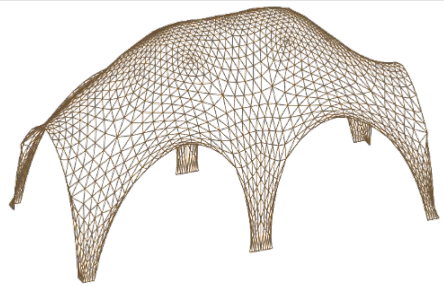
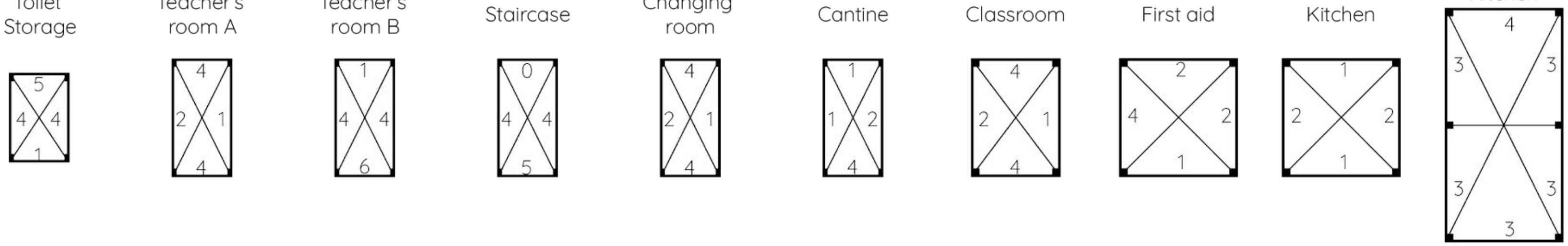
Volume W*D*H(m)	2*2*4m	4*6*5m	4*8*5m	6*8*6m	8*8*5m	8*16*8.5m
Funciton	Corridor	Toilet Storage	Administration room Teacher room Cantine Changing room Stairs	Classroom Sitting area	Kitchen First aid Sitting area Joker's classroom	Joker
Basic tessellation						
Final tessellation						
Form finding						

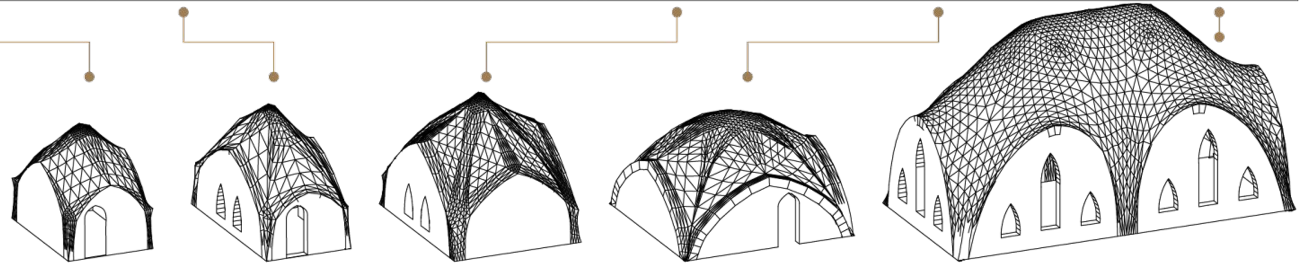
Table of final form for each category of space size

Wall typologies and functions



	Toilet Storage	Teacher's room A	Teacher's room B	Staircase	Changing room	Cantine	Classroom	First aid	Kitchen	Kitchen
0 = no wall	-	-	-	1	-	-	-	-	-	-
1 = wall with door	1	1	1	-	1	2	1	1	2	-
2 = wall with 2 windows	-	1	-	-	1	1	1	2	2	-
3 = wall with 3 windows	-	-	-	-	-	-	-	-	-	5
4 = solid wall	2	1	2	2	2	1	2	1	-	1
5 = perforated wall	1	-	-	1	-	-	-	-	-	-
6 = wall with 1 window	-	-	1	-	-	-	-	-	-	-

Table of wall typology and functions

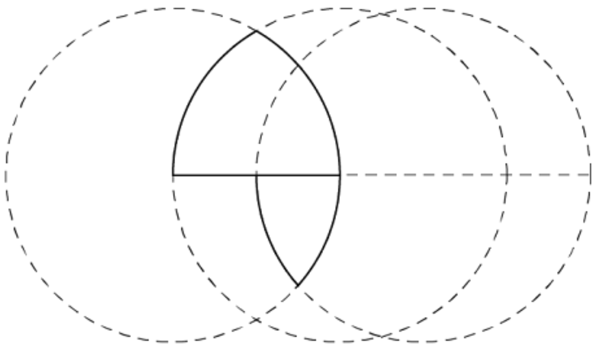


Examples of vaults with variant wall

In the Configuration and the Rule of Game section, the sequence of spaces and the principle of how connectivity between them has been identified abstractly. To bring them more objective, this chapter is focused on further defining the wall typology with vaults together.

In the Table of wall typology and functions, each square represents a different function, and the numbers in it show the typology of the interface of the space. We concluded with 6 types of interfaces and they are marked in the spaces from 0 to 6. Combine the interface types with functions and vaults mentioned forehead, the table of variant final domes is done. This table illustrates how many walls for each kind would need in the construction. It can greatly help to estimate the demand for bricks in the early design stage.

As a result, we have all the elements to compose the domes. The examples of the final form for roof domes are shown underneath the table. Besides these examples, there is still more variants of domes with different orientation of walls are there.



Geometry study for windows and doors

Final result of form and space

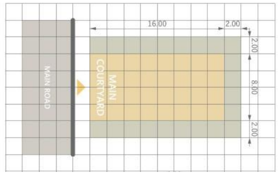
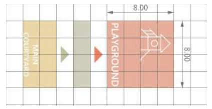
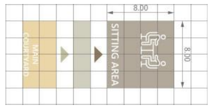
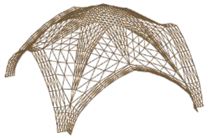
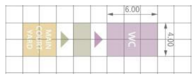
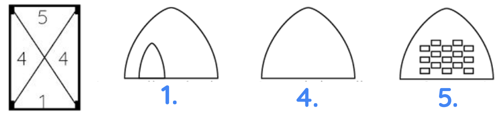
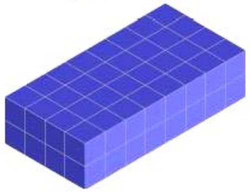
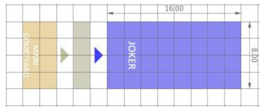
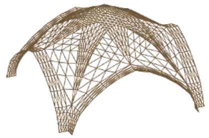
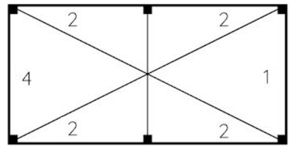
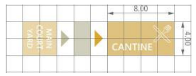
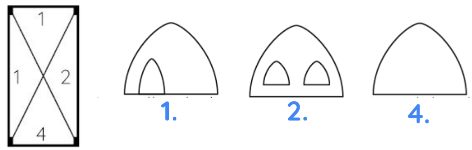
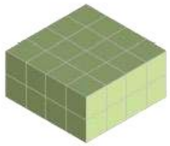
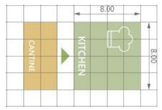
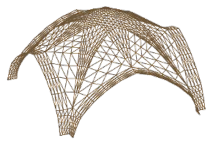
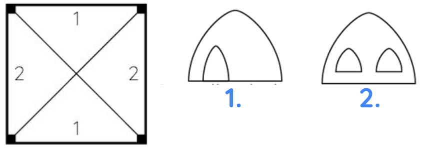
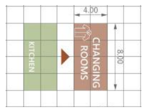
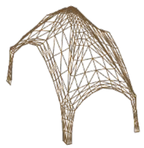
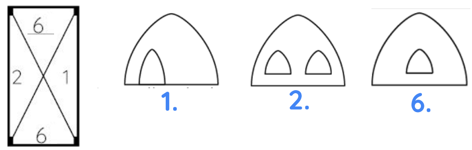
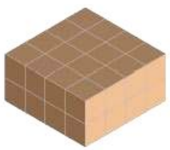
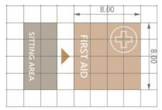
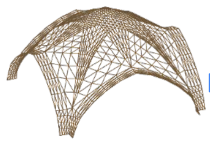
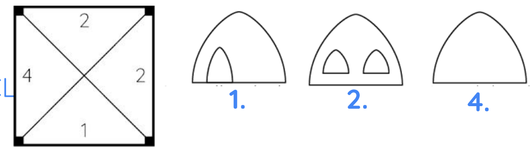
After the configuration, Python programming, and from finding, the components to compose the educational center is complete and we can have the whole view of the appearance of it. The educational center is composed of three main parts, the public space in the center and two educational sets on the side.

On the ground floor, students can enter the school from the main courtyard in the center of the school. The main courtyard with all the public spaces is the common area for all the people involved in the center. There is a canteen, kitchen, first aid, administration room, and playground.

The educational spaces are connected with corridors on the two sides of the main courtyard. This layout enables to have separate space for different approaches, and age ranges of education. Going to higher floors, these two areas also have their own staircases. But for the serving function of the school, people still have a chance to meet each other in the common space.

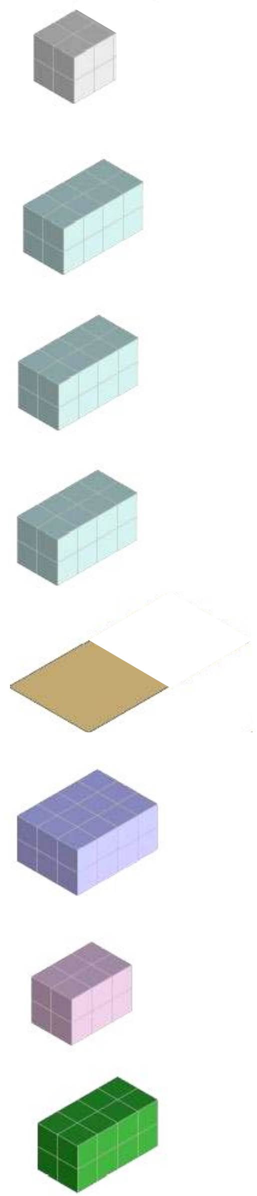
The layout of the school has some positive influence on the climate aspect as the corridor and classrooms surrounding courtyards create shade in the daytime. And the width of classroom is 6 meters which are possible to have natural ventilation from window to courtyard. With corridor links all the functions, it is more comfortable for people in the dry and hot weather.

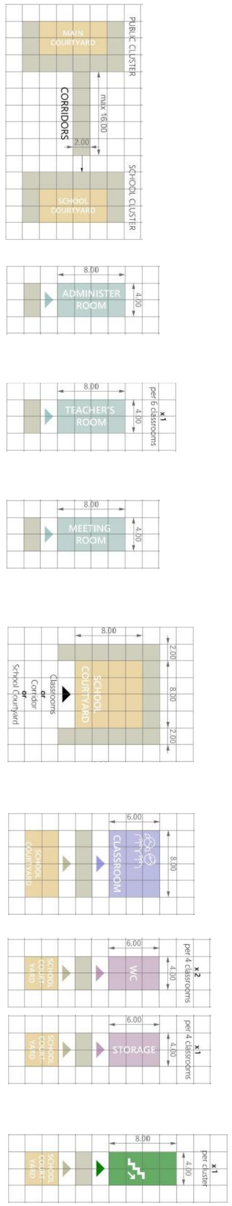
Function Lookup table - Ground floor

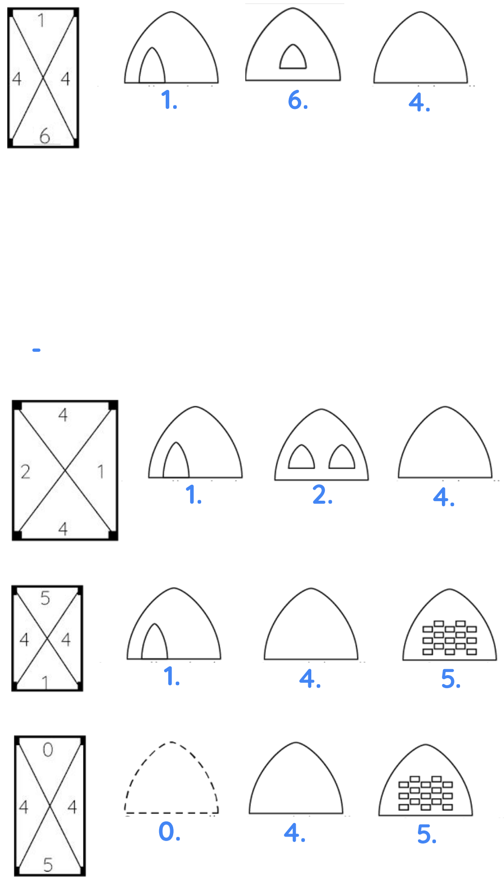
		Isometric	General Dimensions width/ length/ height	Connectivity	Dome form	Wall Typology
	Main Courtyard		16 * 8 * 0 meters		-	-
	Playground		8 * 8 * 0 meters		-	-
	Sitting Area		8 * 8 * 5 meters			-
	Public Toilet		6 * 4 * 5 meters			
	Joker		16 * 8 * 5 meters		 X 2	
SERVICES CLUSTER	Cantine		8 * 4 * 5 meters			
	Kitchen		8 * 8 * 5 meters			
	Changing Rooms		8 * 4 * 5 meters			
	First Aid		8 * 8 * 5 meters		 PUBLIC CL	

Function Lookup table - Ground floor

	Function	Isometric	General Dimensions width/ length/ height	Connectivity	Dome form	Wall Typology
	Corridor		2 * 2 * 5 meters			-
MANAGEMENT CLUSTER	Administration Room		8 * 4 * 5 meters			
MANAGEMENT CLUSTER	Teacher's Room		8 * 4 * 5 meters			
MANAGEMENT CLUSTER	Meeting Room		8 * 4 * 5 meters			
SCHOOL CLUSTER	School Courtyard		8 * 8 * 0 meters		-	-
SCHOOL CLUSTER	Classroom		8 * 6 * 5 meters			
SCHOOL CLUSTER	Toilets or Storage		6 * 4 * 5 meters			
SCHOOL CLUSTER	Staircase		8 * 4 * 5 meters			

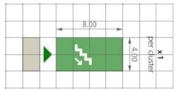
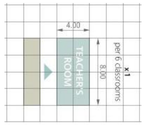
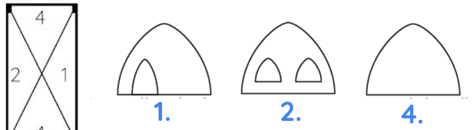
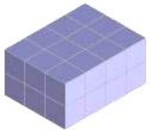
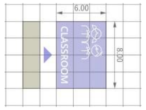
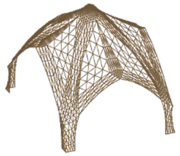
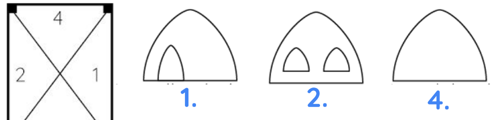
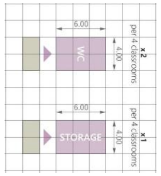
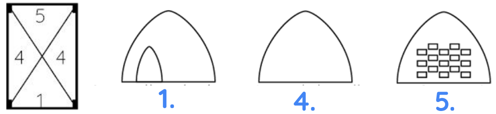
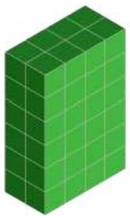
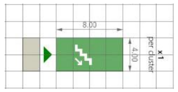
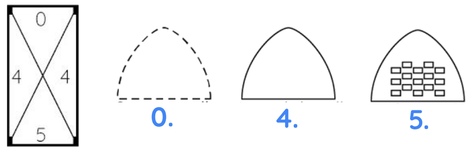
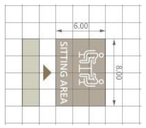
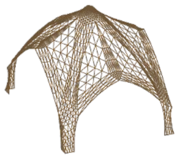
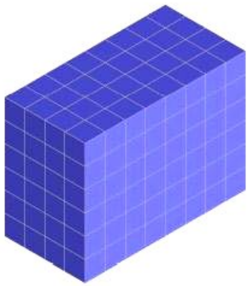
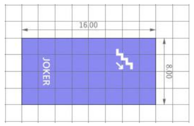
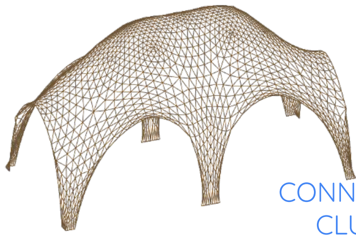
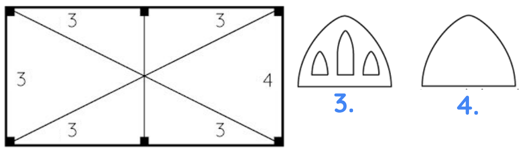




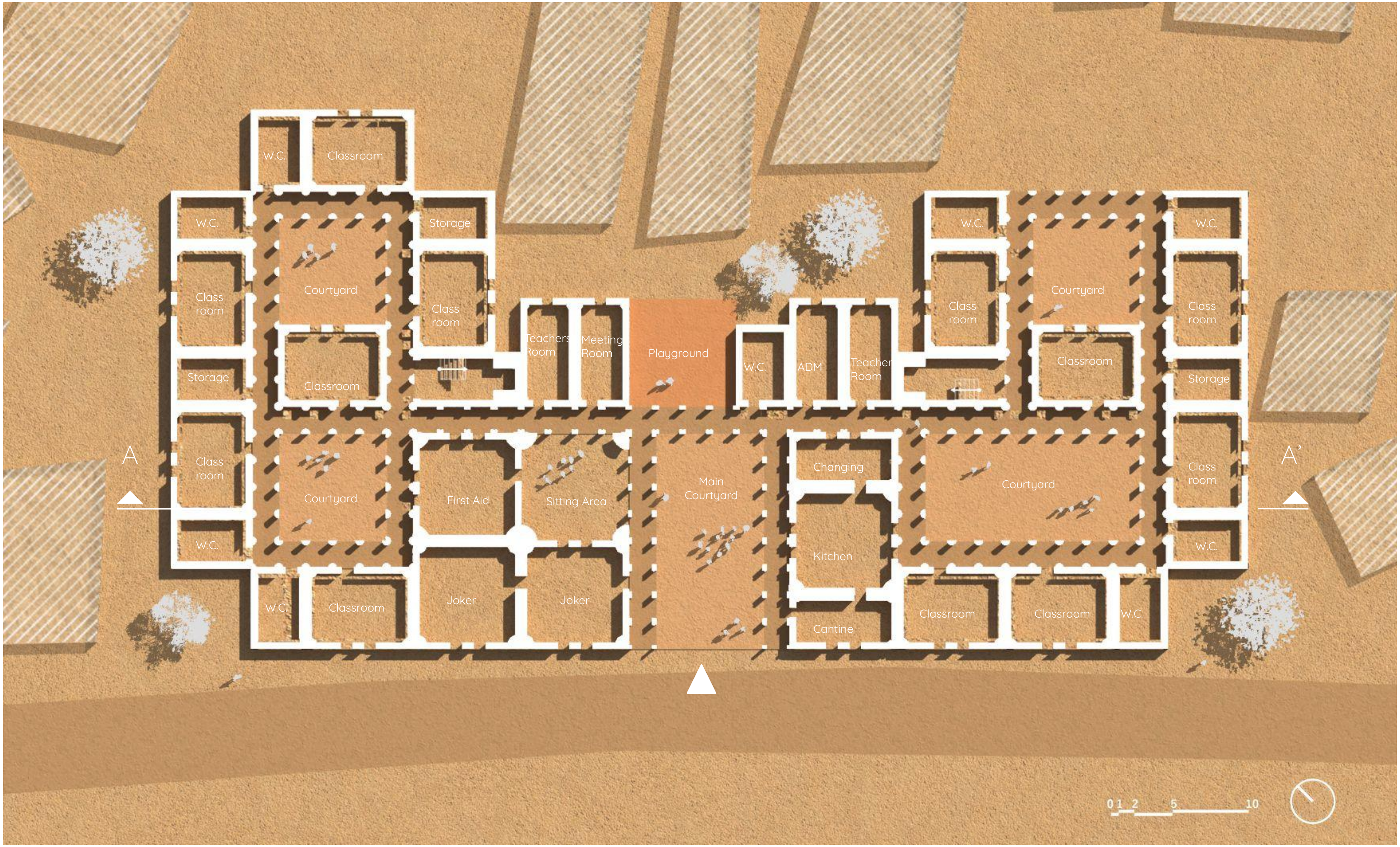


CONNECTIONS CLUSTER

Function Lookup table - First floor

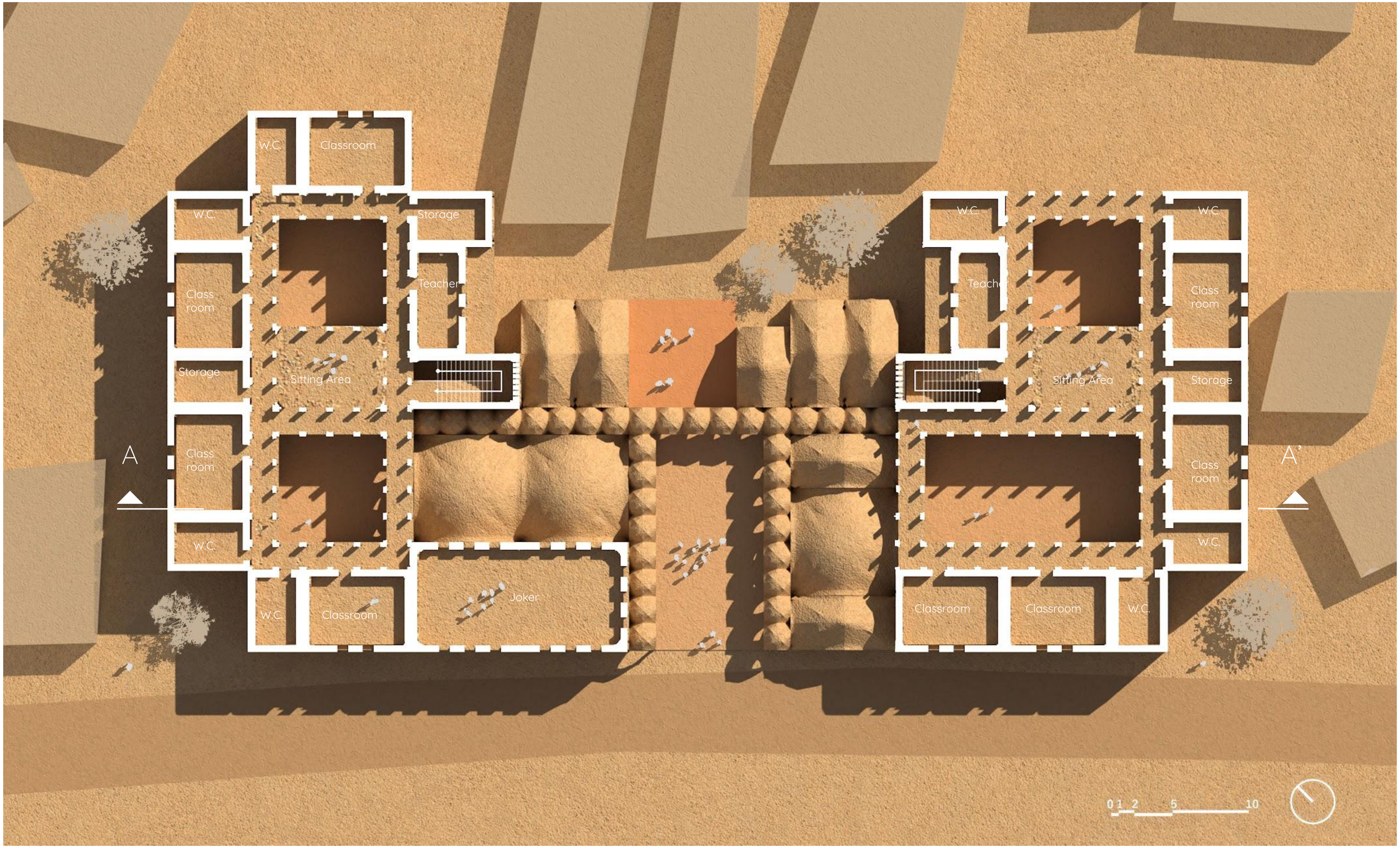
		Isometric	General Dimensions width/ length/ height	Connectivity	Dome form	Wall Typology
	Corridor		2 * 2 * 5 meters			-
MANAGEMENT CLUSTER	Teacher's Room		8 * 4 * 5 meters			
SCHOOL CLUSTER	Classroom		8 * 6 * 5 meters			
SCHOOL CLUSTER	Toilets or Storage		6 * 4 * 5 meters			
SCHOOL CLUSTER	Staircase		8 * 4 * 13 meters			
PUBLIC CLUSTER	Sitting Area		8 * 6 * 5 meters			-
PUBLIC CLUSTER	Joker		16 * 8 * 8,5 meters		 CONNECTIONS CLUSTER	

Final drawings



Ground floor plan

Final drawings



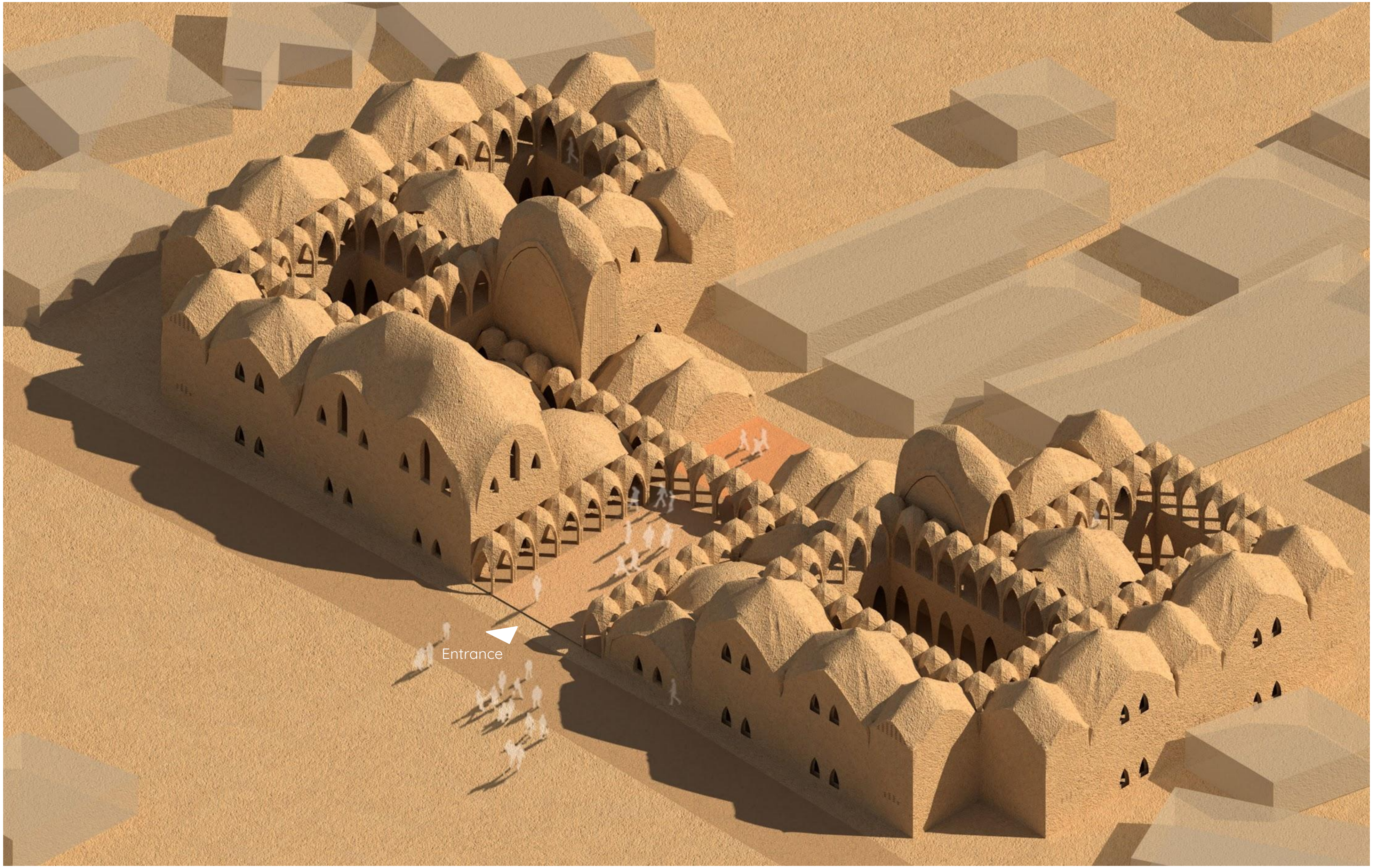
First floor plan

Final drawings

Front elevation 4m 8m 16m 12m 8m 8m 8m 4m

Section AA' 6m 2m 8m 2m 6m 8m 2m 8m 2m 8m 2m 16m 2m 6m

Final drawings



Axonometric Render

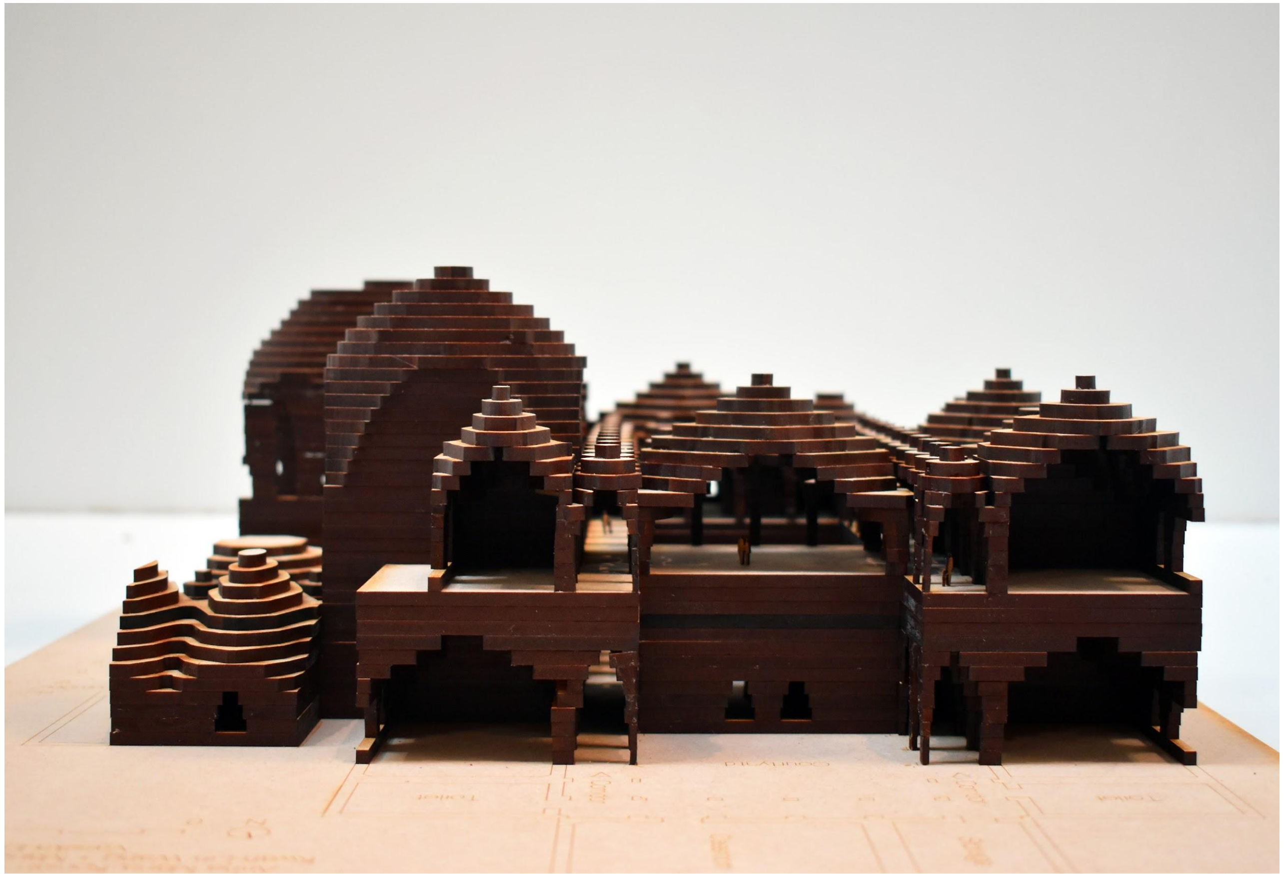
Final drawings

Final drawings

Physical model

Scale 1:100

Physical model
Scale 1:100



03_Structuring

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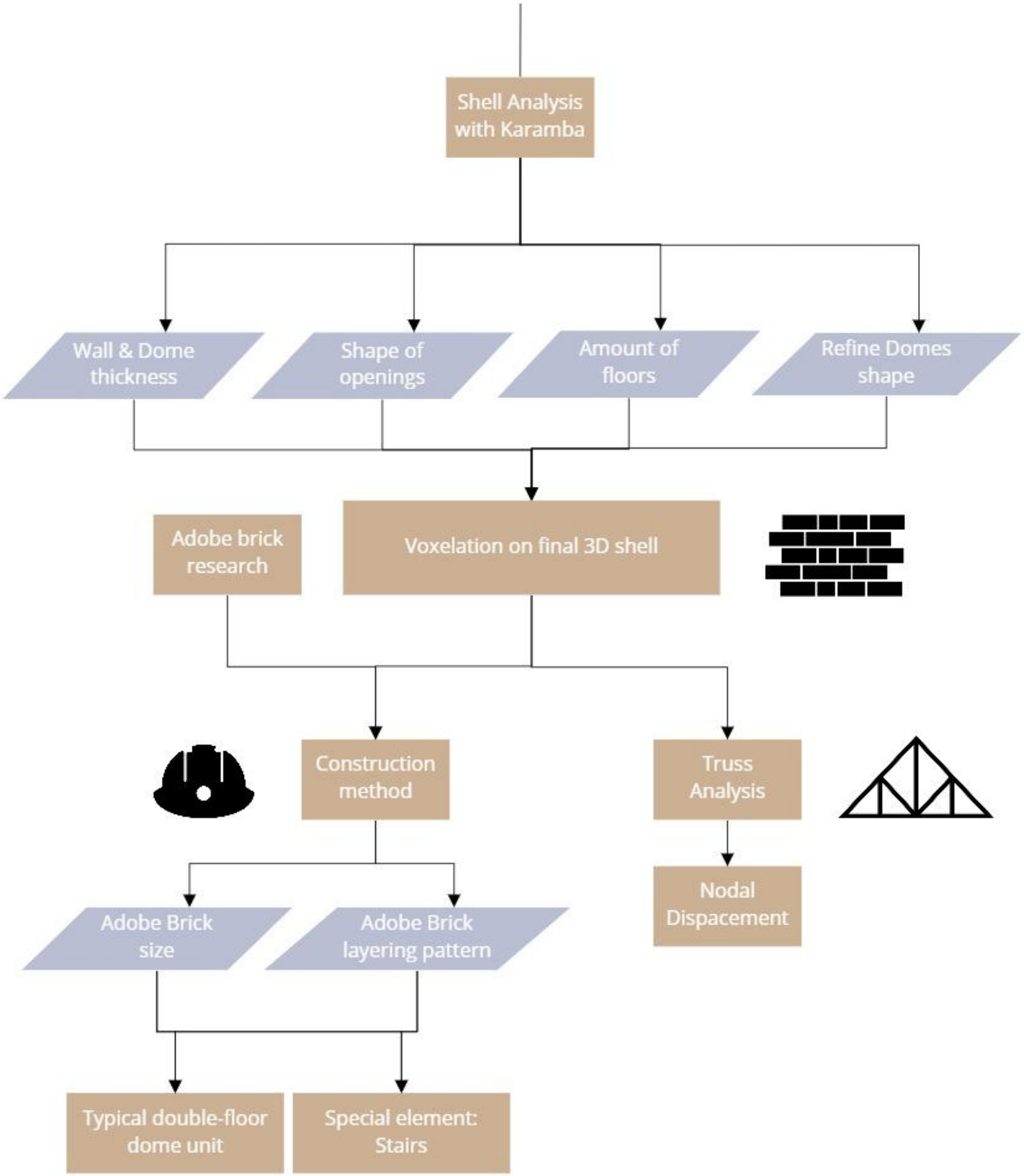
Flowchart

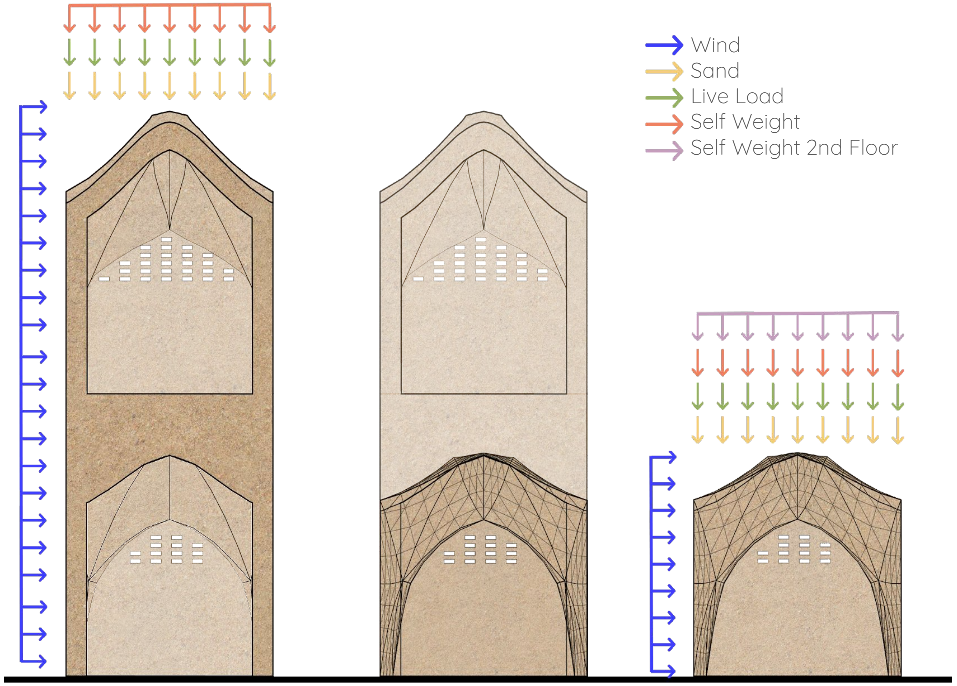

Shell Analysis with Karamba
Wall & Dome thickness
Shape of openings
Amount of floors
Refine Domes shape
Adobe brick research
Voxelation on final 3D shell
Construction method
Truss Analysis
Nodal Dispacement
Adobe Brick size
Adobe Brick layering pattern
Typical double-floor dome unit
Special element: Stairs

Methodology

The structure analyses were executed after the seven types of domes were defined in the configuring stage. The impact of features like wall and dome thickness; the number of floors; and shape openings could be better visualized during the analyses. Consequently, the structure could be improved by changing those variables.

The shells from the ground floor were highlighted and made the main focus during the analysis, since those had the worst scenario, receiving all the loads. A simulation was made for each dome, looking for the deformation and the principal stresses. By simplifying the structure to one mesh, the thickness, columns, gravity, self-weight of the upper floor and earthy filling were applied manually in the numerical calculation.

For the numerical calculation, was used grasshopper and Karamba 3D. The safety factor used in general was 1.5. However, as advised, the safety factor wasn't considered for the deformation. For better performance, columns were added at the edges of each dome.



Methodology

Structural Analysis Process

Geometry Design
One of the project goals was to achieve design flexibility, allowing different layout compositions for the education center and perhaps adding a couple of floors on top. Hence an independent structure was proposed, designed to be structurally sufficient and stable for each space on its own and possible upper floors. Due to the independent structure and the different types and heights of domes, it was decided to have independent walls, meaning that between spaces they don't share the same wall.

Structural Analysis Process

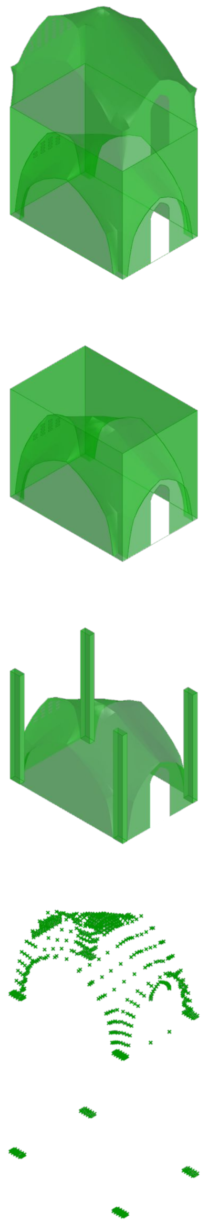
Karamba Setting

To achieve a better stiffness of the structure, the domes and walls were considered as one mesh in Karamba 3D. The thickness of those elements is the same, making the entire system function effectively. In the beginning, the assigned thickness was 20cm, but the results were structurally insufficient, presenting high displacement values and principal stresses. Later the cross-section was increased to 40 cm, resulting in value within the allowed limits. The allowable values for displacement were between 0.5% - 1.0% of the dome spam. For the maximum compression and tensile stresses allowed, those values were respectively 5 MPa and 0.25 MPa.

After assigning the mesh of the structure to a component from Karamba 3D called “mesh to shell”, the points were extracted. By selecting only the ones with elevation almost equal to zero, all the bottom points of the mesh could be related to the support. The support condition allowed rotation in all directions, and the translation was blocked to all directions, replicating the reaction of pin support. The support in all the meshes was represented by points at the boundaries, where the walls were placed, and at the edges, where the columns would be allocated.

The columns were at each corner of the dome. The columns' cross-section wasn't standardized it dimension depended on the dome type. The height of the column would depend on the number of floors. However, as will be presented later, the height used was 5m, since structurally wasn't feasible to grow the building to more than two stores (ground floor and first floor).

W.C. 6 x 8 m	Allowable	Peak Thickness 20cm	Peak Thickness 40cm
Compressive Stress	5 MPa	2.07 MPa	0.8 MPa
Tensile Stress	0.5 MPa	2.07 MPa	0.5 MPa
Displacement (<0.5 %- 1%)	3 - 6 cm	4.41 cm	1.82 cm



Meshes considered in the karamba analysis

Structural Analysis Process

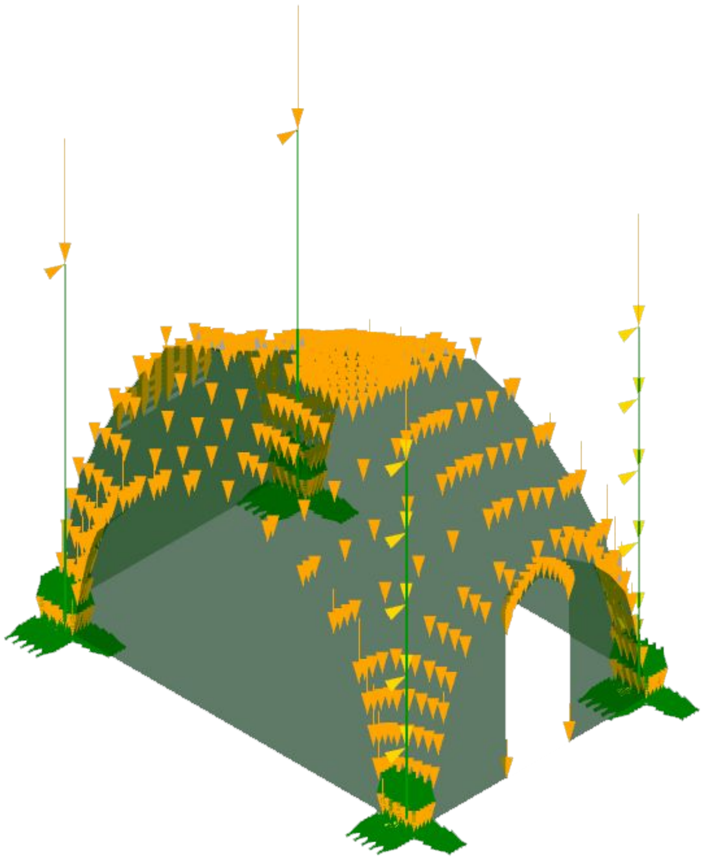
Load Cases

The loads were added separately to each mesh. According to the Karamba 3D component, two load types were used, a constant mesh load and a point load. The first represents a load that is acting at the entire mesh. The second one was used only for gravity. Another division was between vertical and horizontal loads acting on the domes. The horizontal loads are the wind loads. While the vertical loads were the gravity, live load, sand load, filling load and the self-weight of the upper floor.

The earth filling load was necessary to find the volume between the mesh of the ground floor and the slab of the top floor. This volume was multiplied by the density of the earthy bricks. And after it was divided by the floor area of the layout in which the dome was. So far the achieved result is in kg/m2 to transform it into kN/m2 the previous values were multiplied by 0.01. Finally, there is one last multiplication by 1.5 to secure the safety factor at the structure.

The load of the Self-weight of the upper floor depends on if the upper floor is an intermediate floor or if it is the last floor. In the first condition, being intermediate, we could use the same method as the earthy filling load, since the shape and volume would be the same. The second condition, being the last floor a roof, the volume would be different, but the method of calculating it would be the same. We find the volume of the mesh by considering the roof dome, walls, and thickness of 40cm. After finding this volume, which will be less than the earthy filling, we use the same steps previously described for the earthy filling.

For the sand load case, an extreme scenario of a 0.05 m sand stack on top of the roof is considered, which was multiplied by the sand density (kN/m3) and the safety factor of 1.5. In the case of live load and wind load the values were predetermined values, the first value was 4 kN/m2 (Malakatas, 2008) and the second was 0.2 kN/m2 (Habali, 1987). So in the karamba analyses, those values only needed to be multiplied by the safety factor of 1.5.

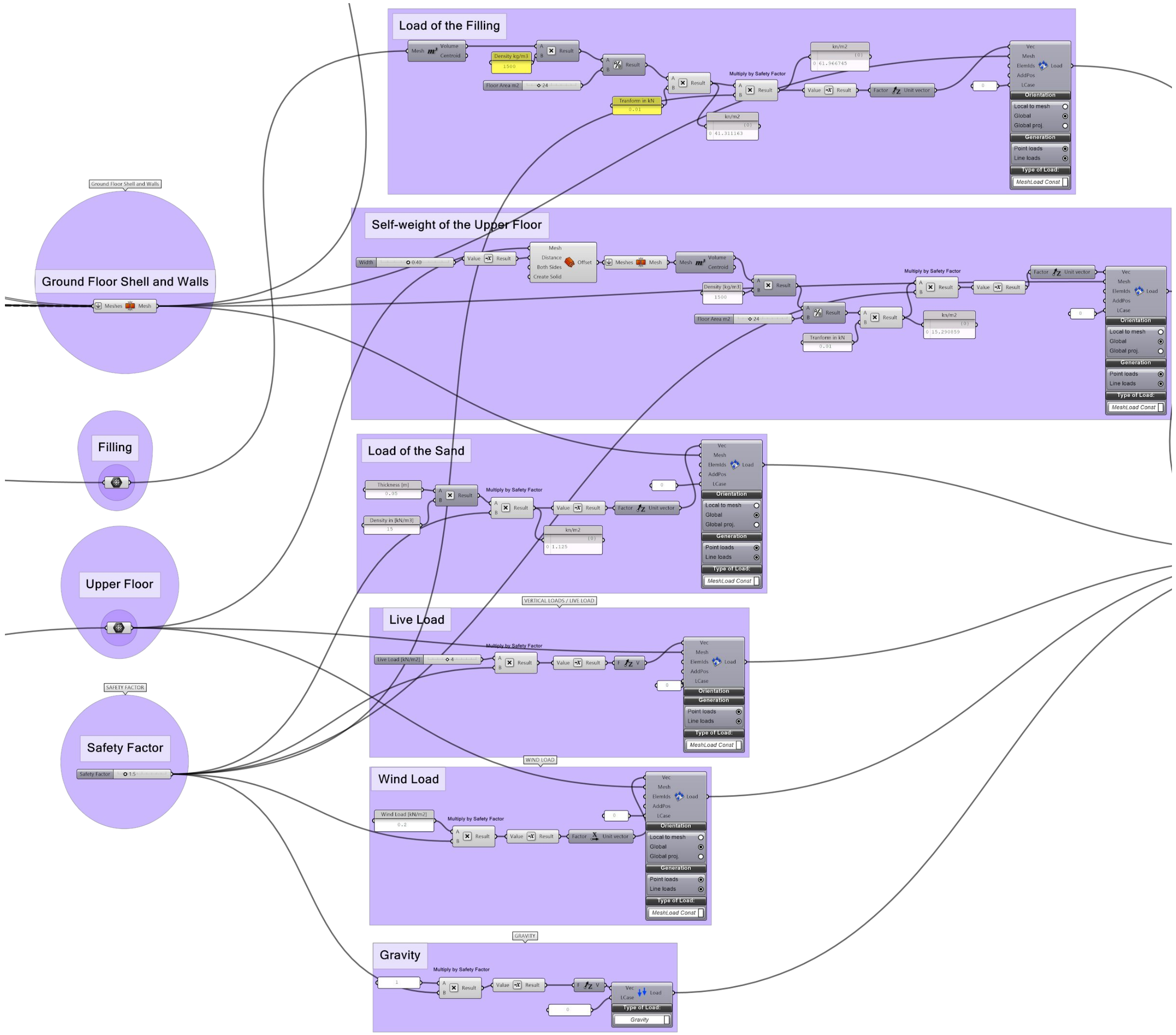


Mesh Load

Structural Analysis Process

Load

Cases



Grasshopper Script of the Karamba Analysis

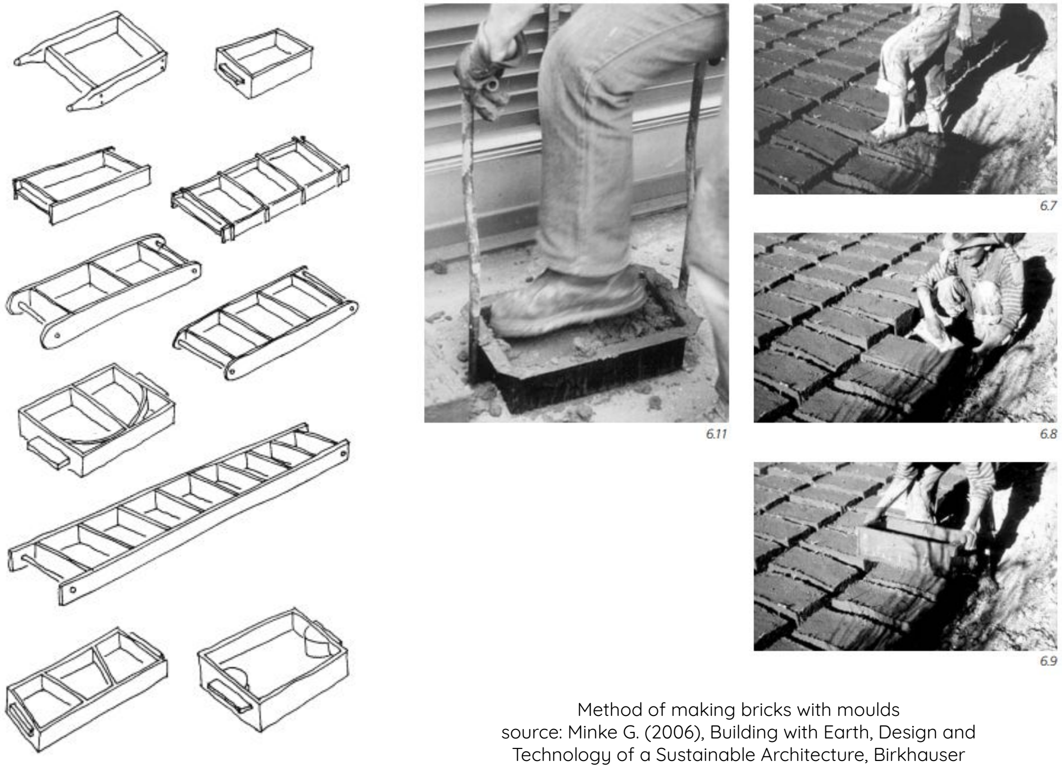
Structural Analysis Process

Material Properties

The material properties and composition used in this project were based on the results of the Bustan group from Earthy 2.0. Therefore the density of the brick material was 1500 kg/m3, while the Yield Strength was 1.3 MPa and the Young's Modulus was 150 MPa. The composition of the brick was made with available material at the Zaatari Camp. The formula for the adobe brick was made of 30% clay, 30% fine sand, 40% coarse sand and 10% water of the total weight of the dry ingredients. To improve the tensile strength of the brick, straw was added in the percentage of 10% of the total mixture (Bustan, 2019).

	Value
Density	1500 kg/m3
Young's modulus	150 MPa
Tensile stress	Max 0.5 MPa
Compressive stress	Max 5 MPa
Yield strength	1.3 MPa

Material properties
source: Bustan, Earthy 2.0, Strength of adobe bricks



Method of making bricks with moulds
source: Minke G. (2006), Building with Earth, Design and Technology of a Sustainable Architecture, Birkhauser

	Proportion
Clay	30%
Fine Sand	30%
Coarse sand	40%
Water	10%
Straw	Additional 10% on the total paste

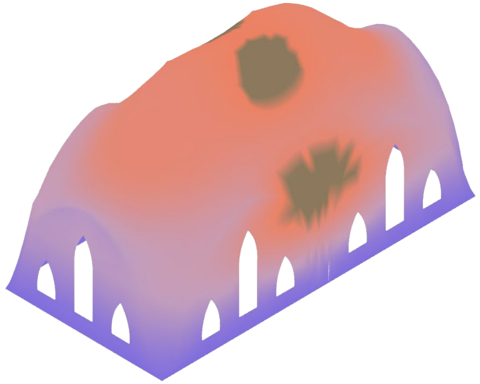
Material composition
source: Bustan, Earthy 2.0, Strength of adobe bricks

Structural Analysis Cases

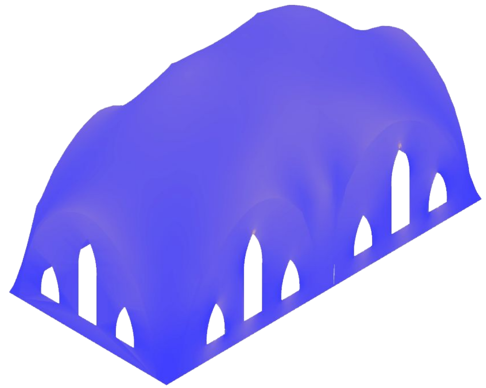
Case 1

- Volume: 8 x 16 x 8.5m
- Function: Joker
- Top Floor: No
- Number of Top Floors: Zero
- Loads: Gravity, Sand Load and Wind Load

Case 1	Allowable	Maximum
Compressive Stress	5 MPa	0.95 MPa
Tensile Stress	0.5 MPa	0.16 MPa
Displacement (<0.5 %- 1%)	8 - 16 cm	2.32 cm



Principal Stresses

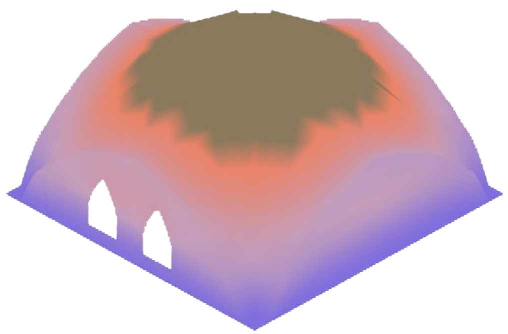


Displacement

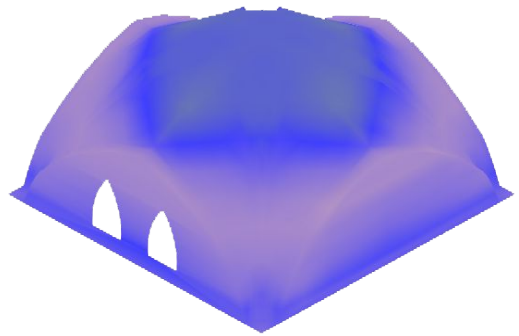
Case 2

- Volume: 8 x 8 x 5 m
- Function: Kitchen, First Aid, Sitting Area
- Top Floor: No
- Number of Top Floors: Zero
- Loads: Gravity, Sand Load and Wind Load

Case 2	Allowable	Maximum
Compressive Stress	5 MPa	0.31 MPa
Tensile Stress	0.5 MPa	0.17 MPa
Displacement (<0.5 %- 1%)	4 - 8 cm	0.5 cm



Principal Stresses



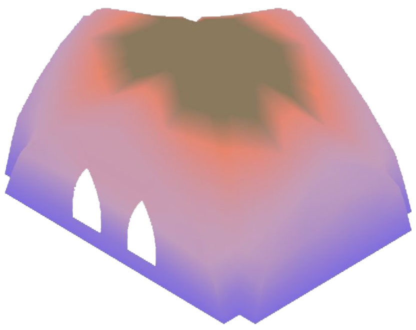
Displacement

Structural Analysis Cases

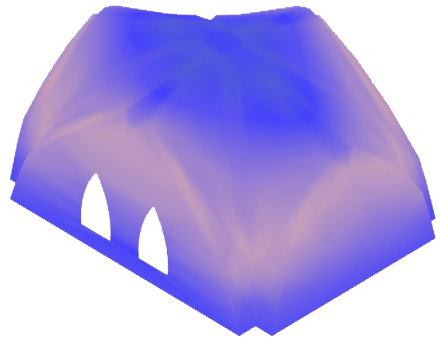
Case 3

- Volume: 6 x 8 x 6 m
- Function:Classroom, Sitting Area
- Top Floor: Yes
- Number of Top Floors: 1
- Loads: Gravity, Sand Load, Wind Load, Live Load, Self-Weight of the Upper Floor and Earthy Filling.

Case 3	Allowable	Maximum
Compressive Stress	5 MPa	1.41 MPa
Tensile Stress	0.5 MPa	0.5 MPa
Displacement (<0.5 %- 1%)	4 - 8 cm	3.09 cm



Principal Stresses

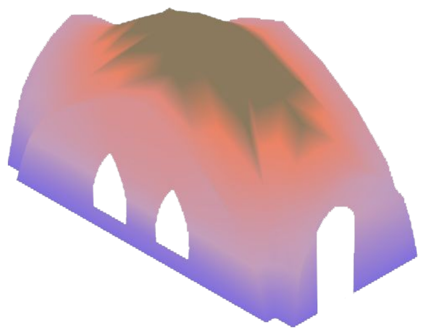


Displacement

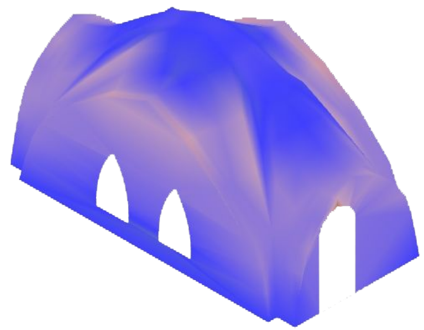
Case 4

- Volume: 4 x 8 x 5 m
- Function: Administration, Cantine, Stairs, Changing Room, Teacher Room and Meeting Room
- Top Floor: Yes
- Number of Top Floors: 1
- Loads: Gravity, Sand Load, Wind Load, Live Load, Self-Weight of the Upper Floor and Earthy Filling.

Case 4	Allowable	Maximum
Compressive Stress	5 MPa	1.39 MPa
Tensile Stress	0.5 MPa	0.49 MPa
Displacement (<0.5 %- 1%)	4 - 8 cm	2.23 cm



Principal Stresses



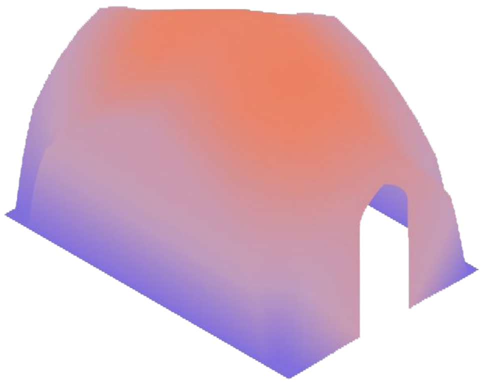
Displacement

Structural Analysis Cases

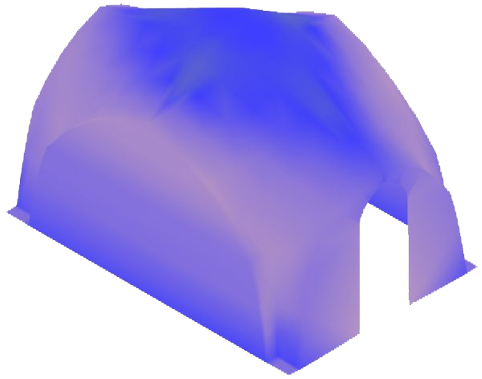
Case 5

- Volume: 4 x 6 x 5 m
- Function: Toilet, Storage
- Top Floor: Yes
- Number of Top Floors: 1
- Loads: Gravity, Sand Load, Wind Load, Live Load, Self-Weight of the Upper Floor and Earthy Filling.

Case 5	Allowable	Maximum
Compressive Stress	5 MPa	0.8 MPa
Tensile Stress	0.5 MPa	0.5 MPa
Displacement (<0.5 %- 1%)	3 - 6 cm	1.82 cm



Principal Stresses



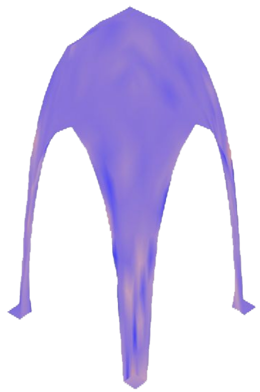
Displacement

Case 6

- Volume: 2 x 2 x 4m
- Function: Toilet, Storage
- Top Floor: Yes
- Number of Top Floors: 1
- Loads: Gravity, Sand Load, Wind Load, Live Load, Self-Weight of the Upper Floor and Earthy Filling.

Case 6	Allowable	Maximum
Compressive Stress	5 MPa	7.63 e-14 MPa
Tensile Stress	0.5 MPa	7.51 e-14 MPa
Displacement (<0.5 %- 1%)	1 - 2 cm	2.82 e-15 cm

Principal Stresses



Displacement

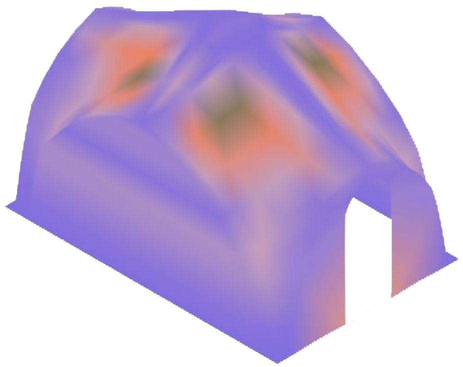
Structural Analysis Cases

Case 7

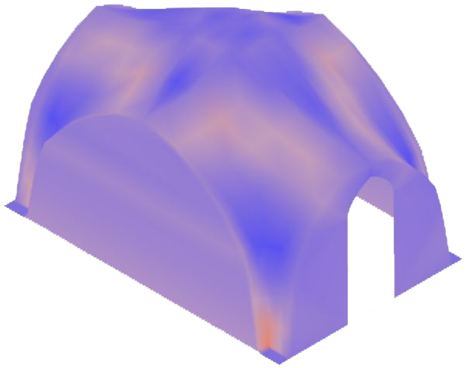
- Volume: 4 x 6 x 5 m
- Function: Toilet
- Top Floor: Yes
- Number of Top Floors: 5
- Loads: Gravity, Sand Load, Wind Load, Live Load, Self-Weight of the Upper Floor and Earthy Filling.

The displacement and principal stresses of this analysis were higher than the allowable. Those values showed that the present structure can not receive more than one top floor. Therefore, this limitation was respected in the Forming stage, and the maximum floor that the project presents are two, the ground floor and one top floor.

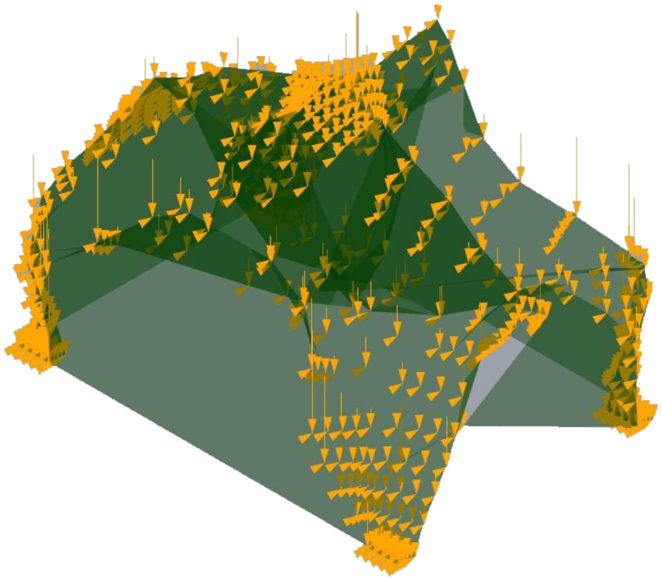
Case 7	Allowable	Maximum
Compressive Stress	5 MPa	1290 MPa
Tensile Stress	0.5 MPa	748 MPa
Displacement (<0.5 %- 1%)	3 - 6 cm	1.1 e +4 cm



Principal Stresses



Displacement

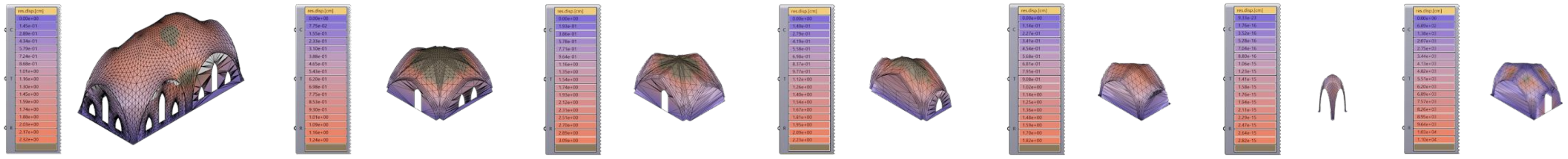


Deformation

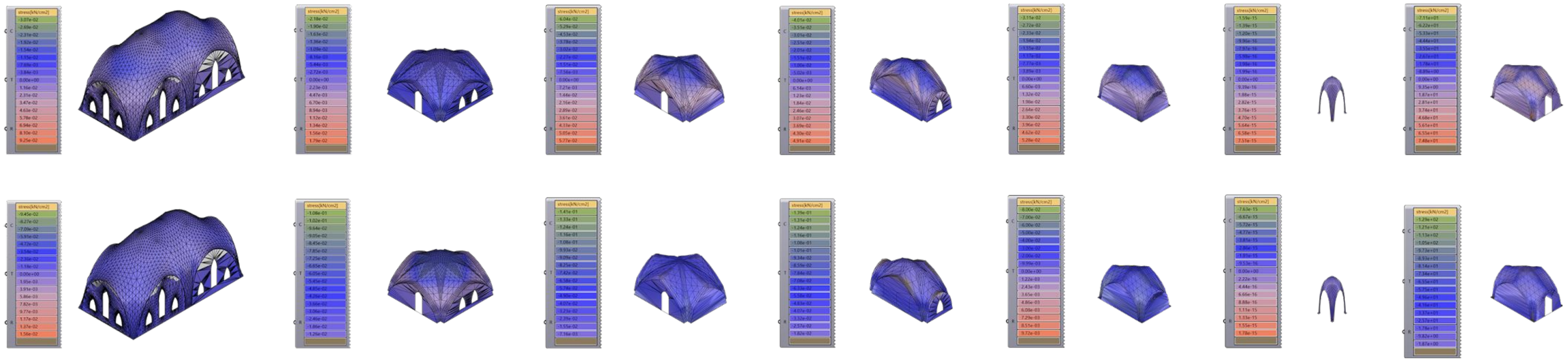
Structural Analysis Cases

Case	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Dimension	8 x 16 x 8.5 m	8 x 8 x 5 m	6 x 8 x 6 m	4 x 8 x 5 m	4 x 6 x 5 m	2 x 2 x 4 m	4 x 6 x 5 m

Displacement



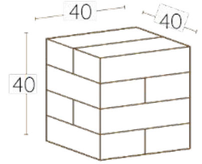
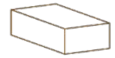
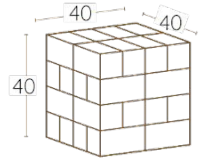
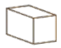
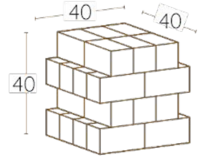
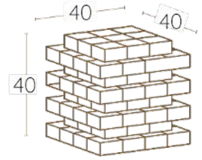
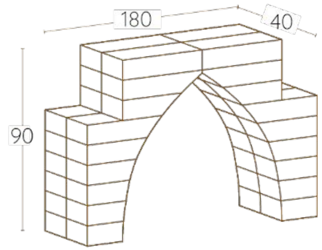
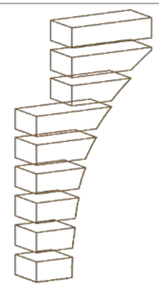
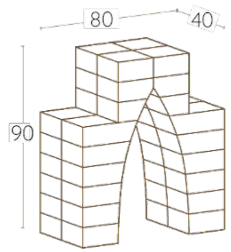
Principle Stress



Brick types and layering methods

In order to build up the educational places, we need to use different types of bricks and variants of methods to construct. To determine the brick size, we have three criteria as the main consideration. 1. The weight of brick should be under 15 kg, for workers can easily work with it. 2. Shape of the brick should be a simple geometry. Meanwhile, it can be produced in low-tech methods. 3. The size of a brick, in the structural analysis, the wall thickness is defined as 40cm have the best structure performance and less material demanding. The brick size should be the divisor number of wall thickness.

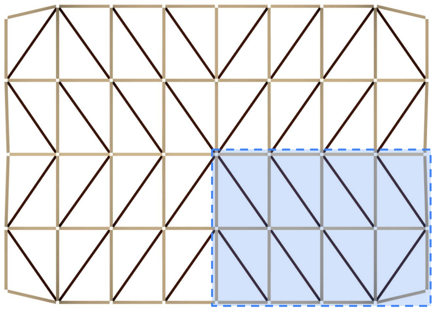
The brick type is finalized into 3 main types with 2 types of opening brick sets. Since the school units are combined with vault and vertical parts, we can use different types of bricks for different parts. The first type of brick, as the biggest type, is used on the vertical walls. Using bigger size bricks can reduce construction time, and materials, furthermore, would make it more stable. The other two types of bricks are mostly applied on the curvature part of the ceiling or roof.

	Vertical sector	Brick type 01	w*d*h (cm) 40*20*10 Weight 12 kg
	Vertical sector and Slanted sector	Brick type 02	w*d*h (cm) 20*10*10 Weight 6 kg
			
	Slanted sector	Brick type 03	w*d*h (cm) 10*10*5 Weight 0.75 kg
	Door sector		w*d*h (cm) 45*20*10 ~20*20*10 Weight 13 ~ 6 kg
	Window sector		w*d*h (cm) 30*20*20 ~20*20*20 Weight 9 ~ 6 kg

Brick sizes and layering methods

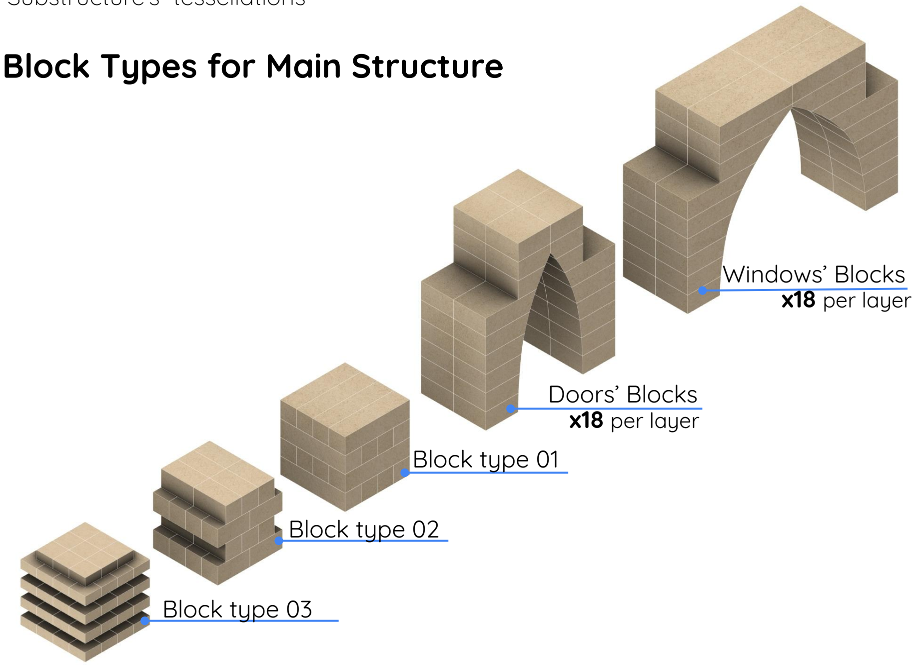
Construction Sequence Methodology

The following approach focuses on the radicality of the construction sequence. Therefore a mainly reusable wooden substructure is set as a guide and as a safety mechanism for the workers. It is quite evident that the tessellations that are used for the vault forming will now act as the main base on which triangular wooden panels will be placed in the next phase. It is noteworthy that most of the substructure's pieces are repeated 4 times in all cases since all vaults are symmetrical both in x and y axis. What is more, all the pieces are totally reusable and after the realization of a building unit, they can be disassembled and moved to the next location. Apart from the following blocks and units that are applied in the structure and the substructure of each building, scaffolds and lifts are necessary in order to secure and speed up the whole procedure.

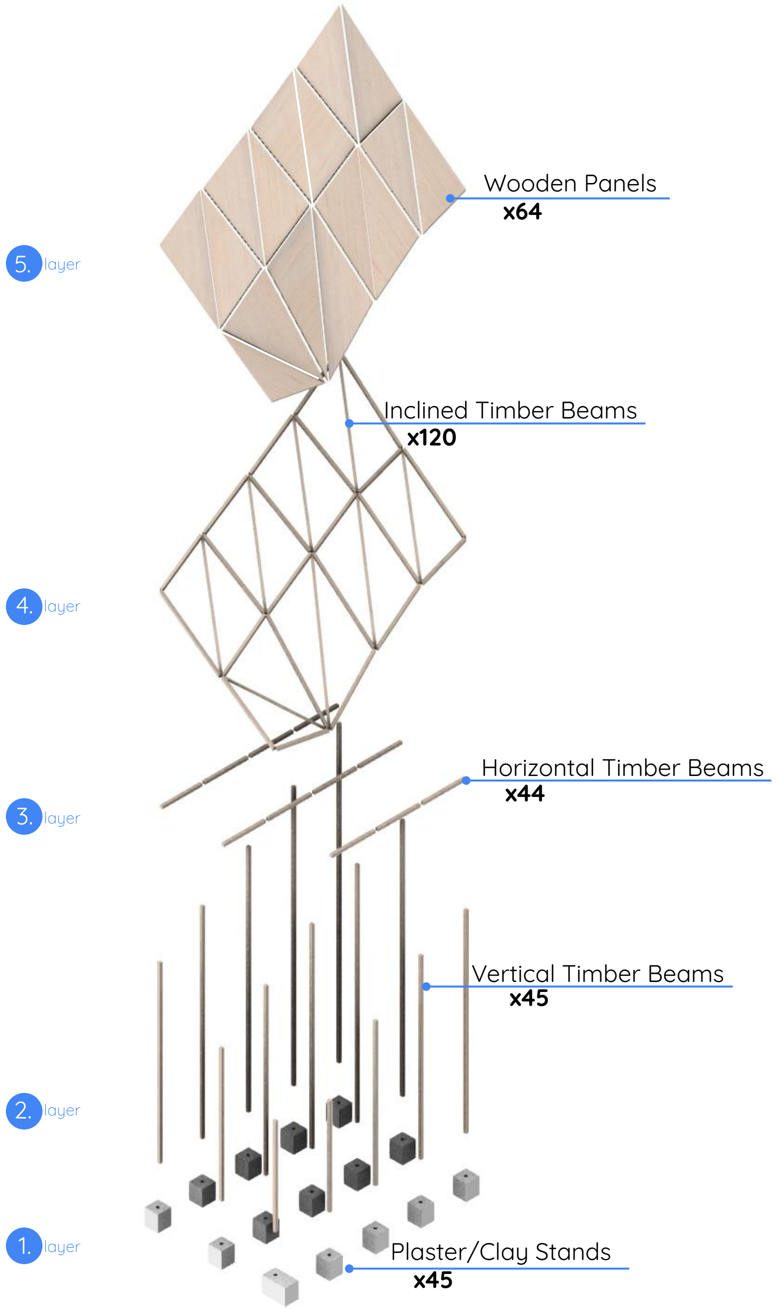


Substructure's tessellations

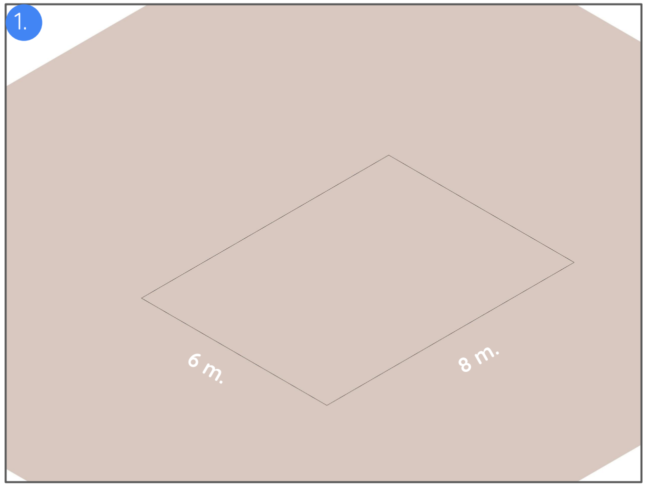
Block Types for Main Structure



Exploded Substructure (¼)

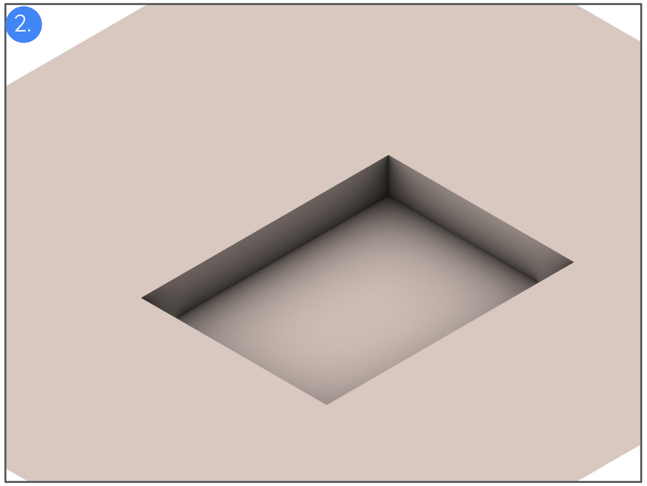


Construction Sequence



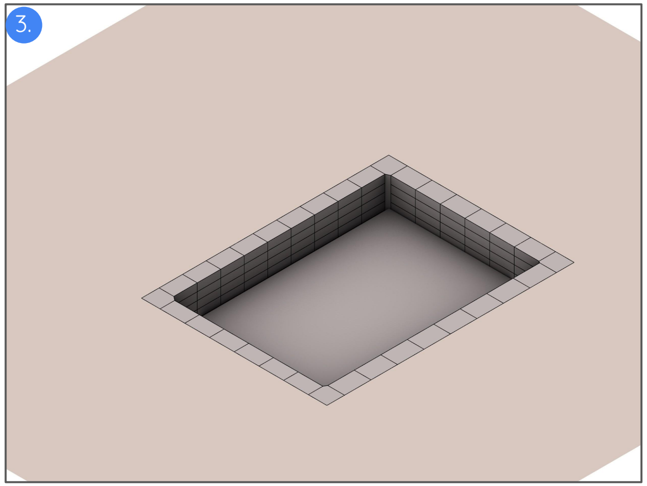
1. Layout

The layout of the building unit should be marked on the floor. In this simplified example the sitting room will be used as a module which is 6 by 8 meters.



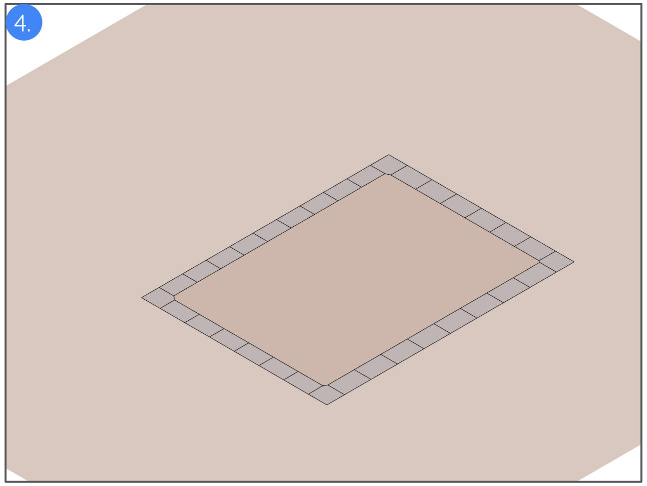
2. Excavation

The site then needs to be excavated.



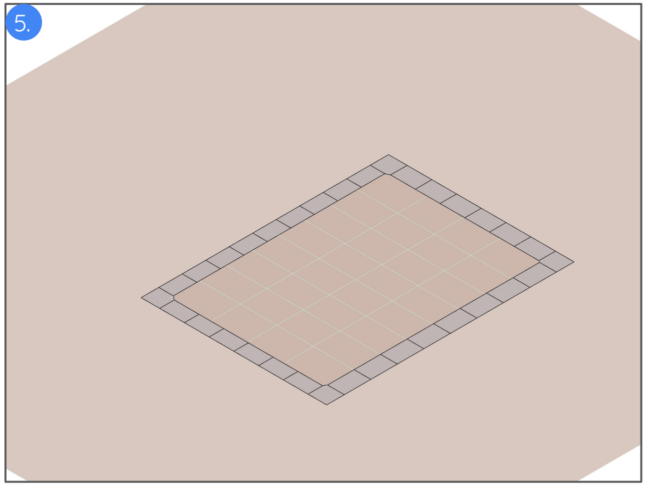
3. Foundation

The foundation of the building is laid with stones.



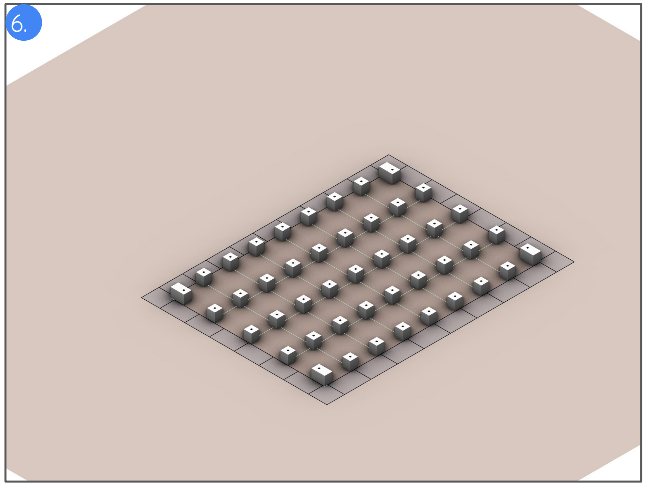
4. Floor

After the foundation has been set the excavated soil is compacted and rammed inside the layout.



5. Grid

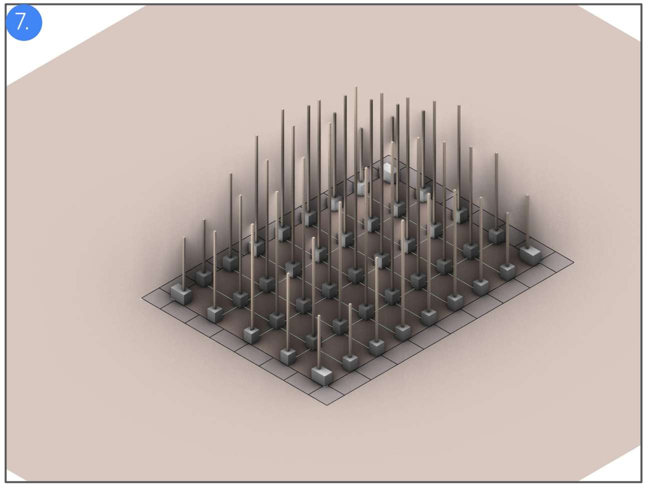
Each side of the floor is divided by 1 meter and by connecting the points of the divisions that are opposite a grid is created. The more divisions results in higher shape resolution.



6. Stands

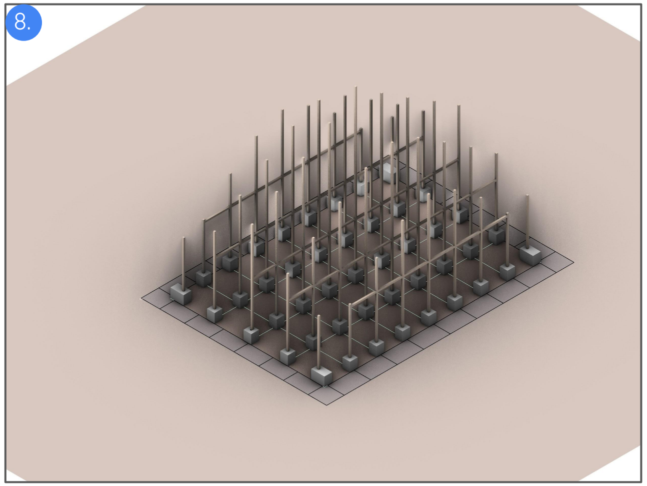
On all the sides' points and on the intersections clay/gypsum stands are placed. For the corners a different stand module is used in order to achieve the correct inclination.

Construction Sequence



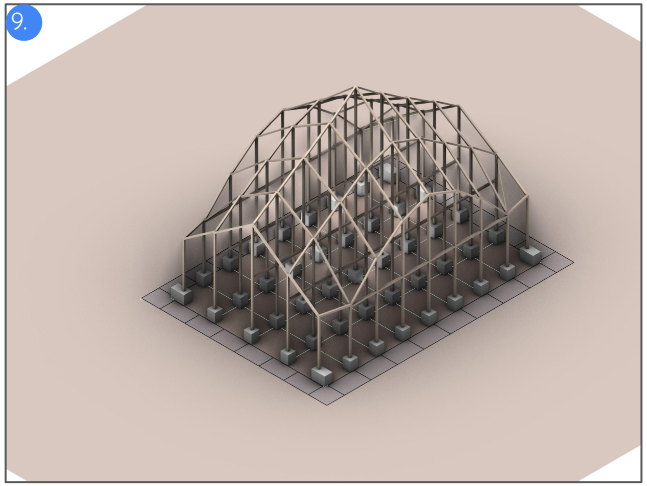
8. Vertical Pillars

In each socket a wooden pillar is placed. These are repeated 4 times because of the symmetry.



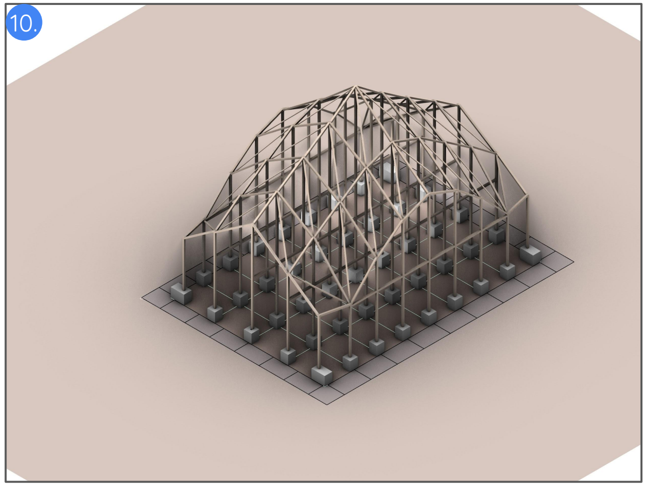
8. Horizontal Beams

Extra horizontal beams are placed in order to offer support. All these have exactly the same length.



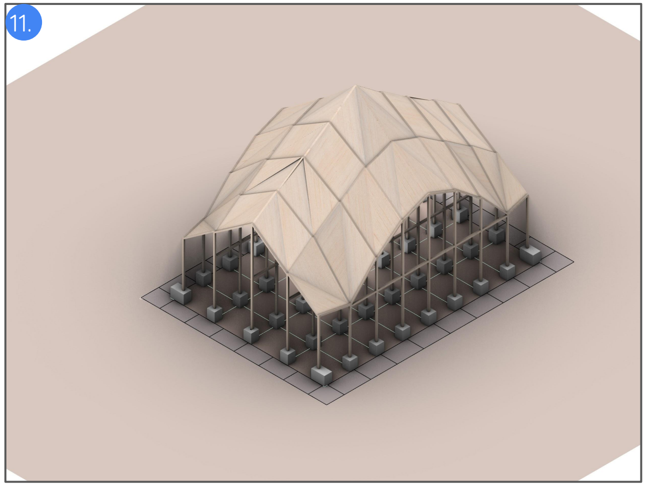
9. Inclined Beams

Inclined wooden beams connect the vertical ones. Once more the elements are repeated 4 times because of the symmetry.



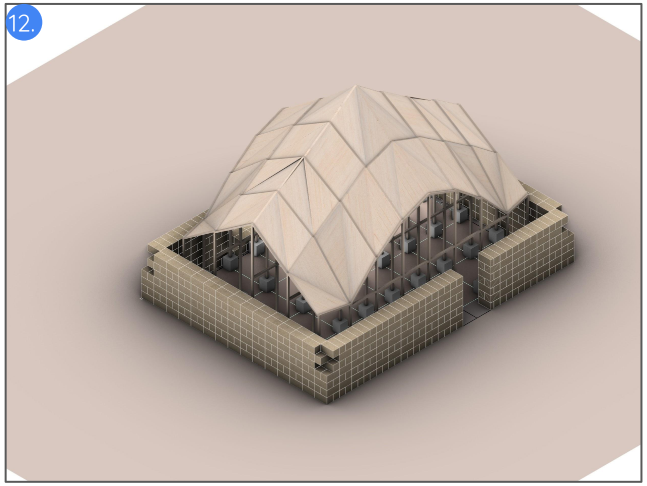
10. Diagonal sticks

Diagonal sticks are then put in order to offer extra support for the wooden panels that are going to be put in the next step.



11. Wooden Panels

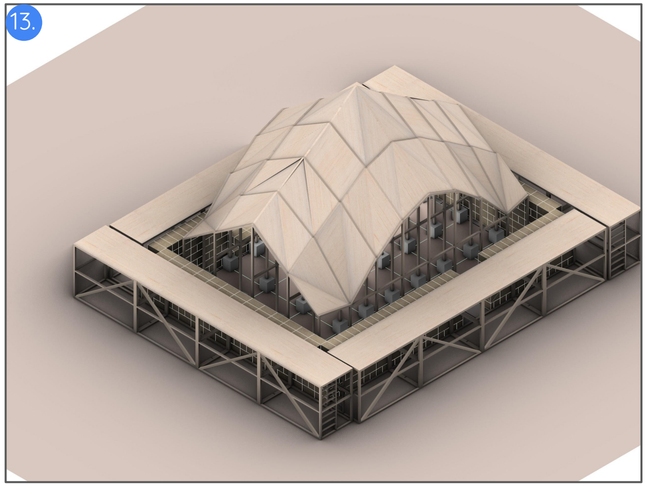
The triangular wooden panels are then placed in order to create the base of the substructure. These are also repeated.



12.Bricks Type 01

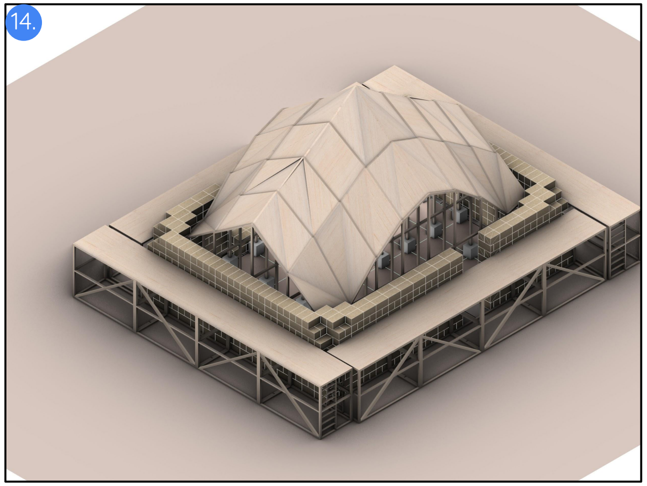
Bricks type 01 are then placed on the top of the foundations creating a wall thickness of 40 cm. At the points where bricks don’t really offer structural support, they can be omitted, like at specific points of the edges.

Construction Sequence



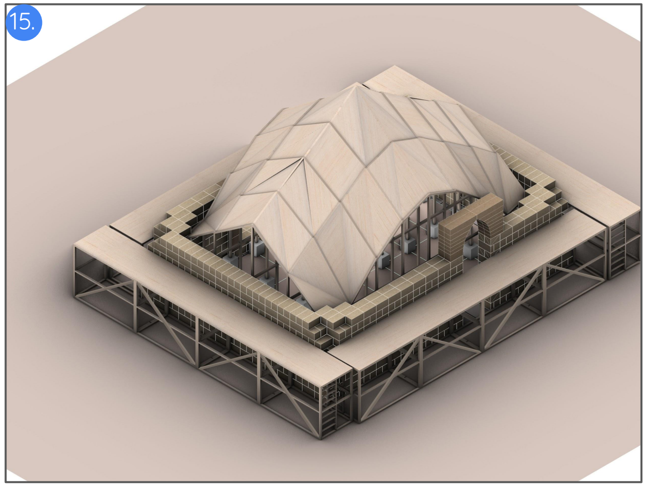
13. Wooden Scaffolds

Wooden scaffolds are used in order to help workers reach higher levels.



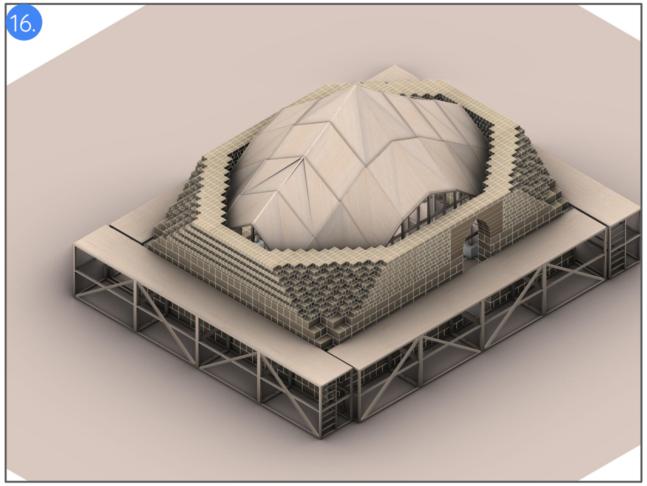
14. Bricks Type 02

A second type of brick is used to create a higher resolution of the roof.



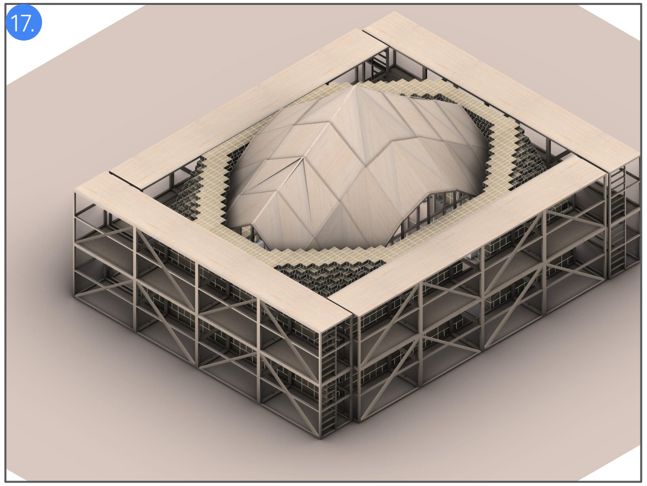
15. Windows’ blocks

For openings, specific blocks are fabricated in order to offer acceleration and easiness in the whole procedure.



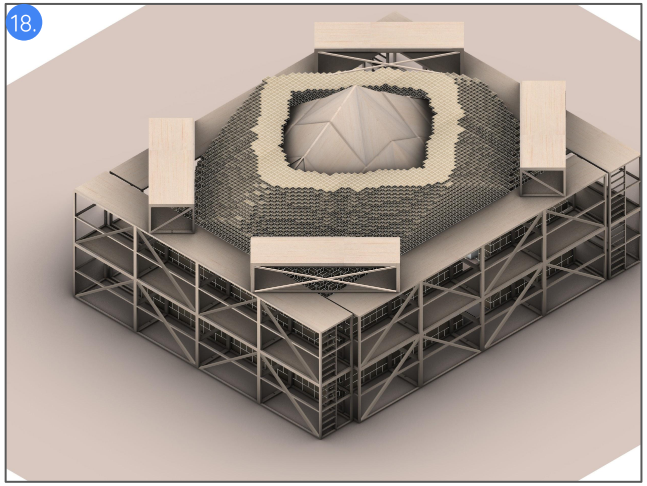
16. Remaining Bricks Type 02

After the windows’ blacks are placed bricks type 02 are used in order to achieve the interlocking between them.



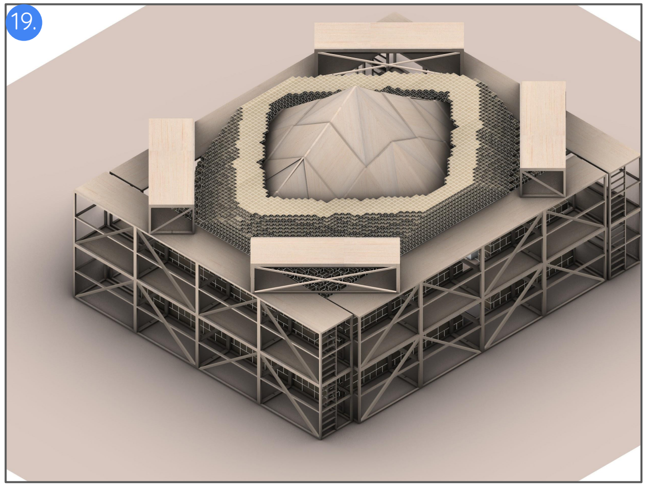
17. Second level of wooden scaffolds

A second level of wooden scaffolds is needed to start using the last type of brick which is the smallest one. In order to uplift the blocks a lift is necessary.



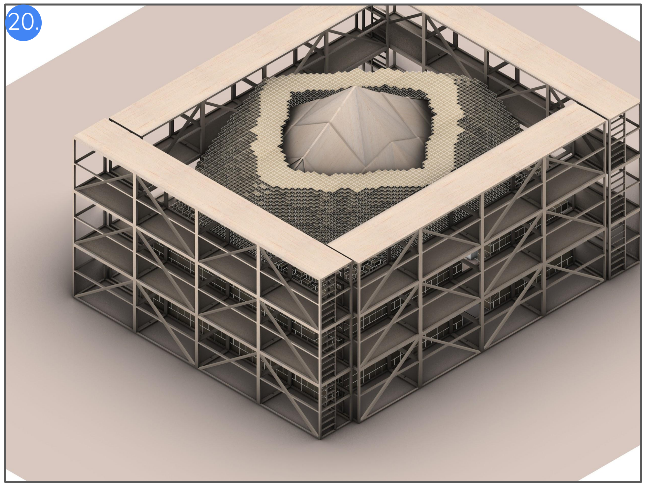
18. Wooden Platforms and Bricks Type 03

Wooden Platforms are also necessary for the workers to reach the most unreachable parts of the structure.



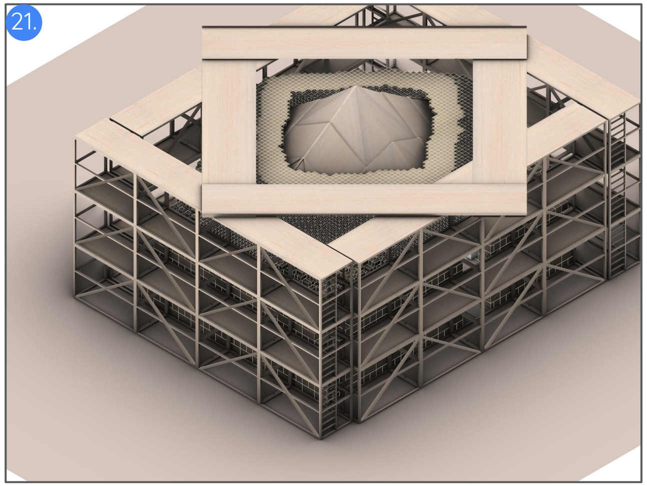
19. Third level of wooden scaffolds

A third level of wooden scaffolds is used in order to complete the roof.



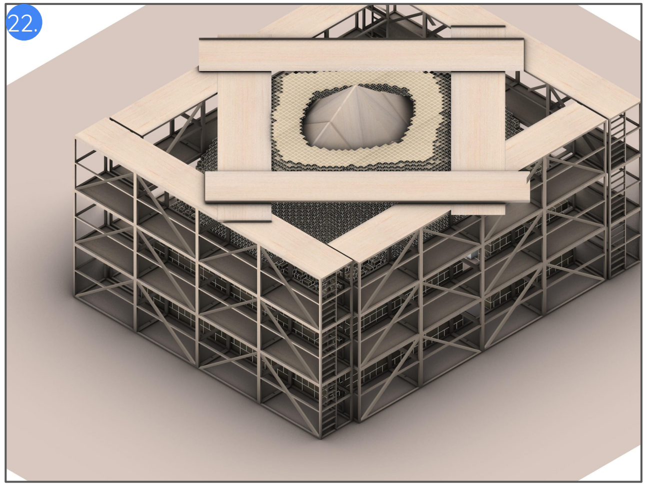
20. Remaining bricks

The remaining bricks are then put in place.



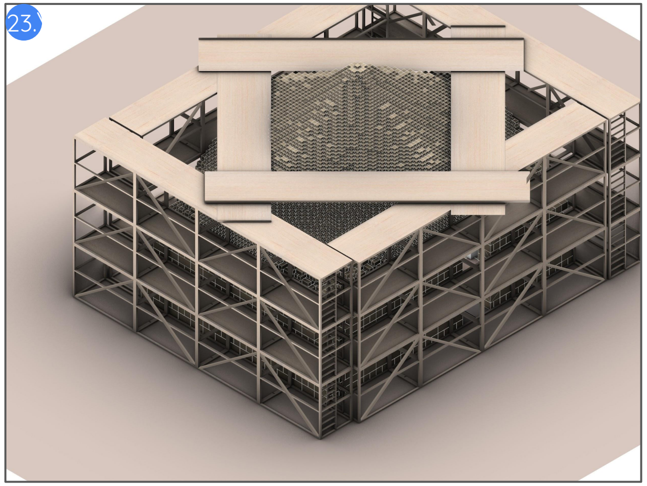
21. Wooden Platforms

Wooden platforms are used once more.



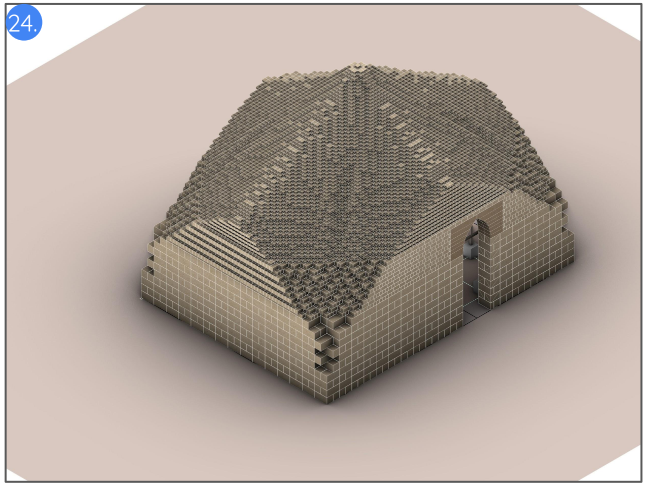
22. Sliding Platforms

By sliding these workers can adjust their place each time and reach inaccessible parts of the construction.



23. Removing Scaffolds

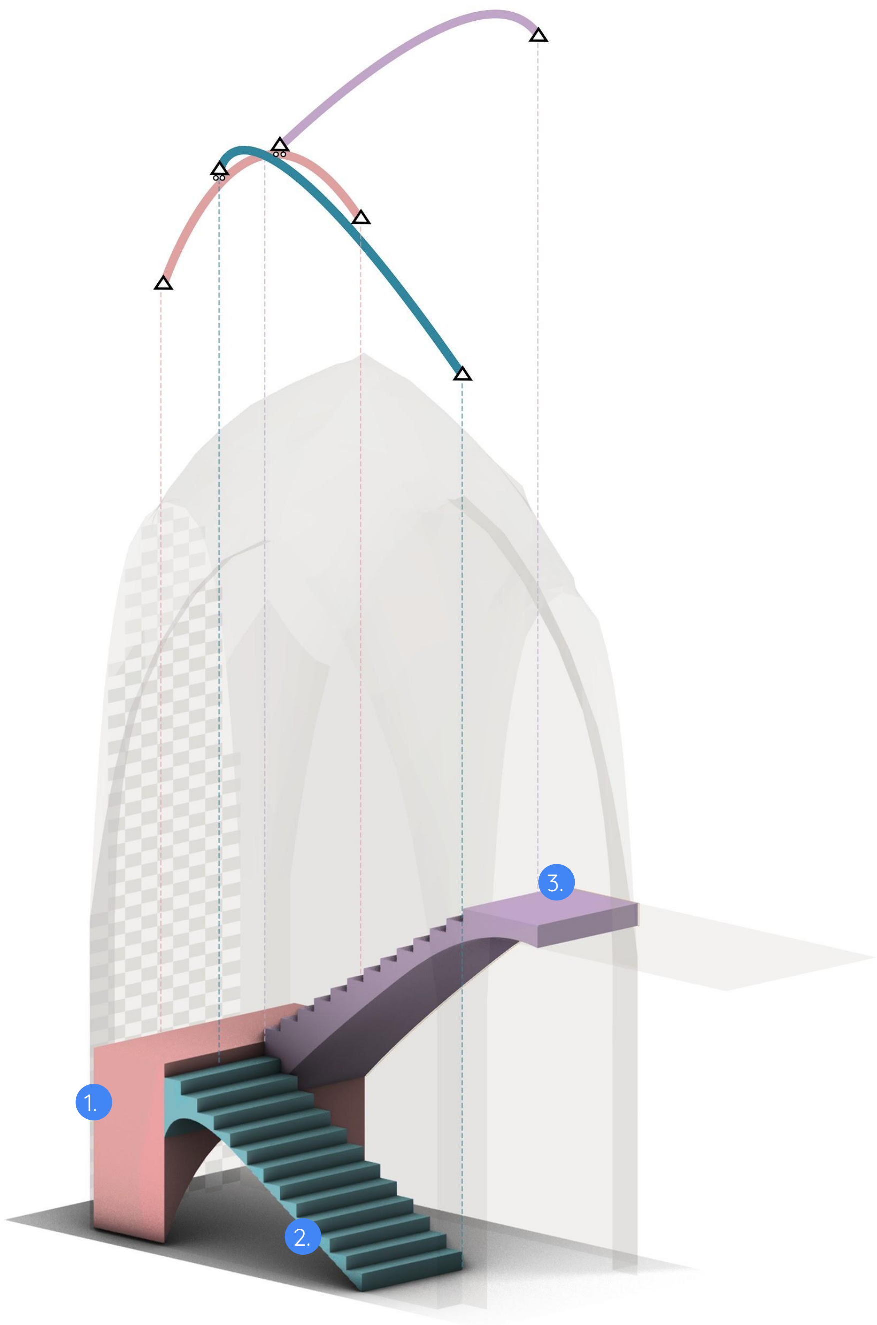
By placing the last bricks the unit is finished and the scaffolds can be removed.



24. Finished Unit

The same approach can be applied in all the units. The square-plan building units are easier to construct because all side divisions heights and repeated elements are the same. (since a=b)

Staircase



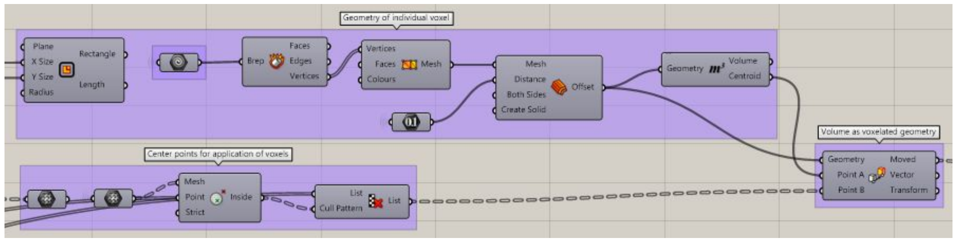
Construction Sequence

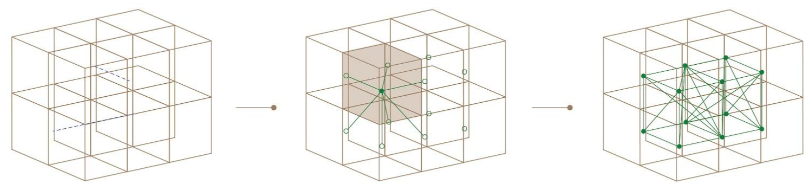
Outer shell and staircase
Staircases' module is divided in two parts, the outer shell and the staircases. Once the outer shell is built by applied the previously mentioned methodology, the construction of the staircase has to takes place.

Sequence
Staircases are composed by three units. Each of them has two construction phases. The first phase is the construction of the arches by bricks and the next one is the brick filling. The outer shell offers lateral support to the units.

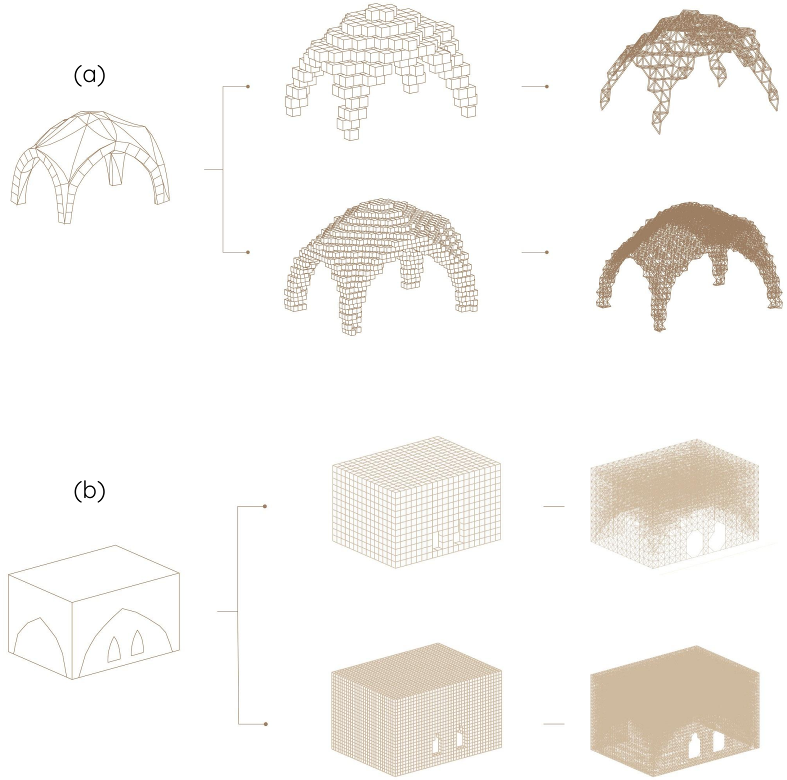
Voxelation

Additionally to evaluating the performance of the shell as a mesh, a voxel-based analysis based on the principles of FEM was conducted. This would allow to discretize the domain of the geometry, and evaluate the structural performance of the whole shell through connecting the discrete elements from which it is composed. This approach was supposed to achieve a better approximation of the brick structure as a set of blocks that interact with each other.
The classroom module was taken into consideration for this analysis and the first part of the process referred to the quantization of its volume. In this regard, the volume which was created after the extrusion of the roof and wall meshes was analysed into 8-noded orthogonal polyhedral voxels. In order to simplify the approach, the difference between the brick types and the different layering patterns was not considered in the analysis and cubical voxels were used.
Later, a lattice based on the 3-dimensional dual graph of the structure was created by connecting the center of gravity of each voxel with the centers of gravity of the voxels with which it shares a common interface.
After developing the script, different experiments were held in order to, firstly, evaluate which part of the volume should be taken into consideration for the analysis and, secondly, define the density of the structure lattice.
Given that the voxels of the wall volume add to the stiffness of the overall lattice and make the structure more coherent, it was decided that the overall volume containing both the roof shell and should be taken into account. Moreover, it was concluded that the density of the lattice should be such that allows the horizontal division of the wall volume in at least 2 voxels.



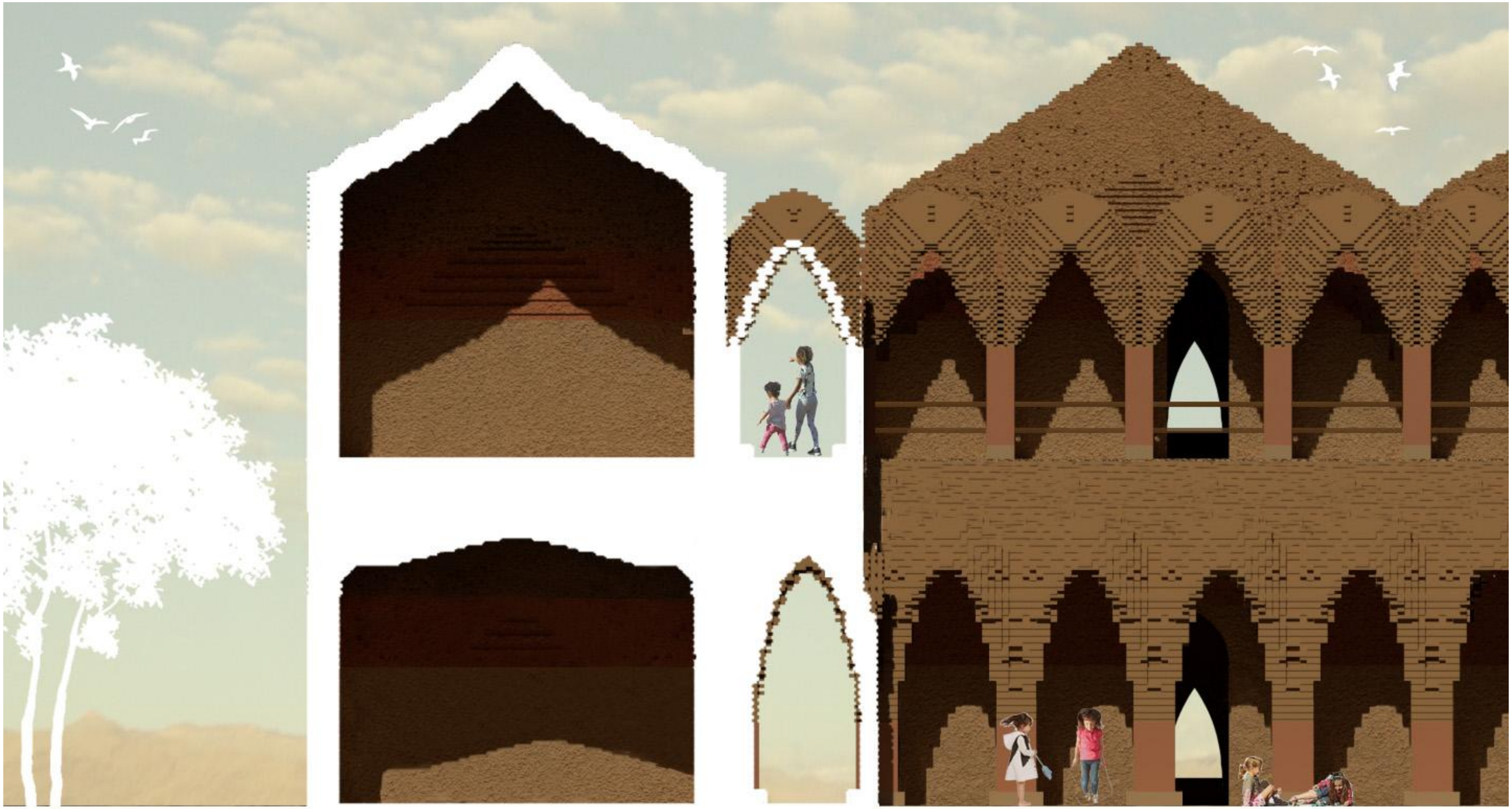


Voxelation methodology



Voxelation experiments regarding the dome (a) and the whole mesh of the module (b)

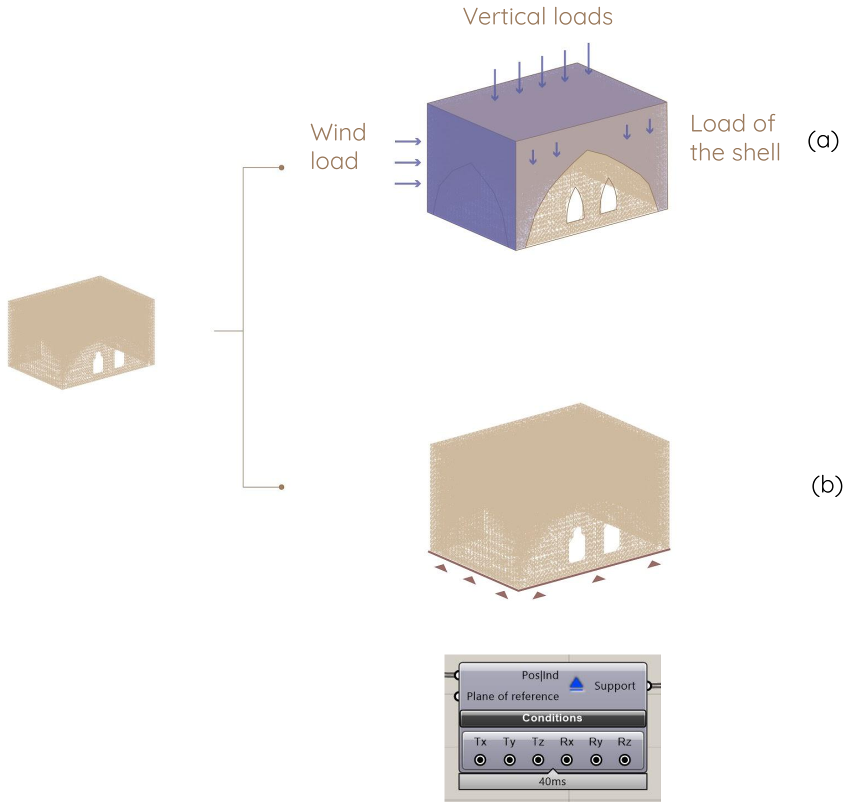
Voxelation



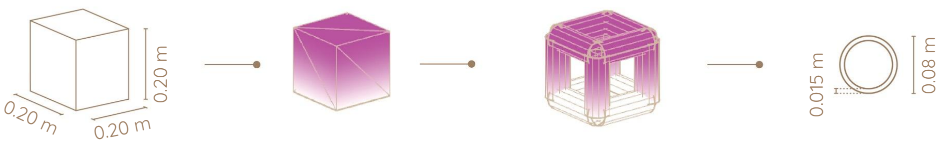
Visualization of a typical section of 2 classrooms and their corridors

Analysis as 3-dimensional truss network

Initial conditions
Given that the thickness of the wall was 40 cm, it was decided that the dimensions of the voxel should be 20cm*20cm*20cm in order to ensure that the wall volume will be analysed horizontally in 2 rows. Further division and densification of the lattice was not intended since it would add up a lot to the time needed for each simulation.
The lattice created was later used in order to form the network of trusses for the analysis. The lines were used in the first place to create a network of beams with circular cross section. These elements were transformed into trusses by cancelling their bending stiffness. It is worth mentioning that values for the diameter and the thickness of this cross section were estimated through comparing the deflections of a cubic voxel as a shell and as a truss network. Deformation was selected since it is a better indicator for the stiffness of the system. In the end, the cross section with the most comparable values was applied.
In order to conduct the analysis the nodes that correspond to the supports were defined, as well as the nodes that receive the different loads each time. Lateral loads, such as wind, were applied to the nodes of the side face, whilst the vertical loads, such as the sand, the live loads and the load of the upper floor were applied to the nodes of the top surface. It is worth mentioning that the gravity was not directly applied as a load, but, instead, the weight force of the shell was calculated taking into account the mesh volume and the material density and was applied as point load to each node of the lattice. This derived from the fact that a direct gravity load could be misleading in the sense that it would consider the weight of the pipes, which do not resemble in terms of shape and volume to the brick blocks.



Distribution of loads (a) and placement of supports (b) in the nodes of the lattice

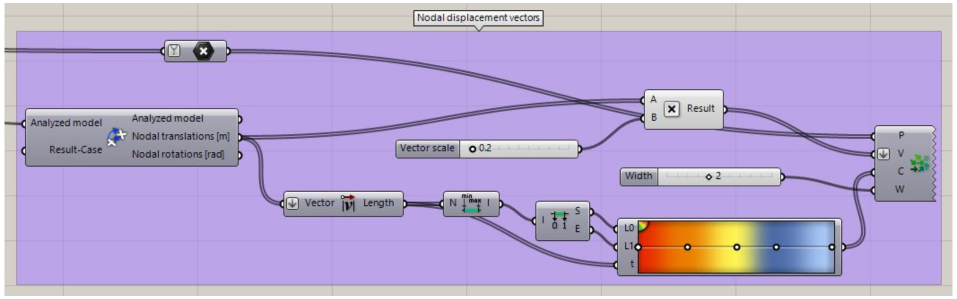


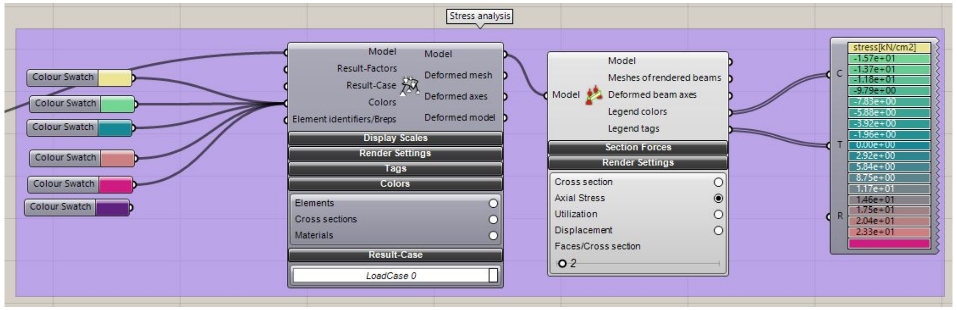
Dimensioning the circular cross section of the truss

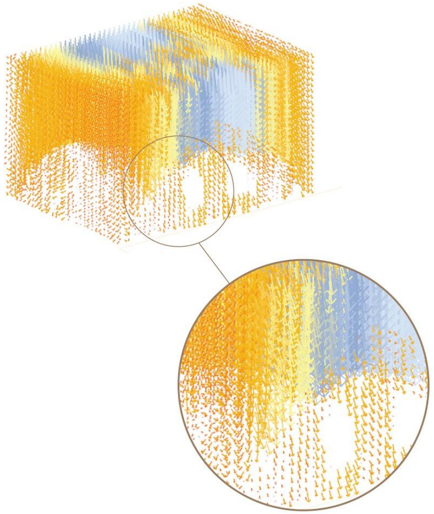
Analysis as 3-dimensional truss network

Results

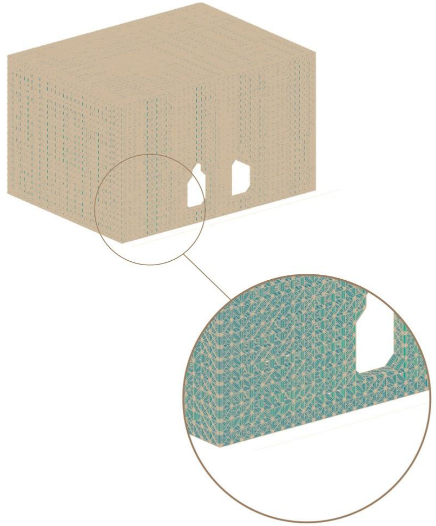
The indicators which were used for the analysis were the nodal displacements of the truss network as well as the compressive and tensile stresses. The nodal displacements were used as an indicator instead of the deformation, since they approximate better the deflection of the overall geometry as a movement of its smaller discrete elements. Although the values of the load cases were the same as in the mesh analysis, which was held in the first place, the resulting values in the voxel-based analysis were considerably higher than the respective limits. However, since the results from the classroom module as a mesh were within the limits, it is concluded that these irregular values are caused by inconsistencies in the simulation model of the voxel-based analysis and not because of the overall shape of the geometry.







(a)



(b)

Nodal displacements (a) and principal stresses (b) after the conduction of the truss analysis

	Peak	Allowable
Compressive Stress	1,57e+02 MPa	5 MPa
Tensile Stress	2,33e+02 MPa	0.5 MPa
Displacement (<0.5-1%)	454 cm	3-6 cm

Maximum resulting values after the conduction of the truss analysis

04_Reflection

Table of contents

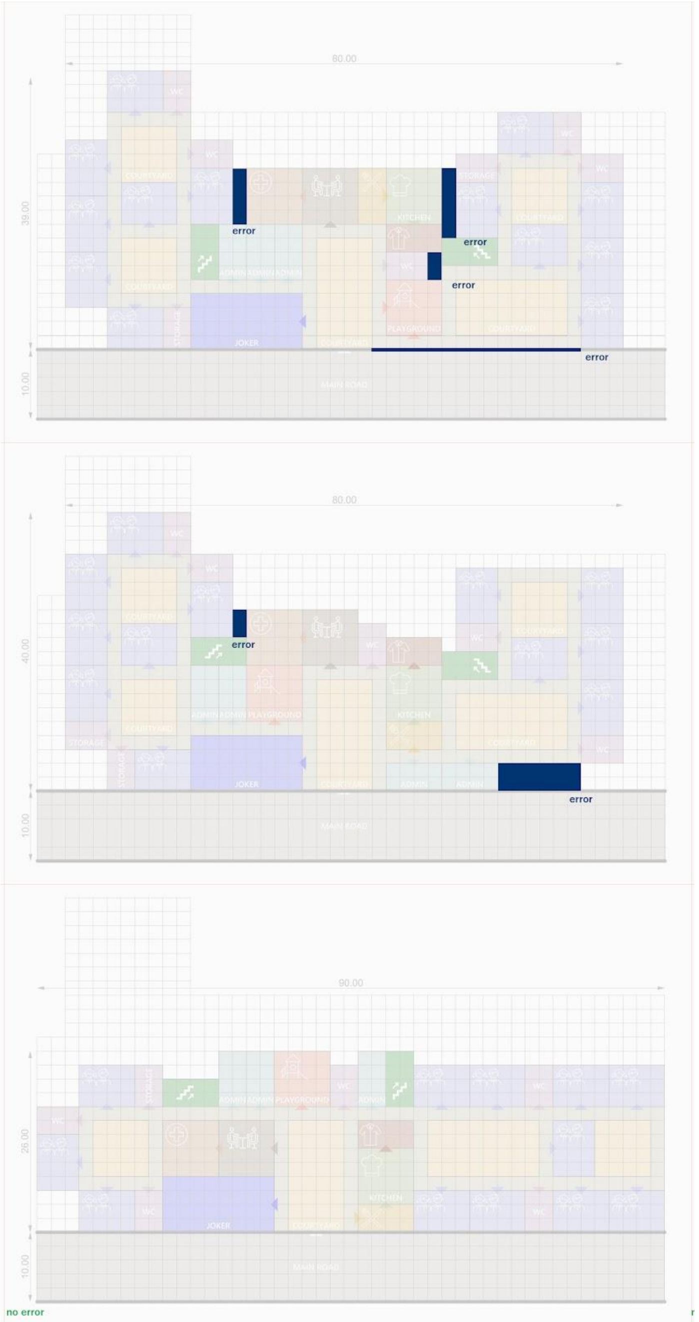
Reflection

Python programming

The python program can generate options with the restriction we set up. However, the results sometimes contain gaps between spaces. These gaps are not ideal to have in the school environment, and they are caused when it is picking the neighbor point. In some cases, it would pick the point in the middle or slightly away from the corner when the distance between two functions is bigger. Maye if we apply pattern array in the way of sequence of spaces should place this problem would be solved, or we should assign them with the same distance as the width of the geometry next to it. Else, we can count the number of points on a straight edge and divide them with the width of the space.
There are two other problems we find out in the result. The first one is sometimes certain components would be partially outside of the grid we set. The second problem is random component reaches scatter configurations. These problems we can only fix manually selecting, moving, and deleting so far.
For the next step of python programming, we would like to work on 3 dimensions. Our script, the interface between spaces is already defined, so it has the potential to connect with grasshopper of form finding and generate wall typology directly. If we succeed to combine them together, then the shape of the whole school can be produced with the shape at once. And this design approach can be handier when we need to design new schools.

Form finding

In the form finding step, since we already apply Karamba together to check the structure performance, we could also do optimization to find the best performance shape. In this concern, we would need to set up the maximum weight, which represents the maximum height and floors, in the simulation. With this approach, the school could have the option to have extra floors above.

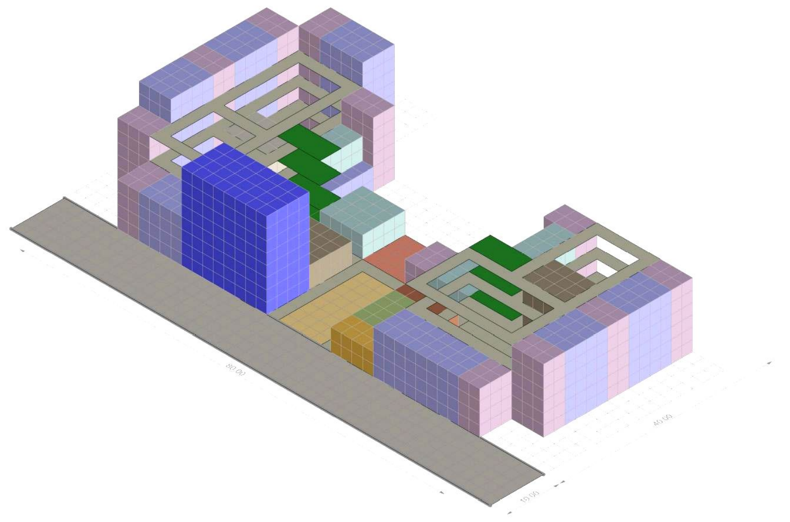


Errors in generated layout

Reflection

Expansion of the school

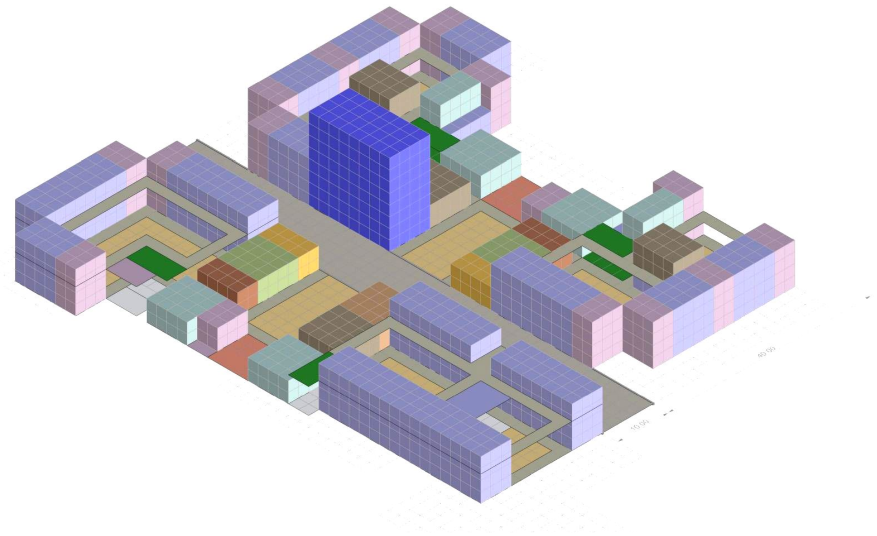
In the future, as the population grows and the community developed, the demand for space in the educational center would increase. Considering the next step of our design, there could have two ways of expanding the facility, vertically and horizontally.
Expansion of more floors on top of our final proposal would have some restrictions and limitations. Firstly, not structurally feasible with the current dome shape and brick property. The designed dome shape can only take one extra floor on top, with more floors adding would increase displacement and cause danger. Secondly, the spatial rule of functions is not yet developed. To have higher floors following our spatial layout logic we need to set more rules in the “Rules of the game” and “Python programming” chapters.
The other option would be an expansion on the other side of the road or on the left side within the same block. Having another facility across the road would create an enclosure environment for the school. On the other hand, it would require a sky bridge as the connection for students can pass the street inside the safe zone. While the bridge would be challenging in structure design and material property. Also, the traffic issue should be taken into account as well.



Horizontal expansion

Construction method

The bricklaying method applied for now would not be the best option in a real construction project. The interlocking method is easier to produce none cutting brick walls with good visualization. But the laying method is based on 40*40*40 cm3 units. This method is not able to build up a stable continuous wall. To improve this problem, we need to create a script based on tracing the wall directly to determine the brick direction. After that, we can decide how to interlock them and what pattern would be more stable.



Vertical expansion

Reflection

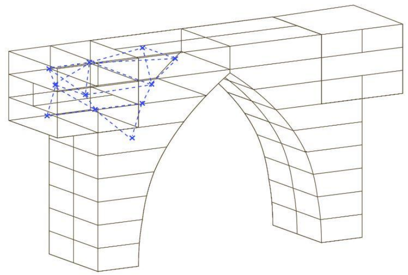
Structure analysis

<u>Mesh based structure analysis</u>

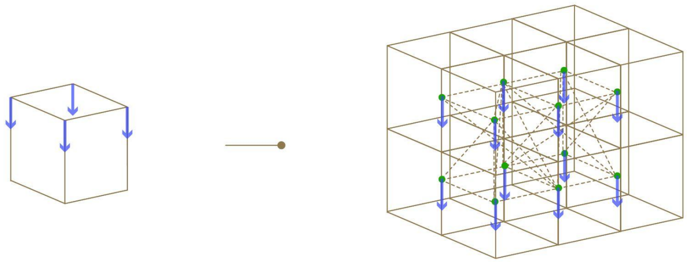
To understand structural performance better, the surroundings and units above should be included in the structural simulation. The units are self-standing structures, but through a group simulation we could find out more possibilities.

<u>Voxel based structural analysis</u>

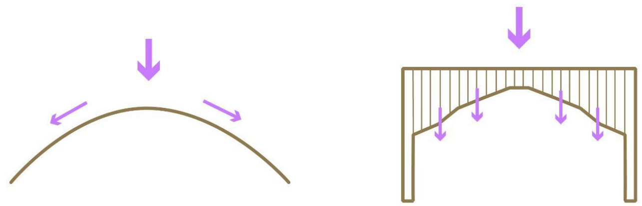
The problem in the resulting values is mostly caused by inconsistencies in the formation of the model for the analysis. Different approaches could be used in order to improve these results and approximate better the performance of the structure.
To begin with, instead of using a cubic voxel of the same size for the voxelation of the whole geometry, polyhedra of different sizes and shapes could be used, based on the dimensions of each brick type. Additionally, the different layering patterns can be taken into account in the creation of the lattice in order to have a better approximation of the coherence of the structure. However, a problem may arise regarding the large amount of data that will need to be processed in this case and, thus, the time needed to execute the simulations.
Regarding the formation of the truss network, the connectivity of the elements in each node should be further investigated in order to simulate better the stiffness between them.
Additionally, the estimation of the dimensions of the circular cross section of the truss could be improved by taking into account not just the performance of a single voxel, but use a set of multiple voxels in order to count also the reactions of the adjacent voxels during the load application.
Lastly, another source of failure may lie on the fact that, whilst on the mesh simulation the rigidity of the overall shape of the shell is taken into account and the forces are also distributed along the length of the arc, the analysis as a truss network is considering every element as separate and the overall shape rigidity is not estimated. In this regard, the forces are not distributed following along the arc, but are emphasizing on the vertical direction leading to extreme nodal displacements. A possible solution to that could be to use a weighted factor in order increase the stiffness of the elements in the diagonal direction and, thus, intend to approximate better the rigidity of the arc shape.



Analysis with polyhedra of different sizes according to the brick types



Use of multiple voxels for dimensioning the cross section of the truss



Different directions in the force distribution

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Thank you