POLITECNICO
MILANO 1863

Scuola di Architettura, Urbanistica e Ingegneria delle Costruzioni
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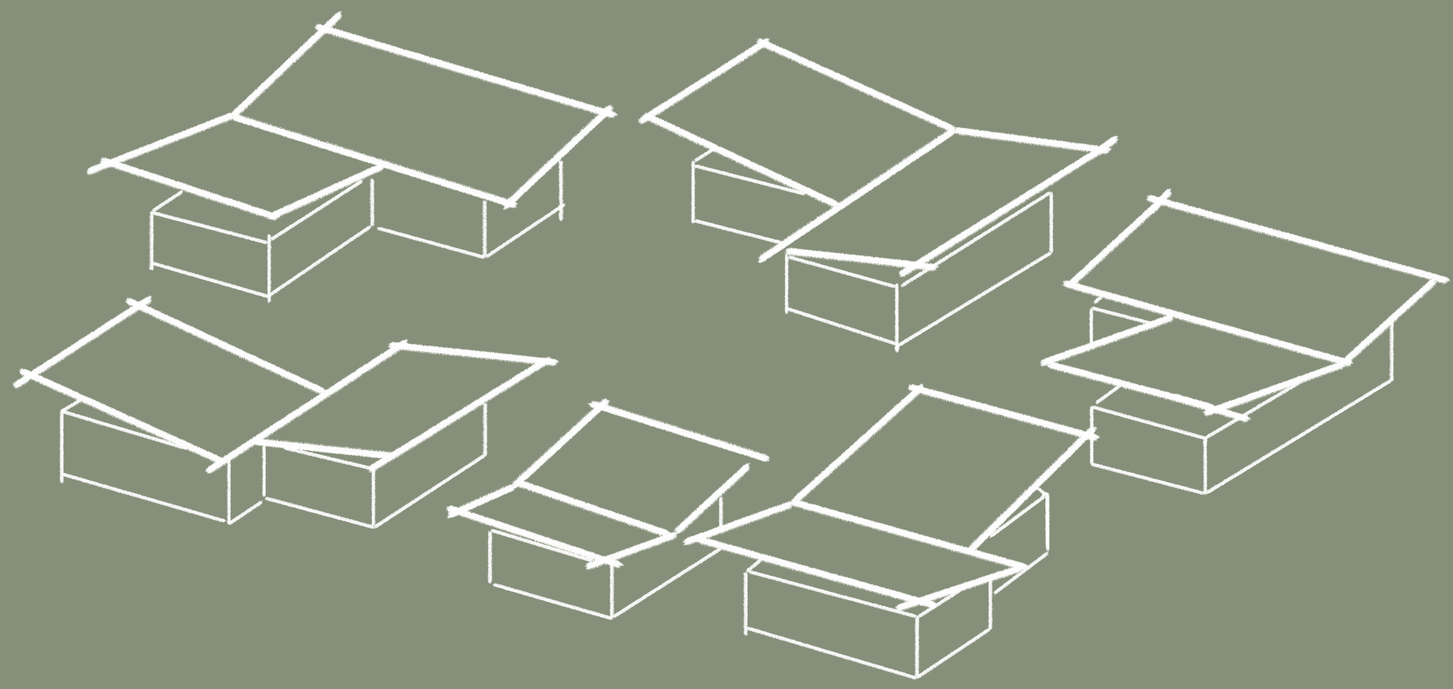

LE VILLAGE

RESEARCH ON RAW EARTH BIO-BRICKS FOR THE DESIGN OF A SCHOOL IN SENEGAL

I. CONTEXT ANALYSIS

Board 01 - Tanaff valley in Casamance
Board 02 – City of Baghere
Board 03 – Climate analysis
Board 04 – Education situation

II. VERNACULAR ARCHITECTURE

Board 05 – Diola, Mandinka, Peuls
Board 06 – Architecture in Baghere

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Board 08 – SWOT and objectives

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Board 10 – Anandoloy centre, Bangladesh
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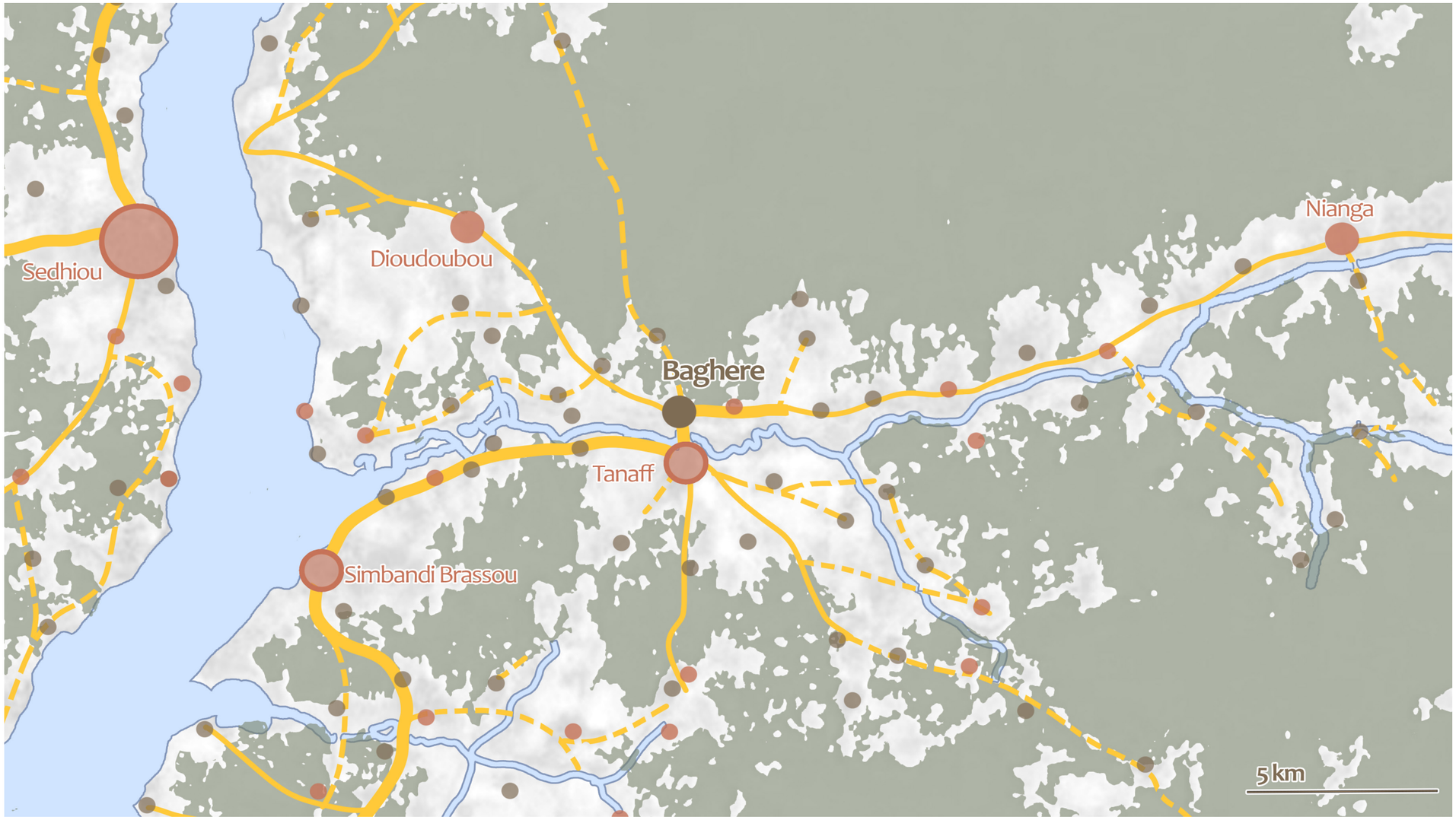
I. CONTEXT ANALYSIS



The project takes place in Senegal, a sub-saharian country located on the West coast of the African continent. The Casamance region is located in the south of the enclave of Gambia. It is crossed through by the river Casamance, taking its source in Kolda. The river has multiple meanders and marigots which irrigate the whole region, allowing rice cultivation and luxurious vegetation. Baghere is positioned in the Tanaff valley. This region is rural and poor, with many small villages and an underdeveloped road network. Many villages around have a primary school, but only Tanaff and Simbandi Brassou provide higher education. Sedhiou, the capital of the region of the same name, has many facilities for children education but its position accross the river and lack of bridge make it difficult to reach.

LEGEND

Urban network

- Baghere
- Cities with secondary schools
- Cities with primary schools
- Cities without school

Road services

- National roads
- Two lanes roads
- Dirt roads

Natural Landscape

- Water
- Forest
- Constructed area

Diarifa Village
Football Field
Balmadou Forest
Balmadou Forest
Drilling
Abandonned school
Tabandian - 2km
Sandiniari - 25 km
Sedhiou - 30 km
City Hall
BAGHERE
Project Area
Regional road
Bakidiouto village
Mosque
Kolda Town - 60 km
National Road 6
Mosque
Tanaff - 1 km
Zinguinchor Town - 120 km
Tanaff Valey
N
0
100 m

Baghere - Sedhiou Region - Senegal, Africa
12°39'45.92"N - 15°25'39.61"O


Abandoned school @Balouo Salo


Mosque @Balouo Salo

Located on the shore of the Casamance river, Baghere village was created in 1911 by Cherif Younousse Aïdar. With 2500 inhabitants, its economy mainly relies on agriculture. The village organisation is typical of the region. The main road connects all the important public infrastructures. There are a city hall, a mosque, a small health center and a football field. The only school of the village is currently severely damaged making it unusable. Children are forced to go in other villages to attend classes.

Construction:
- Residential houses
- Important public buildings
- Project area
- Drilling

Environnement
- Sandy soil
- Forest
- Rice Fields
- Other Fields
- Tannaff Valley
- Maximum water level

Accessibility
- National roads
- Regional roads
- Dirt roads

CLIMATE ANALYSIS

City : Baghere, Senegal
Climate : Tropical
Climate characteristics : Hot and humid

The temperature in Sedhiou varies between 17°C in winter and up to 40°C in spring. The average humidity level goes from 20% in the dry season and 90% during the rain season. This high level of humidity combined with the high temperatures creates discomfort.

The climate in the south of Senegal can be broken down in 3 parts throughout the year :

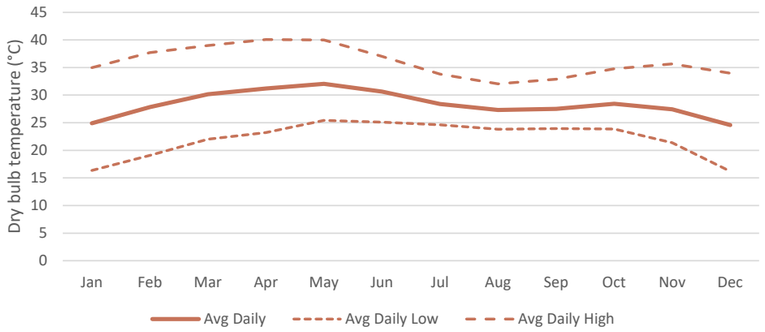
The winter season from November to February is characterized by the dry harmattan, a wind blowing from the North-East. It is a cold and dry season with an important solar illumination.

The spring season from March to May has the highest temperatures. The wind direction switches : the trade wind blows from the South-West.

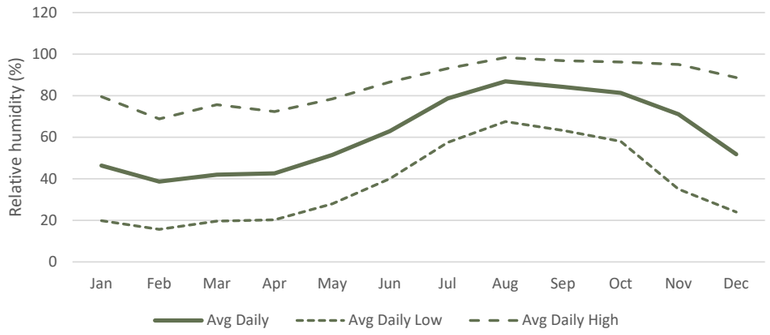
The rain season takes place between June November and has high levels of humidity and medium heat. The wind blows from the South towards the North. The heavy rain is almost a constant during this period.In the summer, the sun is at North.

Data source : NOAA data 2007-2021 for Kolda, Senegal

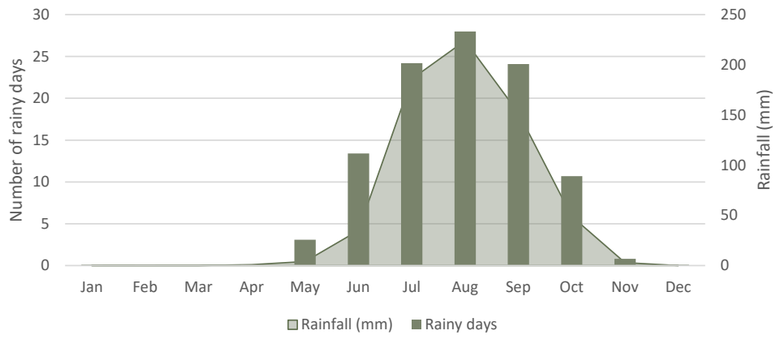
Temperature (°C)



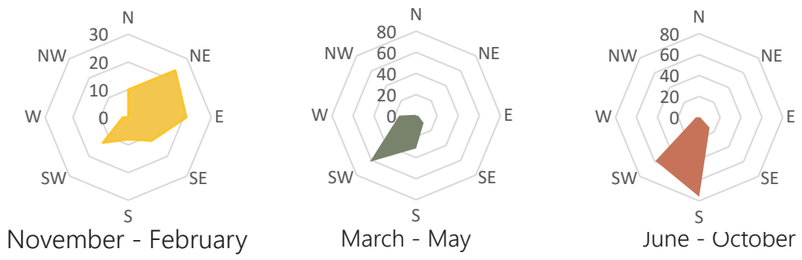
Relative humidity (%)



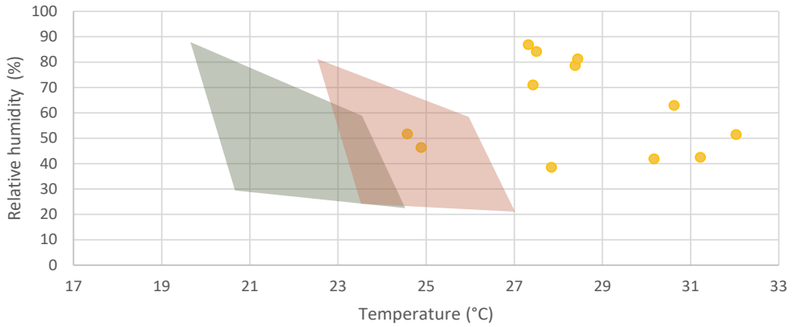
Rainfall



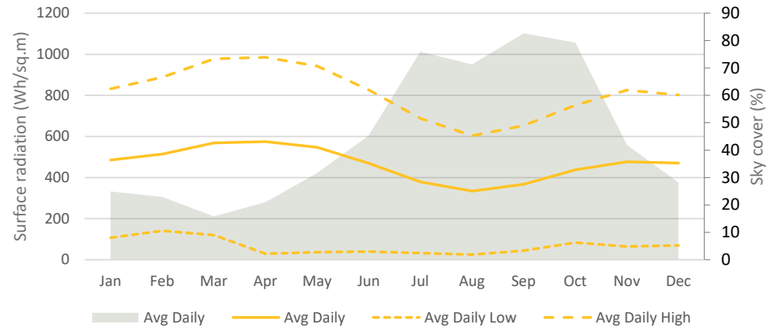
Main directions of the wind



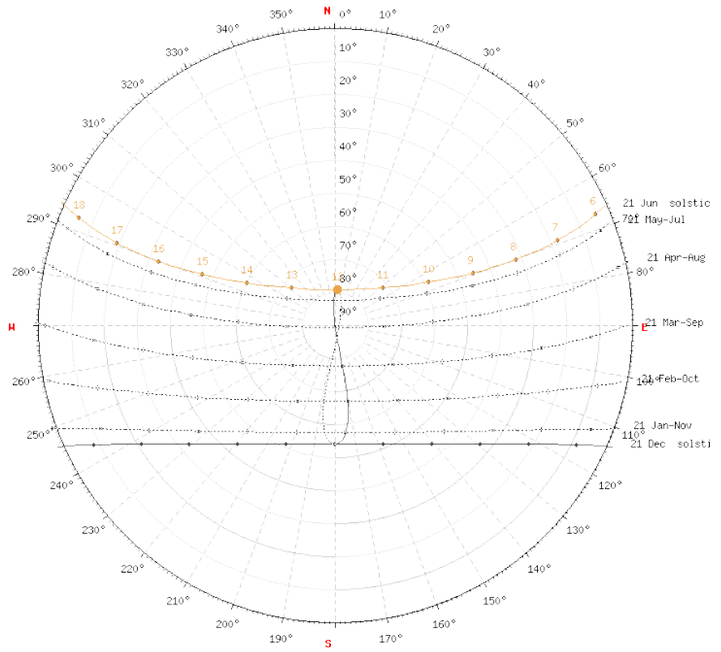
Comparison with ASHRAE55 comfort zones



Solar radiation and sky cover



Solar diagram



EDUCATION IN SEDHIOU

Altough education is mandatory between the ages of 6 and 16 years old, more than half of the population has quitted the education system before middle school.

In Sedhiou, the enrollment rate at primary school is particularly impressive. However, the success rate at exams is rather low making one question the quality of the education provided.

The teaching staff is indeed outnumbered by students and the classrooms are overcrowded. 1/3 of primary school teacher in Sedhiou does not have the high school diploma required for their function.

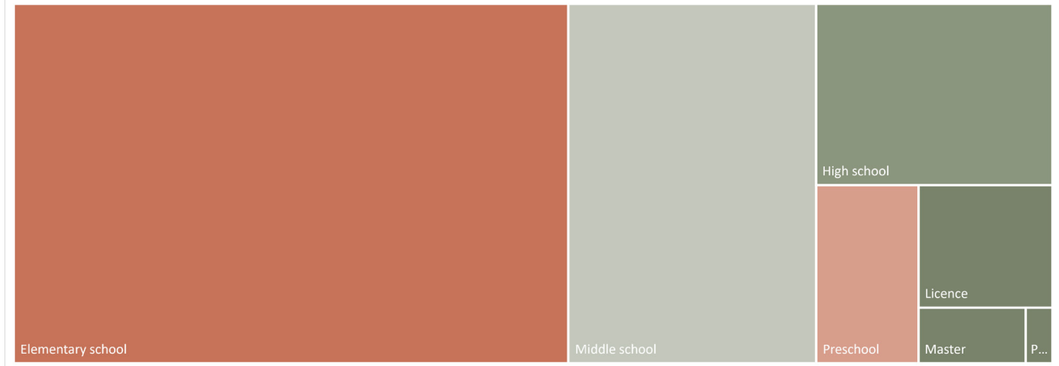
Moreover, the schools are often inadapted. Both the sanitary and educational equipment is lacking. Many schools in Sedhiou also reported that they could not provide all the hours of teaching required due to the inadequate climate.

In addition, some disparities between genders still subsist. The gender gap widens with every level of education, pushed by early marriages and pregnancies, social bias and lack of sanitary equipment to name a few.

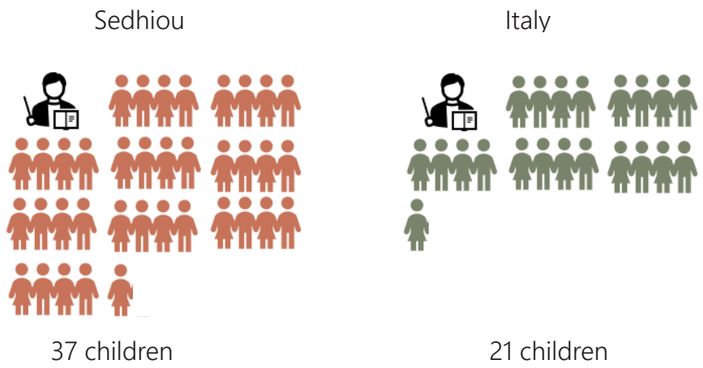
Education is critical for young people as it develops autonomy, critical thinking, and provides access to a lot of opportunities for work.

The abandoned school of Baghere @Balouo

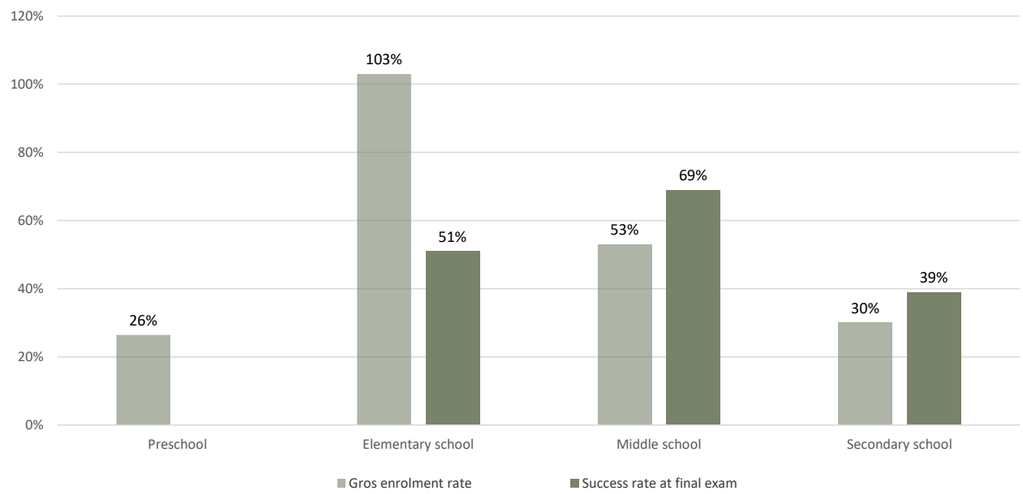
Education level among the population in Senegal in 2018



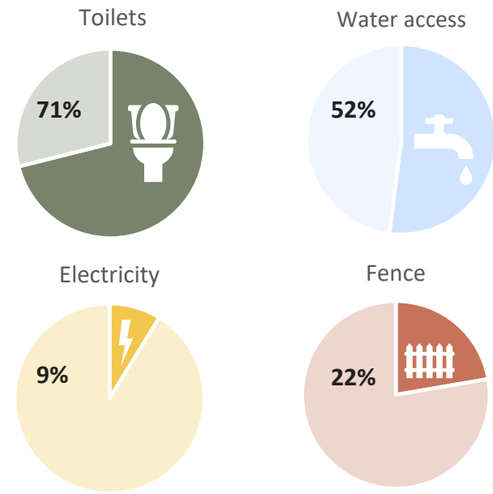
Number of students per teacher in primary school



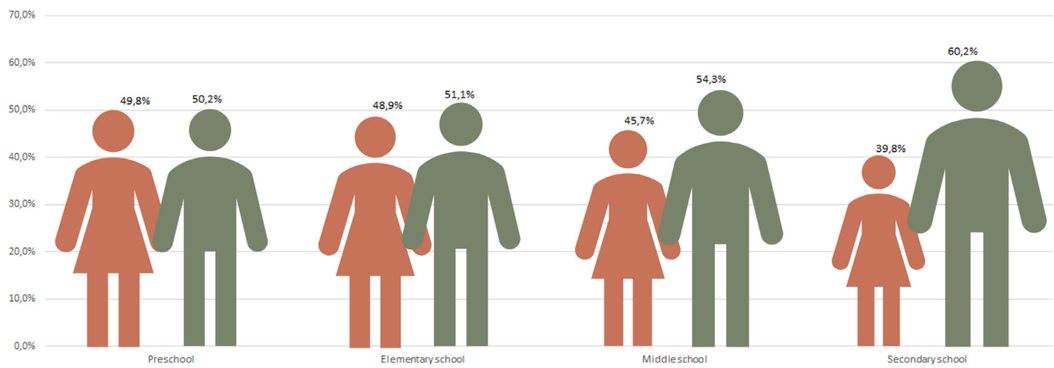
Gross enrolment rate and success rate at final exams in Sedhiou in 2018



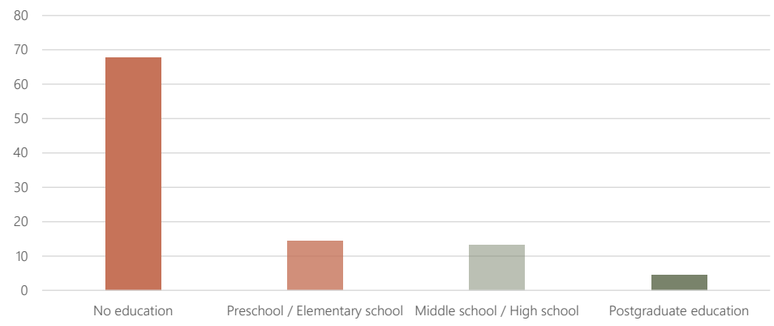
Percentage of schools equipped in Sedhiou



Distribution of students by gender in Sedhiou in 2018



Unemployment rate among the active population in Senegal in 2018

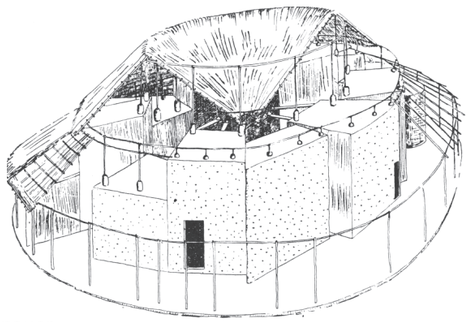


Data sources : ANSD

II. VERNACULAR ACHITECTURE

DIOLA PEOPLE

House with impluvium



@Norbert Schoenauer

Diola people

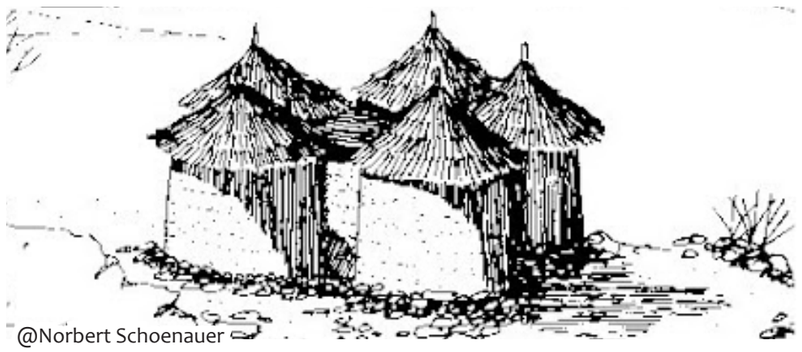
- Cultivators of rice and fishermen
- Sedentary people
- Community living with no caste system
- Important music culture

Traditional architecture

- Individual square clay houses
- Interior courtyard the 'impluvium' that collects rainwater
- Unified thatch roof on dedicated wooden structure
- Interior canopy for the community
- Exterior canopies for the individuals
- Individual gardens

MANDINKA PEOPLE

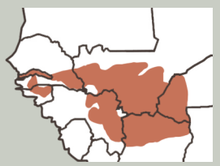
Mandinka huts



@Norbert Schoenauer

Mandinka people

- Farmers and craftsmen
- Sedentary people
- Community living with a caste system
- Important music tradition
- Predominant ethnic group in Sedhiou

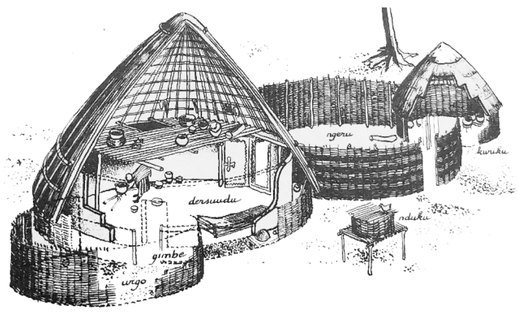


Traditional architecture

- Individual cylindrical or rectangular houses
- Clay brick (adobe) walls
- Conical thatch roof
- Organization of multiple houses in a dwelling

PEULS PEOPLE

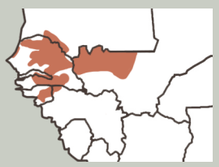
Peuls domes



@Jean Paul Bourdier

Peul people

- Cow breeders
- Nomad people
- Individual living
- Important oral tradition



Traditional architecture

- Individual dome shaped house
- Wooden structure
- Foliage/ straw/ animal hides cover
- Movable houses
- Wooden enclosure for the animals

ARCHITECTURE IN BAGHERE

- **DISPOSITION IN THE SPACE**

Apart from the crowded center of the village, where the buildings are simply placed along the streets, the buildings are arranged into settlements. Buildings are grouped together to form a household and sometimes encircled by a wooden fence. The urban fabric is sparse and can be described as informal.

- **SHAPE**

The more traditional buildings have a circular plan and a conical roof. They are becoming ever less common as most buildings in Baghere are square or rectangular, with hipped or gabbled roofs.

- **DIMENSIONS**

The buildings have modest dimensions, from 8 m to 15 m for the housing blocks and up to 20 m for public buildings.

- **HEIGHT**

All buildings in Baghere are single-storey, and have rather low walls, from 2 to 3m high at their lowest point.

- **OPENINGS**

They are few small openings to avoid compromising the structural integrity. Newer construction sometimes have larger openings.

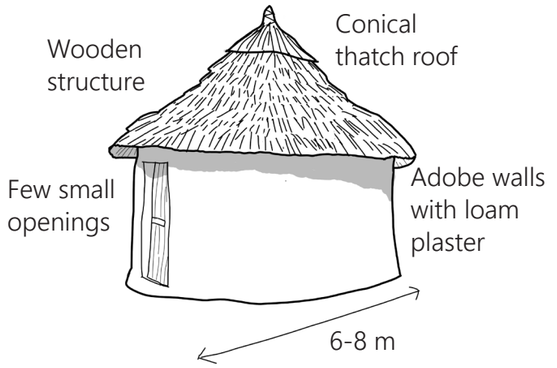
- **COLOR PALETTE**

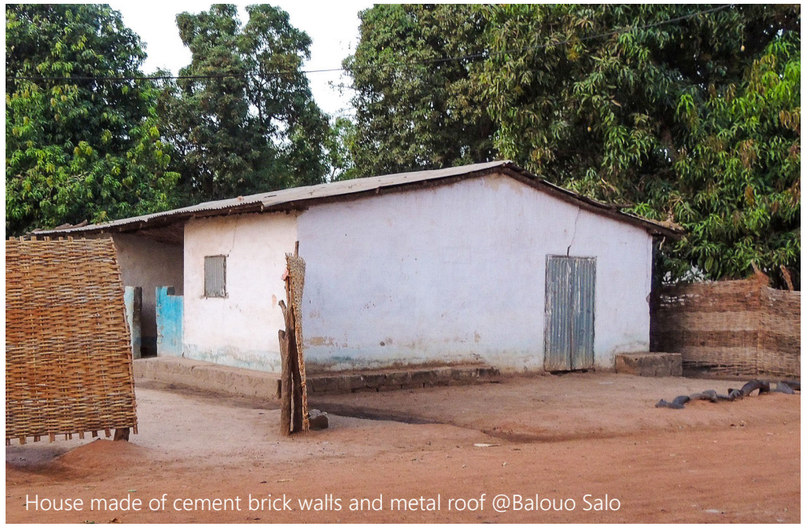
Traditional buildings as well as some modern ones are the color of the earth, orangey brown. Newer building tend to be painted white.

Circular houses made of adobe walls and straw roofs @Balouo Salo

Fenced settlement @Balouo Salo

TRADITIONAL HOUSING

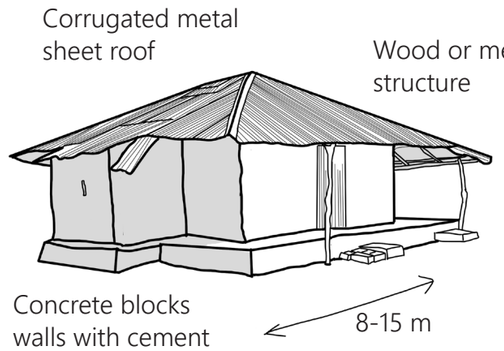




House made of cement brick walls and metal roof @Balouo Salo

Abandoned school of Baghere @Balouo Salo

MODERN BUILDING



House made of clay walls and metal roofing @Balouo Salo

Hybrid house @Balouo Salo

HYBRID CONSTRUCTION

- Mix of traditional and modern building techniques
- Combined advantages of modern and vernacular techniques
- Incompatibility of materials

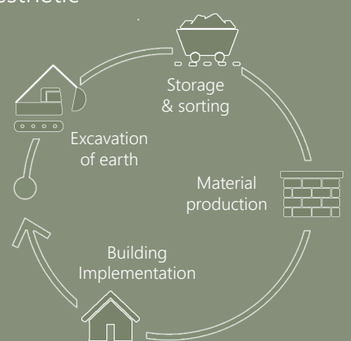
III. BUILDING WITH EARTH

RAW EARTH, AN IDEAL MATERIAL

One third of the population lives in a raw earth building. Being used for thousands years, the local exploitation of this ressource has generated a large variety of great vernicular constructions. Also called clay concrete as the clay plays the role of binder for all larger particles in the loam, it is a notable sustainable material.

Ideal composition:
14% of clay, 22% of silt, 62% of sand and 2% of gravels and water

Advantages :
- Locally available ressources
- Sustainable material
- Economical material
- Good working conditions
- Local participation
- Indoor and outdoor comfort
- Great accoustic regulation
- Good thermal inertia
- Great hygrothermal and humidity regulator
- Reconnecting human to nature and culture
- Law maintenance
- A flawless life circle
- Aesthetic



Drawbacks :
- Implementation time of the material
- Absence of professional rules
- Specific know-how required
- Water resistance

MONOLITHIC TECHNIQUES


@Grobler Du Preez

COB

Soil clods piled up and compacted manually or mechanically

⊕ Robust technique
Minimum number of tools
Freedom of shapes

⊖ Slow drying


@Andrea Tabocchini

RAMMED EARTH

Soil poured into formworks and compacted in layers by a tamping machine

⊕ Aesthetic
Possibility of prefabrication
Very robust technique

⊖ Cost of the machine
Know-how

SMALL ELEMENTS TECHNIQUES


@Frederik Bekas

ADOBE

Soil moulded by hand or with formworks

⊕ Easy production
Easy implementation
Economical

⊖ Compressive strength smaller than CEB


@Amaco

COMPRESSED EARTH BRICKS

Mixture of wet sandy soil placed in a mould and compressed mecanically

⊕ Speed and precision
Possibility of prefabrication
Very robust technique

⊖ Cost of the machine

FILLING TECHNIQUES

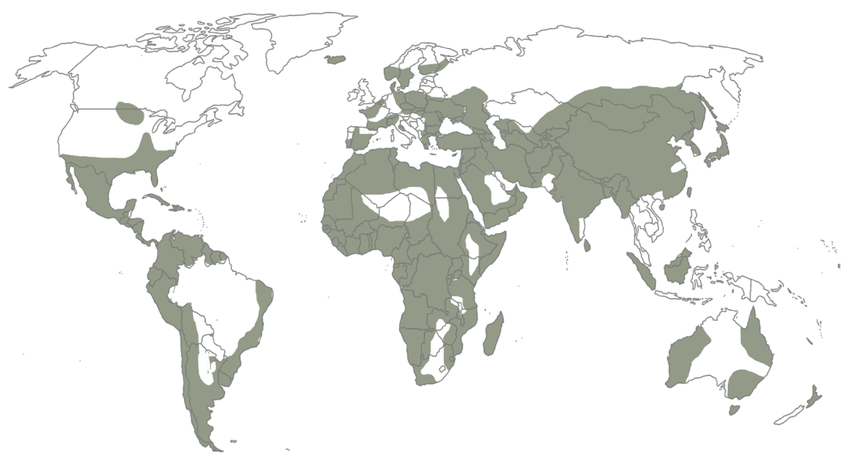

@Rod Waddington

WATTLE AND DAUB

Material composed of a mixture of fine clay and vegetable fibers, applied on a wooden frame

⊕ Light
Few tools required
Antisismic

⊖ Non-load bearing soil


Raw earth construction distribution

IV. GUIDELINES & OBJECTIVES

Strengths

Social
Strong community spirit
Agricultural skills
Local partners for education: UNICEF, PAM, PAEF-PLUS...

Environment
Flat terrain
Position along the main street of Baghere
Proximity with the town hall

Facilities
Active mosque of Baghere

Construction
Autoconstruction culture and skills

Weaknesses

Social
Struggling existing school system

Environment
Potentially dangerous fauna
Proximity to a high circulation road

Facilities
Poor water system
Unreliable electricity supply

Construction
Generational loss of vernacular construction skills
Limited tools and engines available

Opportunities

Social
Young population
High enrolment in primary school
Growing inclusivity in society
Existing projects and programs for the youth

Environment
Proximity to the river
Ecosystem services
Arable land

Facilities
Water access through the drilling

Construction
Autoconstruction culture and skills

Threats

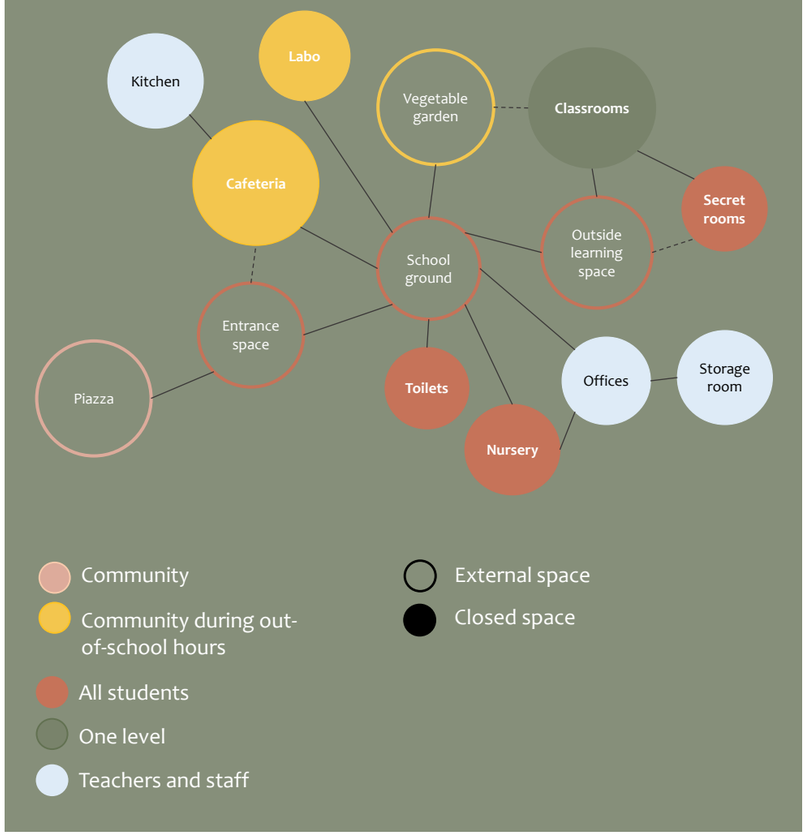
Social
Control of the Islamic hierarchy
Cultural bias against girls' education
Lack and underqualification of teaching staf

Environment
Important rainfalls
Regular drought
Extreme heat
Occasional strong winds

Facilities
Remoteness from big cities
Bad road quality

OUR OBJECTIVES

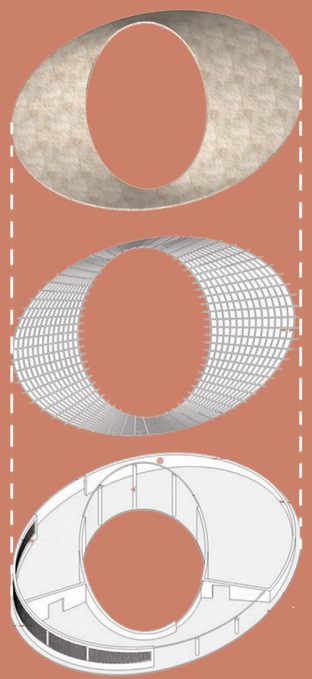
- Inspire confidence in students and empower girls in education through architecture
- Improve the working condition of the teachers to tackle the issue of outnumbered teaching staff in school
- Provide services for the wellbeing of all students and staff
- Make school a shelter from the harsh tropical climate
- Use local natural and recycled building materials to limit the environmental impact of construction
- Involve the whole community in the building and maintenance of the school



V. ARCHITECTURAL DESIGN

FASS SCHOOL

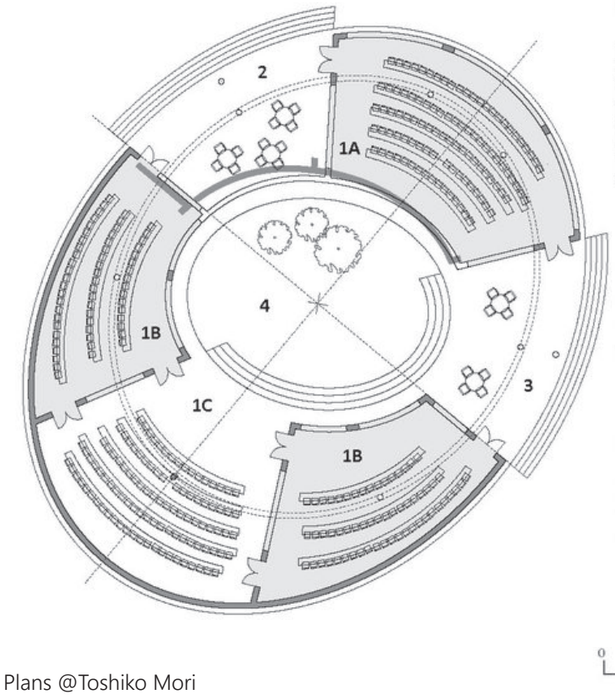
Architect : Toshiko Mori
Year : 2019
Location : Fass, Senegal
Area built : 280 m²
Area covered : 520 m²



Blow up by Toshiko Mori Architect

Key words:
Centered, Impluvium, Perforated walls, Local materials, Flexibility

@Iwan Baan



LEGEND

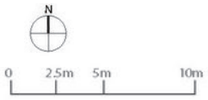
1 A-C	CLASSROOM
2	FLEX SPACE/ CLASSROOM
3	ENTRY
4	AMPHITHEATER/ PLAYGROUND
5	WC
6	TEACHER RESIDENCE #1
7	TEACHER RESIDENCE #2
8	STUDY / LIVING AREA

AREA

SCHOOL:	5,685 SF
RESIDENCE:	1,950 SF
TOTAL:	7,635 SF

SEATING

CLASS 1A:	80 students
CLASS 1B:	60 students
CLASS 1C:	100 students
TOTAL:	300 students



Plans @Toshiko Mori

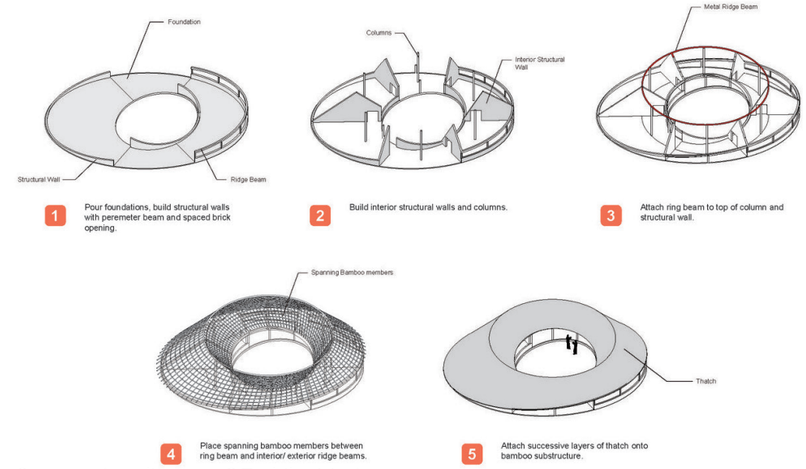
Located in Senegal, this four classrooms school is the first elementary school for the region and can welcome up to 300 pupils. Inspired by the traditional hut of the Diola people of Casamance, it has been built with local and traditional skills and materials.

- Centered oval shape as the traditional Diola impluvium
- Alternation between closed rooms and open spaces on the courtyard
- Four classrooms and two flexible spaces arranged around a courtyard
- Protection of courtyard from external agents

- Traditional thatch roof : improve climatic comfort
- Varying angle of the traditional pitched roof
- Short edged roof
- Two slopes roof with a pitch consistently minimum 45 degrees
- A unique form to maximize rainwater runoff and collect

- Classrooms walls in localy mud-brick : high thermal mass
- White painted walls to reduce heat
- No glass window but perforated walls to ventilate and ensure a good air flow throughout the building
- Moveable partitions to allow a flexible use of the classrooms

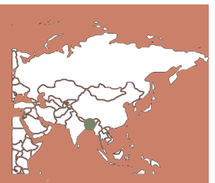
- Natural ventilation : perforated wall and height
- Cooling properties : mud-bricks and thatch as main materials
- Water system to collect rain water and conduct it in a existing aquifer



Construction diagram @Toshiko Mori

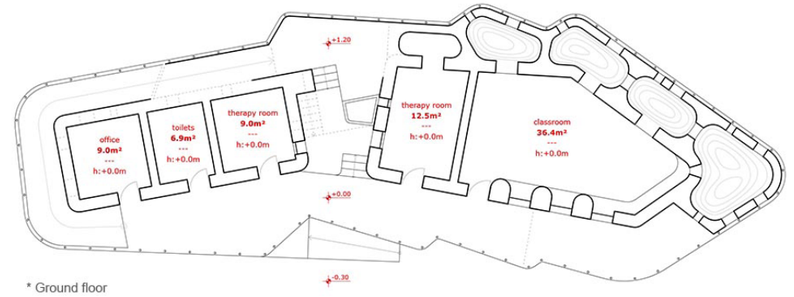
@Iwan Baan

ANANDALOY CENTER



Architects : Anna Heringer
Year : 2018 - 2021
Location : Dipshikha, Bangladesh
Area : 253 m²

* First floor



* Ground floor

Plans @Studio Anna Heringer

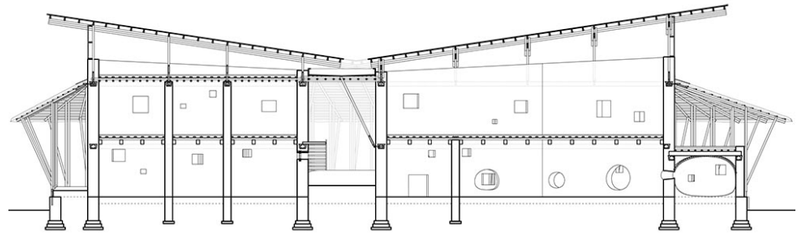
Located in Bangladesh, Anandoloy centre is a therapy centre for people with disabilities. It is also a place for textile workshops. Anandoly means in the local dialect “the place of profound joy” which echoes perfectly to all the life that will be safe, renewed. The aim was also not only to provide therapeutic treatment for disabled people but also to give them an access to learning and to work.

- Two floors levels building
- Curved walls to embody the beauty of human difference
- Building surrounded by a continous porch to create an outdoor circulation
- Snuggling rooms directly connected to classes : «secret» informal small spaces with organic curves

- Traditional roof with metal sheet supported by a bamboo structure
- Bamboo structure that relies either on bricks columns or on the floor
- Long edged roof to protect from the rain
- One slope roof oriented towards the exterior

- Walls in cob
- Roof frame, pillars and ceilling in bamboo
- Lower roof in straw
- Upper roof in metal sheets

- Natural ventilation : regular openings
- Cooling properties : cob as main construction technique and roof in straw

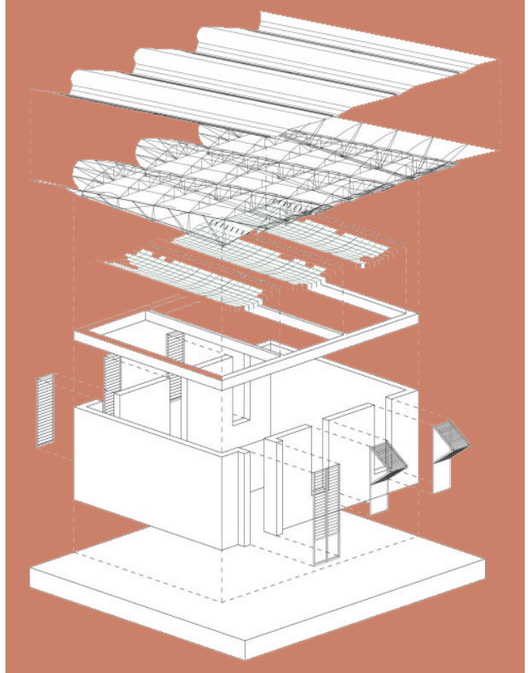


Section @Studio Anna Heringer

Key words:
Snuggling rooms, Bamboo, Cob, Curved walls, Accessibility

DANO HIGH SCHOOL

Architects : Kere Architecture
Year : 2006 - 2007
Location : Dano, Burkina Faso
Area : 370 m²



Blow up by Kere Architecture

Key words:
Modules, Natural ventilation, Double roof, Vaulted ceiling, Local bricks, Louvers

@Erik-Jan Ouwerkerk

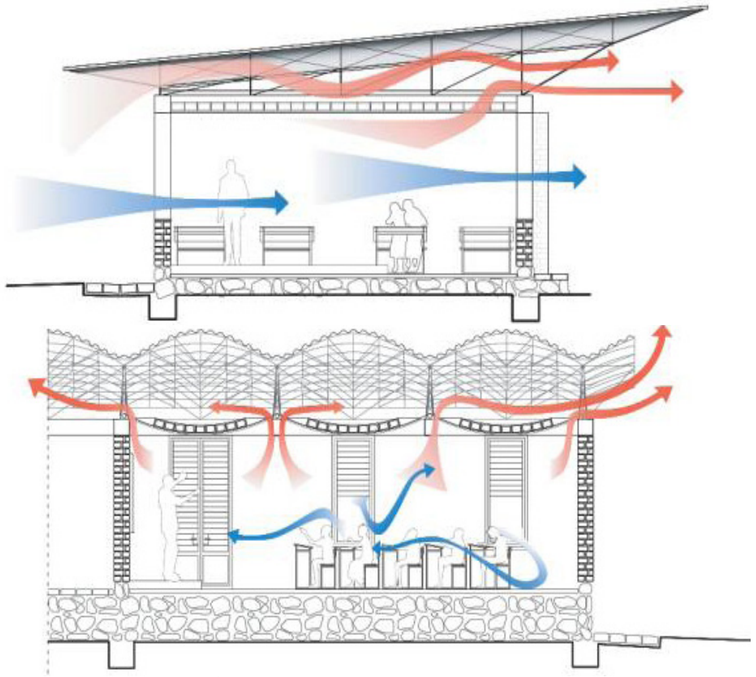
Located in Burkina Faso, this school of three classrooms, one computer room and one office is environmentally sustainable and appropriate to the local climate conditions. The main material are raw earth bricks as it is not only locally available but also have great thermal properties. To be the best adapted to the climate, differents passive strategies such as the use of louvers or the double roof to increase natural ventilation were implemented.

- Buildings oriented towards the West
- Independent modules under a single roof
- Shaded seating area below ground level to host more informal lessons

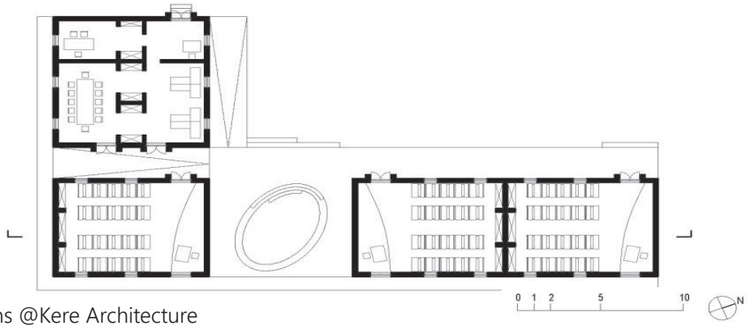
- Double envelope roof : corrugated steel roof fixed on a steel structure
- Classroom's ceilling with upside-down plaster vaults
- Medium edged roof : Protection of the crumbly clay walls from rain
- One slope roof oriented towards the exterior of the modules

- Classrooms walls in compressed earth bricks : high thermal mass
- Structure ensured by continous beams covering all the perimetral walls
- No glass window but movable louvers to ventilate the building

- Natural ventilation : Double roof and louvers
- Cooling properties : laterite stones as main material
- Orientation toward the West to keep the buildings cool



Climate diagram @Kere Architecture



Plans @Kere Architecture

@Erik-Jan Ouwerkerk

KAMANAR SCHOOL

Architects : Dawoffice : David Garcia, Aina Tugores
Year : 2021
Location : Thionk Essyl, Senegal
Area : 1900 m²

Located in Senegal, this school can served up to 500 pupils. It was built as a response to the only over crowed secondary school in the area of Thionck Essyl. Different modules with harmonious form are arranged into a grid to enable the school to grow over time if necessary. It has been built with local and traditional skills and materials.

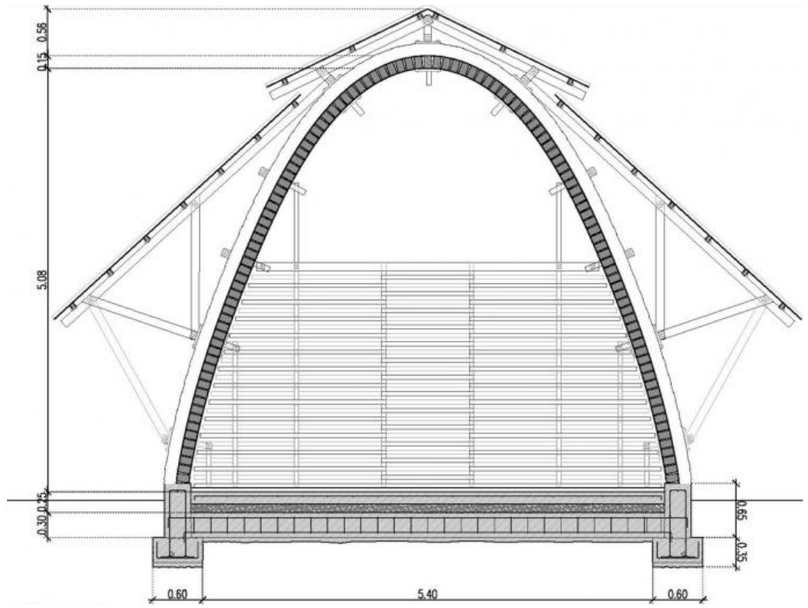
- Independent single, double or triple modules arranged into a grid
- Adaptive system over time with the possibility to add modules to extend it
- Buildings oriented towards the East
- Projects thought around the existing trees and plants

- Double envelope roof
- Classroom's ceilling vaulted in compressed eart blocks in continuity with the walls which support a corrugated metal roof with an archetypal hut shape
- Medium edged roof : Protection of the crumbly clay walls from the rain
- Two slopes roof oriented towards the exterior of the modules

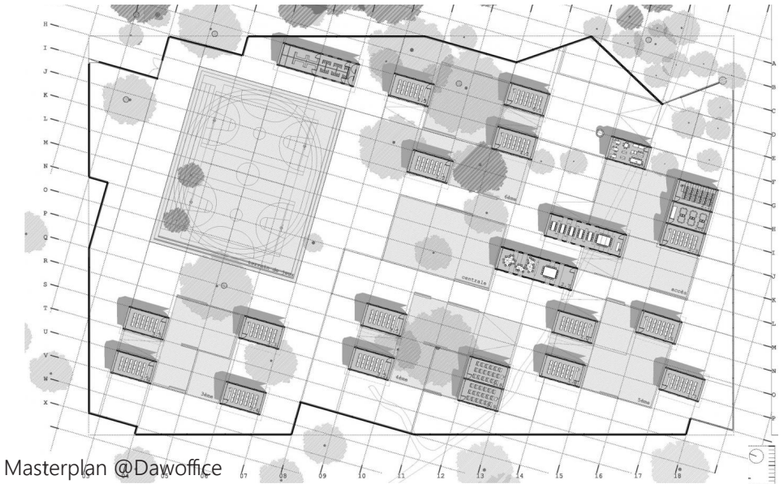
- Classrooms walls in hand pressed earth blocks of local clay, soil, and 8% cement : high thermal mass
- No glass window but vertical wood loovers on the whole height of the wall to ventilate and ensure a good air flow throughout the building
- Two wood lattice walls ensure the closing of the «awla»

- Natural ventilation : perforated wall and height
- Cooling properties : mud-bricks as main material
- Orientation towards the Est to cool down buildings with natural ventilation

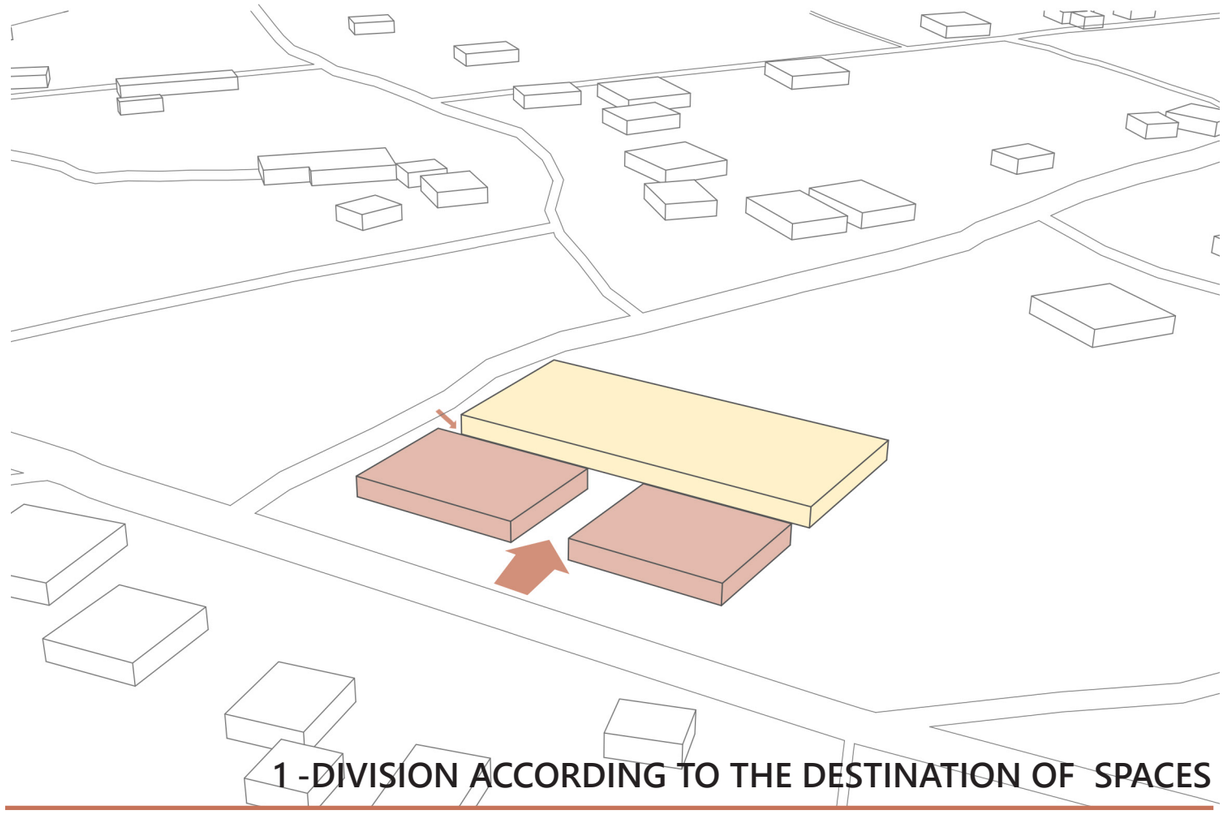
Key words:
Modules, Arrangement in grid, Orientation, Extansible, Hand pressed earth bricks, Vault, Vertical openings



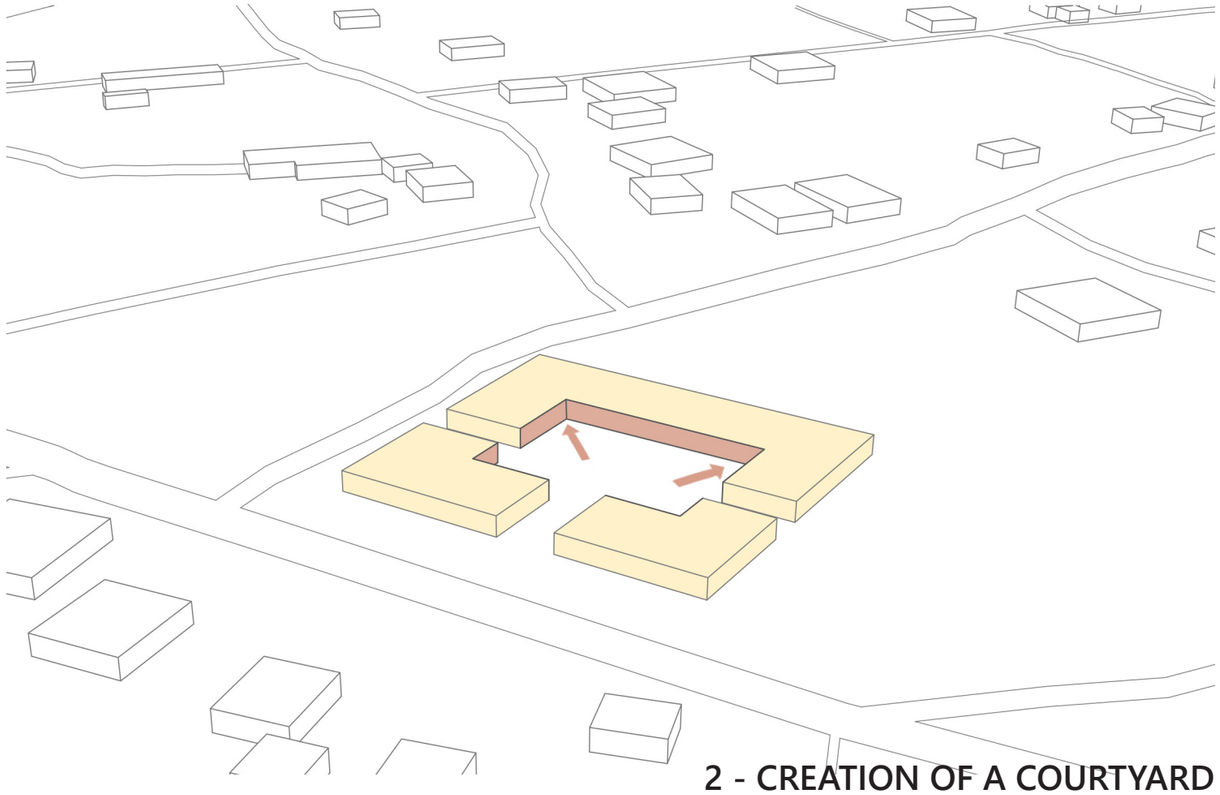
Section @ Dawoffice



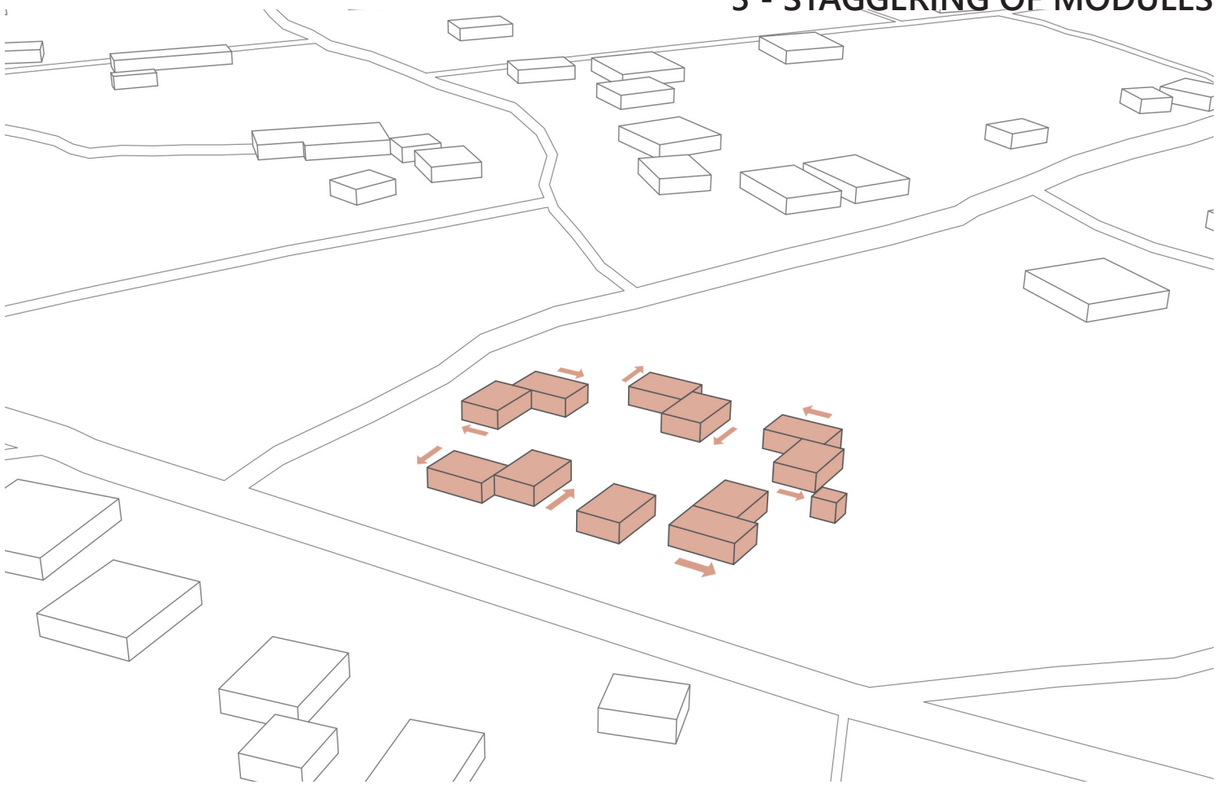
Masterplan @Dawoffice



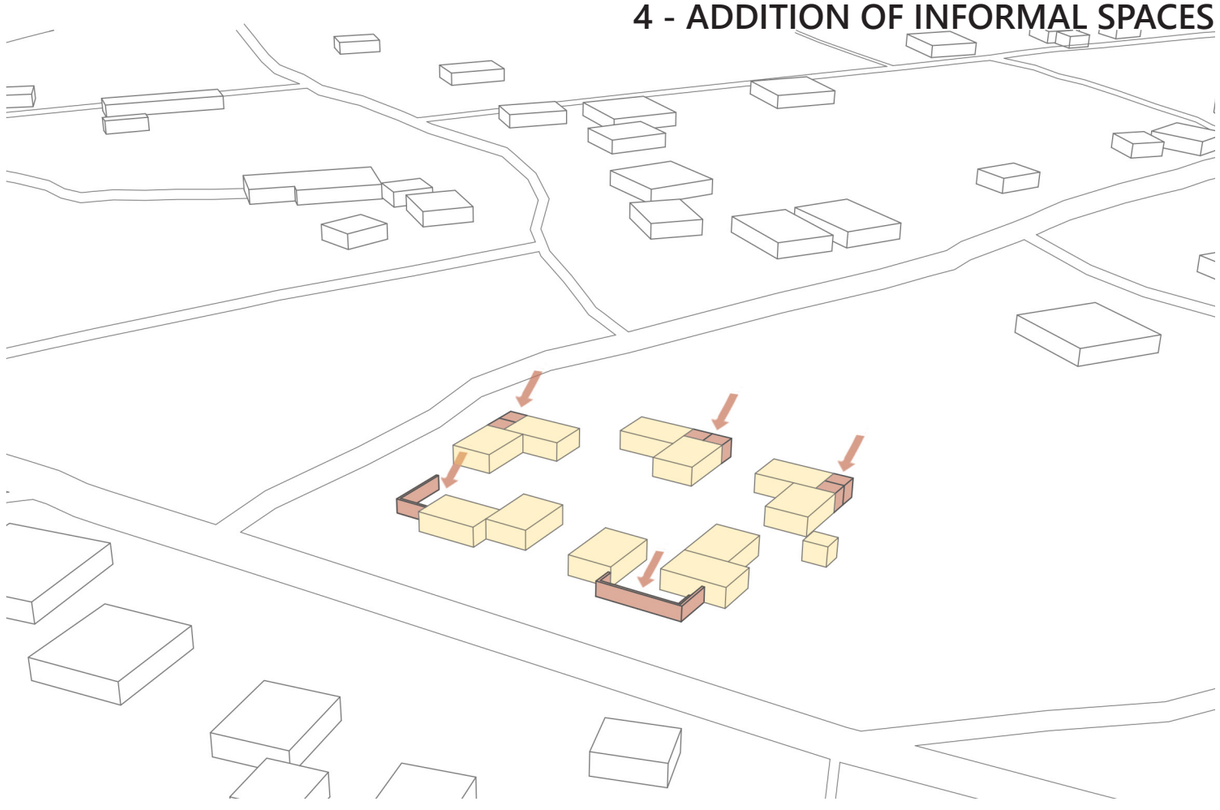
1 -DIVISION ACCORDING TO THE DESTINATION OF SPACES



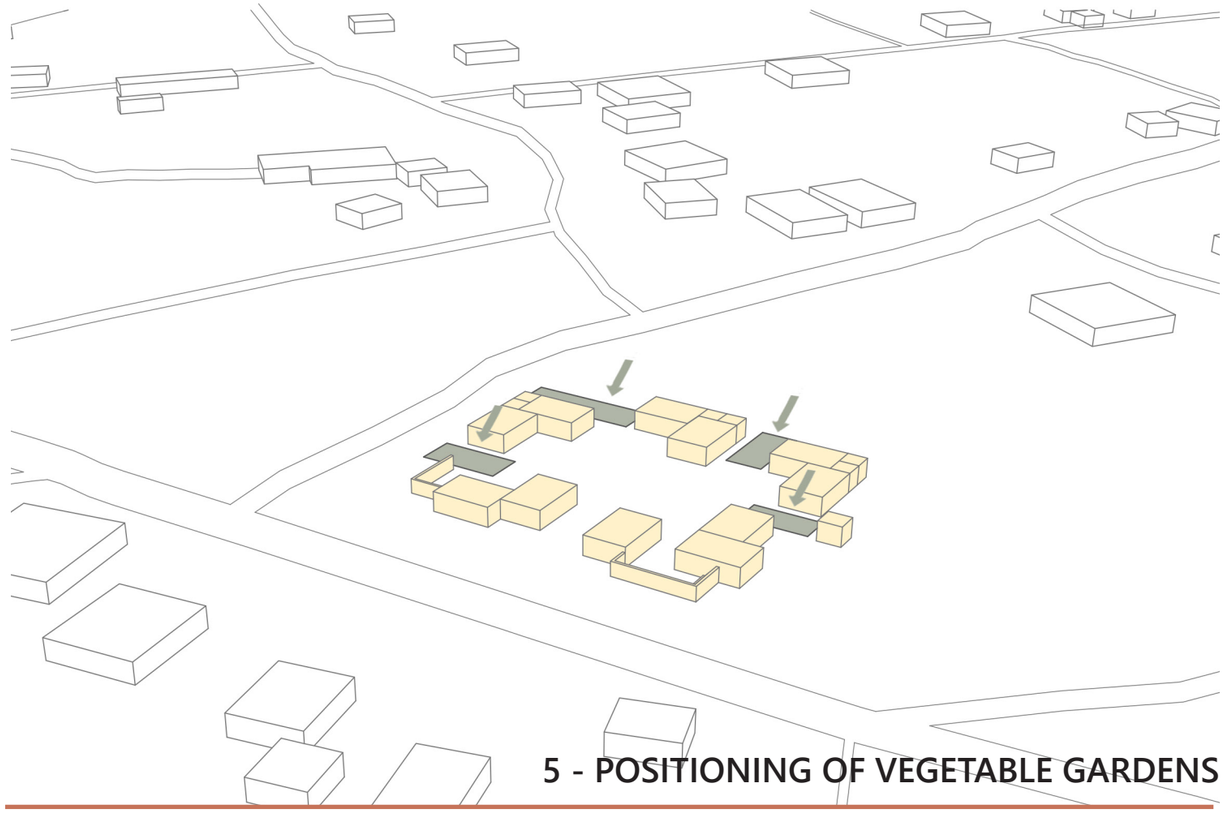
2 - CREATION OF A COURTYARD



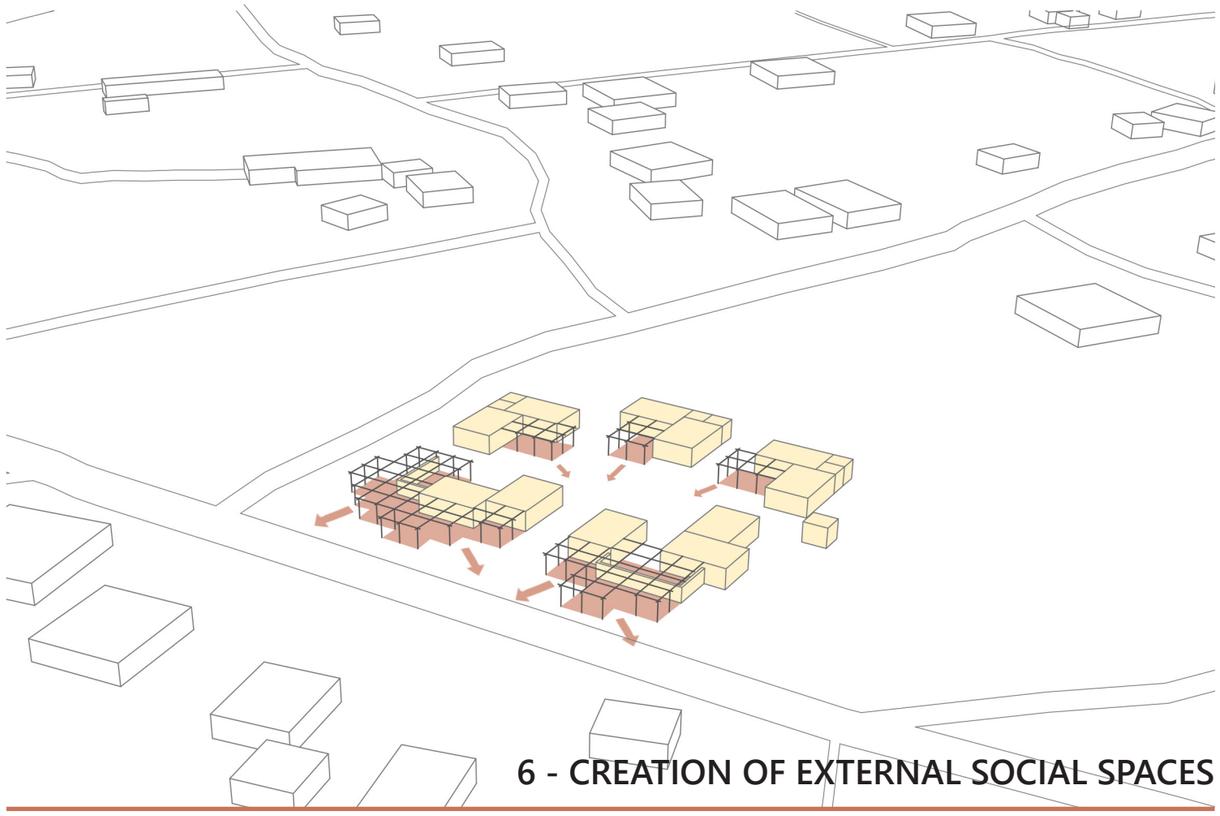
3 - STAGGERING OF MODULES



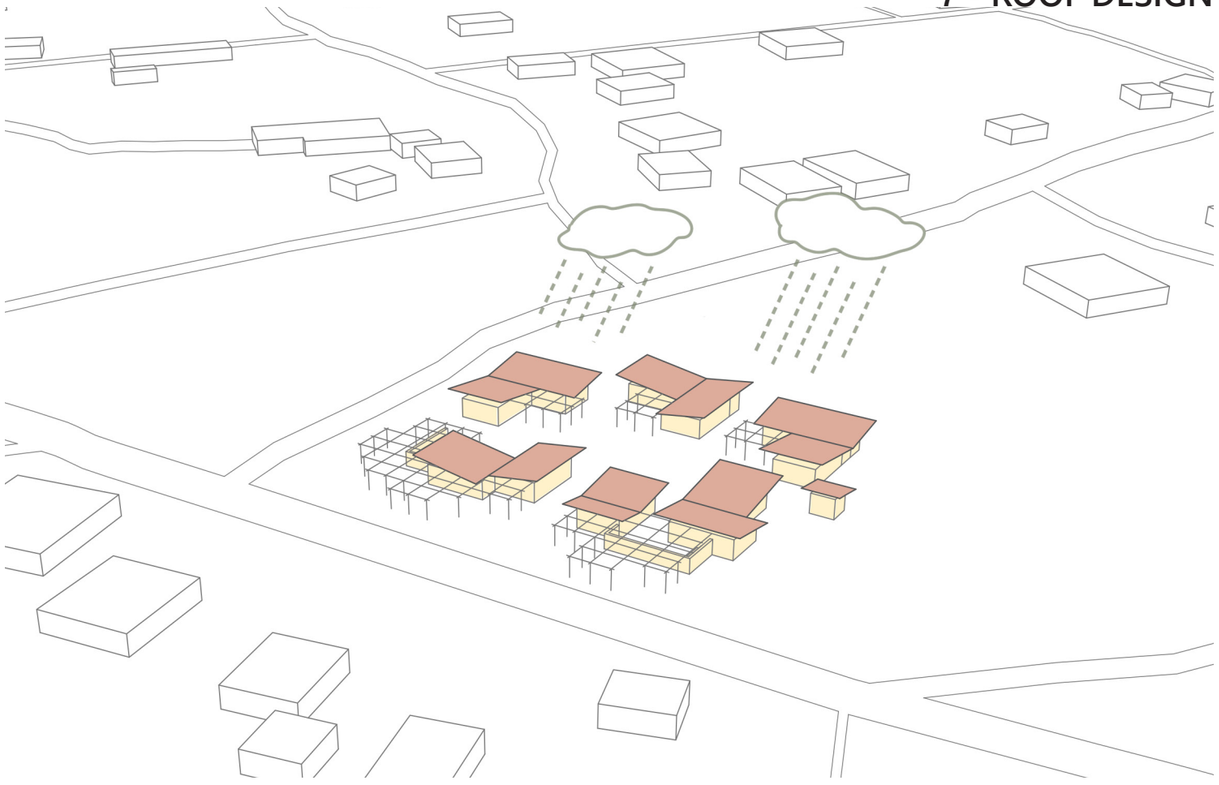
4 - ADDITION OF INFORMAL SPACES



5 - POSITIONING OF VEGETABLE GARDENS



6 - CREATION OF EXTERNAL SOCIAL SPACES



7 - ROOF DESIGN

8 - EXTENSION POSSIBILITIES

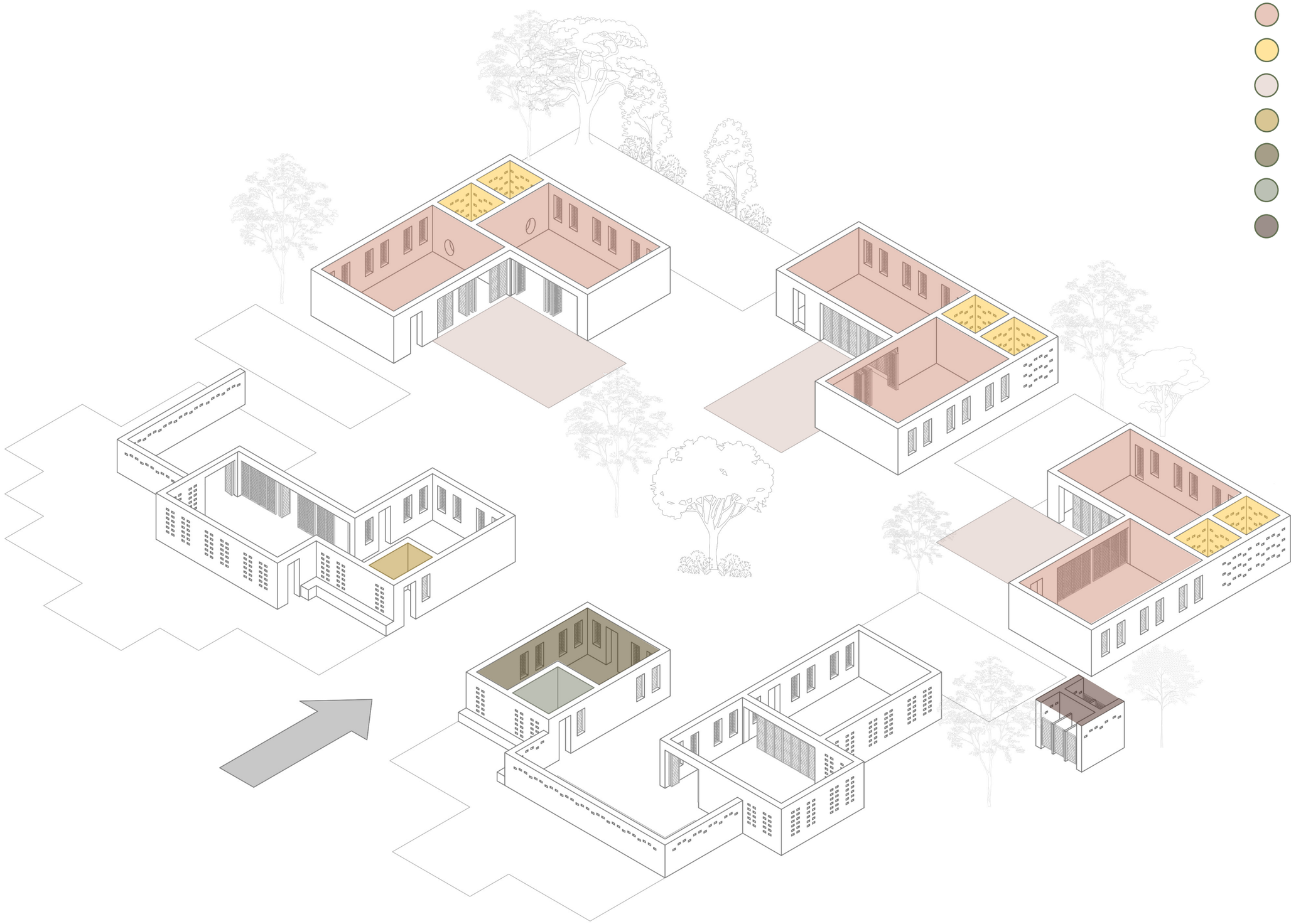

50 m

LEGEND :

1. Classroom
2. Secret room
3. Vegetable garden
4. Open classroom
5. Courtyard
6. Terrace
7. Cafeteria
8. Reception
9. Piazza
10. Teachers' meeting room
11. Stockagio
12. Sick room
13. External Auditorium
14. Laboratory
15. Ventilated pit toilets

N

0 1 2 5 10

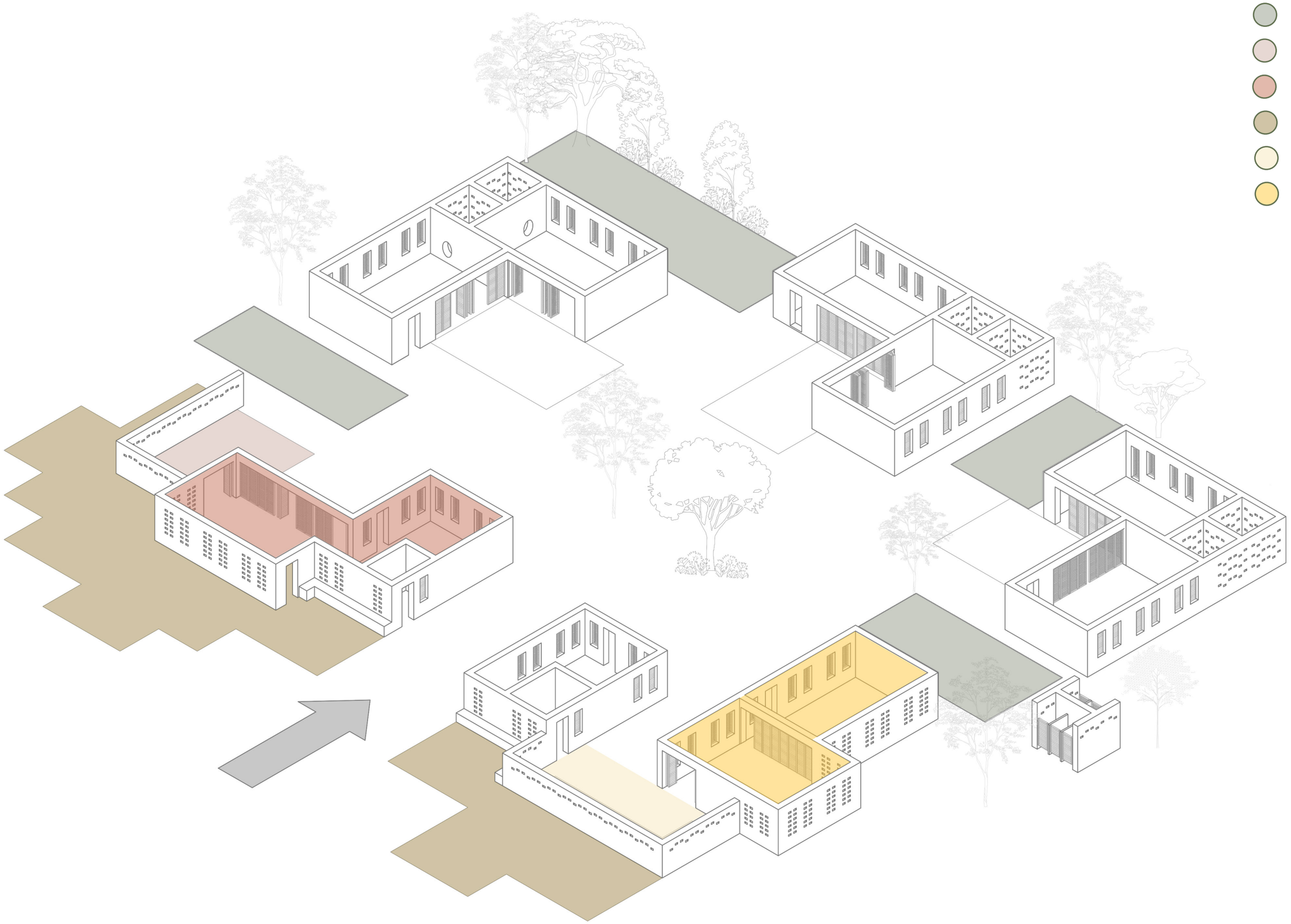


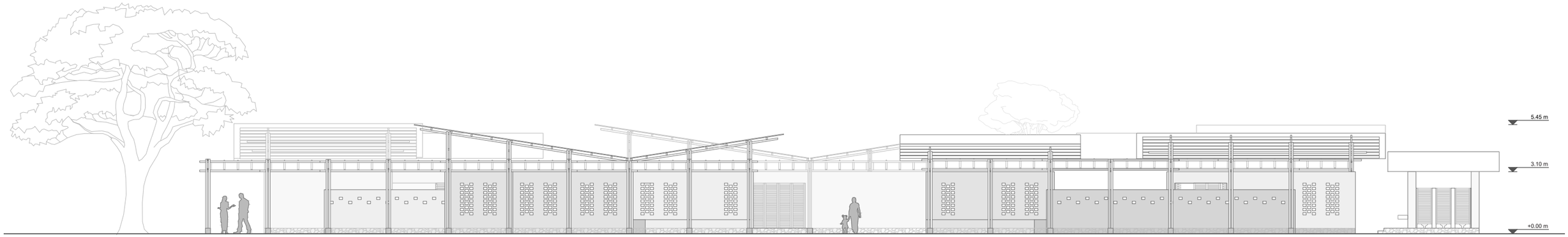
LEGEND

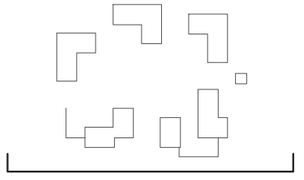
- Classrooms - 324 m²
- Secret rooms - 54 m²
- Open classrooms - 162 m²
- Reception - 5,7 m²
- Teachers room - 44,2 m²
- Sick room - 9,8 m²
- Toilets - 9 m²

LEGEND

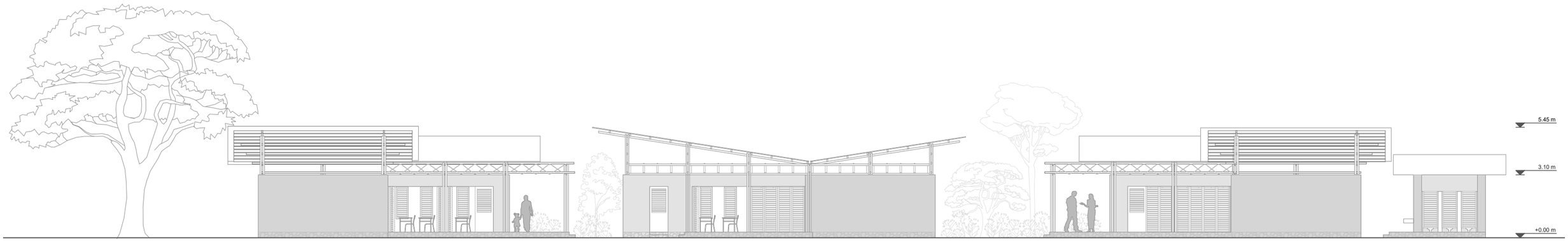
- Vegetable gardens - 306 m²
- Terrace - 54 m²
- Canteen - 102,3 m²
- Piazza - 351 m²
- External Auditorium - 72 m²
- Laboratory - 108 m²

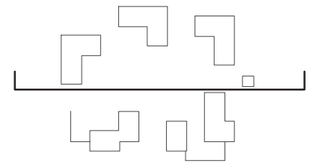




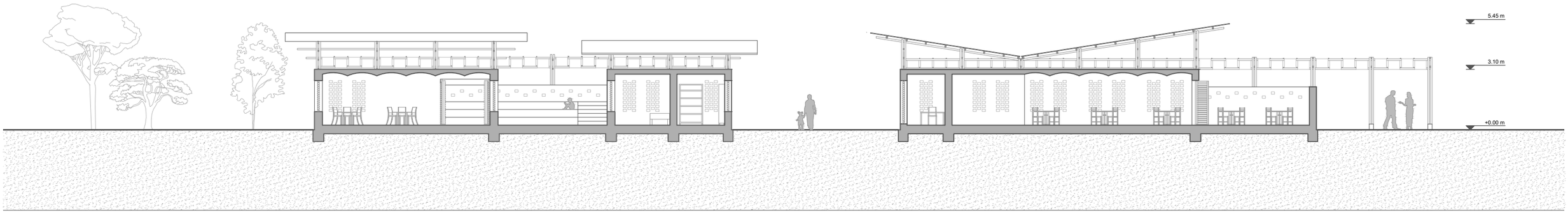


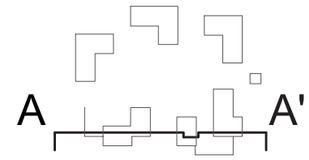
ENTRANCE ELEVATION - 1:200



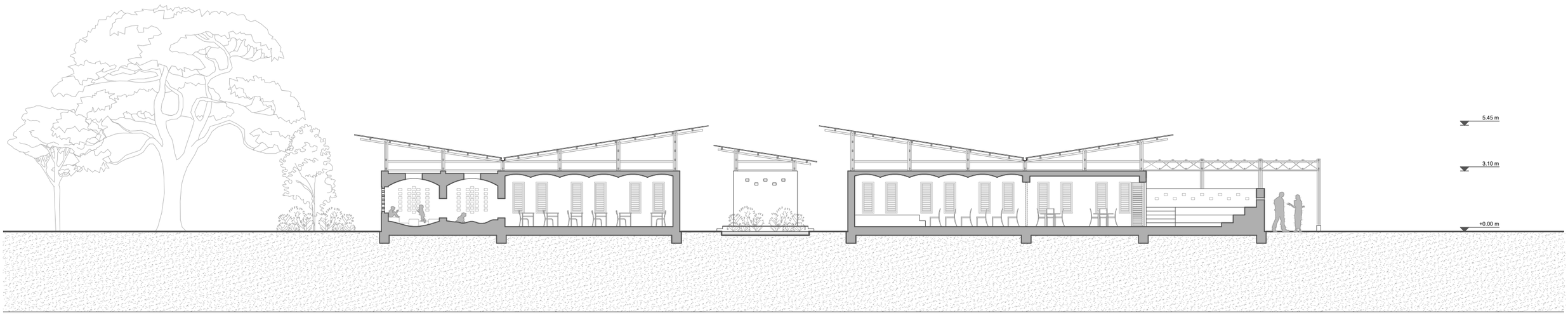


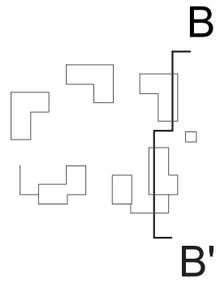
COURTYARD ELEVATION - 1:200





SECTION AA’ - 1.200





SECTION BB’ - 1.200


ROOTS

VI. CONSTRUCTION DETAILS

R 01

Sheet metal roof

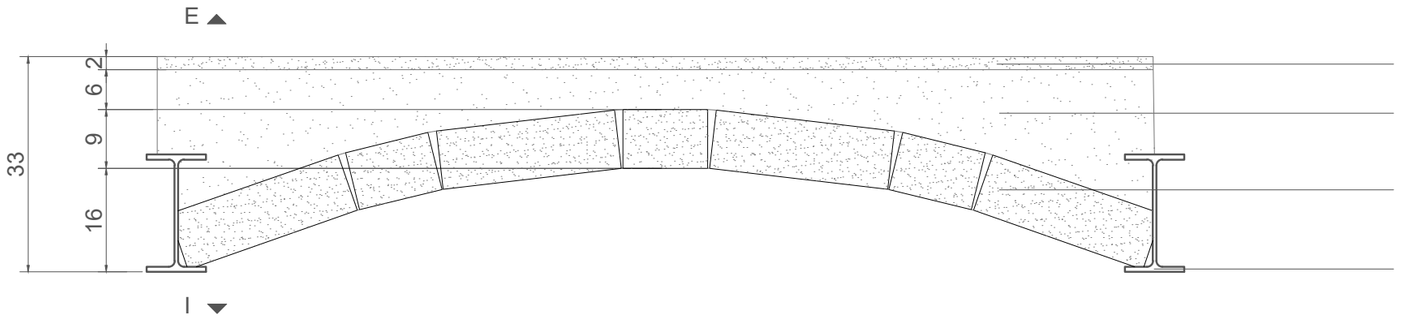
Corrugated iron roof sheet, Thickness : 0.75 mm

Samba wood support beam, 12 x 6 cm

Samba wood beam, 12 x 6 cm

C 01

Jack arches ceiling
U-value : 1,95 W/(m².K)



Loam mortar made from earth, lime-casein stabilizer and additional sand, Thickness : 2 cm

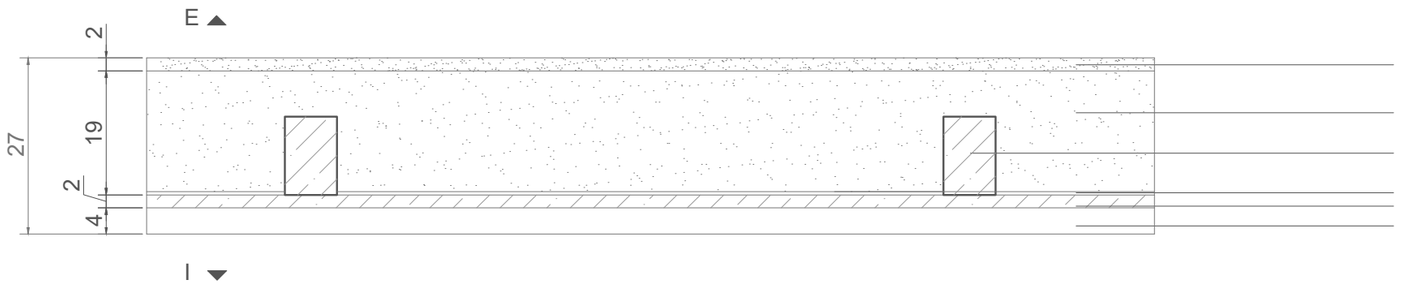
Clay-straw lightweight loam, Thickness : 10 cm

Compressed earth bricks, 29.5 x 14 x 9 cm

Iron IPE 180 beam, Height : 18 cm

C 02

Ceiling of the secret rooms
U-value : 1,48 W/(m².K)



Loam mortar made from earth, lime-casein stabilizer and additional sand, Thickness : 2 cm

Clay-straw lightweight loam, Thickness : 10 cm

Samba wood beams, 8 x 12 cm

Straw matting, Thickness : 0.5 cm

Samba wood boards, Thickness : 2 cm

Clay plaster, Thickness : 4 cm

Compressed earth bricks

The bricks are made from sifted earth, 15% of fine gravel in volume, and 0.5% of straw in mass. The details of the composition are found in the experimental research section.

Lightweight straw loam

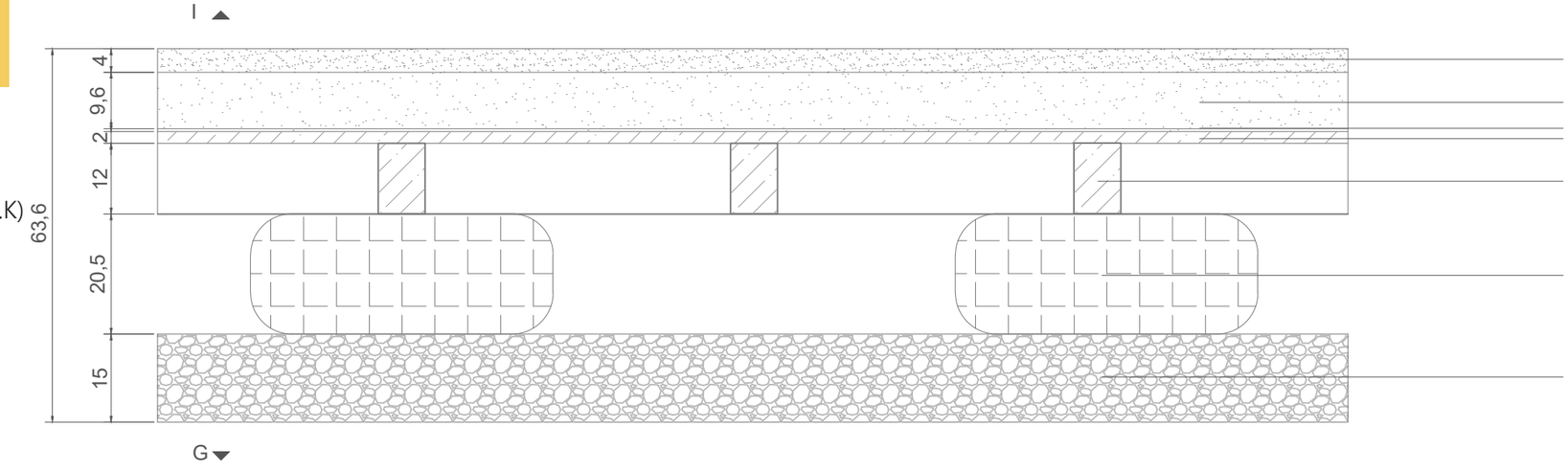
The mixture of straw and loam has a density around 700 kg/m³. Usually employed in the wattle-and-daub technique, it is not loadbearing but it is an insulating lightweight filling material.

Stabilized loam mortar

A solid and waterproof surface can be obtained by stabilizing earth with lime-casein glue (made from hydraulic lime and fat-free white cheese) with additional chalk.

F 01

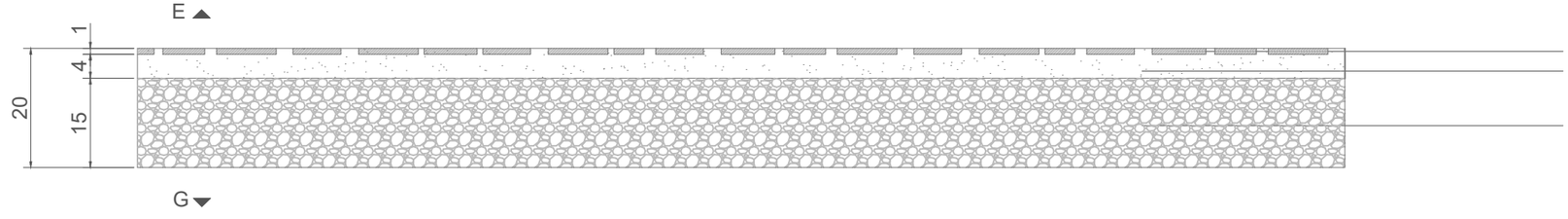
Raised floor
U-value : 1,26 W/(m².K)



Loam mortar made from earth, lime-casein stabilizer and additional sand, Thickness : 4 cm
Clay-straw lightweight loam, Thickness : 10 cm
Straw matting, Thickness : 0.5 cm
Samba wood boards, Thickness : 3 cm
Samba wood beams, 8x12 cm
Pneumatics filled with earth and stone, Height : 20,5 cm
Compacted gravel, Height : 15 cm

F 02

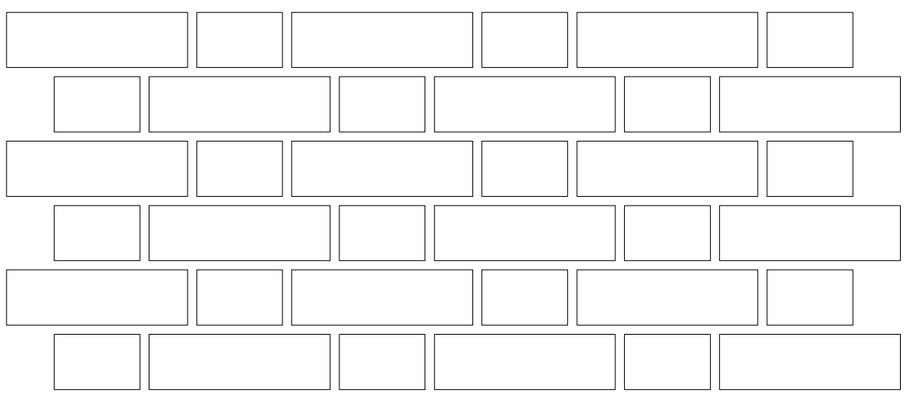
Pathways



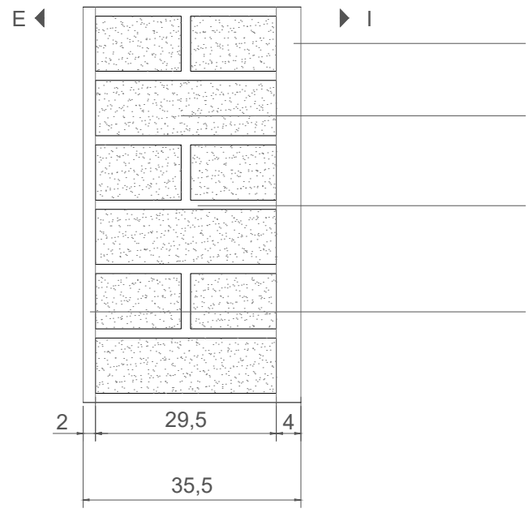
Repurposed broken tiles, Thickness : 1 cm
Stabilized earth with cement, Thickness : 5 cm
Gravel, Thickness : 15 cm

W 01

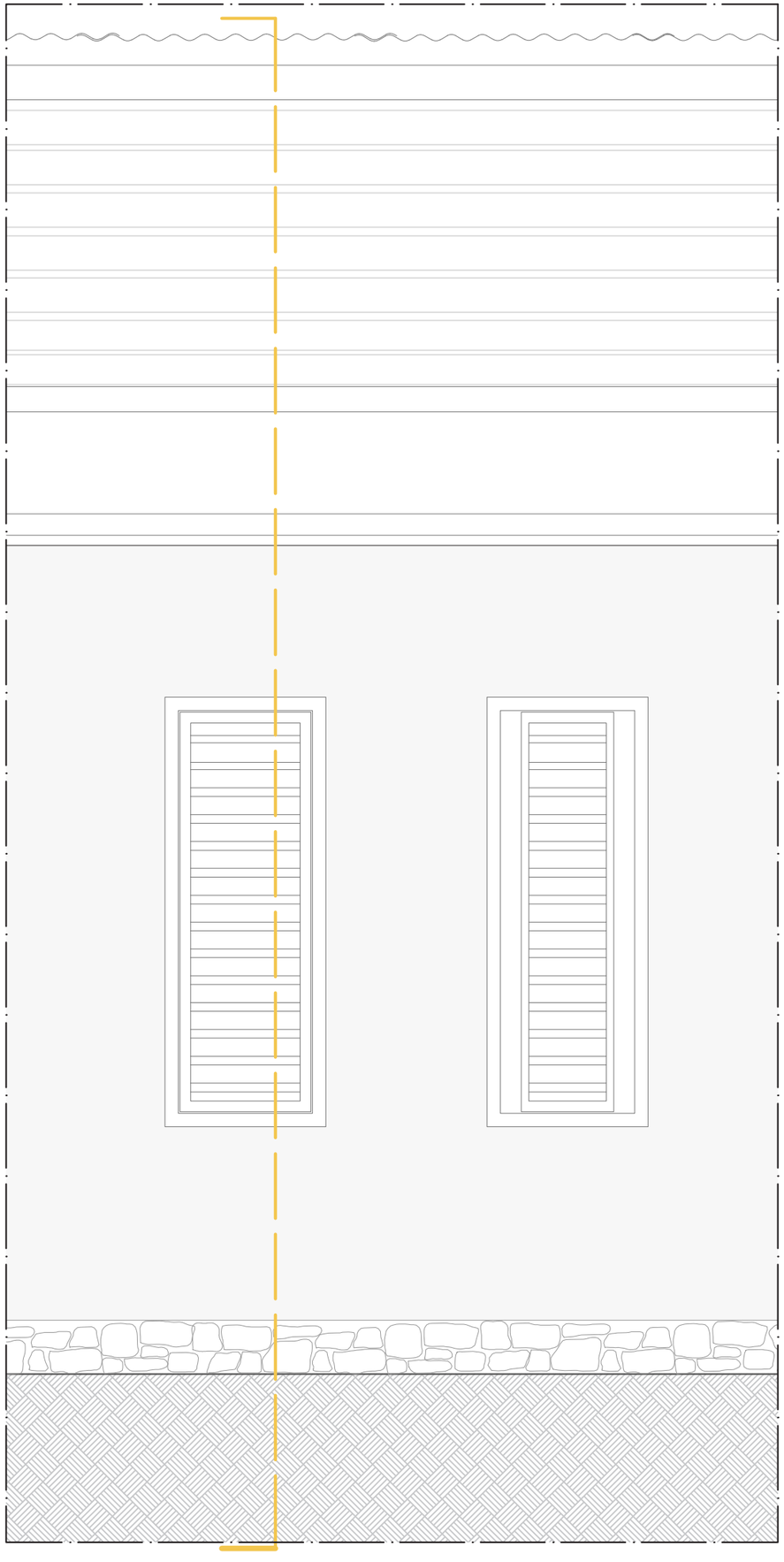
Earth bricks wall
U-value : 2,41 W/(m².K)



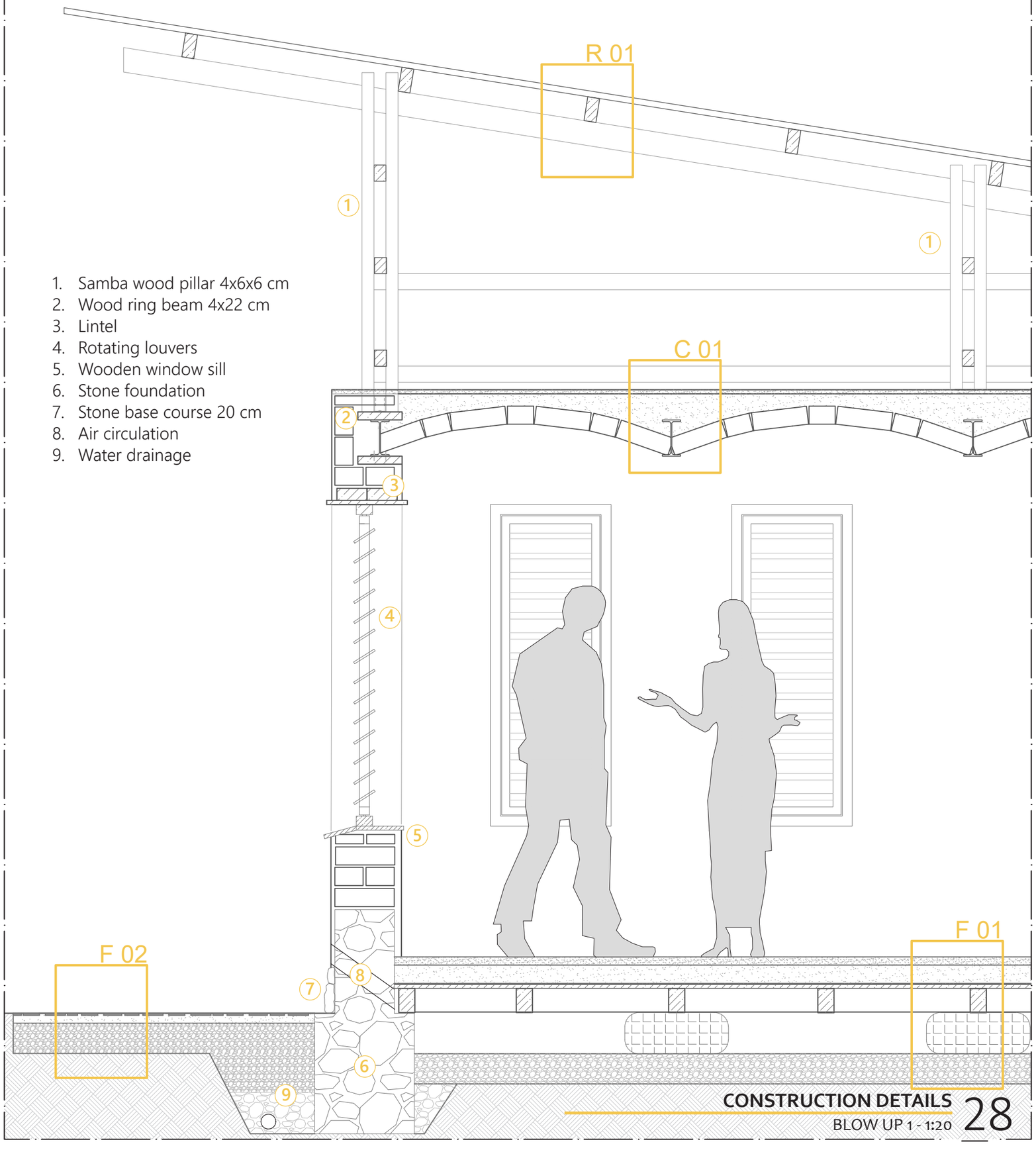
Flemish bond pattern

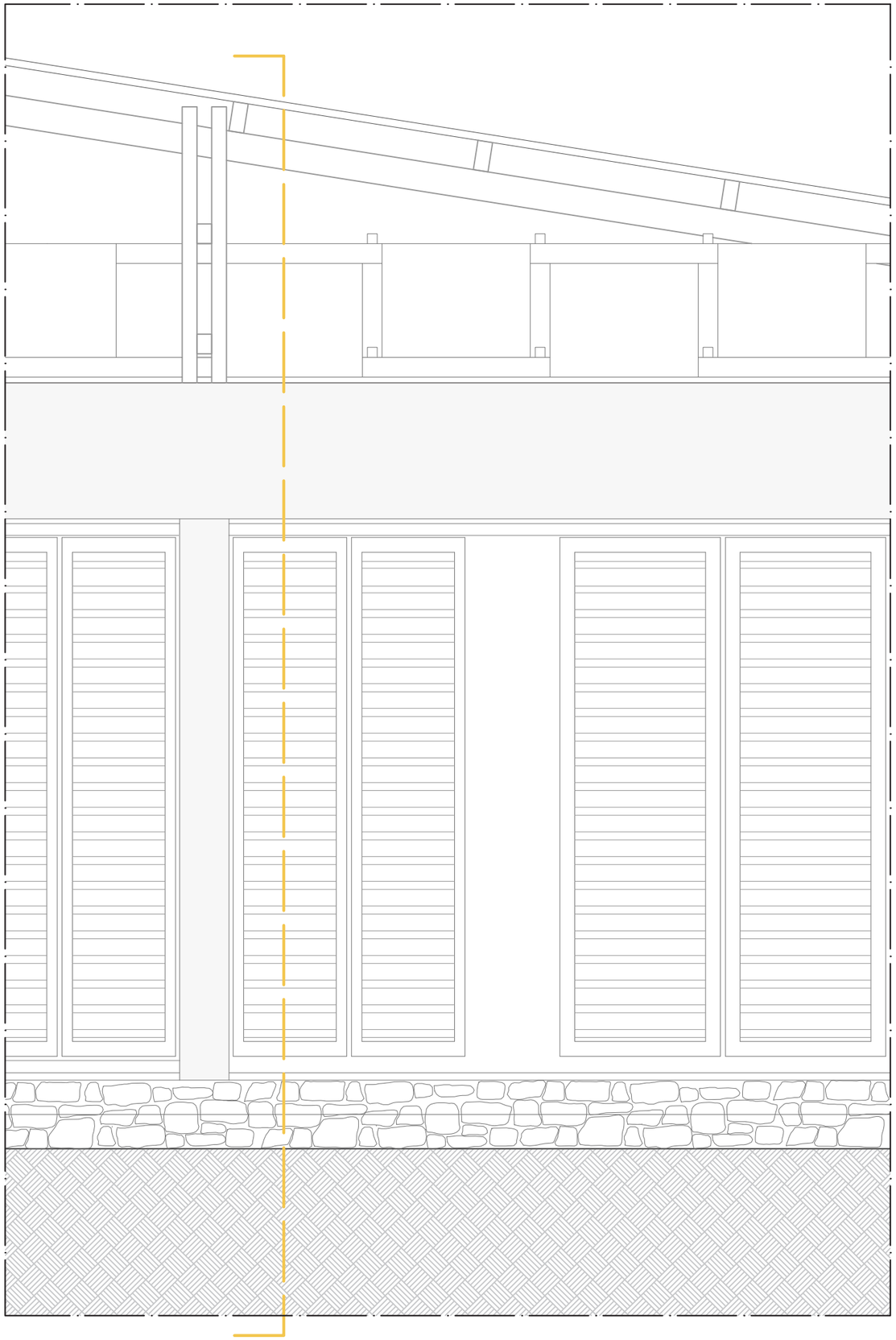


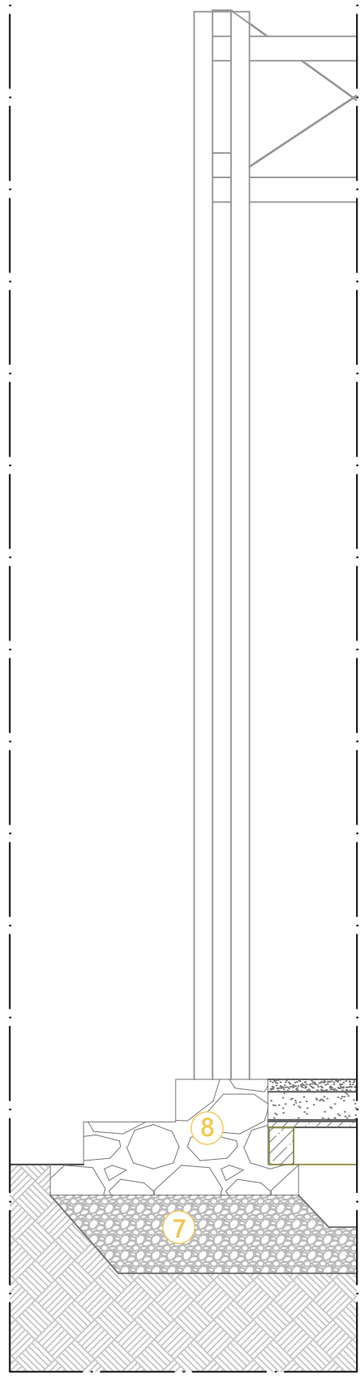
Clay plaster, Thickness : 4 cm
Compressed earth bricks in flemish bond pattern, 23.5 x 11 x 9 cm
Loam mortar, Thickness 1,5 cm
Lime-clay plaster, Thickness 2 cm

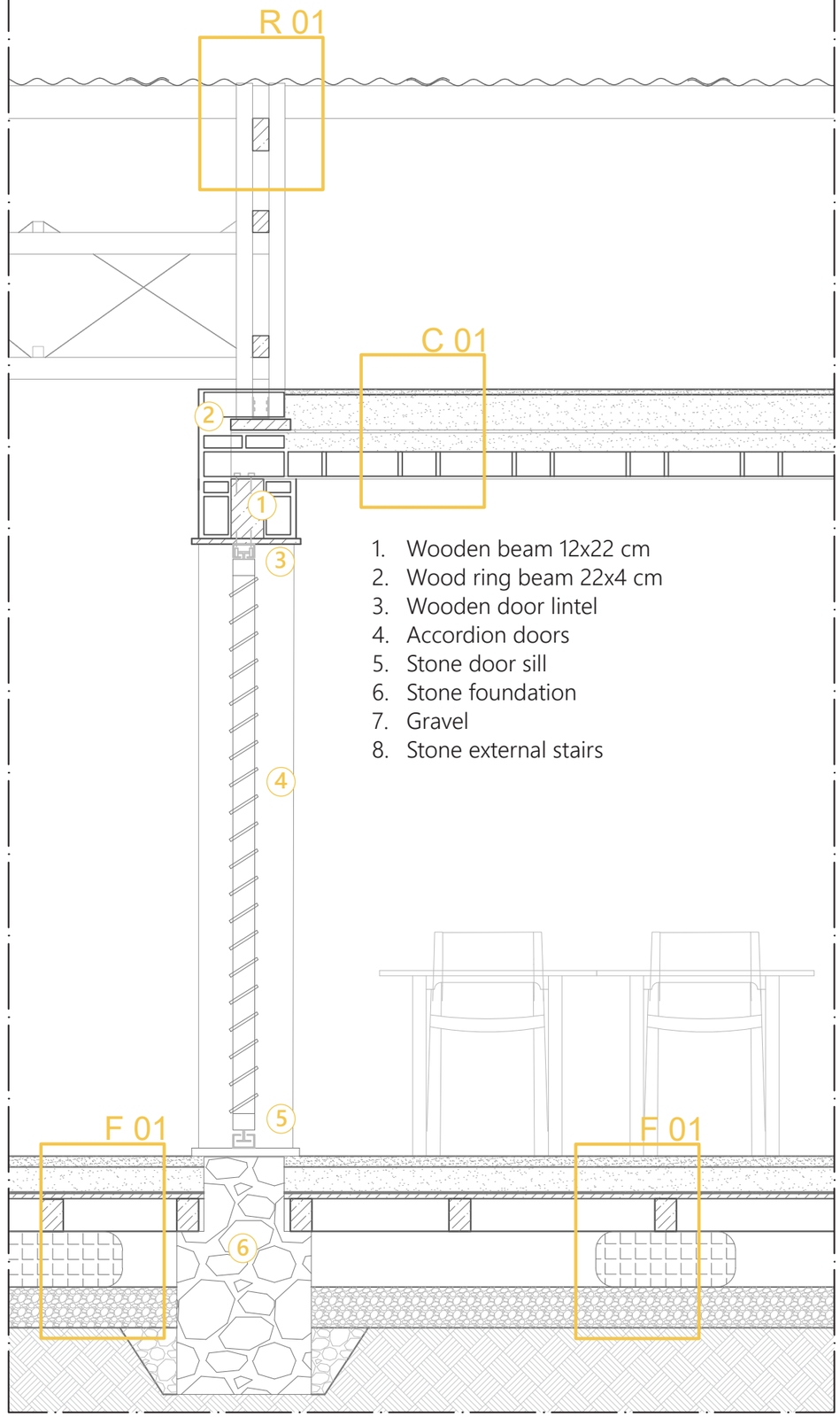


1. Samba wood pillar 4x6x6 cm
2. Wood ring beam 4x22 cm
3. Lintel
4. Rotating louvers
5. Wooden window sill
6. Stone foundation
7. Stone base course 20 cm
8. Air circulation
9. Water drainage



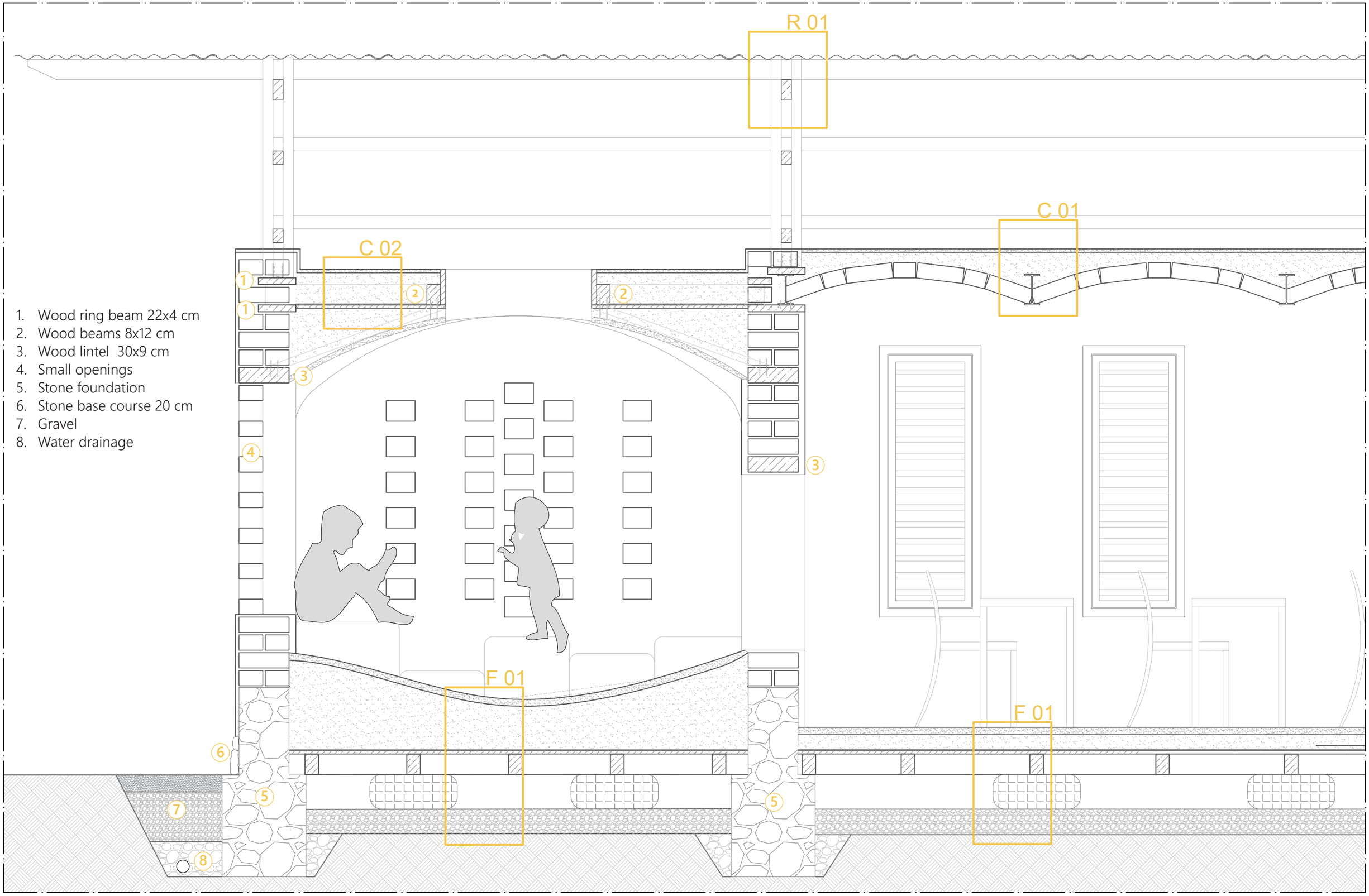






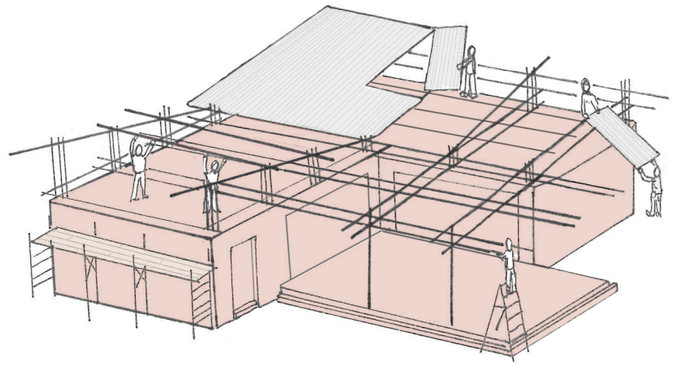
1. Wooden beam 12x22 cm
2. Wood ring beam 22x4 cm
3. Wooden door lintel
4. Accordion doors
5. Stone door sill
6. Stone foundation
7. Gravel
8. Stone external stairs

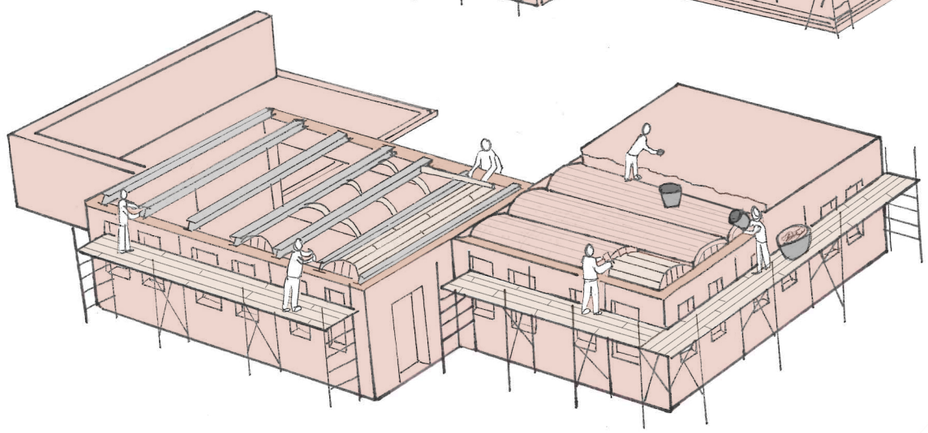
1. Wood ring beam 22x4 cm
2. Wood beams 8x12 cm
3. Wood lintel 30x9 cm
4. Small openings
5. Stone foundation
6. Stone base course 20 cm
7. Gravel
8. Water drainage



5. ROOF

- Fabrication of pillars
- Hooking the joists
- Metal sheets positioning
- Fixing downpipes
- Manufacture of pergolas



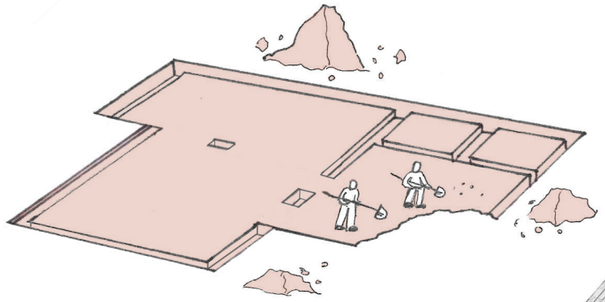


4. CEILING

- Beams installation
- Formworks positioning
- Masonry on vaults
- Filling with lightened earth
- Plastering

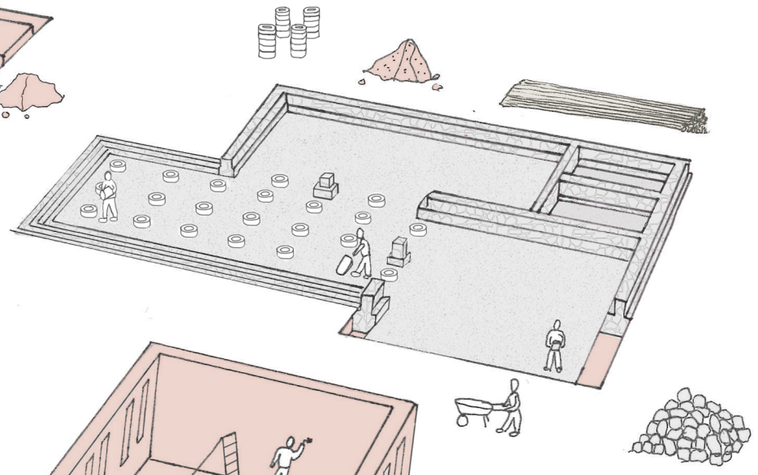
1. EXCAVATION

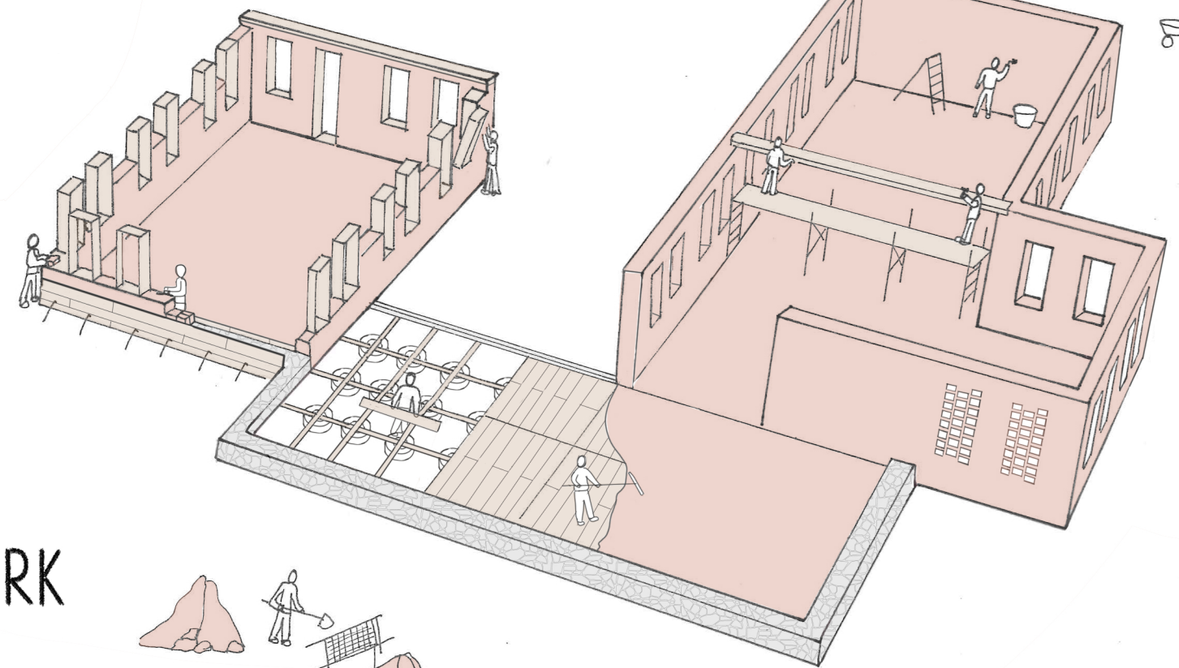
- Excavation
- Earth Storage



2. FOUNDATIONS

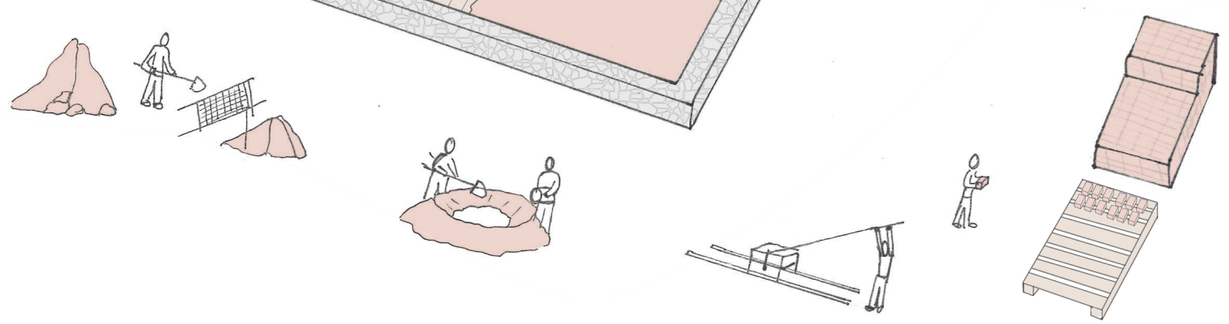
- Stone foundations
- Gravel placement
- Placing and filling tyres



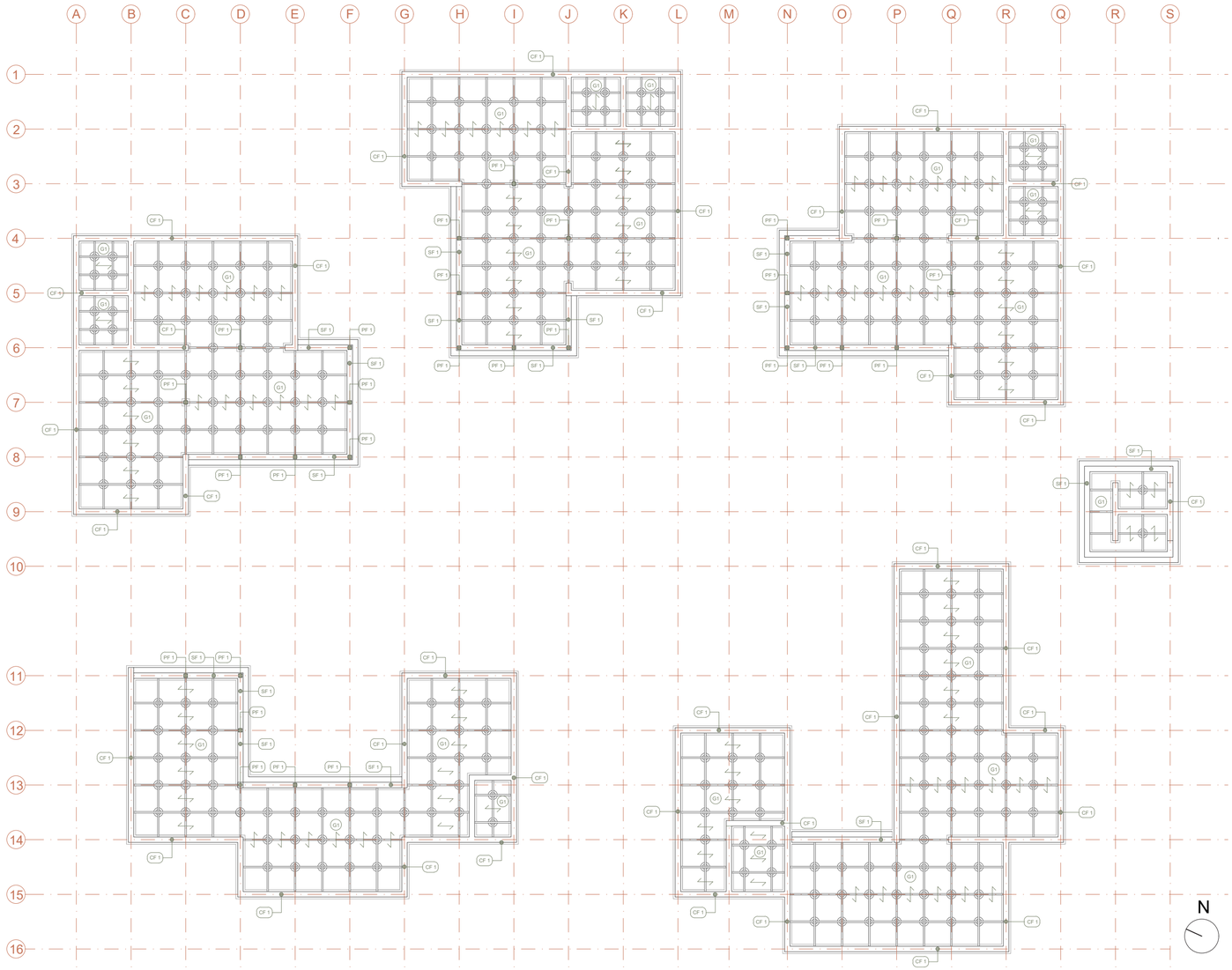


3. BRICKWORK

- Bricks production
- Masonry
- Floor installation
- Structure docking
- Plastering

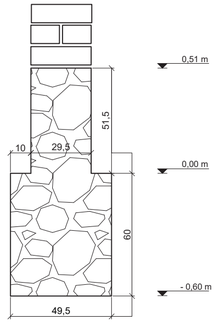


VII. STRUCTURAL DESIGN



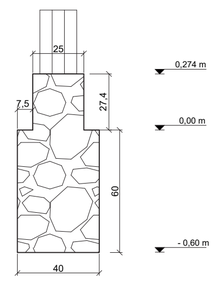
LEGEND 1:20 :

CF 1



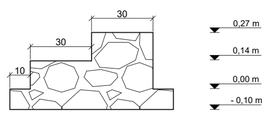
Continuous foundation in laterite stones

PF 1



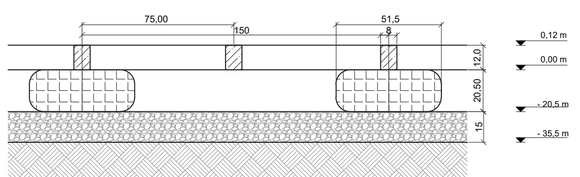
Punctual foundation in laterite stones

SF 1

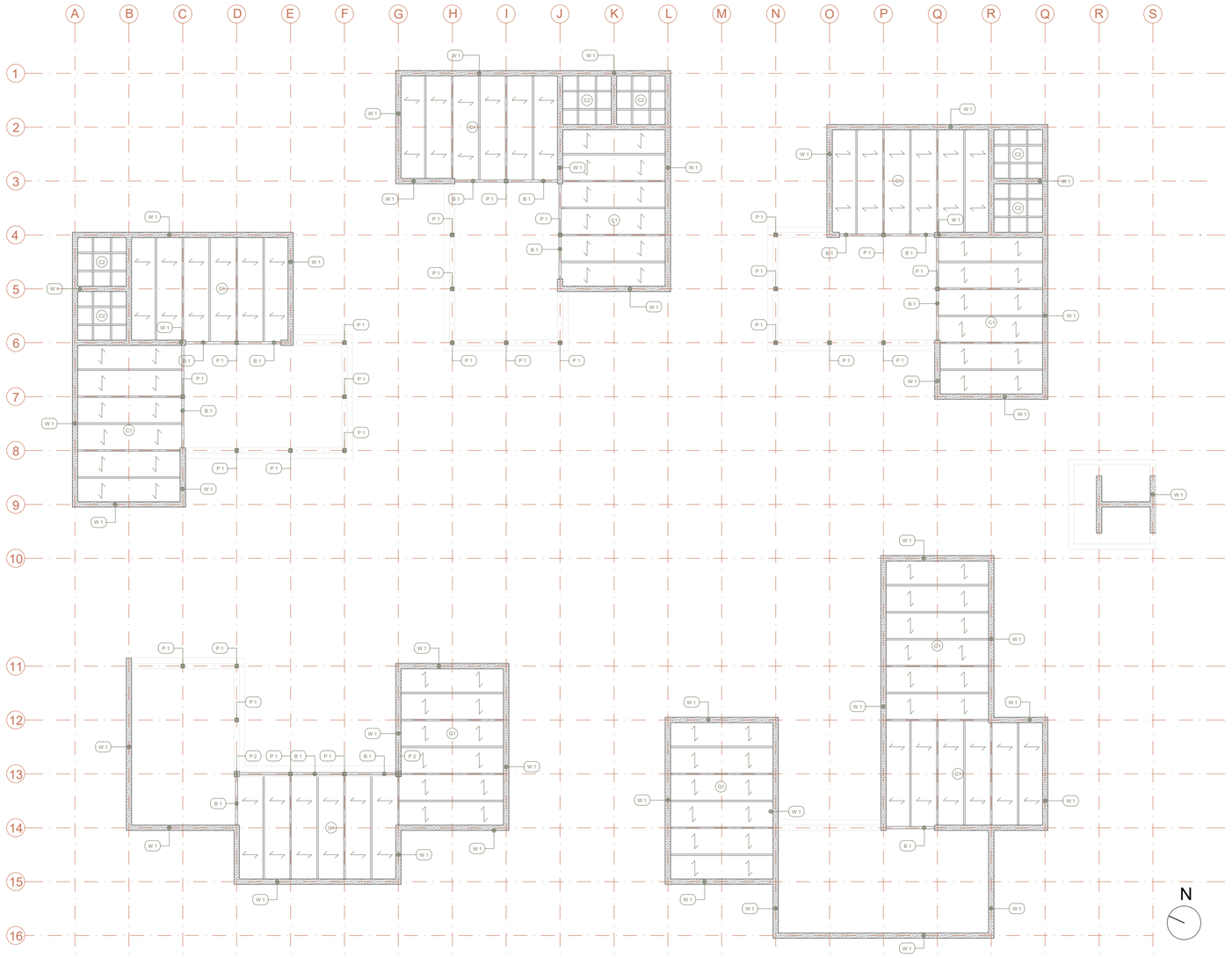


Stairs foundation in laterite stones

G1



Ground floor in pneumatics and gravels wooden beam system



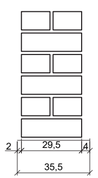
LEGEND 1:20 :

B 1 — Samba wood beam 12x22 cm

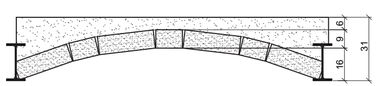
P 1 — Samba wood pillars system made of four wood pillars of 6x6 cm

P 2 — Samba wood pillar 20x20 cm

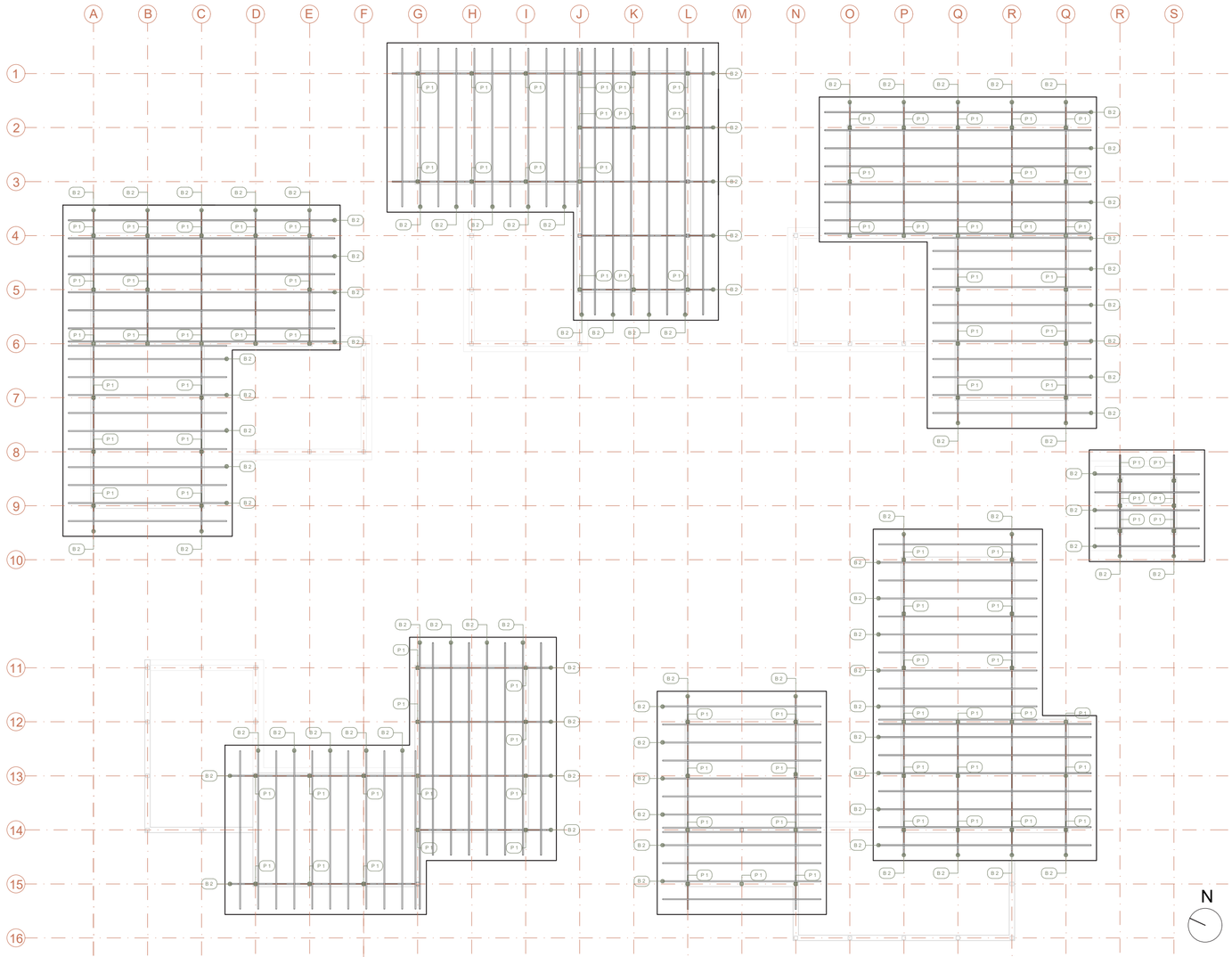
W 1 — Wall in compressed raw earth bricks th. 29.5 cm



C1 — Jack arches ceiling in IPE 180 beam and raw earth bricks



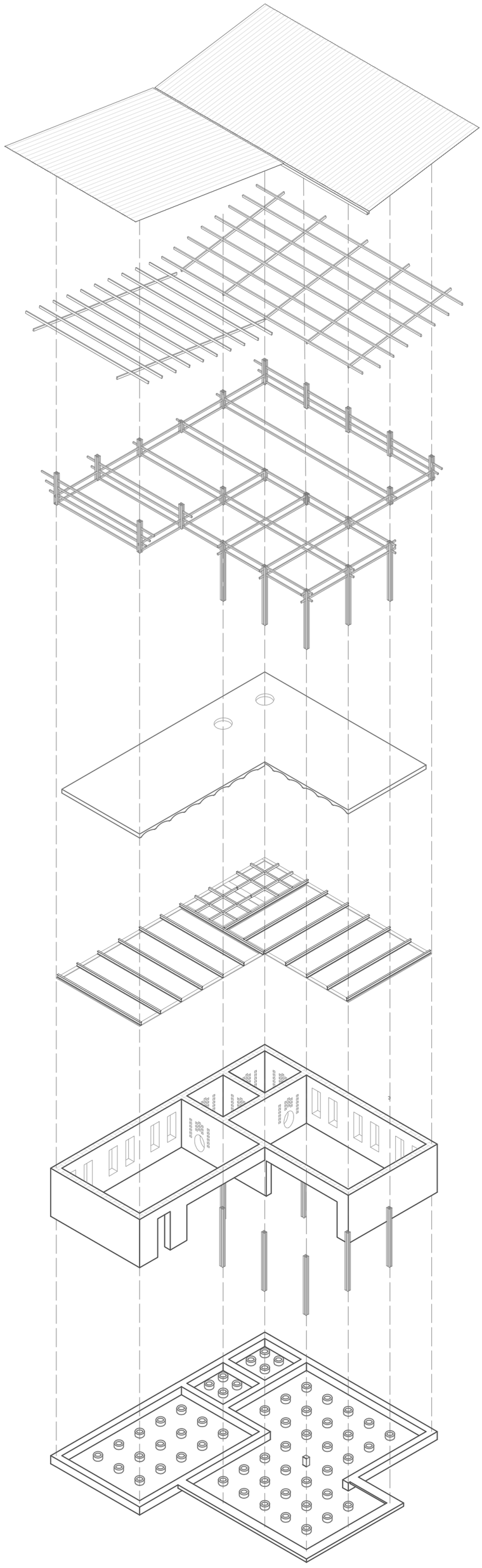
C2 — Formwork ceiling in wooden beam system



LEGEND 1:20 :

B 2 — Samba wood beam 12x22 cm

P 1 — Samba wood pillars system made of four wood pillars of 6x6 cm



Roofing : Corrugated sheet metal

Roof support : Wooden beam structure

Roof structure : Wooden pillars and horizontal grid

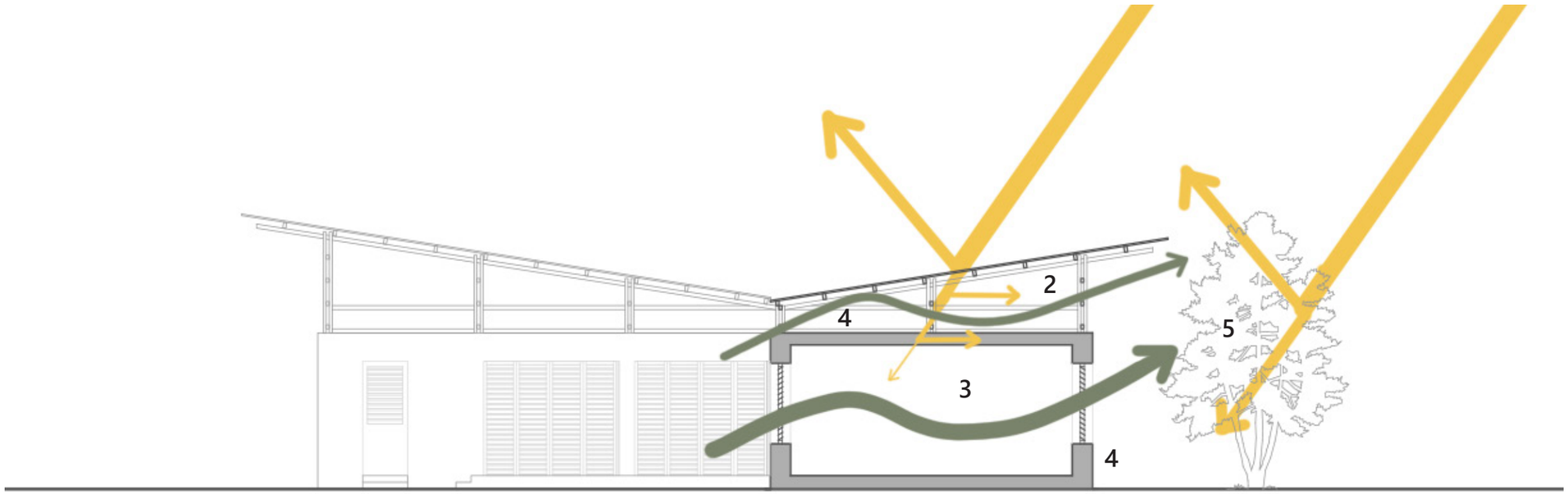
Ceiling : compressed bricks Jack arches and lightweight strawloam

Ceiling support : metallic IPE beams and coffered ceiling

Vertical structure: Compressed earth bricks masonry and wooden pillars

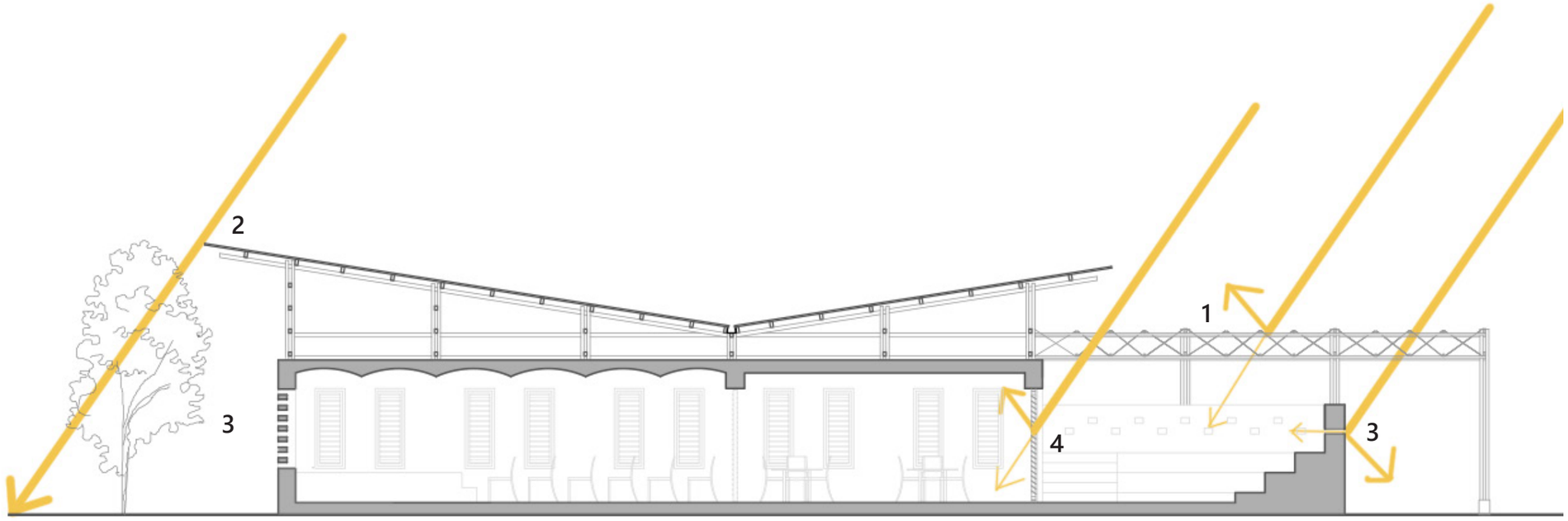
Foundation : Stone foundations and repurposed tyres filled with earth and gravels

VII. PASSIVE DESIGN



PASSIVE STRATEGIES FOR THERMAL COMFORT

1. Orientation of the facades
2. Double roof
3. Natural ventilation
4. Hygrothermal regulation by raw earth
5. Vegetation and external shading

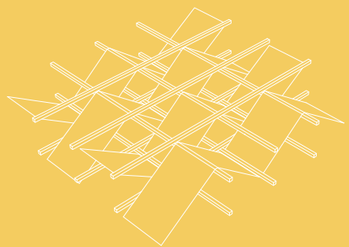


PASSIVE STRATEGIES FOR VISUAL COMFORT

1. Shading by pergolas and vegetation
2. Roof overhang
3. Small openings on strategic facades
4. Adjustable louvers

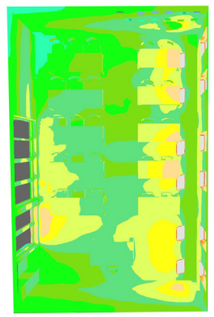
SIMPLE OPENINGS

PERGOLAS WITH FABRICS

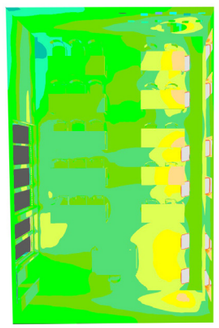


PERGOLAS AND ADAPTED LOUVERS

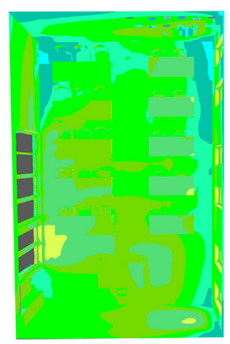
CLASSROOM - 15 APRIL 10am
Clear sky



ai = 1382 lux

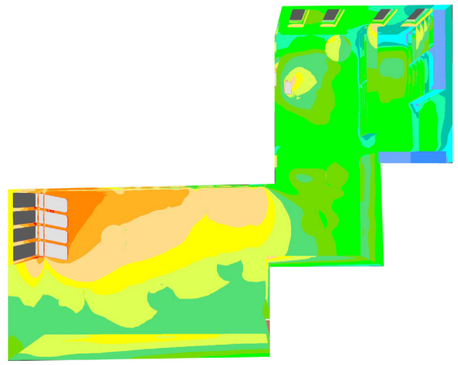


ai = 1320 lux

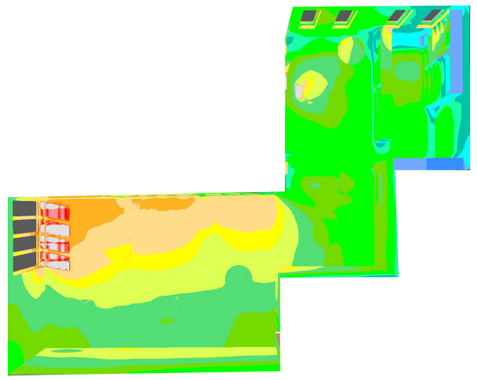


ai = 306 lux

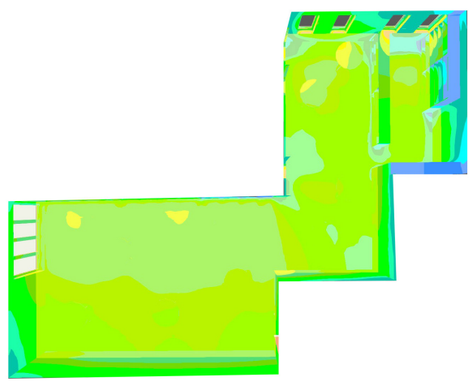
CAFETERIA - 15 APRIL 12am
Clear sky



ai = 1335 lux

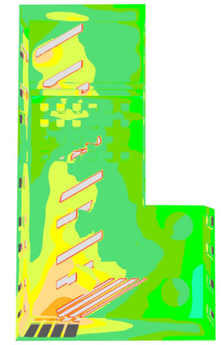


ai = 816 lux

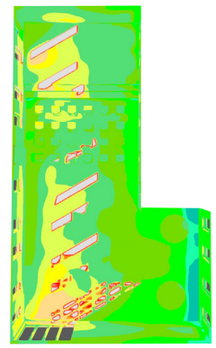


ai = 268 lux

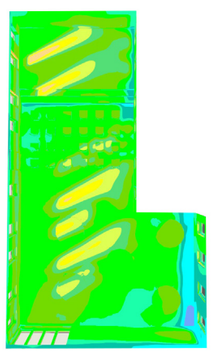
LABORATORY - 15 APRIL 10am
Clear sky



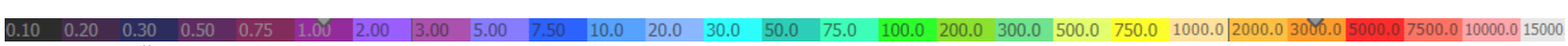
ai = 1816 lux



ai = 1472 lux



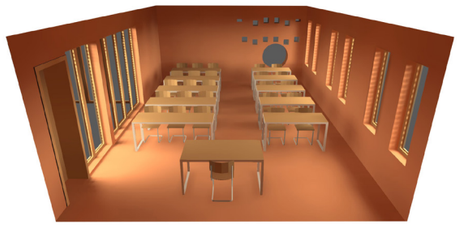
ai = 315 lux

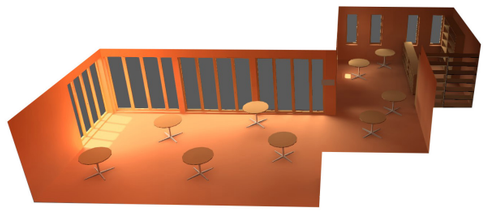


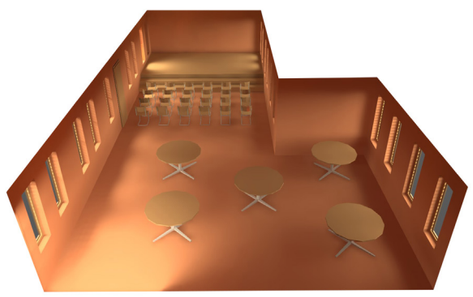
ai : average illuminance

15 APRIL 12am - clear sky

BEFORE OPTIMIZATION







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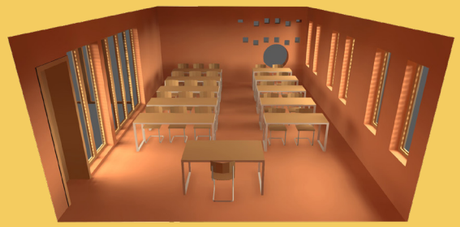
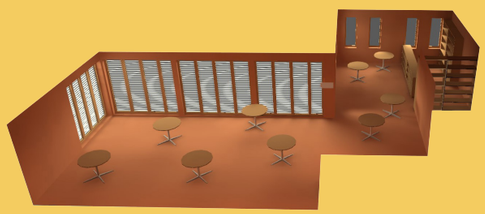
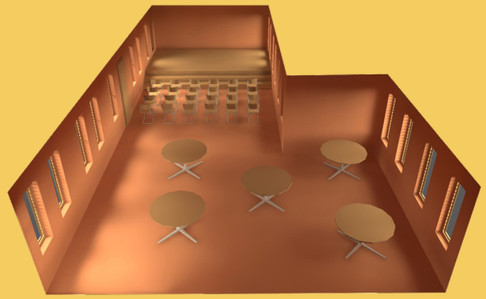
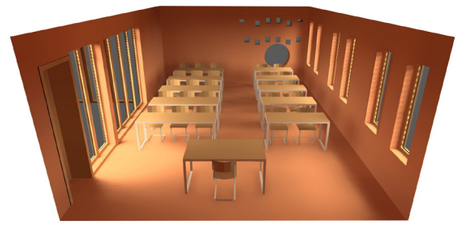


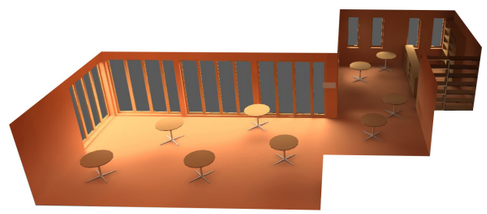


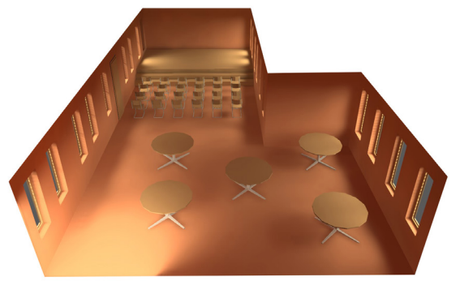


15 AUGUST 12am - overcast sky

BEFORE OPTIMIZATION







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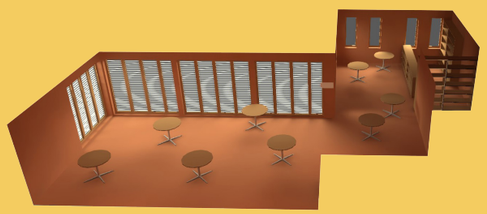
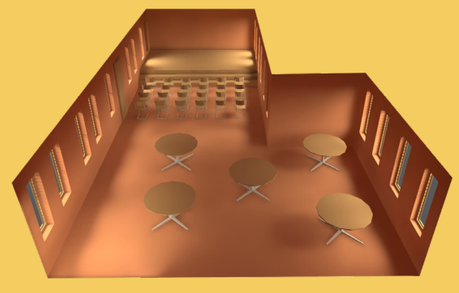
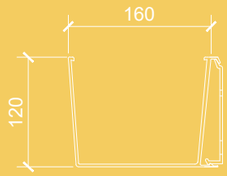




RAINWATER COLLECTION

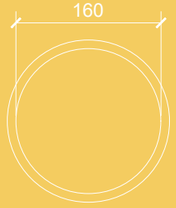
The collection of rainwater is an important feature of the project. Protecting the buildings from the tropical rain season was a challenging aspect in the design of the school. The water collection will allow some direct water supply for a better hygiene of students and staff alike. The excess rainwater will also be of used in the cultivation of the multiple vegetable gardens to ensure food production along the year. The rainwater collection system was dimensioned according to the local rain intensity and the daily use of the buildings. Galvanized steel pipes were preferred for aesthetic reasons, while cheaper PVC pipes were used underground.



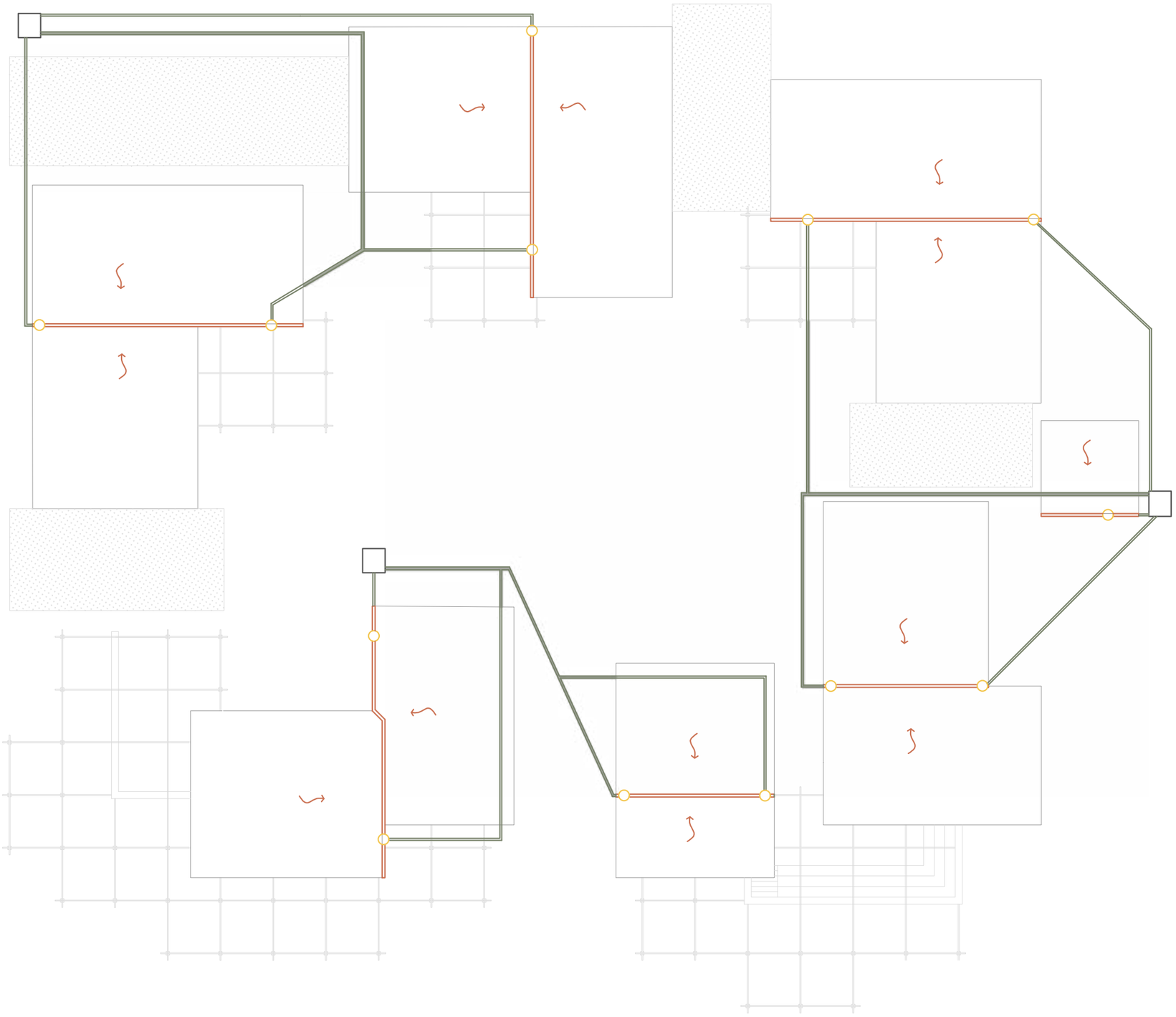
Gutter
Galvanized steel
160x120mm
0.5% slope

Drainage column
Galvanized steel
Ø80mm

Underground pipe
PVC
Ø110mm
0.5% slope



Underground pipe
PVC
Ø160mm
0.5% slope

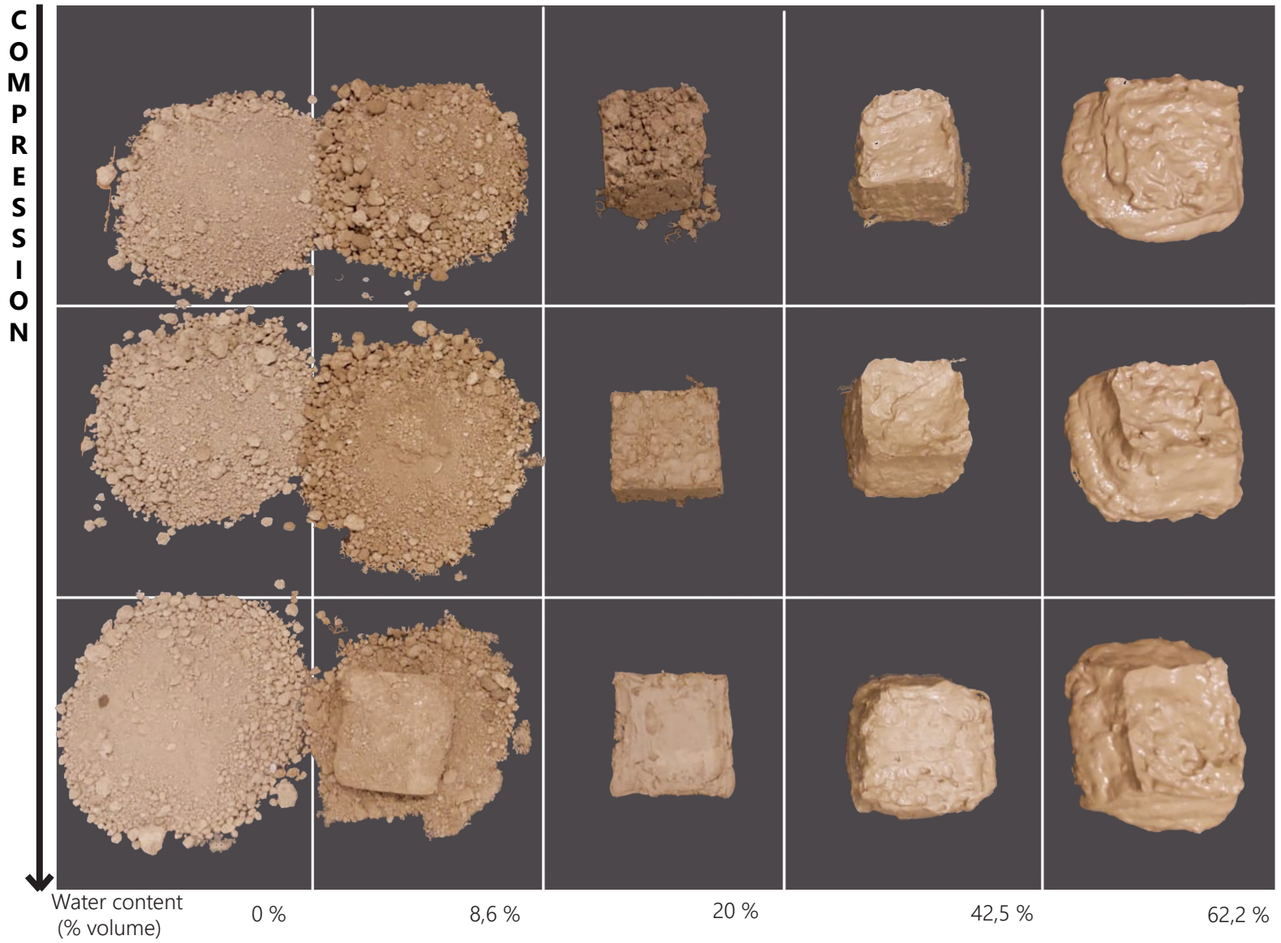


Gutter
Drainage column
Underground pipe
Wells

N

0 1 2 5 10 20

IX. RESEARCH ON BIO-BRICKS



TEST CARASAZ

OBJECTIVES :

Transform raw earth into a building material using its three phases

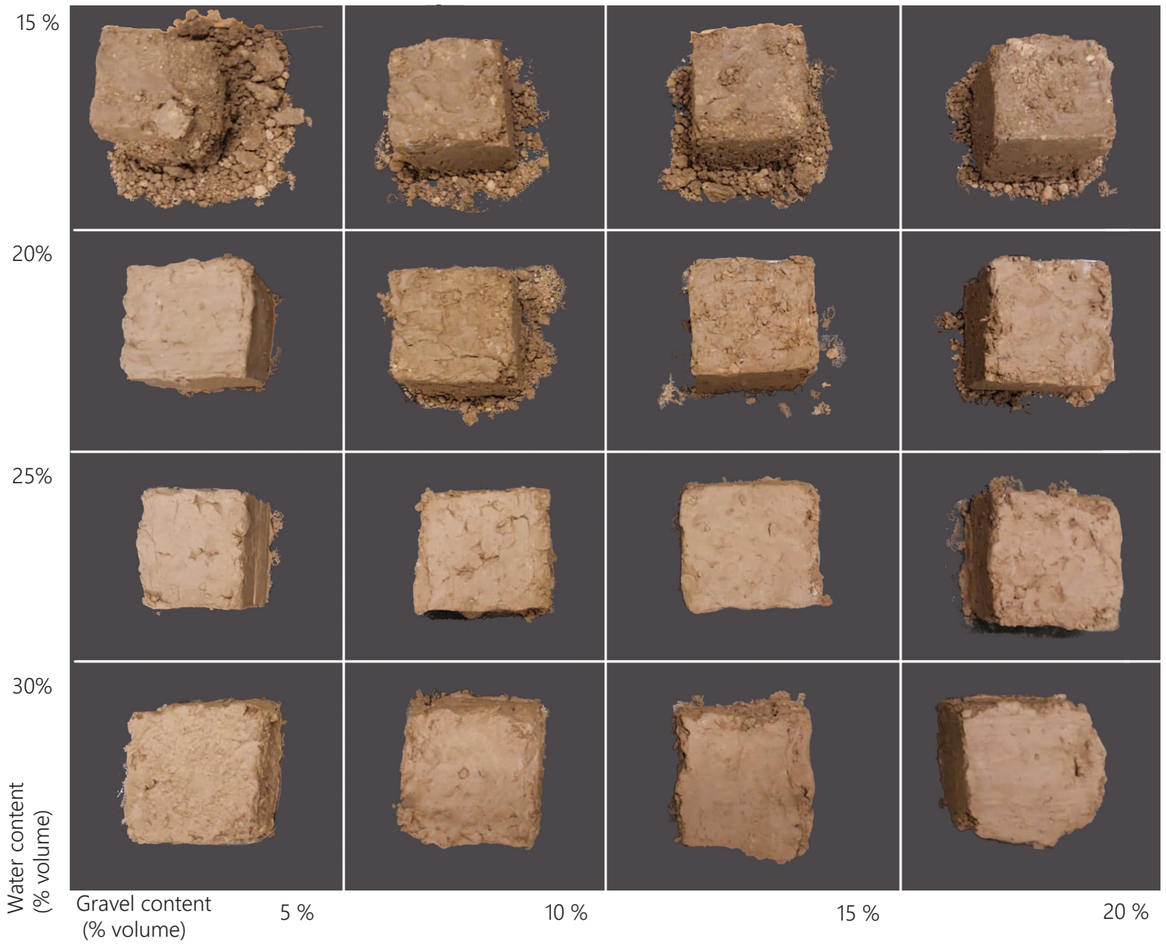
PROCESS :

- Creation of several samples by mixing soil and water measured in a graduated bucket
- Filled mixture poured directly into a 15 x 15 x 15 cm wooden mould for the first raw, hand compressed for the second raw and compressed with a stick for the third raw
- Placement of the samples in a matrix to compare them

RESULTS :

Importance of compression for bricks

Proportion of water : around 20 % in volume



TEST GRAVELS - WATER

OBJECTIVES :

Evaluate the best proportions of gravels and water for bricks

PROCESS :

- Creation of several samples by mixing soil, gtavels and water
- Filled mixture directly compressed into a 15 x 15 x 15 cm wooden mould
- Creation of a gravel - water matrix

RESULTS :

Proportion of water : [20 ; 30] % in volume

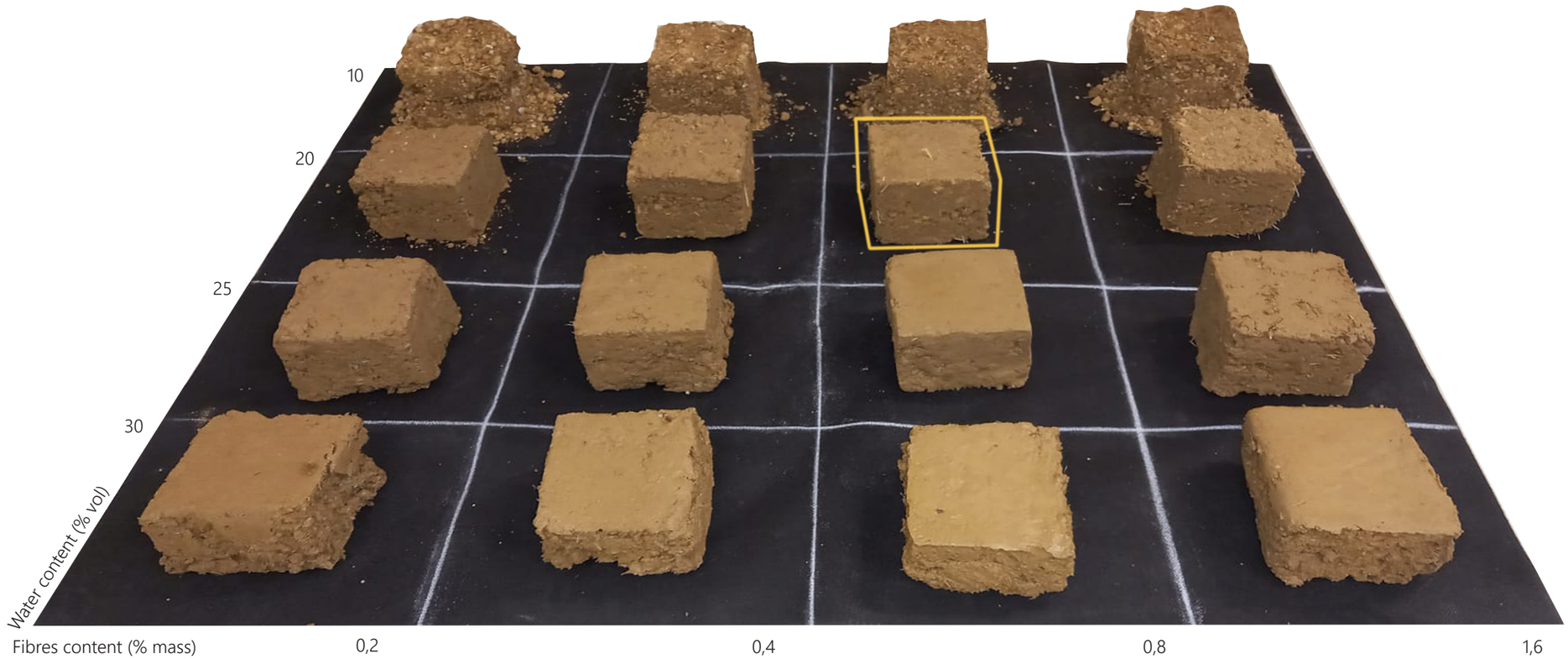
Gravel quantity : 15 % in volume

BAMBOO

CHARACTERISTICS :

- Density ρ = 700 kg/m³
- Specific heat : 1,8 J/kg.K
- Thermal conductivity : 0,17 W/mK
- Vapour diffusion ressitance: Tendency to absorb water
- Dimensions : 3 - 5 mm
- Availibility : Locally
- Environmental impact : Low impact

MIX DESIGN BAMBOO



Objectives :
Determine the best proportions of water and bamboo fibres for raw earth bricks

Procedure :
Create a matrix in which the proportions of water and fibre vary

Observations :
- Fibres
Hold together bricks and maintain their aspect

- Water
Acts as a binder and with its content increasing, the mixture becomes more plastic, malleable and uniform. Above a certain percentage, in this case 30%, the brick becomes too viscous and loses its shape as soon as it comes out of the mould.

	Unmolding	Aspect	Deformability
10 %	Very easy	Crumbling	Friable
20 %	Easy	Compacted / faintly lumpy	No deformability
25 %	Stick to mould	Compacted / smooth	Slightly sagging
30 %	Stick to mould	Smooth	Easily deformable

Mix Design chosen :

Fibres content (% mass) : 0,8 %

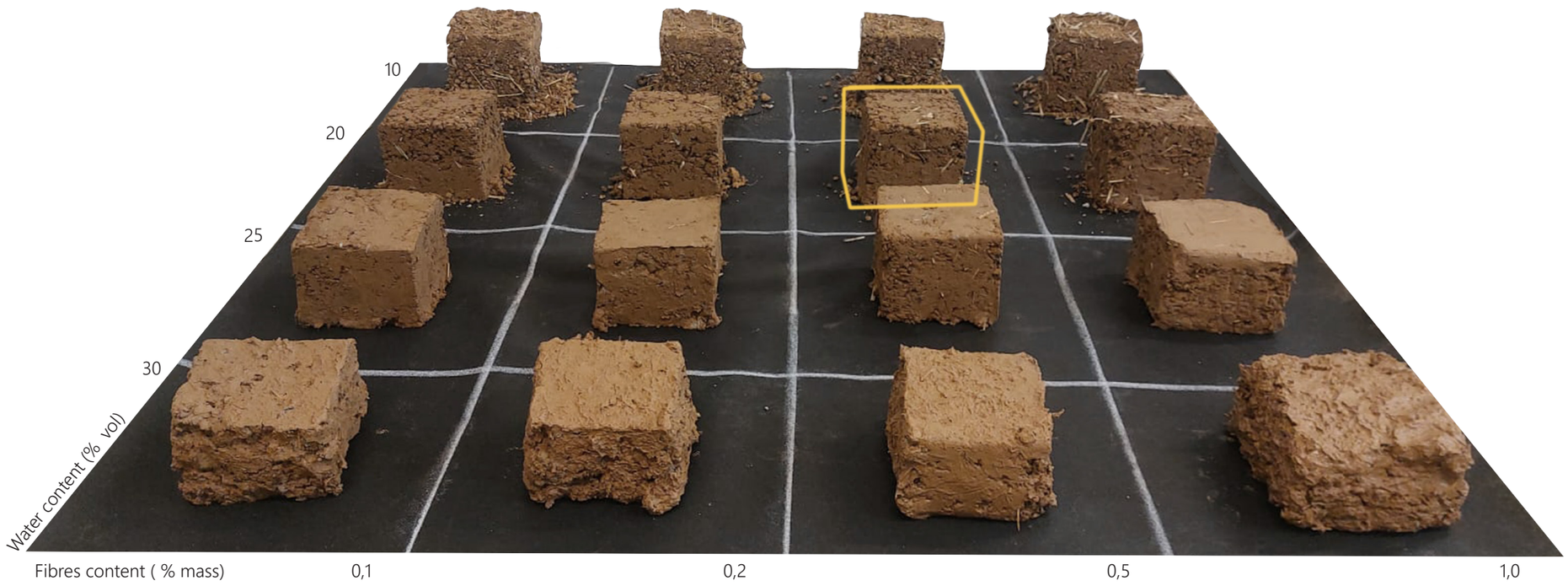
Water content (% vol) : 20 %

STRAW

CHARACTERISTICS :

- Density ρ = 58 kg/m³
- Specific heat : 1900 J/kg.K
- Thermal conductivity : 0,06 - 0,094 W/mK
- Vapour diffusion resistance μ : 1,15
- Dimensions : 3 - 5 mm
- Availibility : Locally
- Environmental impact : Low impact

MIX DESIGN STRAW



Objectives :
Determine the best proportions of water and straw fibres for raw earth bricks

Procedure :
Create a matrix in which the proportions of water and fibre vary

Observations :
- Fibres
Hold together bricks and maintain their aspect

- Water
Acts as a binder and with its content increasing, the mixture becomes more plastic, malleable and uniform. Above a certain percentage, in this case 30%, the brick becomes too viscous and loses its shape as soon as it comes out of the mould.

	Unmolding	Aspect	Deformability
10 %	Very easy	Crumbling	Friable
20 %	Easy	Compacted / faintly lumpy	No deformability
25 %	Stick to mould	Compacted / smooth	Slightly sagging
30 %	Stick to mould	Very smooth	Easily deformable

Mix Design chosen :

Fibres content (% mass) : 0,5 %

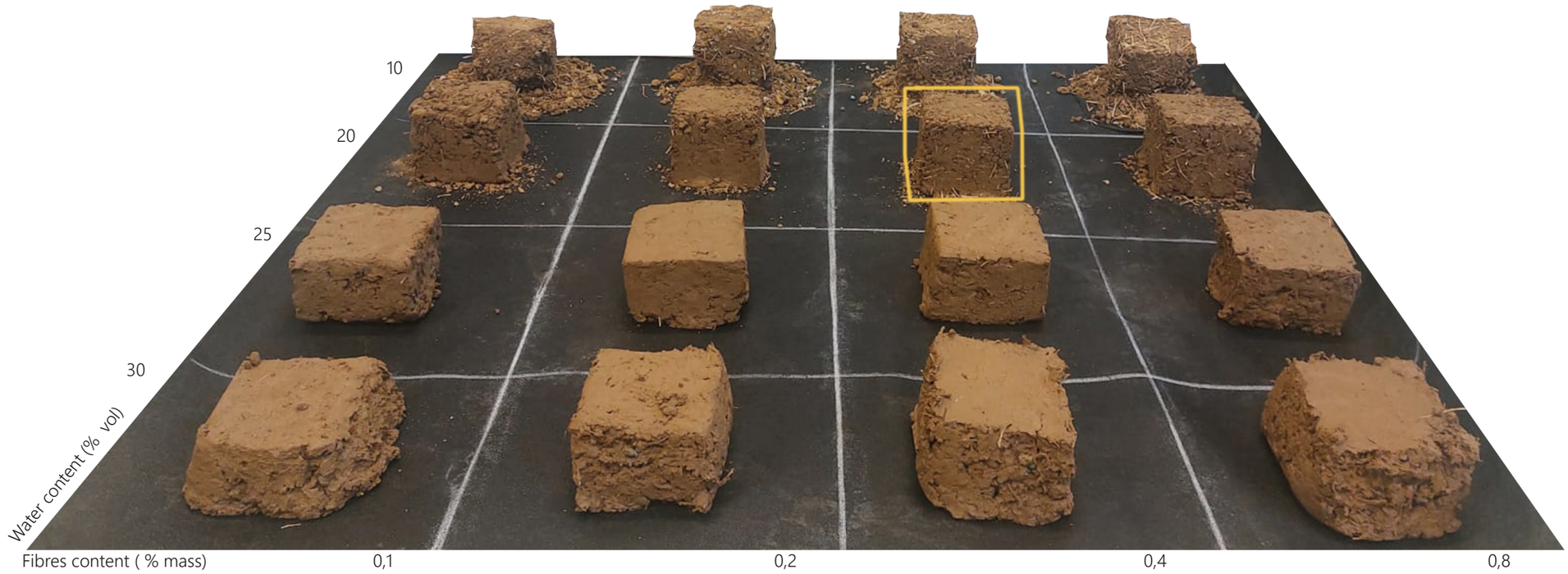
Water content (% vol) : 20 %

WOOD - Pine

CHARACTERISTICS :

- Density ρ = 500 kg/m^3
- Specific heat : 2300 J/kg.K
- Thermal conductivity : 0.1213 W/mK
- Vapour diffusion resistance μ : 40
- Dimensions : 3 - 5 mm
- Availibility : Locally
- Environmental impact : Low impact

MIX DESIGN WOOD



Objectives :
Determine the best proportions of water and wood fibres for raw earth bricks

Procedure :
Create a matrix in which the proportions of water and fibre vary

Observations :
- Fibres
Hold together bricks and maintain their aspect

- Water
Acts as a binder and with its content increasing, the mixture becomes more plastic, malleable and uniform. Above a certain percentage, in this case 30%, the brick becomes too viscous and loses its shape as soon as it comes out of the mould.

	Unmolding	Aspect	Deformability
10 %	Very easy	Crumbling	Friable
20 %	Easy	Compacted / faintly lumpy	No deformability
25 %	Stick to mould	Compacted / smooth	Slightly sagging
30 %	Stick to mould	Smooth	Easily deformable

Mix Design chosen :

Fibres content (% mass) : 0,4 %

Water content (% vol) : 20 %

1

SIEVING OF THE SOIL

CREATION OF THE BUILDING MATERIAL

2

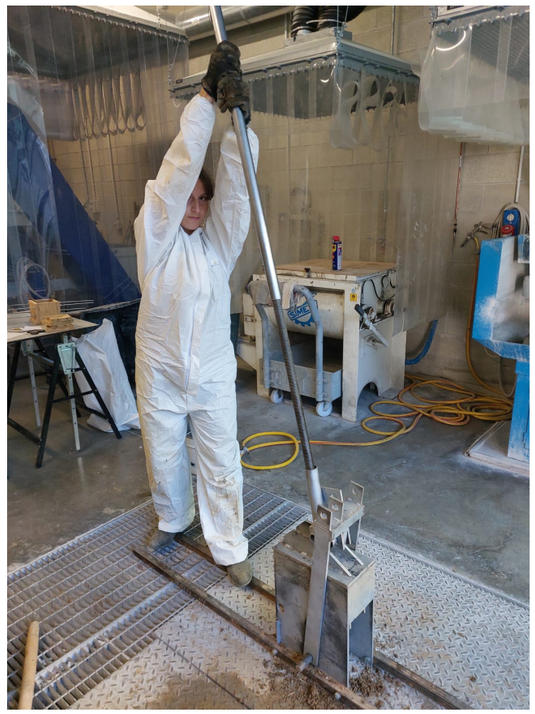
SAMPLE CREATION

3 FILLING OF THE MOULD PRESS

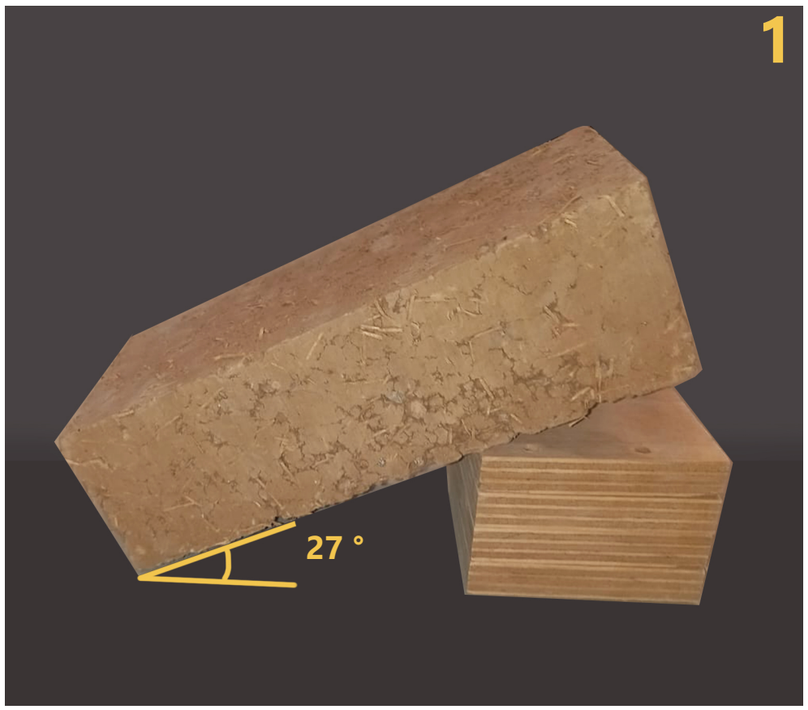
4 COMPRESSION OF THE SOIL

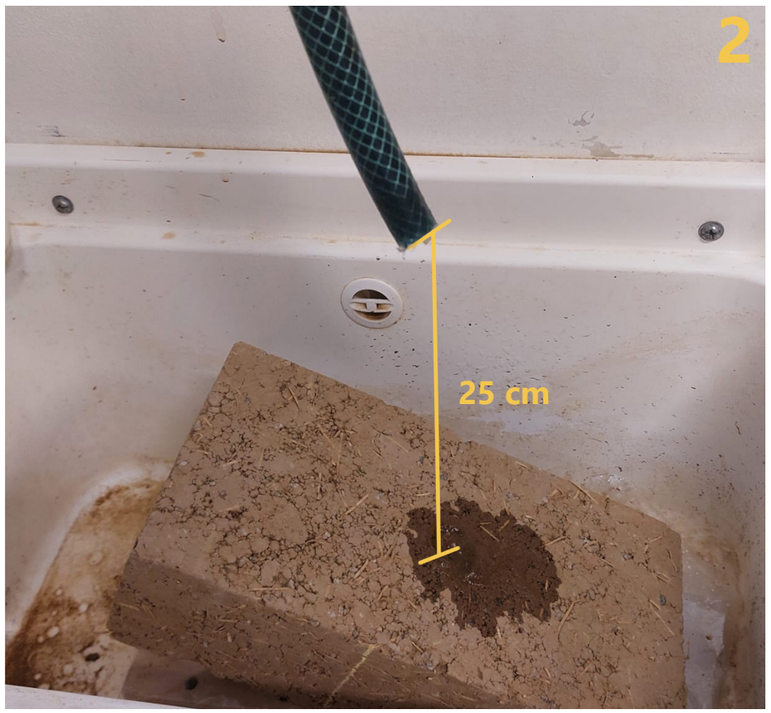
5 EXTRACTION OF THE BRICK

BRICK CREATION



PROCESS :





RESULTS INTERPRETATION :

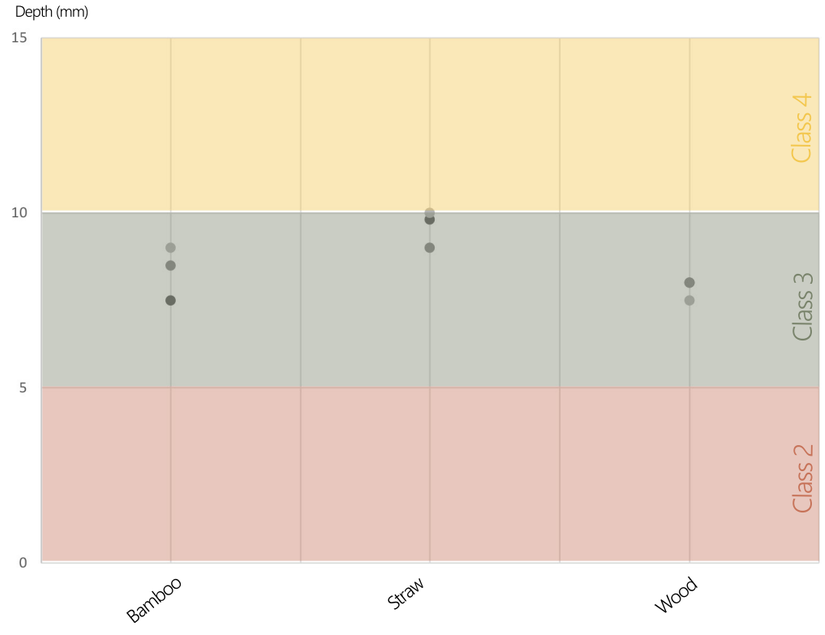
Property	Criteria	Class
Hole's depth D (mm)	0 < D < 5	2
	5 ≤D < 10	3
	10 ≤ D < 15	4
	D > 15	5 (not accepted)
Depth of moisture penetration U (mm)	< 120	Accepted
	≥ 120	Not accepted

1. Positioning the brick at 27°
2. Draining 100 mL of water for 26 min 18 s at 25 cm
3. Measuring the hole's depth
4. Breaking the brick with a chisel placed in the hole created by erosion
5. Measure the depth of moisture penetration

Conclusion : Being in Class 3 erosion, if well separated from soil humidity with a good laterite stone foundations and protected from the rain with a long edged roof, the projected bricks can resist erosion overtime.

Material	Bamboo	Straw	Wood
Mean hole's depth D (mm)	8,3	9,6	7,8
Erosion Index	3	3	3
Depth of moisture penetration U (mm)	21	26,6	24
Erosion status	Accepted	Accepted	Accepted

Erosion test results



Comparative results chart

BAMBOO


CB 1

CB 1	
Diameter [mm]	95
Height [mm]	180
Weight [kg]	2,546
Volume [m^3]	$1,28.10^{-3}$
Density [kg/m^3]	1995,5

Dimensions of CB1


CB 2

CB 2	
Diameter [mm]	96
Height [mm]	181
Weight [kg]	2,559
Volume [m^3]	$1,31.10^{-3}$
Density [kg/m^3]	1953,26

Dimensions of CB2


CB 3

CB 3	
Diameter [mm]	95
Height [mm]	181
Weight [kg]	2,574
Volume [m^3]	$1,28.10^{-3}$
Density [kg/m^3]	2006,29

Dimensions of CB3

RESULTS

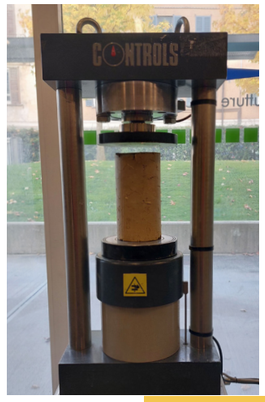
N° test	Maximum load [kN]	Maximum stress [kN]	Average stress f_{cm} [kN]
CB1	17,35	2,45	2,46
CB2	17,03	2,35	
CB3	18,19	2,57	

STRAW


CS 1

CS 1	
Diameter [mm]	95
Height [mm]	181
Weight [kg]	2,606
Volume [m^3]	$1,28.10^{-3}$
Density [kg/m^3]	2031,23

Dimensions of CS1




CS 3

CS 3	
Diameter [mm]	95
Height [mm]	190
Weight [kg]	2,699
Volume [m^3]	$1,35.10^{-3}$
Density [kg/m^3]	2004,07

Dimensions of CS3


CS 6

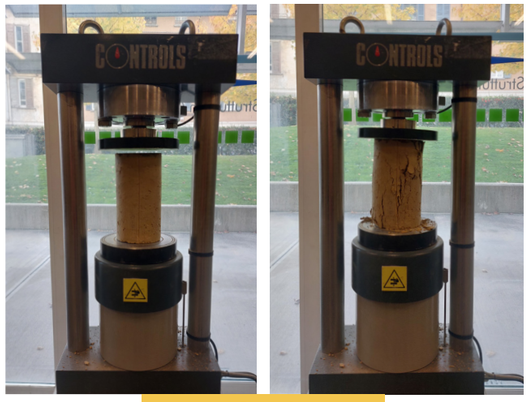
CS 6	
Diameter [mm]	95,5
Height [mm]	180,5
Weight [kg]	2,632
Volume [m^3]	$1,29.10^{-3}$
Density [kg/m^3]	2035,69

Dimensions of CS6

RESULTS

N° test	Maximum load [kN]	Maximum stress [kN]	Average stress f_{cm} [kN]
CS1	18,01	2,54	2,38
CS3	16,00	2,26	
CS6	16,69	2,33	

WOOD



CW 1

CW 1	
Diameter [mm]	95
Height [mm]	180
Weight [kg]	2,536
Volume [m^3]	$1,28.10^{-3}$
Density [kg/m^3]	1987,65

Dimensions of CW1

CW 2

CW 2	
Diameter [mm]	96
Height [mm]	180
Weight [kg]	2,553
Volume [m^3]	$1,30.10^{-3}$
Density [kg/m^3]	1959,50

Dimensions of CW2

CW 5

CW 5	
Diameter [mm]	95
Height [mm]	180
Weight [kg]	2,579
Volume [m^3]	$1,28.10^{-3}$
Density [kg/m^3]	2021,35

Dimensions of CW5

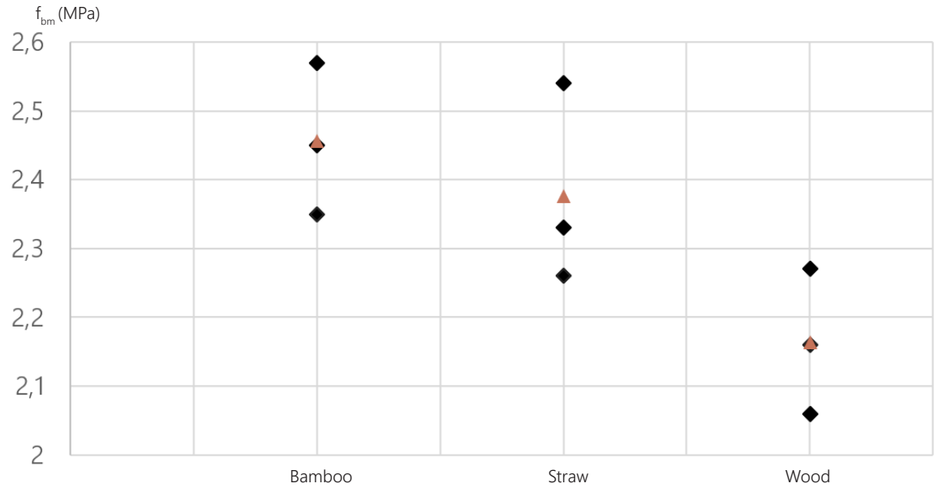
RESULTS

N° test	Maximum load [kN]	Maximum stress [kN]	Average stress f_{cm} [kN]
CW1	16,08	2,27	2,16
CW2	15,63	2,16	
CW5	14,57	2,06	

ANALYSIS

CS5

CB1



Comparative compressive stress chart

The static test emphasized the role of natural fibres and their mechanical properties. One can state that bricks are sensitive to the applied forces and as concrete, it resists better in compression than in tension. By comparing the static test results of fibre reinforced bricks and fibre free brick, the positive effects of fibres on the strength and toughness of the material can be noticed. This is explained by the fibres interactions with the material that not only reduce shrinkage cracks but also enhance the material ductility. This is very useful during the production process but also in the long run to resist external loads.

Comparing the statics results for the different types of fibres used, we can state that bamboo fibers reinforce better regarding its compressive stress, then straw and then wood. Due to the low number of samples, the material can't be classified but an estimation of its classification can be suggested. All bio-bricks tested correspond to a compressive class CS 2 single value. Besides, CS 2 is the minimum earth block class required for load-bearing situations.

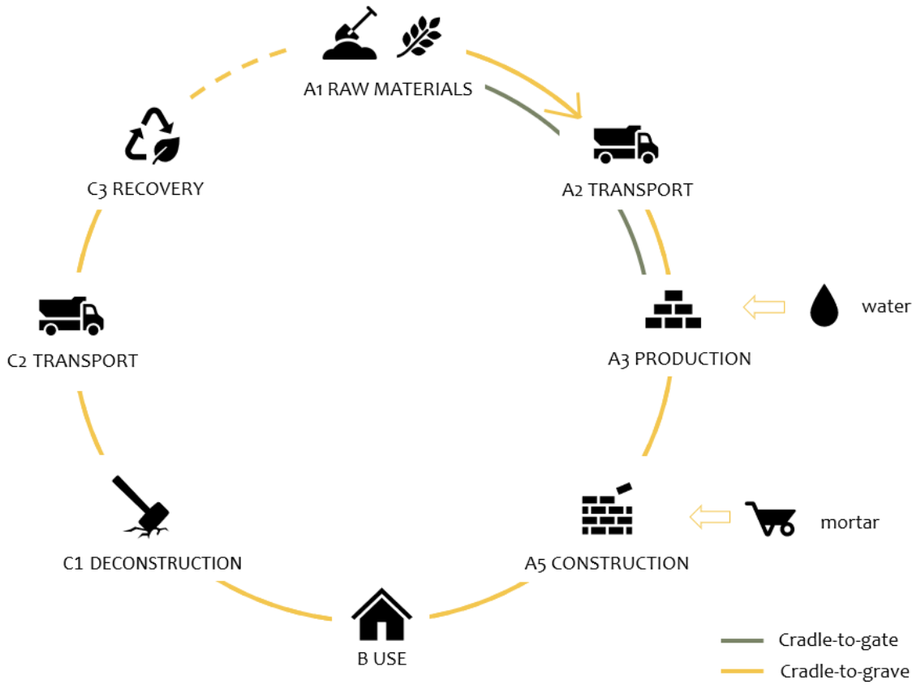
Compressive strength Mean value (MPa)	Compressive strength Smallest single value (MPa)	Class of block compressive strength CS
$\sigma > 5,0$	$\sigma > 4,0$	CS 4
$3,8 < \sigma < 5,0$	$3,0 < \sigma < 4,0$	CS 3
$2,5 < \sigma < 3,8$	$2,0 < \sigma < 3,0$	CS 2

Compressive strength classes (CS) for earth blocks @DIN 18945 (2013-08)

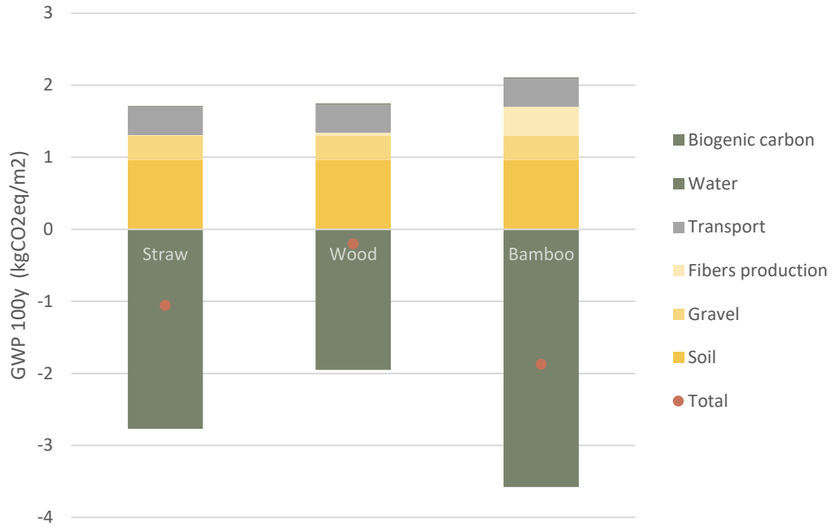
X. LIFE CYCLE ASSESSMENT

LCA OF THE BIO-BRICKS

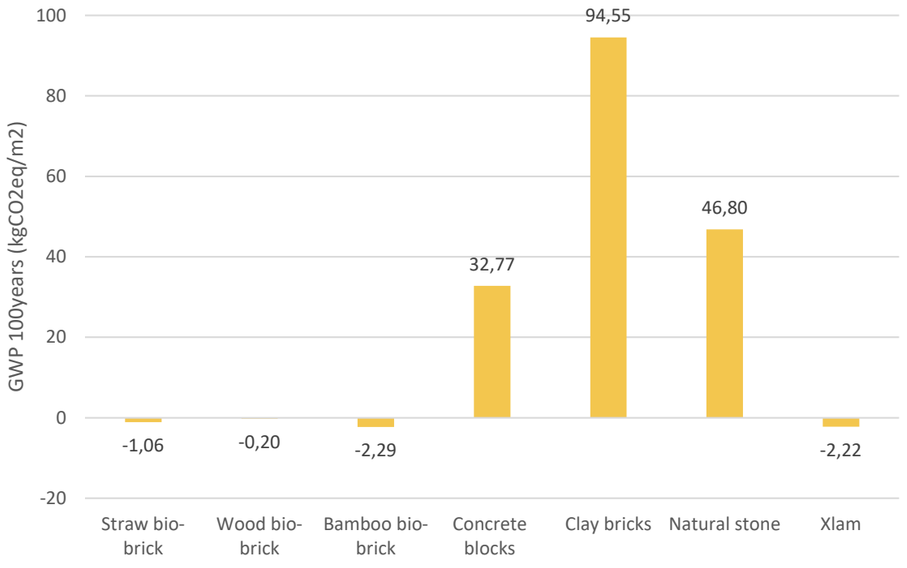
The life cycle assessment of the bio-bricks allows us to confront their physical capacities with their environnmental impact. It was calculated using the ecoinvent 3.7 database.



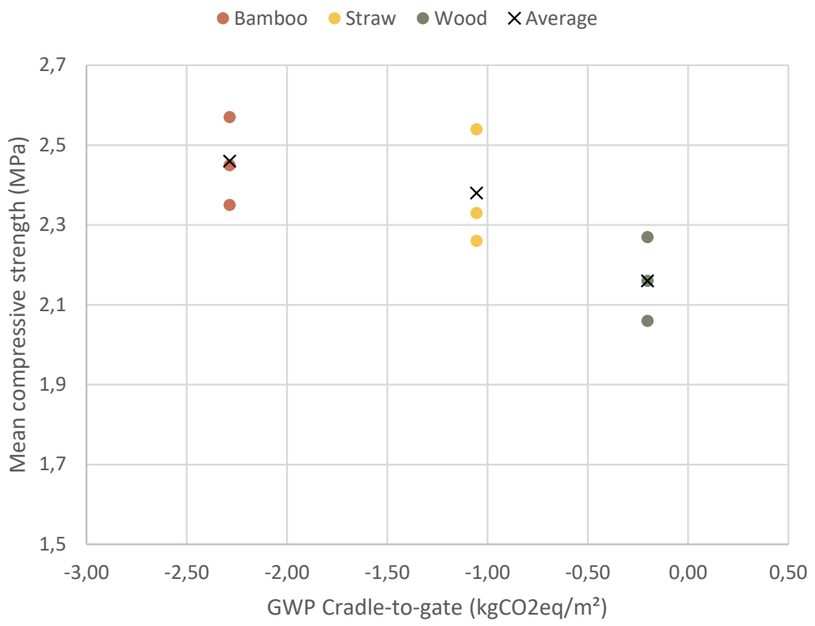
Life cycle of the loadbearing compressed brick wall



Cradle-to-gate GWP of the bio-bricks



Comparison of GWP for 1 m^2 of wall of the same loadbearing capacity

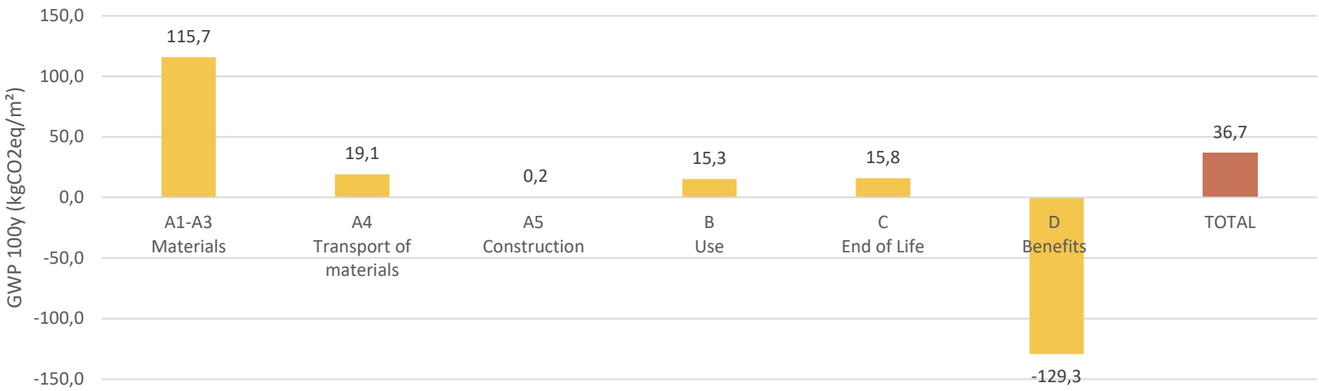


GWP and compressive strength of the bio-bricks

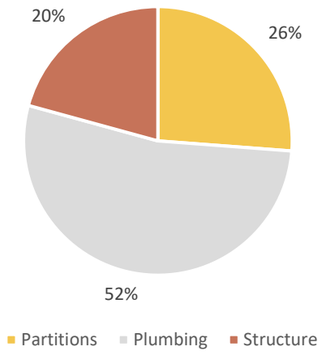
LCA OF THE PROJECT

The life cycle assessment of the whole project was made using the ecoinvent database and OneClick LCA. It allows us to compare our project's environnmental impact with other school construction's.

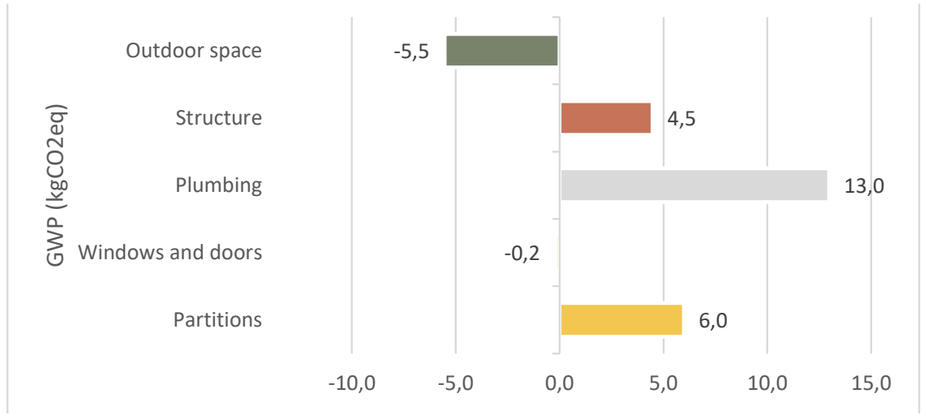
Global Warming Potential of the building by phases



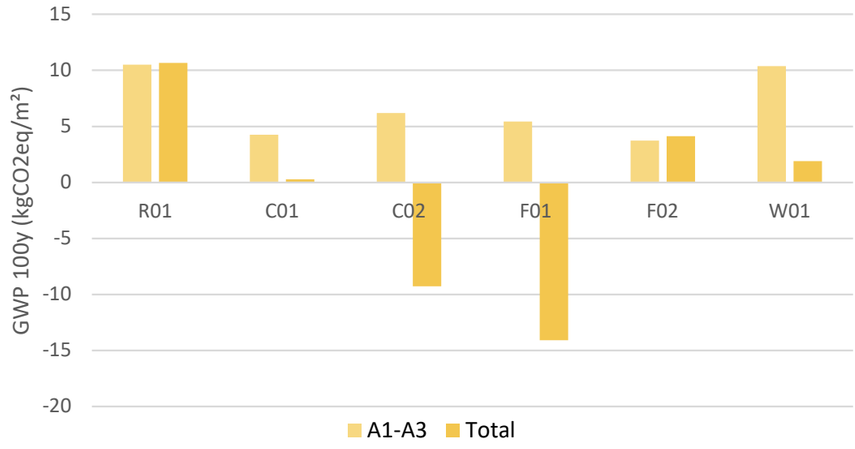
Global Warming Potential by category



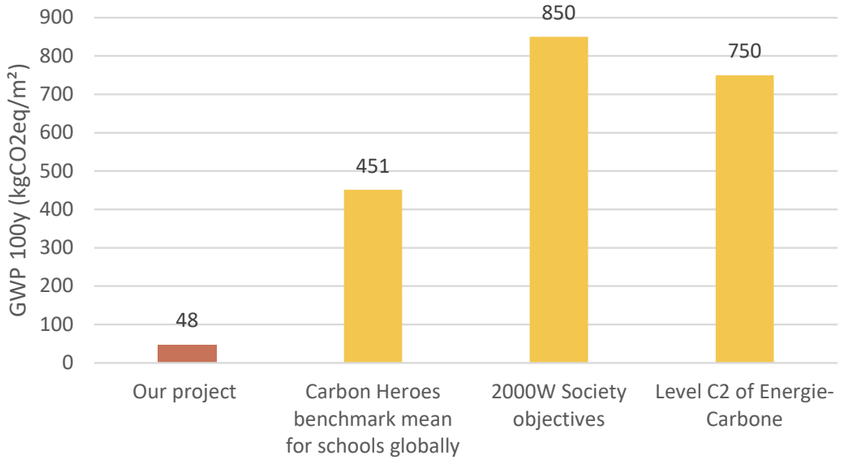
Global Warming Potential by category



Global Warming Potential of the partitions



Comparison to benchmark and objectives



The most important impacts are due to the plumbing system with metallic and PVC pipes, and to the partitions, particularly the metal sheet roof.

The overall impact of the building during its lifecycle is low with only 55 kgCO2eq/m² without accounting for external areas. It is less than 1/8 of the mean impact for a school worldwide according to the Carbon Heroes benchmark. The building would attain the maximum level for the French Energie-Carbone label, and is in line with the 2000W Society objective of 8,5 kgCO2eq/m².y.