CoWorking Port

Master Thesis

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May 2015

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Aalborg University
Architecture & Design

Semester: MSc 04
Project period: February - May 2015
Pages: 87

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ABSTRACT

The intention of this project is to create a new space, which will serve the people of the city of Porto. Moreover, the project will focus on a coworking space for young professionals.

The uniqueness of the city architecture was the starting point for the design and a leading value. Being inspired by the unconventional character of the designing area the main focus for the design was to use all of its advantages. The aim was to revitalise the site, so it will be an interesting place on the city map.

CONTENT

INTRODUCTION

INTRODUCTION

The thesis has evolved from an architectural competition for a coworking space in Porto in which the project also competed.

The project's focus is on the space to work for young people as well as on revitalizing the site area.

The city of Porto is a well known touristic destination and every year many people visits it. However, it does not help the local people to feel good in the centre of their city. Many of them are escaping into the suburbs, leaving the centre for tourists and a night life.

The aim of the project is to create a coworking space very close to the old city centre to revive the area. It will provide a good conditions for freelancers and independent contractors, which should stimulate a development of entrepreneurship and local community.

METHOD

Good architecture must simultaneously fulfill various criterias. Aesthetics of a designed building is only a piece of a puzzle which involves such aspects as functionality, sustainability, or technical requirements and limitations. The process of designing a building is complicated and involves knowledge and specialists from different branches that cowork with each other on different stages. Furthermore, it is not possible to assess all requirements at early stages of a project, what may lead to unsatisfactory results or delays.

In this project the Integrated Design Process was applied to improve the workflow and thus assure that the final results will meet all the criteria for a good architecture. The integrated design process consists of five phases – problem, analysis, sketching, synthesis and presentation. Additionally, it implies iterativeness. It means that at every stage the current results must be evaluated and before they are satisfying the designer may need to return to a previous phases. Different methods are used to assess the project during the process, such as creating physical models, sketching, 3D modelling, CAD drawing, lightning or construction simulation and analysis with software like Velux Daylight Visualizer or Robot Structural Analysis.

Due to the diverse and demanding location of the site during the designing phase various building shapes were considered. Many directions proved to be unsatisfactory on different levels of the analysis because they did not solve all the aspects such as blending in the surrounding or construction limitations. This required repeating various phases until reaching satisfying results.

Additionally, the project was also prepared for a competition with a deadline in the middle of April 2015. This required reaching the presentation phase of the integrated design process very early, what allowed to perceive problems which would later be significantly harder to solve.

TECTONIC

Nowadays, the capabilities in architecture are almost unlimited. Whatever the architect will design, it can be built, anywhere. The fact that limitations almost do not exist, allows to let the imagination run wild. This leads to having the same architecture all around the world – It is the same in terms of presented values, where the focus is put on creating an architecture which will suit the designer and the client, but not necessarily the environment.

The globalisation in architecture creates a surrounding that does not any more have its identity. As a result, the architecture feels out of place or the place loses its uniqueness completely.

Kenneth Frampton in his “Towards a Critical Regionalism: Six Points for an Architecture of Resistance” says, that architecture has to have an authentic connection to a place.

“The fundamental strategy of Critical Regionalism is to mediate the impact of universal civilisation with elements derived ‘indirectly’ from the peculiarities of a particular place.”

Critical Regionalism is about making architecture which coexists with the surrounding. The good design needs to be a part of the whole, not separate element. Critical Regionalism does not mean that architecture cannot be modern – it should be. But with respect to the place and nature.

“The bulldozing of an irregular topography into a flat site is clearly a technocratic gesture which aspires to a condition of absolute placelessness, whereas the terracing of the same site to receive the stepped form of a building is an engagement in the act of ‘cultivating’ the site.”

Designers cannot adjust the site to their ideas, it should be the opposite. The topography, climate or light should be a designing factor which will help to generate/shape/create something unique.

Steven Holl said: *“Architecture surrounds you, in the same way as music surrounds you”*. Thus, it should not be without a soul, but rather full of values and harmony.




PROGRAMME

COWORKING

Coworking space is a fairly fresh idea for a place to work for people from different branches. In the era of the Internet and "global village" many people, especially among freelancers such as software developers and graphic designers, started working remotely from their homes.

While initially this may seem to be a great opportunity, because one can avoid costs and time of transportation as well as work in a comfortable environment, in a long term perspective it brings many disadvantages. At home there are many new distractions, the place is very monotonic what often limit one's creativity and simply there is no one to talk with. Hence, people started seeking other places to work.

Natural and still very popular choice are cafes, but they do not solve the problem completely. Therefore, groups of people begun renting places to create their own offices and with time first commercial coworking spaces were opened.

Nowadays, a demand for this kind of offices is still growing and every bigger city needs to offer a space for freelancers as well as for small companies like startups.

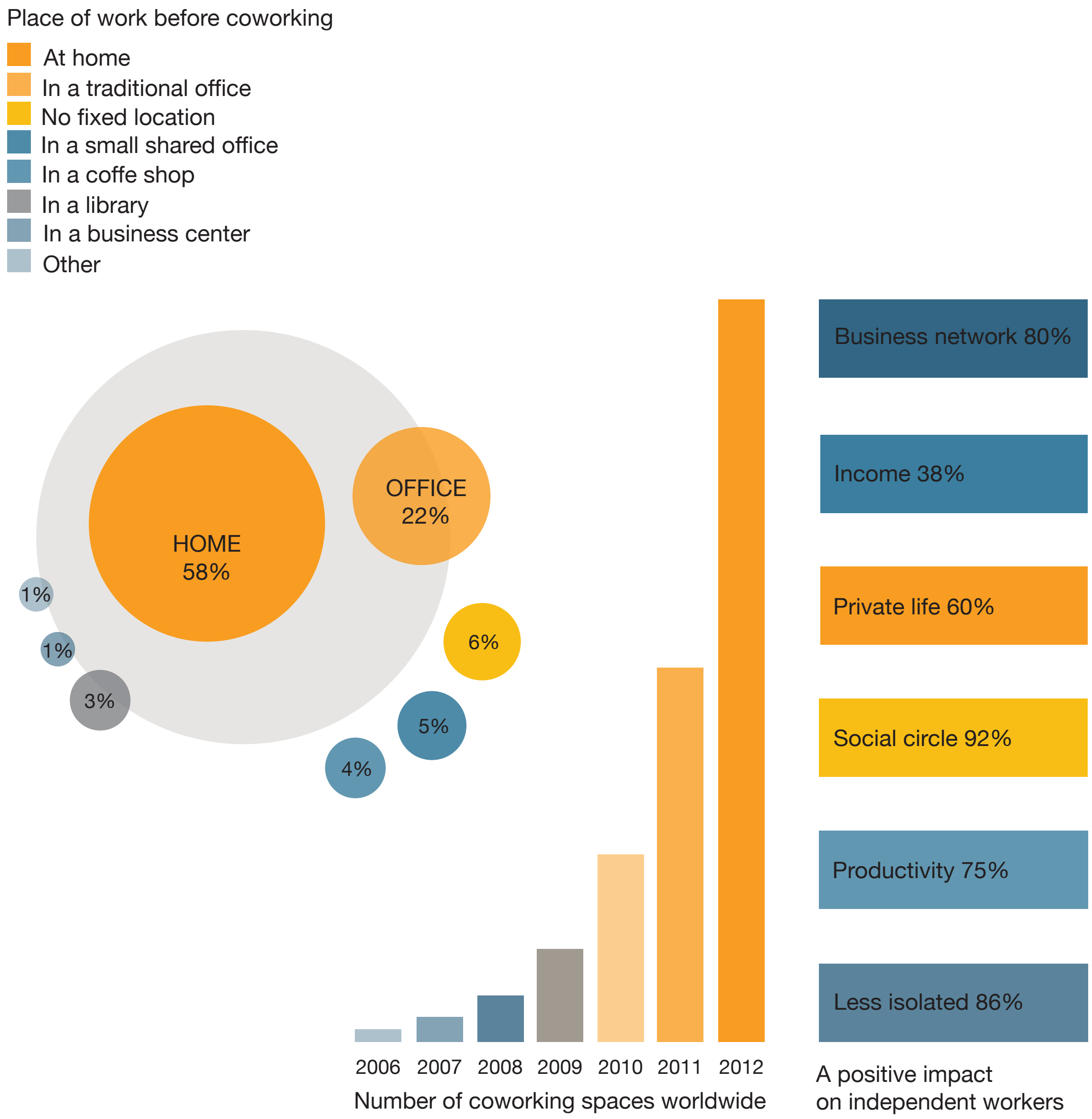
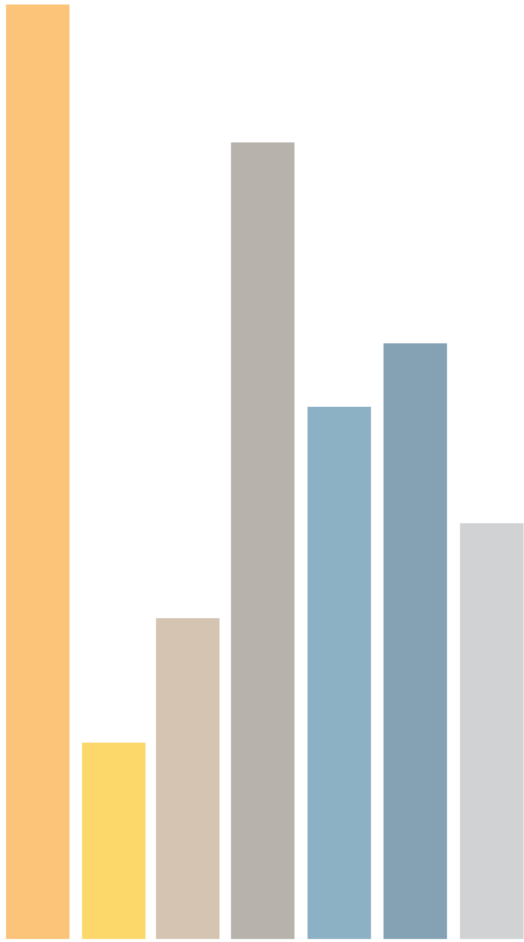


Fig. 2.1. Coworking statistics (Infographicsmania, 2012)

PROGRAMME

The programme for the project consists of functions divided into two groups: for private and public use. In the private part there is a coworking space with group rooms, dining area with kitchen and printing rooms. In the public part there is a restaurant, bar, gym and conference rooms.



COWORK SPACE	1500 m^2
LOBBY	60 m^2
ADMINISTRATION	
Offices	30 m^2
Meeting area	20 m^2
Archives	30 m^2
Restroom	40 m^2
SERVICES	
Printing area	20 m^2
Stationery	15 m^2
Zen space	80 m^2
Kitchen	60 m^2
Dining area	120 m^2
Bar	80 m^2
Technical room	25 m^2
Meeting area	160 m^2
Conference room	200 m^2
Group activities area	160 m^2
Proffesional support office	30 m^2
Restroom	
PUBLIC GYM	350 m^2
GREEN SPACES	
PARKING	50 places

Fig. 2.2. Programme (AWA Competitions, 2015)

ANALYSIS

PORTUGAL

Portugal is located in the western part of the Iberian Peninsula and is the most western country in the continental Europe. Its only land border neighbour is Spain (on north and east) and on west and south it is bordered by the the Atlantic Ocean. The landscape of northern Portugal is characterised by hills and mountains, crossed by several rivers while the southern part is mostly plain.

The two biggest cities are Lisbon (the capital of Portugal) and Porto. Both are located on the western coastline and have population of respectively 550.000 and 237.000 inhabitants and their metropolitan areas reach respectively 2 and 1.4 million people.

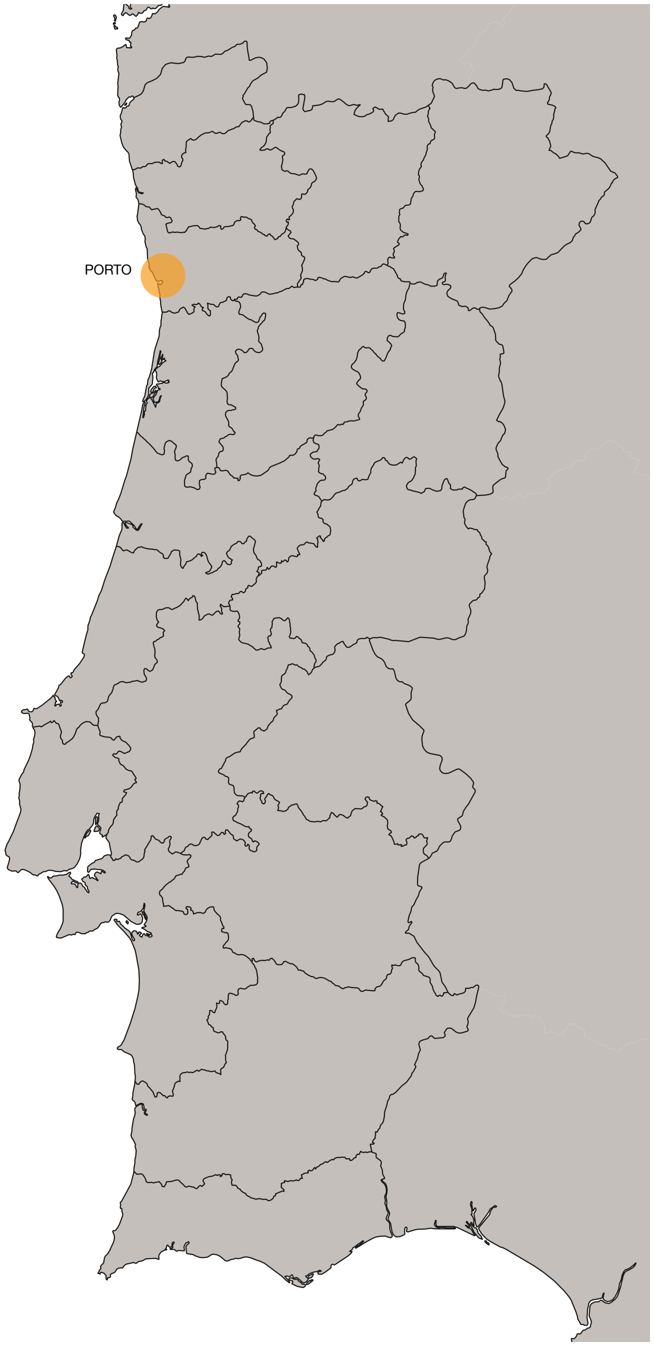


Fig. 3.1. Map of Portugal (Wikipedia, 2015)

Fig. 3.2. City of Portugal

Fig. 3.3. Seaside in Portugal

Fig. 3.4. Azenhas do Mar – city on a cliff

Fig. 3.5. Lisbon

PORTO

Porto (also known in English as Oporto) is a city located in the northern part of Portugal along a side of the Douro river estuary. It is one of the oldest cities in Europe and in 1996 its historical centre was proclaimed a World Heritage Site by UNESCO. Its rich architecture every year attracts millions of tourist which can enjoy the famous port wine named after the city and is stored in cellars along the Duoro river.

On the opposite, southern side of the river lies the city of Vila Nova De Gaia. Both steep banks are connected by remarkable bridges built by such engineers as Gustave Eiffel and Edgar Cardoso. Dense, historical centre of Porto is full of characteristic steep and narrow streets and diverse architecture.

Fig. 3.6. Old city centre

Fig. 3.7. Ponte Luis I bridge

Fig. 3.8. City square in the old city centre

Fig. 3.9. Typical Porto street

Fig. 3.10. Cascades of tarraces

Fig. 3.11. Famous port wine cellars

CLIMATE IN PORTO

Portugal is one of the warmest European countries and the climate there can be defined as a mediterranean climate.

Porto has warm, dry summers and mild, rainy winters. However, even during winter the long periods with sun and mild temperatures are common.
During the summer the average temperature is between 16°C and 27°C. The occasional heat waves are possible and then temperature can reach even 40°C.
In winter time the average temperature is 5°C in the morning and rises into 15°C in the afternoon. Very seldom the temperature falls below 0°C at night.

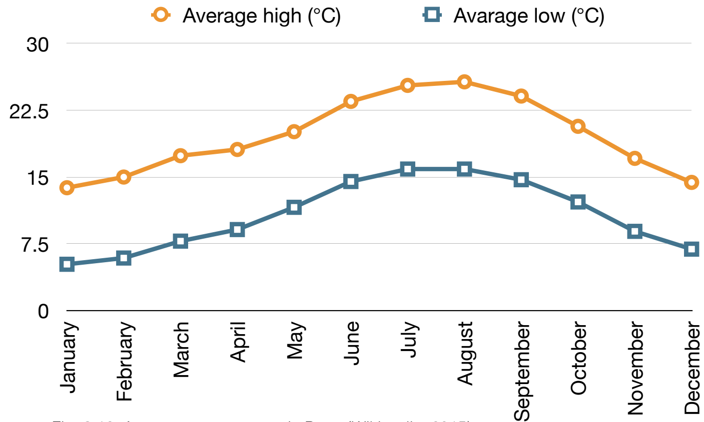


Fig. 3.12. Average temperatures in Porto (Wikipedia, 2015)

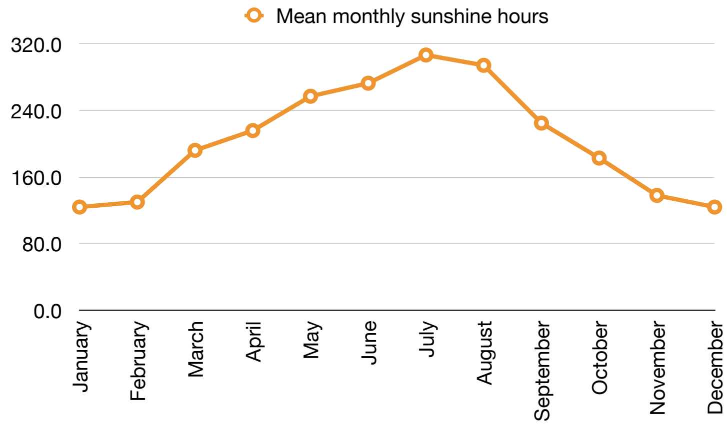


Fig. 3.13. Mean monthly sunshine hours in Porto (Wikipedia, 2015)

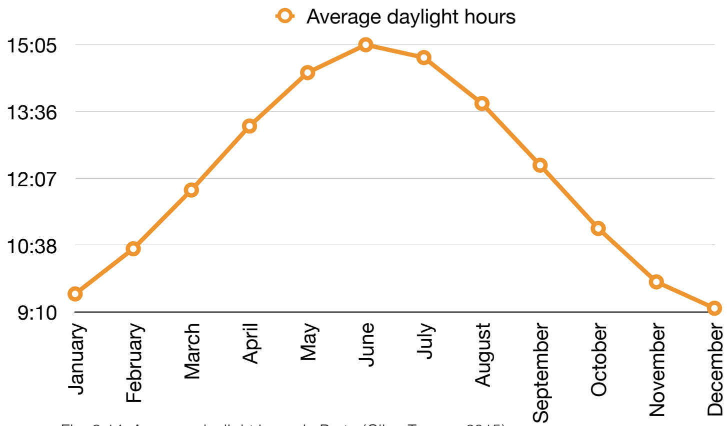


Fig. 3.14. Average daylight hours in Porto (ClimaTemps, 2015)

SITE IN A CONTEXT

Site of the project is placed close to the old city center of Porto, which is listed by UNESCO. The specific character of the buildings creates the atmosphere one of a kind. Location between two bridges, on a high slope of the riverside make the area even more attractive.

The site is an unused area, which is very visible from the bridges and the opposite side of the river. The empty space disturbs the characteristic city panorama.

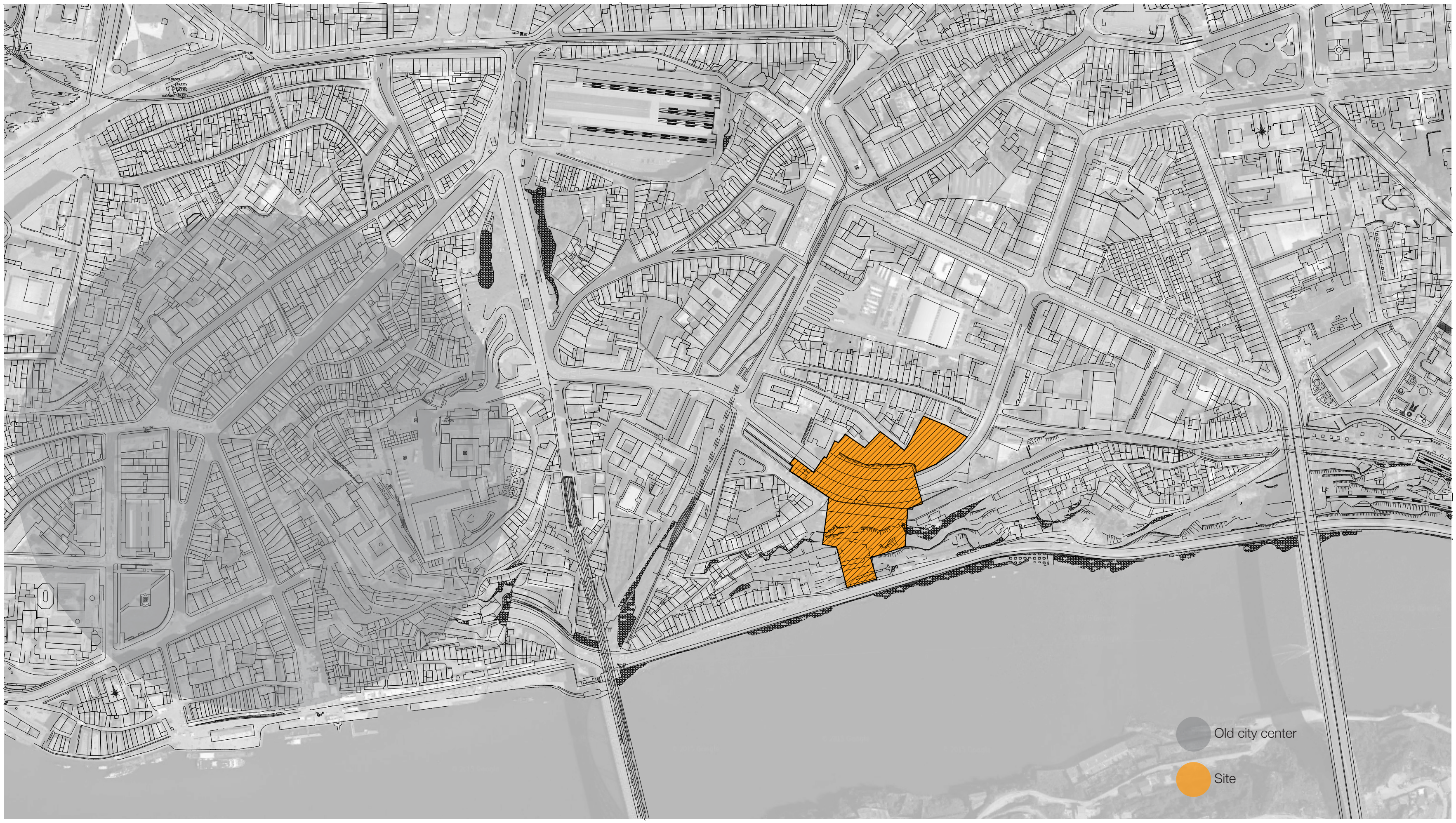


Fig. 3.15. Site in a context

SITE

The site can be described as an area which is full of potential, with a great view to the bridge Ponte Luis I, the hallmark of the city. One part of the site is located on a steep, southern slope and ends just on the riverbank. In the middle of the site there is a road which goes partially above the ground. The only current function of the area is a car park which is located under the road. The northern part of the site is much less steep, partially completely flat.

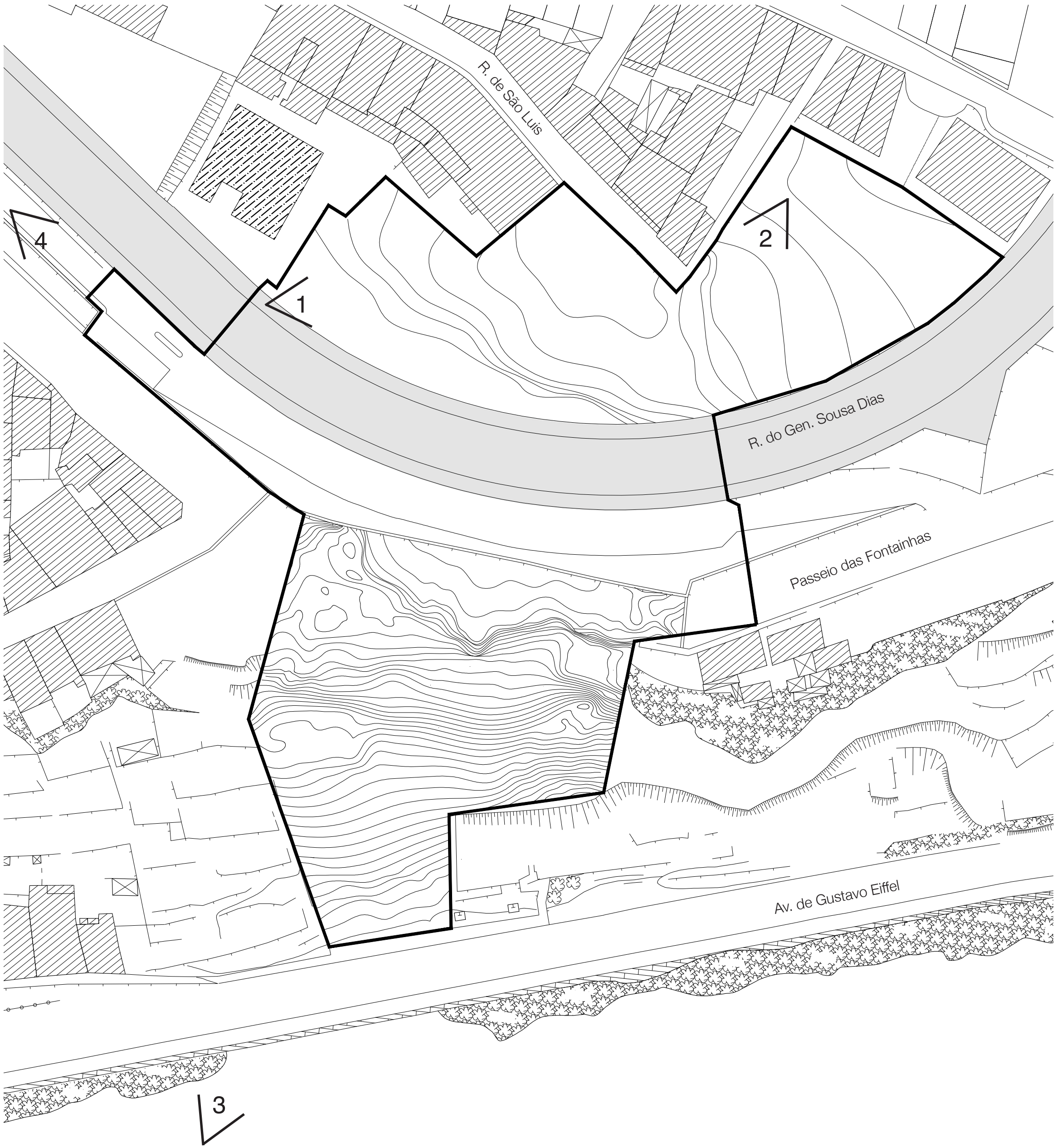


Fig. 3.16. Situtation

Fig. 3.17. Photos of the site

VIEWS FROM THE SITE

The views are the great advantage of the site. Two of the bridges are clearly visible as well as the opposite side of the river, where characteristic cellars for port wine and a lot of greenery are placed. Directly on the western side of the site the buildings of the old city centre starts.

Fig. 3.18. Views from the site




INSPIRATION

In the city of Porto I found very characteristic and inspiring slim shape of houses. The buildings are principally a parallelepiped form, sharing side walls in a row. The narrow shapes fill the entire city centre. They are especially exposed on the banks by the Douro river, where countless little houses placed on different levels create a colourful mozaique of the city.

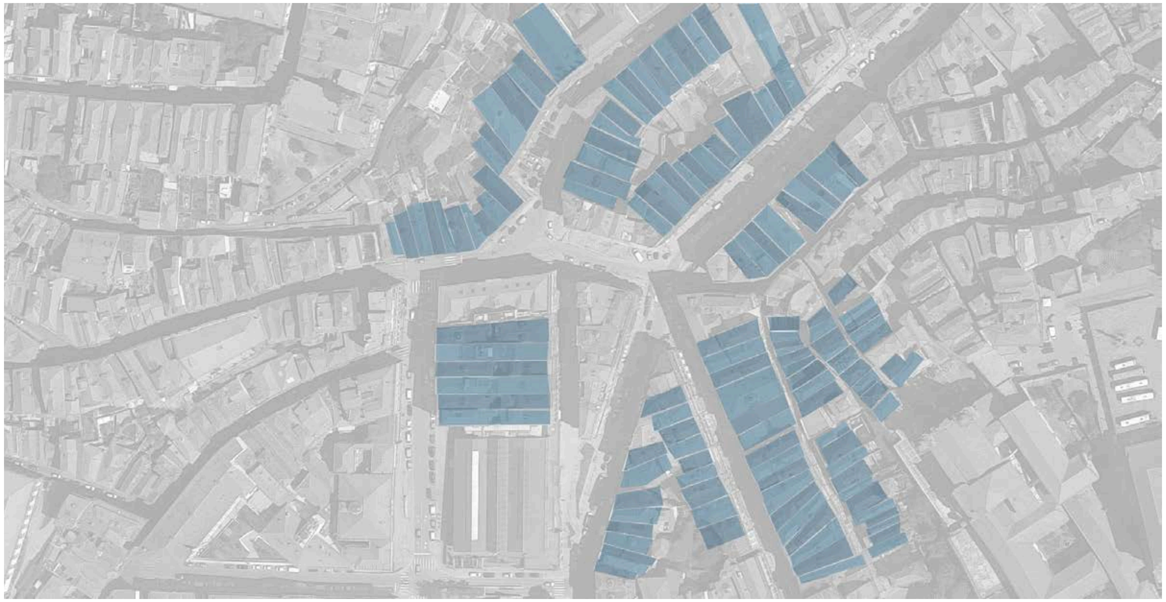
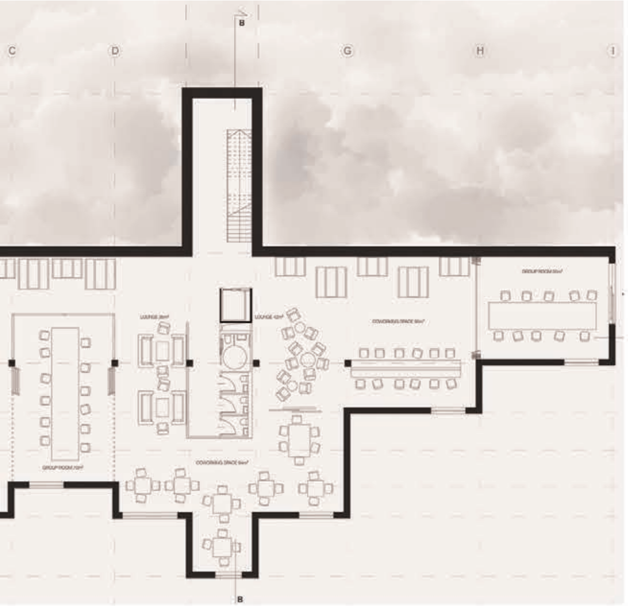


Fig. 3.19. Characteristic shapes

Fig. 3.20. Colourful mozaique of the city

The good building is not one that hurts the landscape, but one which makes the landscape more beautiful than it was before the building was built.

— Frank Lloyd Wright




PRESENTATION

CONCEPT

The site inspires through being an empty gap in the urban panorama. The shape of the building should blend in the character of the surrounding buildings and continue the rhythm of the city.

The aim of this project is to fill the urban gap with a modern design with a respect for the environment.

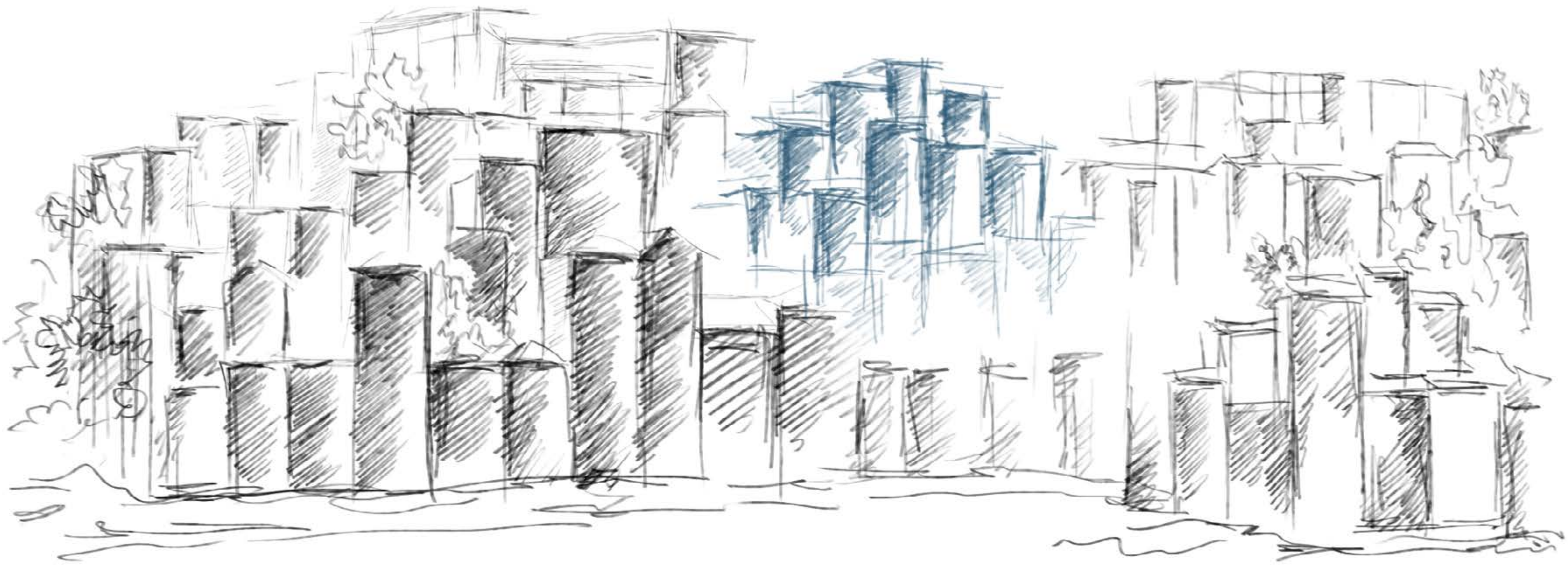


Fig. 4.1. Concept drawing

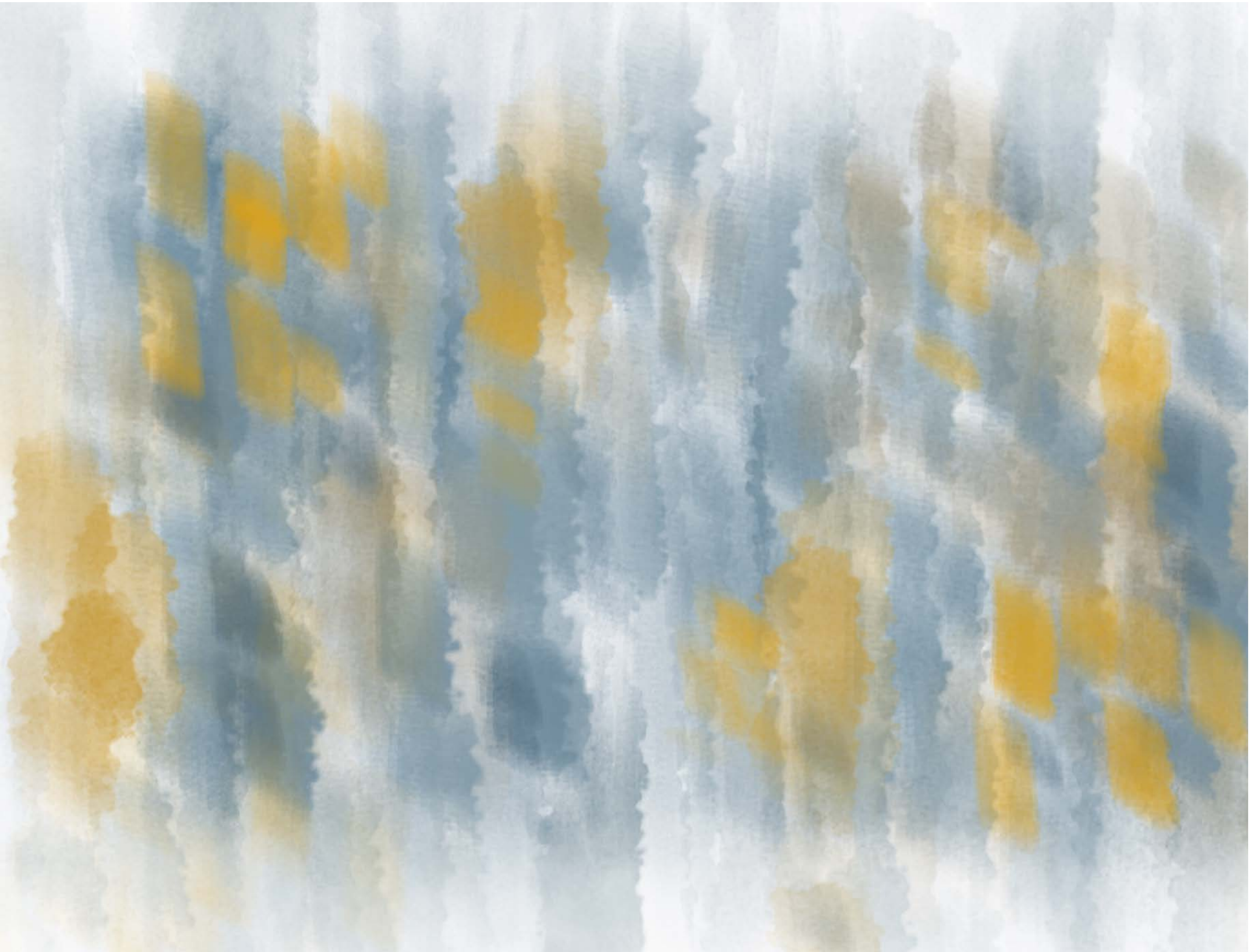


Fig. 4.2. Porto inspiration painting

Fig. 4.3. Visualisation from the river side

Fig. 4.4. Visualisation of the building in its surrounding

CONCEPT OF THE TRANSITION

The idea of the transition, the characteristic part of the design, evolved in an early stage of the designing.

On an account of having two parts of the site divided by the road, the building was also divided into two. The small sections, imitating the surrounding city buildings volumes, were then spaced not to be in one line.

The necessity to connect the two parts led to the solution that one of the volumes will be extended, creating a transition between the two of them. Two ways of achieving this result were possible – under or above the road. The way of placing it under the road would result in having a dark corridor that would be reduced to the technical role. Therefore, the transition was created above the road, with big windows providing a great view to the city. Thus, the connection was emphasised as an advantage of the whole design, making it more unique and distinctive.

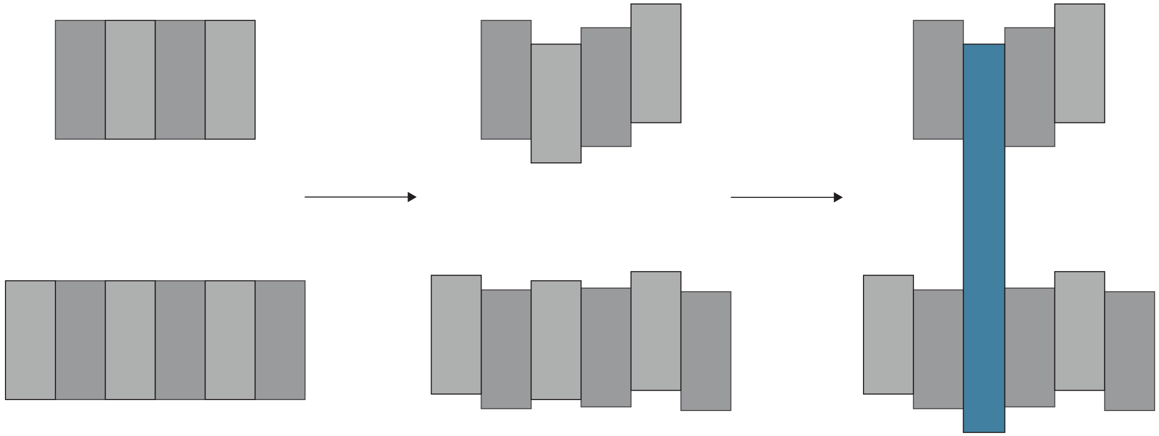


Fig. 4.5. Concept of the transition

MASTERPLAN

The master plan presents the overall urban development on the site.

On the northern part, where the designed building meets the existing ones a public square was created. It will serve as a meeting point, placed next to the gym, cafe and green leisure area. In order to revitalise the area, beside the indoor gym, the outdoor gym among the trees of the green area was planned.

On the southern part of the site, which is located on the steep slope terraces were designed. As an inspiration served the existing concrete walls, which were built to reinforce the hill, however they are perceived as disfiguring the area. The designed terraces will have the same function of reinforcing the ground. Moreover, they will serve as a green gardens with a fascinating panorama.

Cascades of the terraces connect the building with the level of the river.

Fig. 4.6. Masterplan

Axonometry diagram

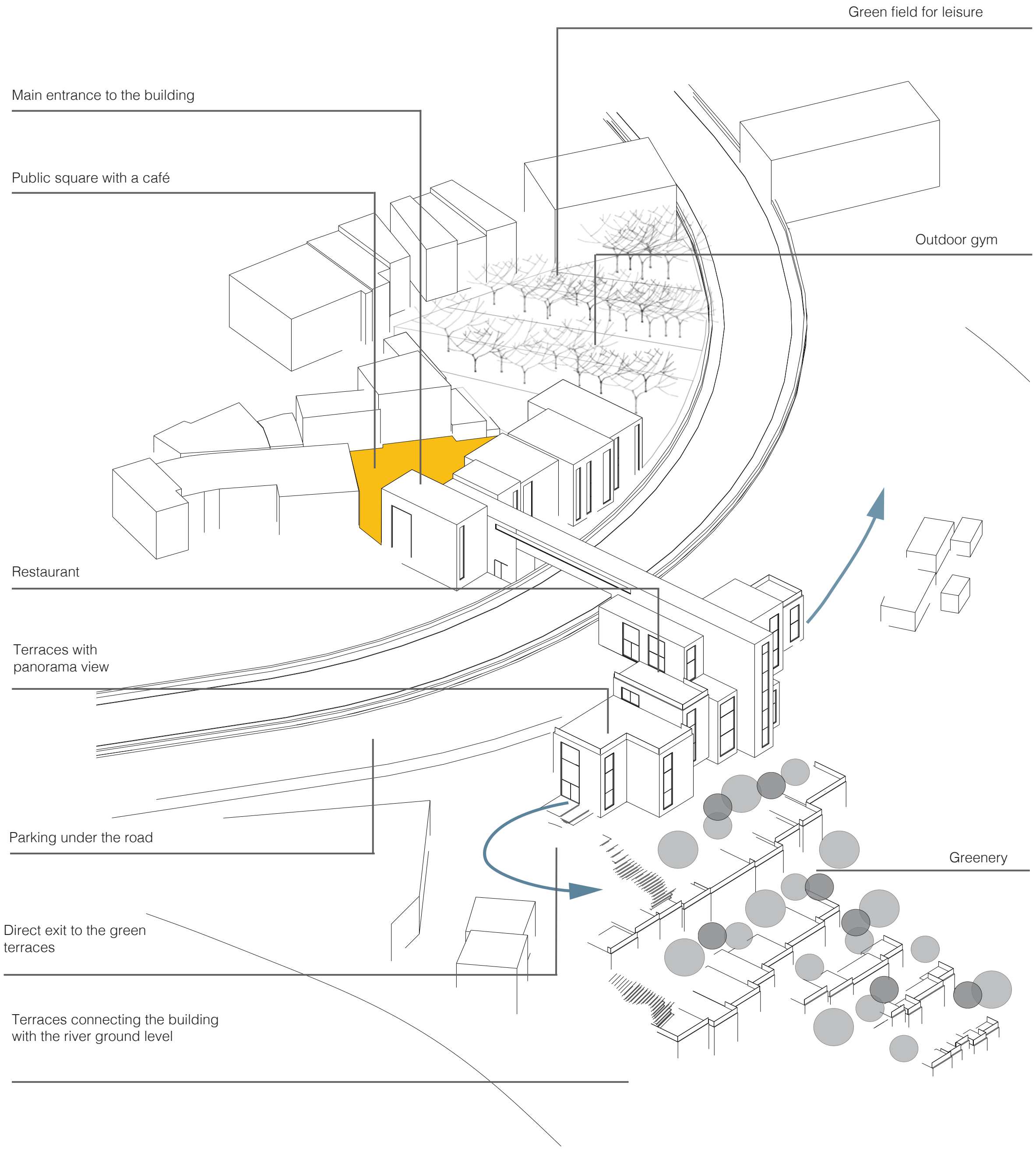


Fig. 4.7. Axonometry with functions

Fig. 4.8. Visualisation of the public square

PLAN

The level 0 was set where is the car parking and the most flat part of the site. The building has in total seven floors and on most of them the coworking areas are intertwined with other functions.
The special character has the Zen space, which is 8m high and 4.5m wide. It has a big vertical window, which is the only source of light. The idea for the place was to create a room with calm and inspiring atmosphere.

The other function is a restaurant with a view to the bridge Ponte Luis I from the inside as well as from the spacious terrace.
From the northern side, on the square, a cafe and gym were designed – functions which will gather people and help to revive the place.

Technical rooms	64.5m^2
Service room	5.4m^2
Bathroom	26m^2
Locker rooms	66m^2
Shared kitchen	90m^2
Dining area	115m^2
Lounge areas	274.5m^2
Group rooms	283m^2
Coworking space	1024m^2
Printing/stationery	40m^2
Gym	321m^2
Conference rooms	251m^2
Restaurant	145m^2
Zen space	60m^2
Professional support office	30m^2
Entrance halls	75m^2
Lobby	50m^2
Bar	104m^2
Archives	34.4m^2
Administration	17.4m^2
Office	37.2m^2
Meeting area	164m^2
Cloak room	14m^2
Coffee bar	18m^2
Magasin	7.5m^2
Restaurant kitchen	36m^2
Meeting room	43m^2
Terraces	158m^2

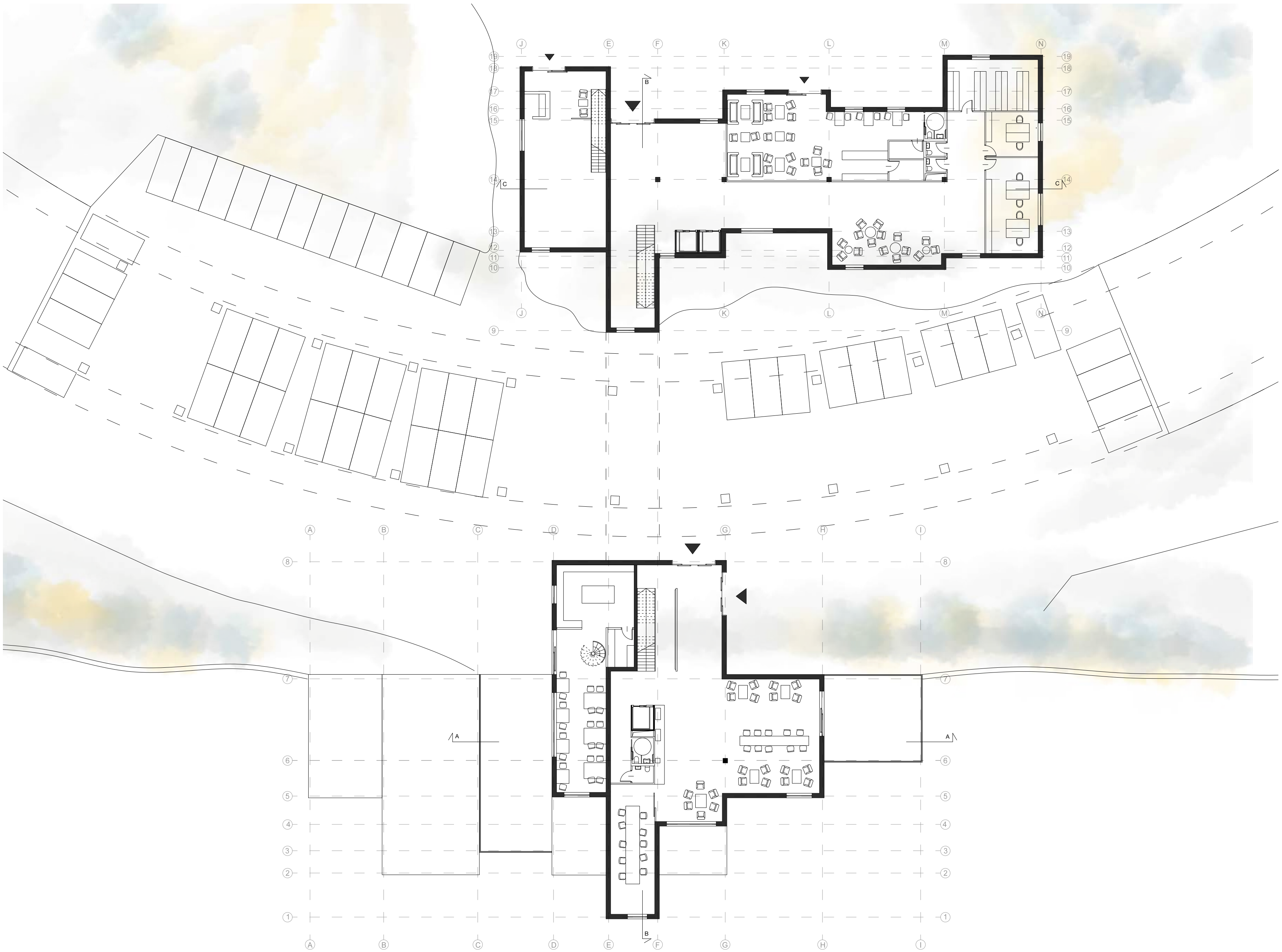


Fig. 4.9. Plan level 0

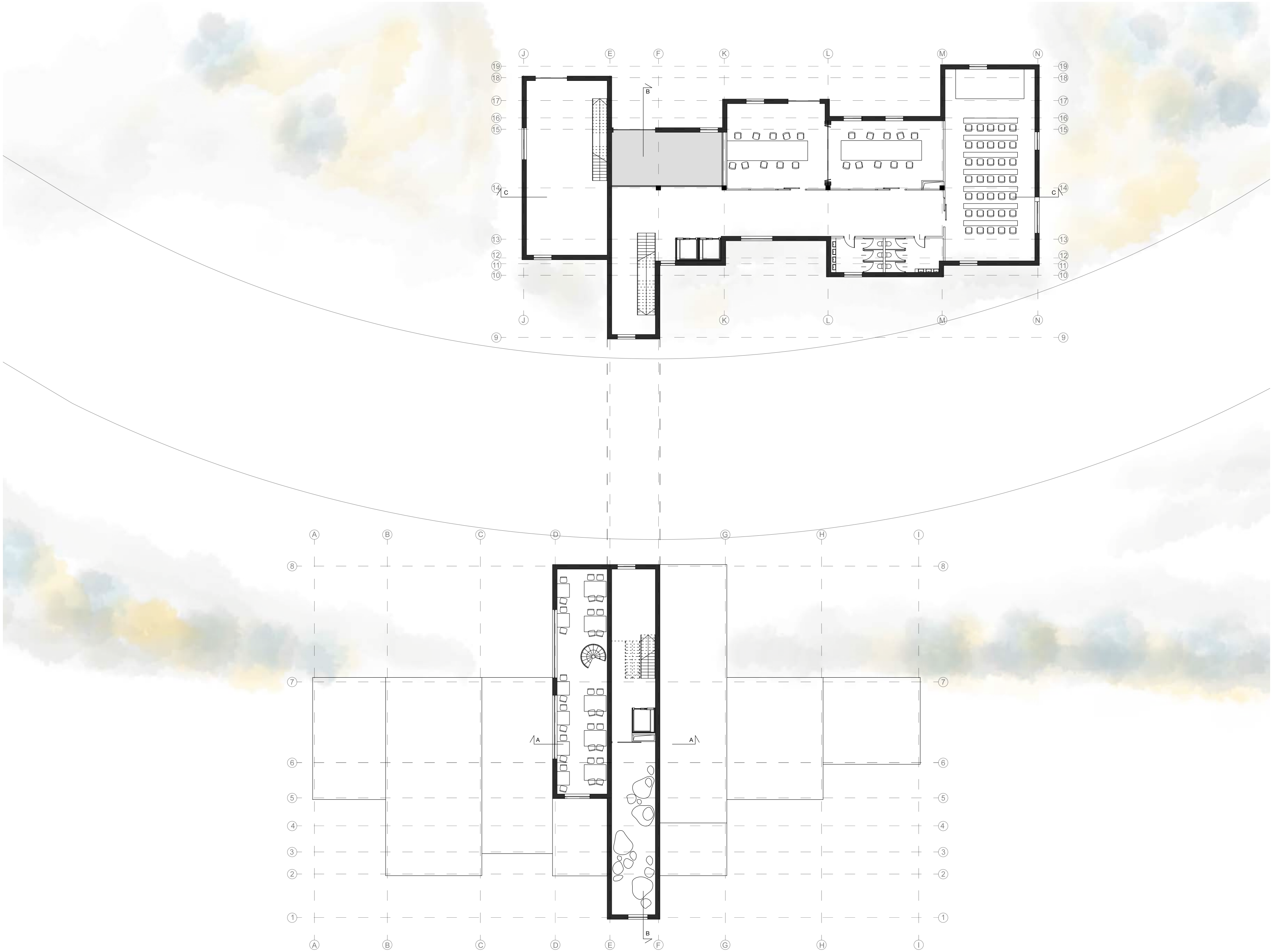


Fig. 4.10. Plan level +1

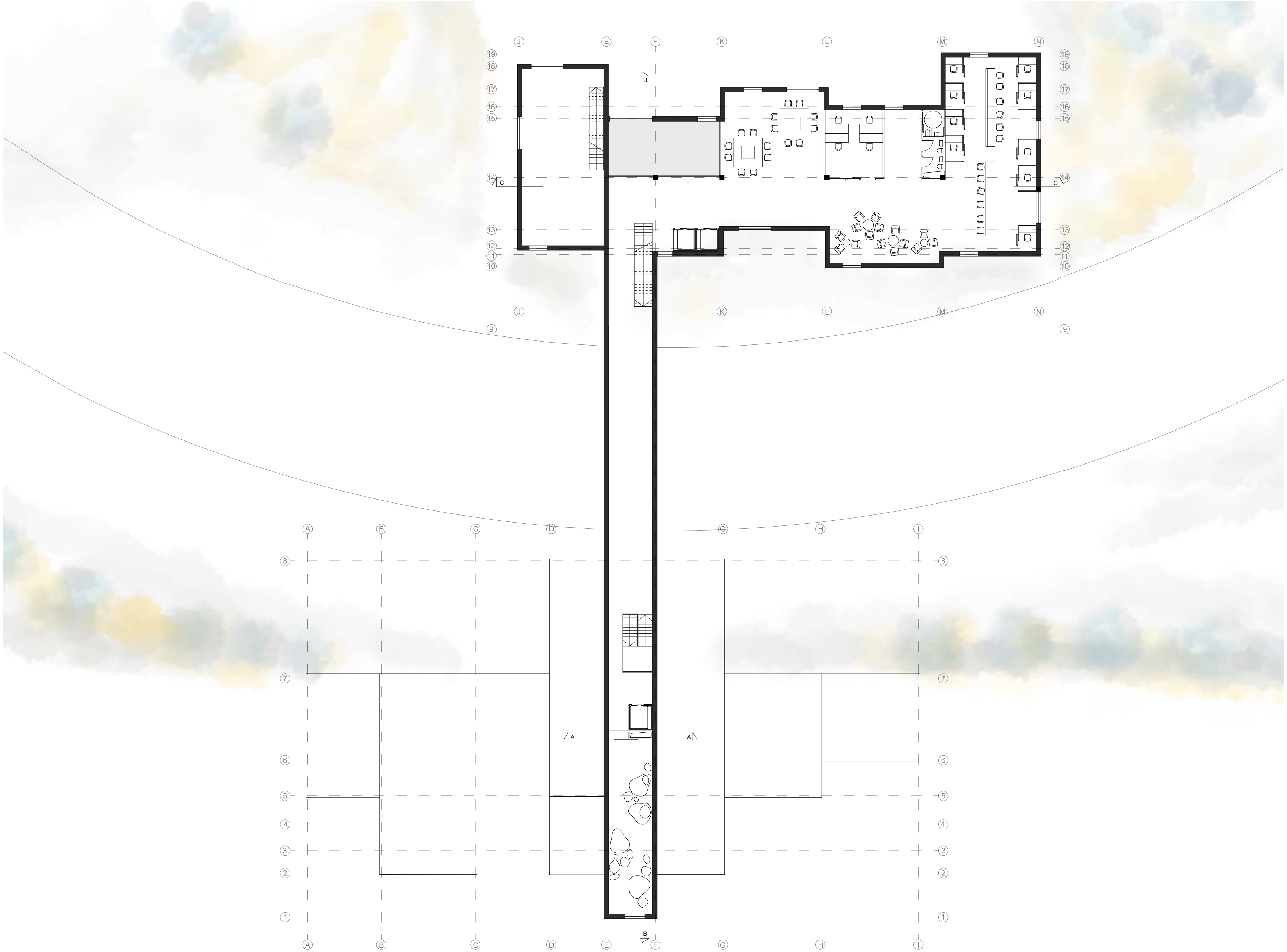


Fig. 4.11. Plan level +2

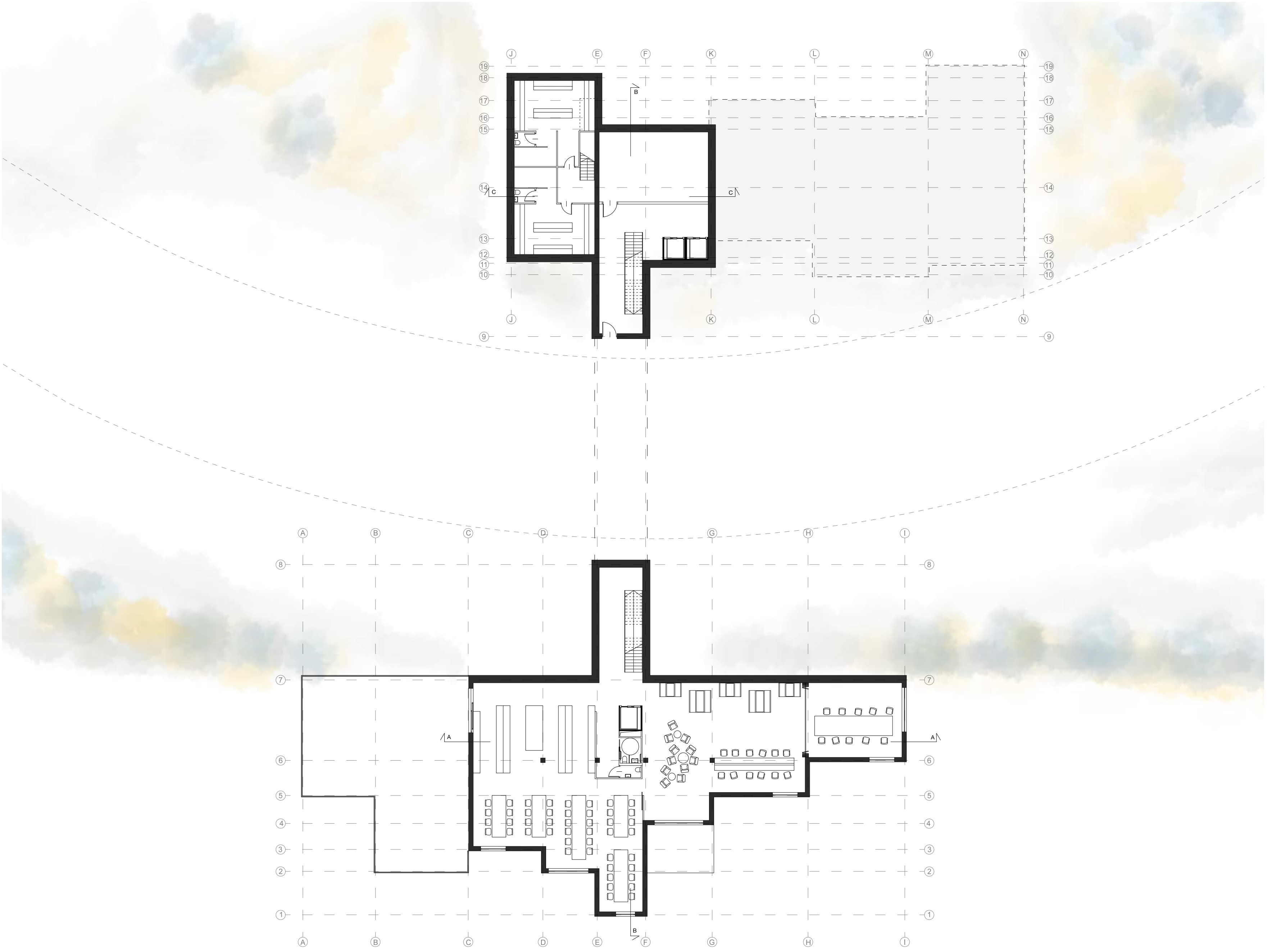


Fig. 4.12. Plan level -1

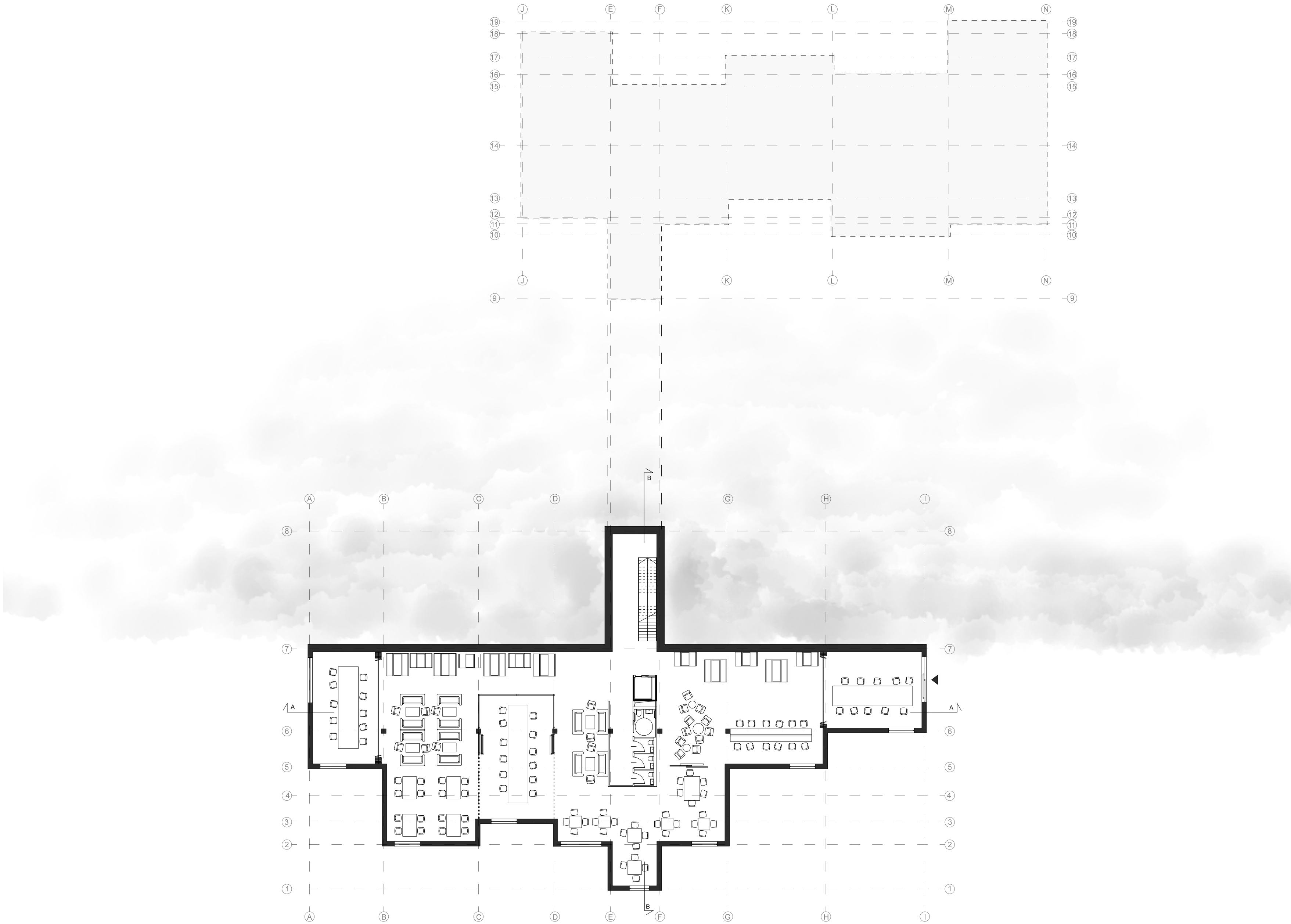


Fig. 4.13. Plan level -2

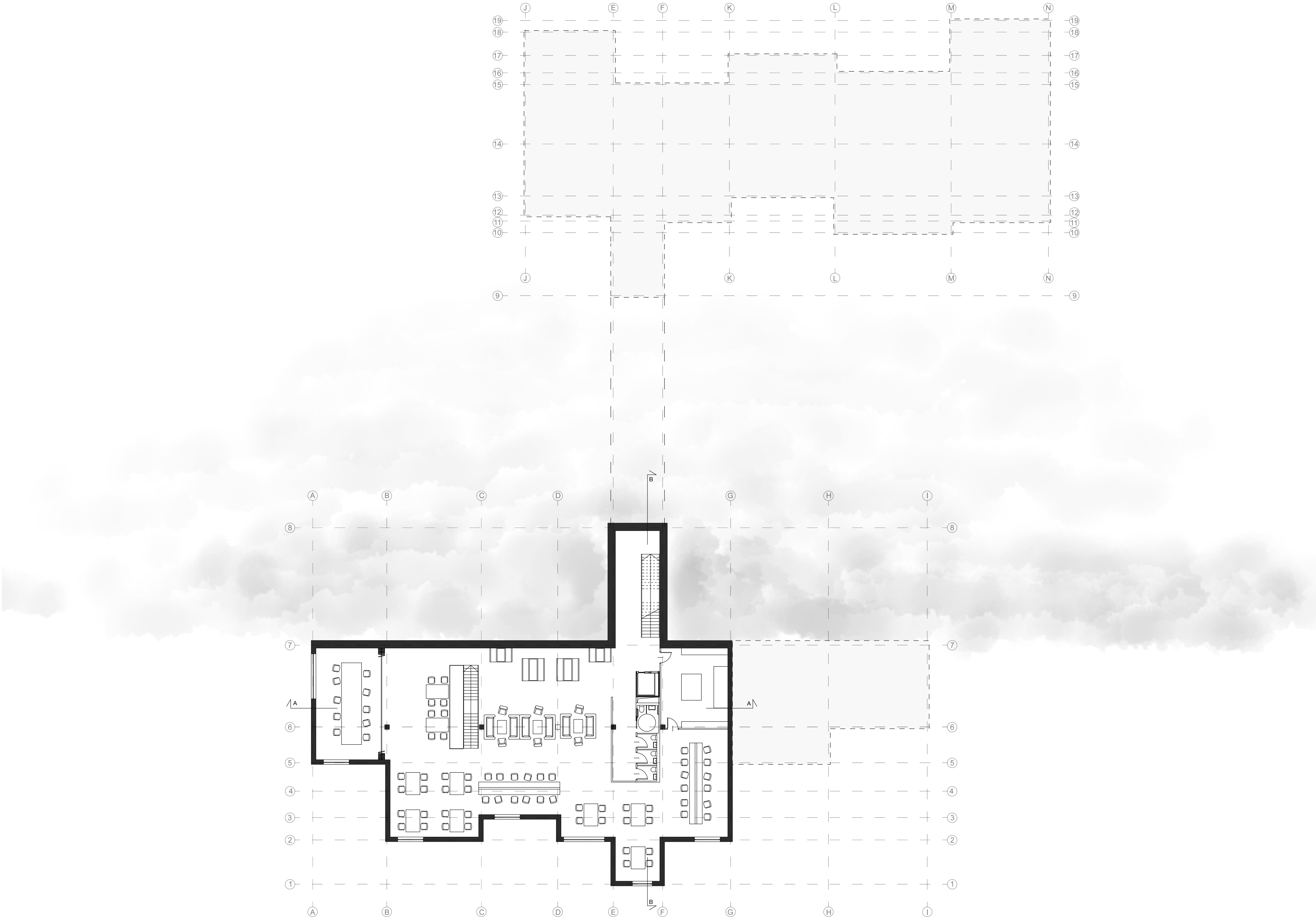


Fig. 4.14. Plan level -3

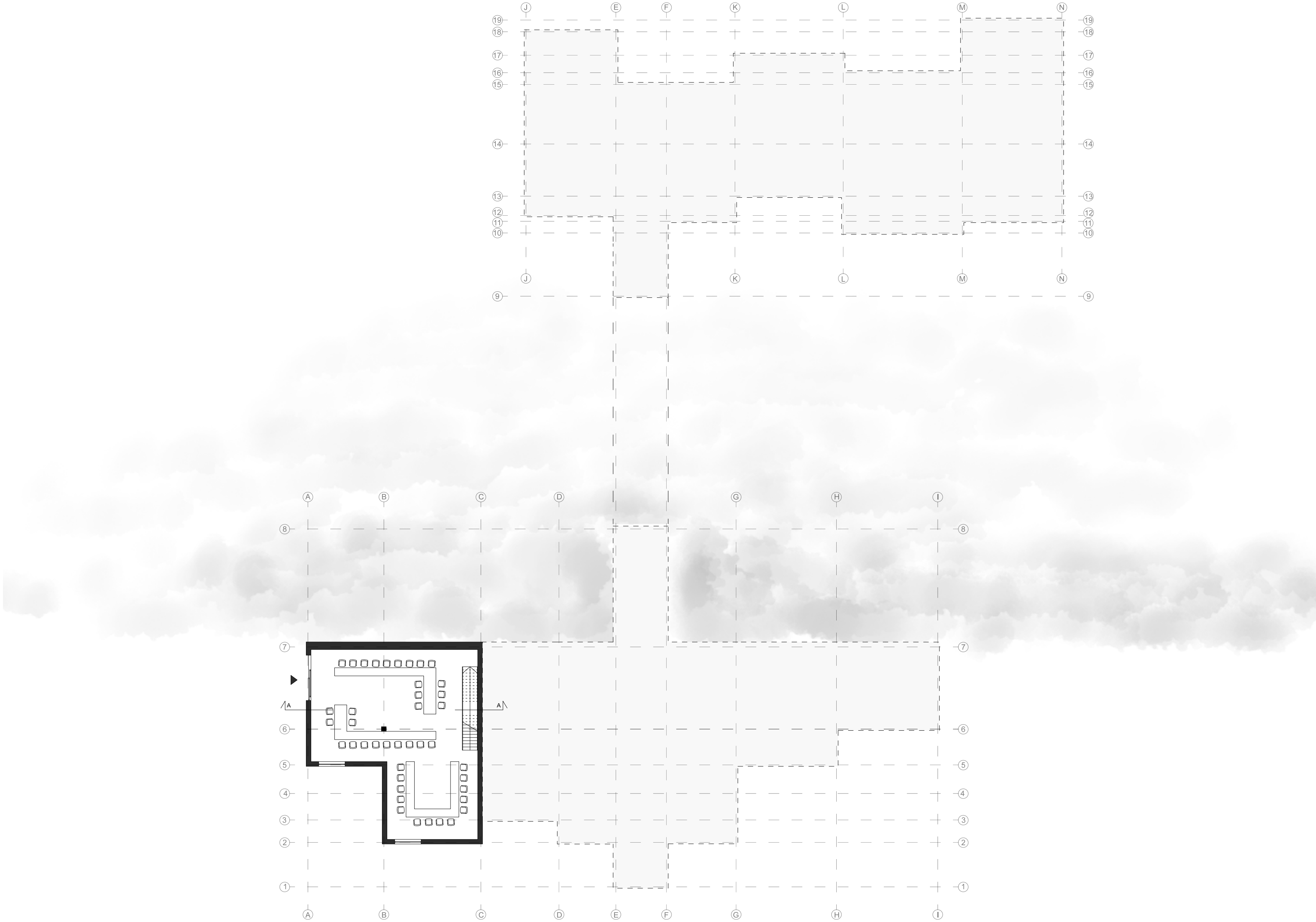


Fig. 4.15. Plan level -4

ELEVATIONS

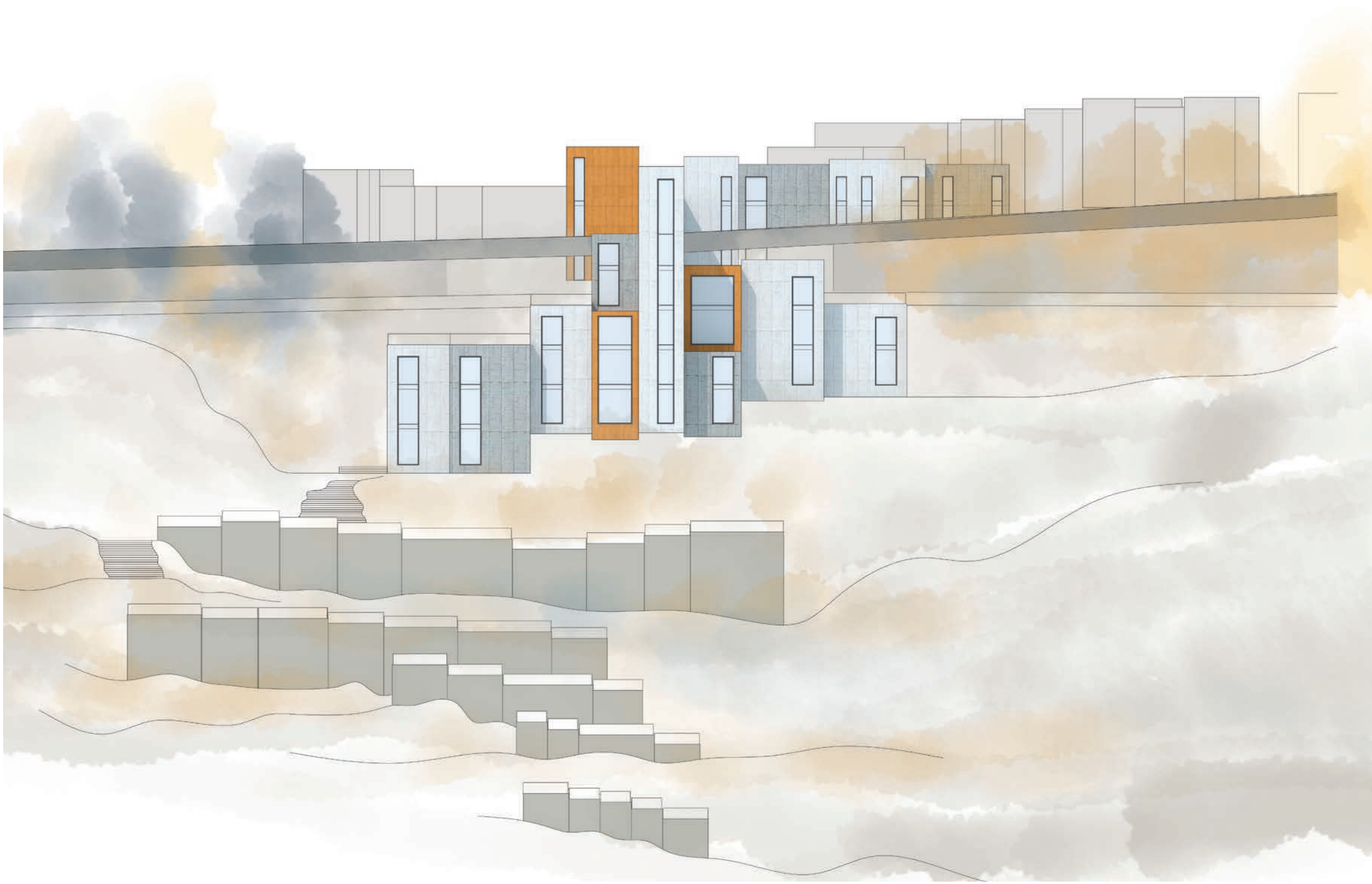


Fig. 4.16. Elevation south

Fig 4.17. Elevation north

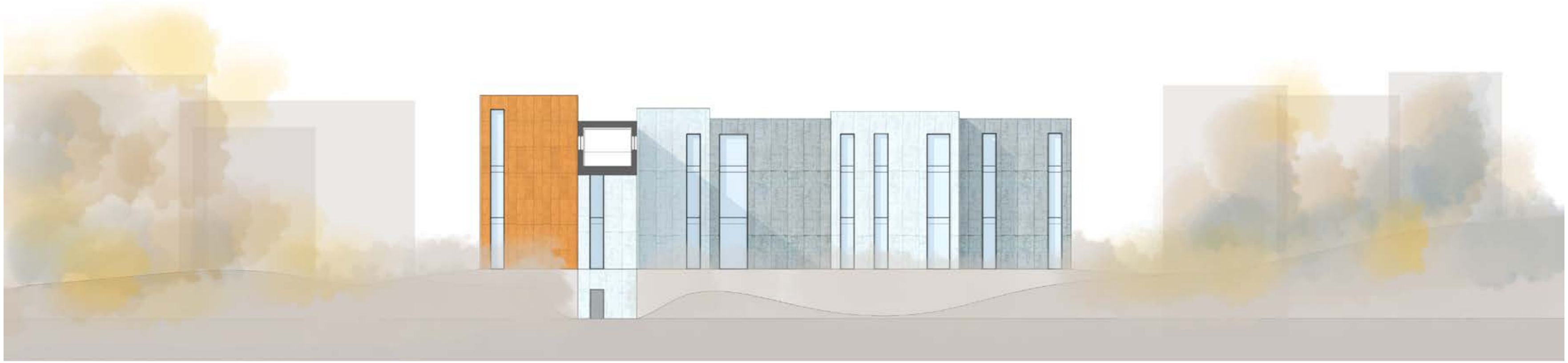
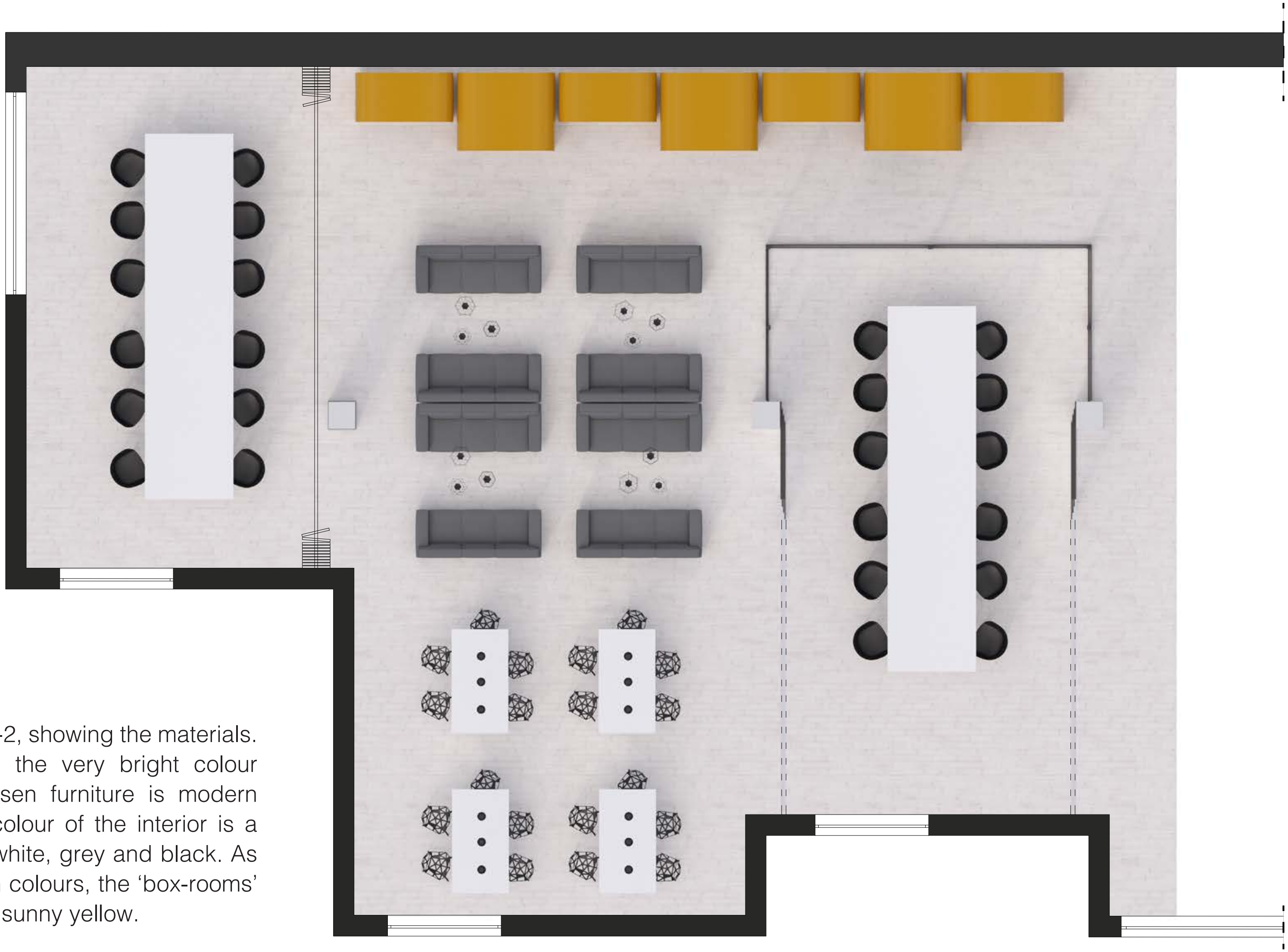


Fig. 4.18. Elevation south from the street

Fig. 4.19. Elevation east


Fig. 4.20. Elevation west

INTERIOR



Part of the plan, level -2, showing the materials. The wooden floor in the very bright colour were used. The chosen furniture is modern and functional. The colour of the interior is a natural bright wood, white, grey and black. As a contrast to the calm colours, the 'box-rooms' are designed as dark sunny yellow.

Fig. 4.21. Interior plan with materials

Fig. 4.22. Visualisation of the coworking space

Fig. 4.23. Visualisation of the lounge area

Fig. 4.24. Visualisation of the zen area

SECTIONS

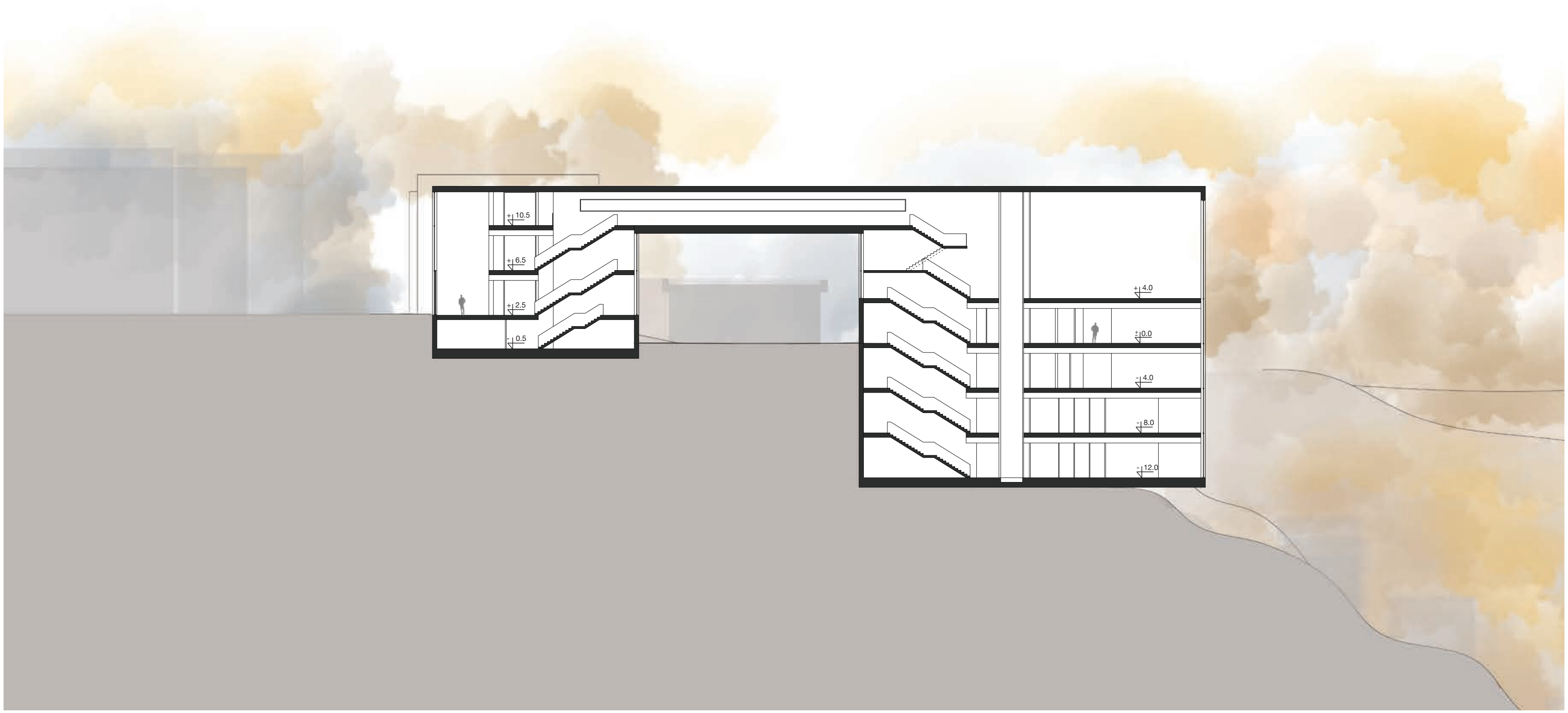


Fig. 4.25. Section B-B

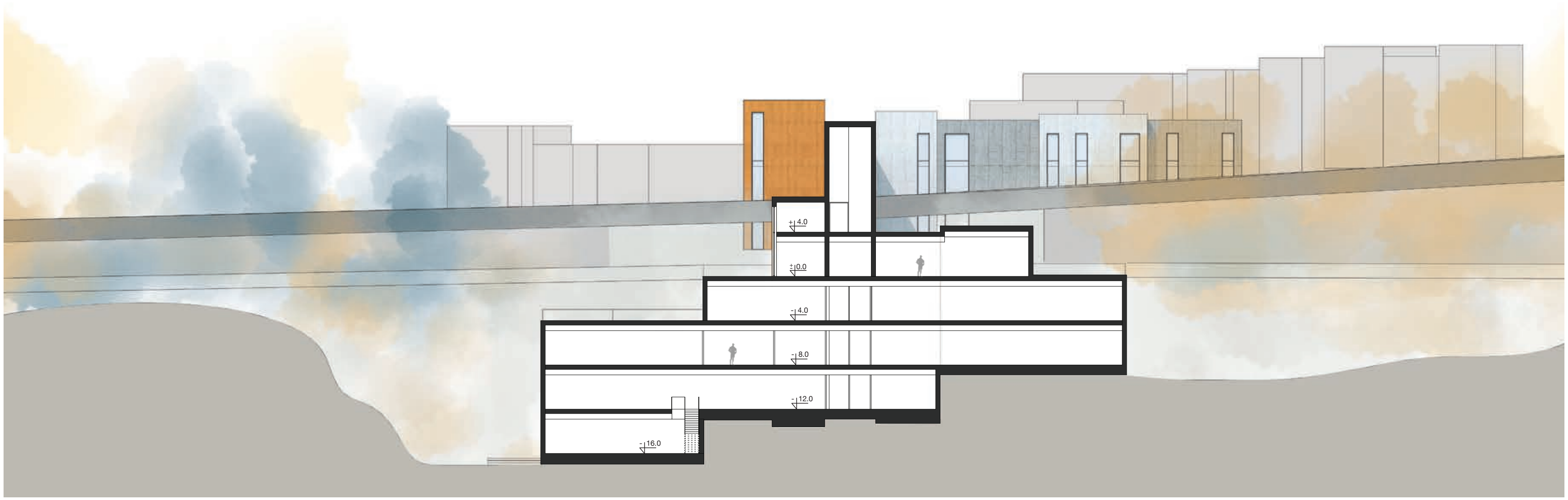


Fig. 4.26. Section A-A

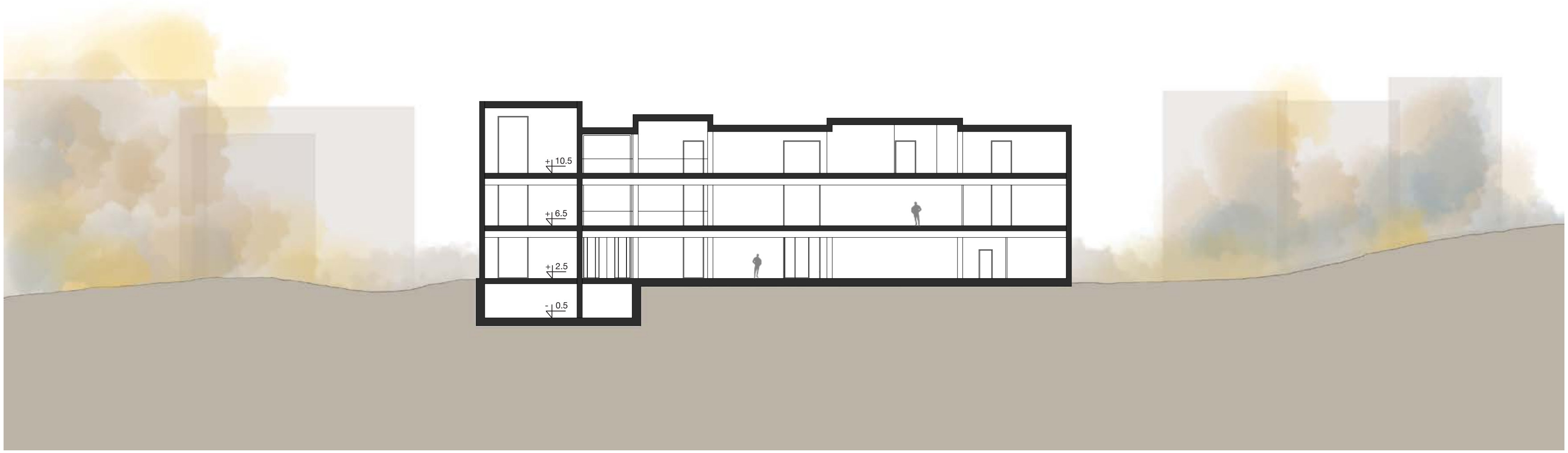


Fig. 4.27. Section C-C

STRUCTURE

The structure of the building was designed in concrete. The bearing walls and columns are on a grid, repeating the division of the building into segments. The interior is influenced by the structure – the functions are distributed according to the grid.
The bearing walls are designed from in-situ concrete in order to achieve the interesting texture on the outside walls. As the material of the bearing wall should be visible from the outside, the insulation layer is placed from the inside of the building.
This solution was first considered as incorrect, but many references confirm the choice. For instance the Vodafone Headquarters in Porto (Barbosa & Guimaraes architects) or Colour Concrete House in Yokohama (architectural office TNA), were made with the same principle. This is the only solution where the use of the materials is honest. In other case the concrete bearing wall with insulation has to be covered with concrete plates and pretend to be a solid concrete.

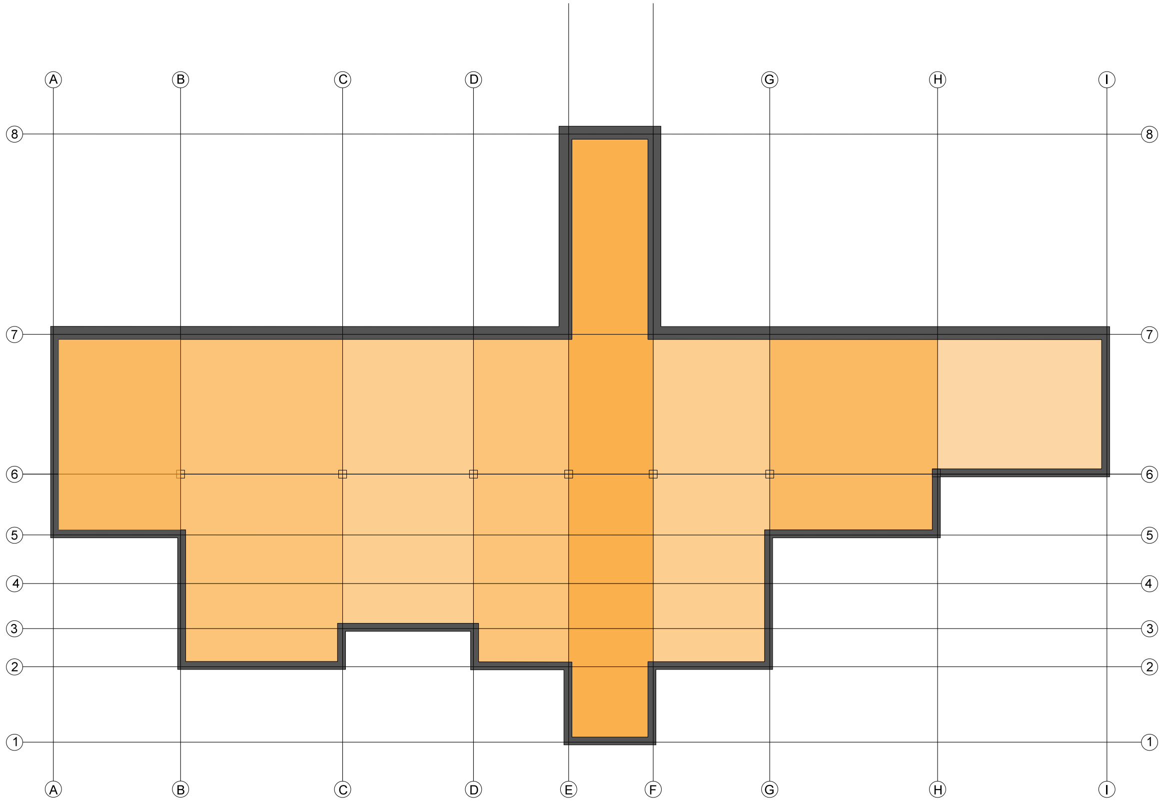
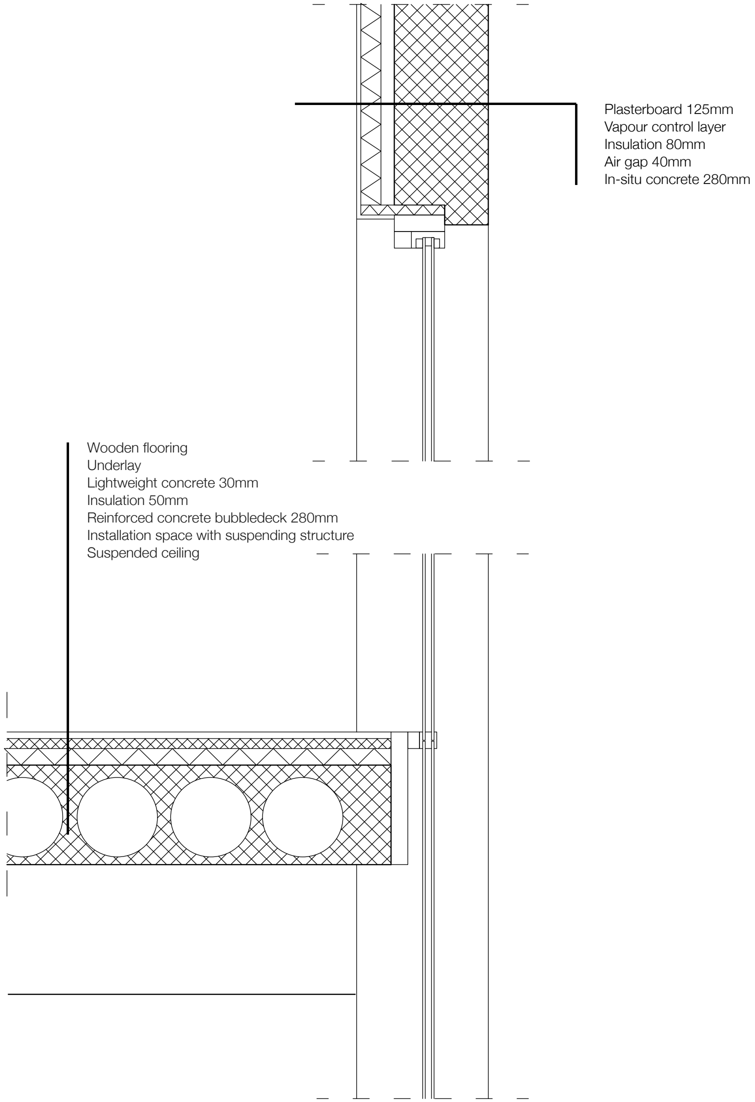
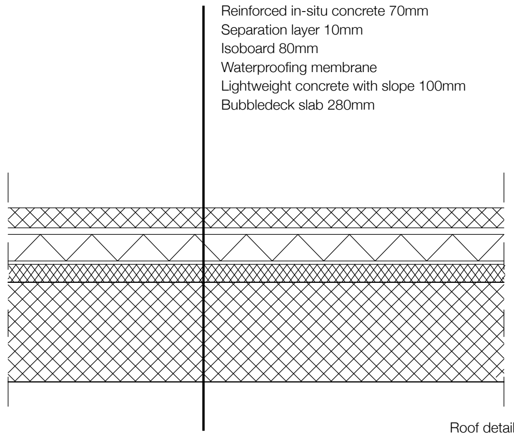


Fig. 4.28. Structure diagram

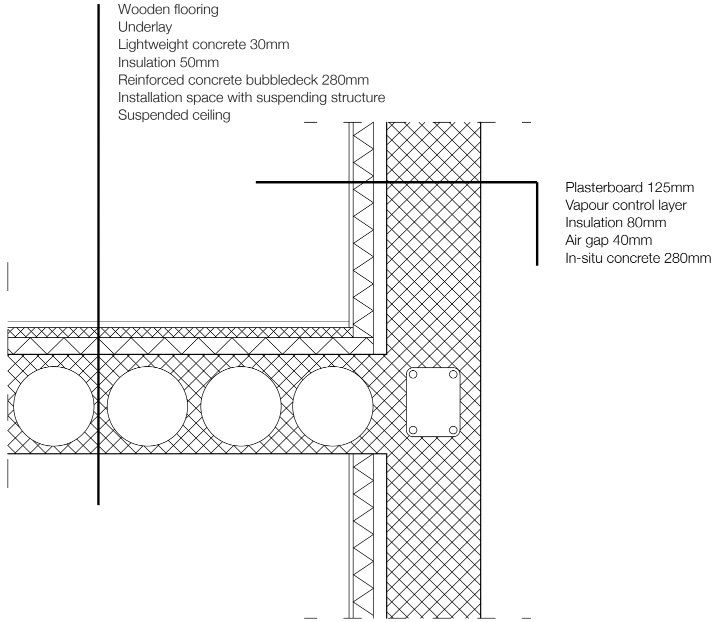
DETAIL



Section window



Roof detail



Slab with wall connection

Fig. 4.29. Details

CONCLUSION

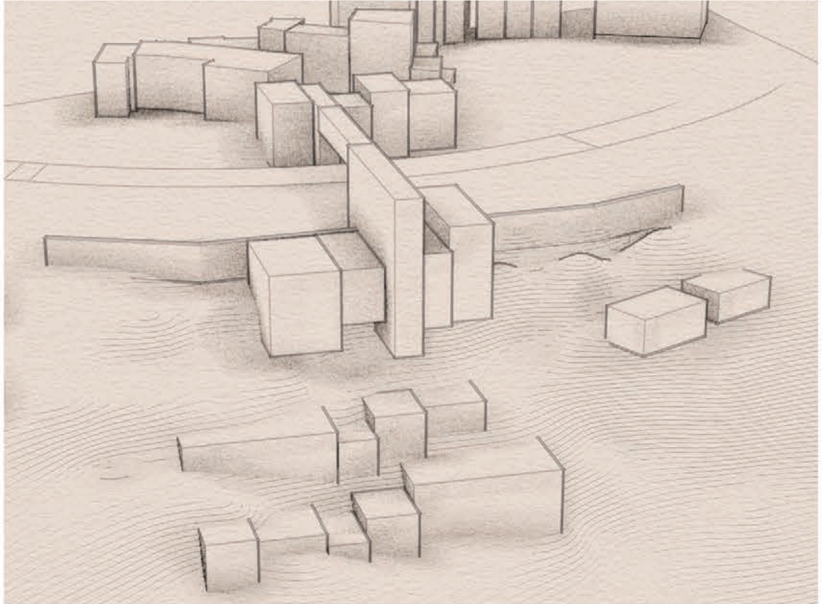
The main focus through the designing process was to create a building which will respect the neighbourhood. The main guides were found by extracting the most characteristic shape – a slim cuboid.
To make the building more integrated into the surrounding, its volume was divided into sections and placed wall by wall on different levels and depth.

The topography of the site formed the final shape of the building. One part is on a steep slope, more like a terraced building, while the other is placed on a flat area and, together with the existing buildings, it creates a public square.

“A building should appear to grow easily from its site and be shaped to harmonize with its surroundings (…)” —Frank Lloyd Wright

The building was formed to have a perceptible connection with the neighbourhood, but representing the architecture of these days. The similarity is through the overall principle of shape, to respectively fill the gap in the urban fabric.
The designed proposal belongs to the panorama repeating the same rhythm of the city.

Fig. 4.30. Visualisation from the riverside

PROCESS

LOCATION ON THE SITE

One of the first designing stages was to test different placing on the site. Many options were considered, however quite early the idea of the narrow boxes and a transition above the road evolved.

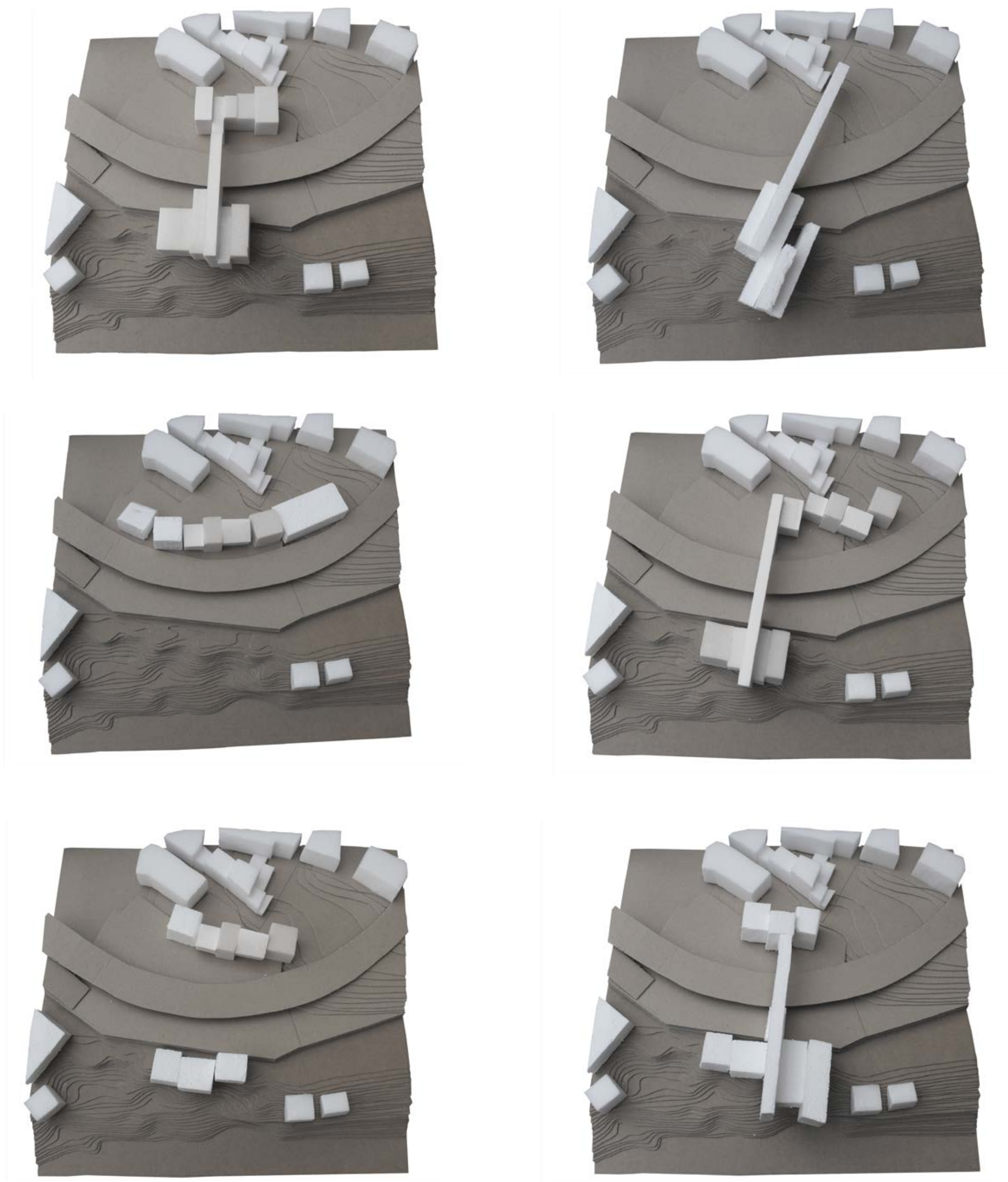
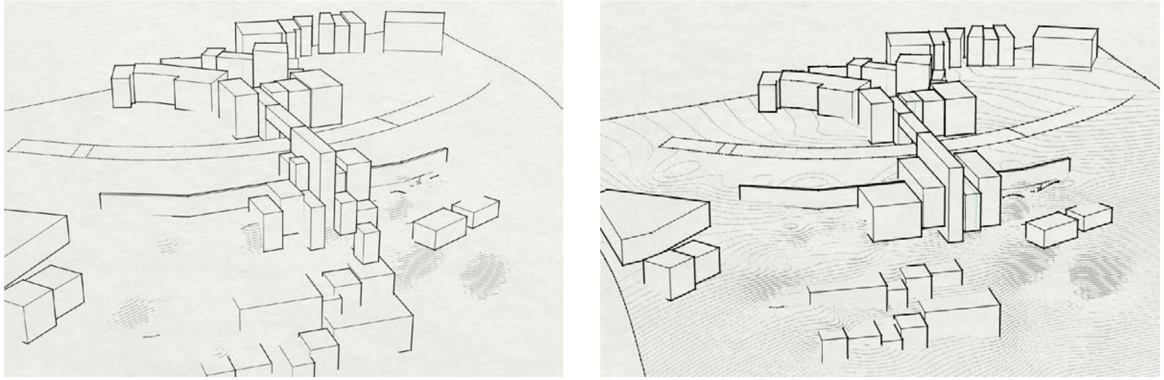


Fig. 5.1. Tests of different building locations

TESTS OF THE SHAPE

After the primary idea was chosen, the tests of the proportions and divisions were performed. Although the basic idea was fixed, the tests of the final shape took a long time. The variations were not only about the shape itself, but also how the building suit the surrounding.



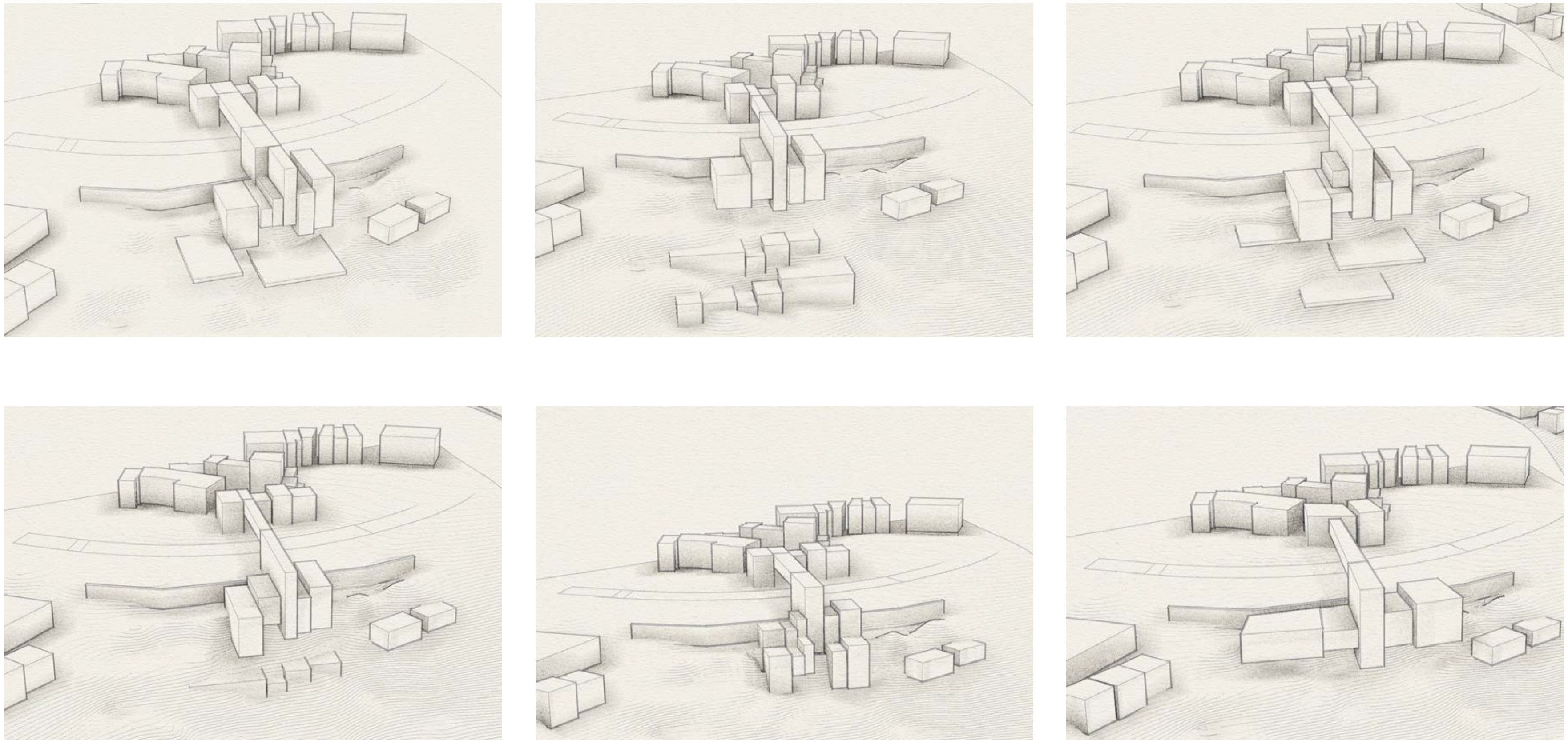
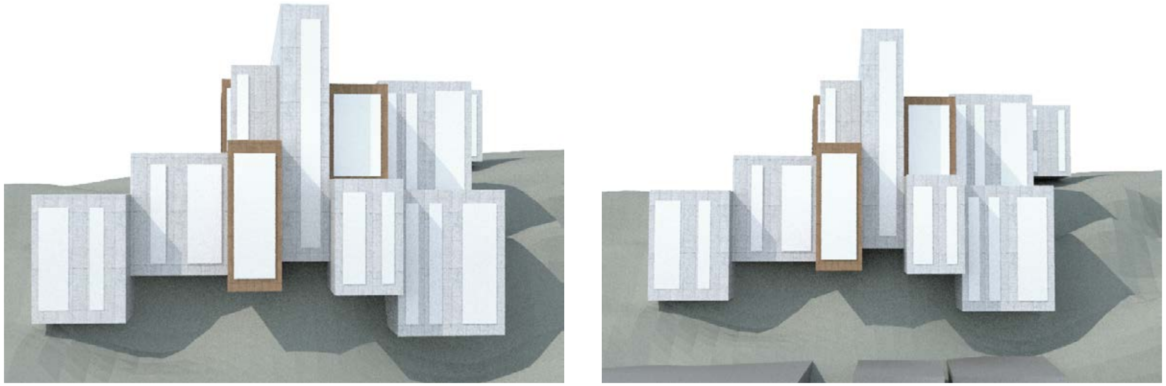


Fig. 5.2. Tests of different building shapes

ELEVATION / WINDOWS

When the outline of the building was nearly fixed, the tests of the openings were made. The challenge was to create an interesting look, but not to overload the elevation. It was also important to keep in mind issues like overheating when using too big windows.



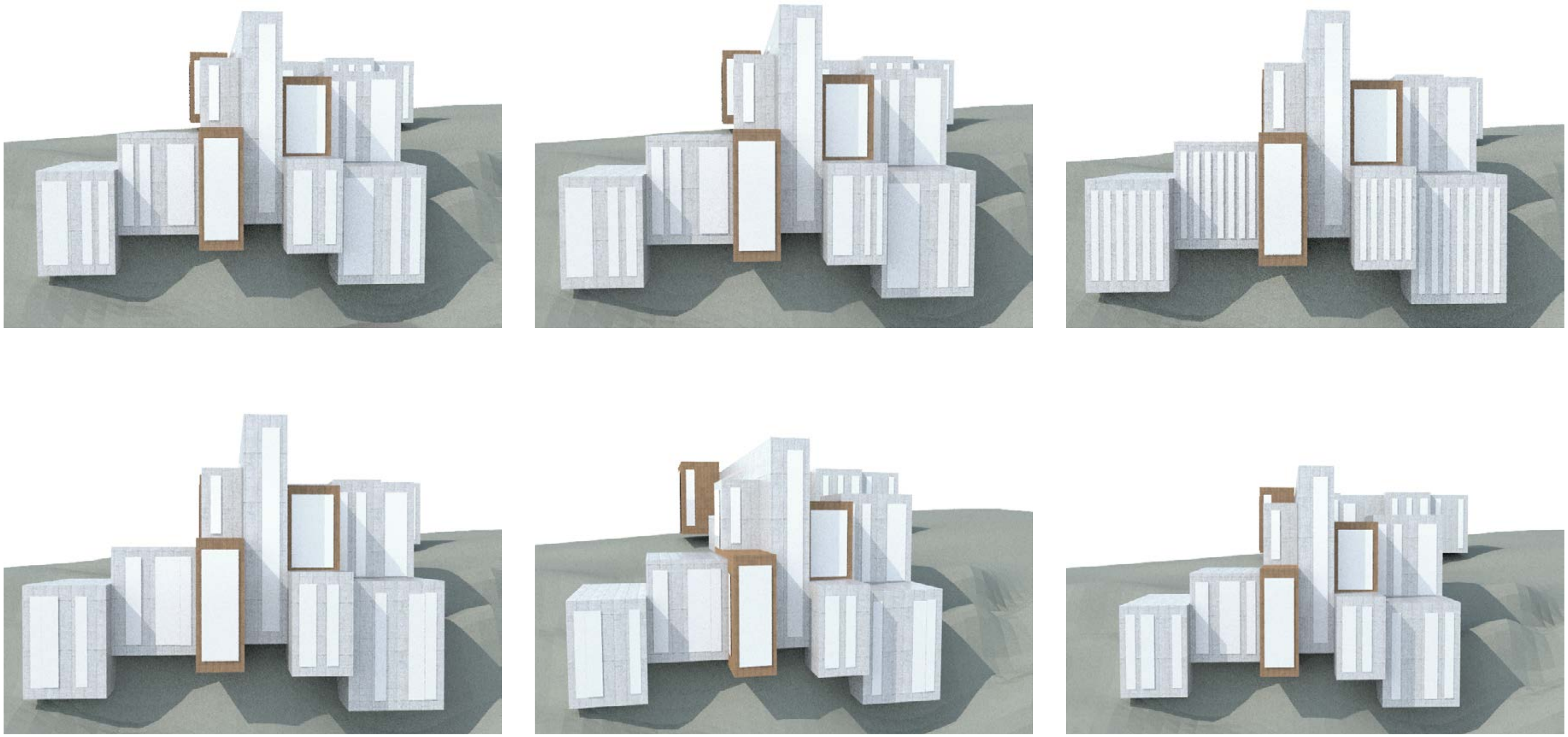


Fig. 5.3. Tests of different elevations

DAYLIGHT

The daylight factor simulation was made in Velux Visualizer. The chosen floor for the tests was level -2, which has the biggest depth from the windows and has the biggest area. As the result shows, the average of minimum 2% of daylight is fulfilled. However, in some places there is a lack of light, but this should not be an disadvantage. In that places the yellow boxes were designed, which serve as a 'private rooms' and have internal lights. The other solution is that in darker places there are lounge areas. They does not require a daylight, since it can be a zone for relaxing and chatting.

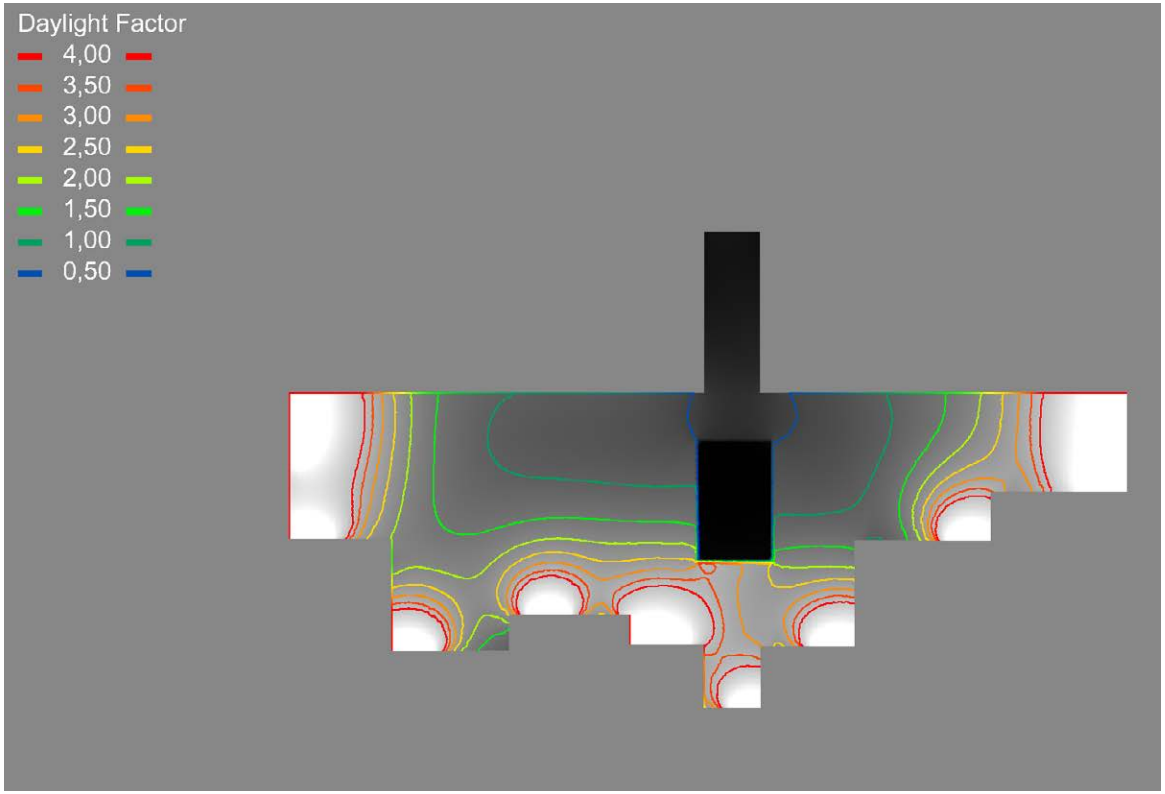


Fig. 5.4. Daylight factor simulation

Fig. 5.5. Visualisation prepared for the competition

The materials for the building were chosen by the criteria of modern look, but at the same time suiting the old surrounding. The materials used in the design were corten steel, concrete (in-situ) and coloured concrete. These three materials were applied alternately in order to achieve the look of separate sections.

MATERIALS


Fig. 5.6. Corten steel


Fig. 5.7. Coloured in-situ concrete


Fig. 5.8. In-situ concrete

CONSTRUCTION

Reinforced concrete was chosen as the material for the structural system of the building. The constructing elements are bearing walls and columns.

For the slab the BubbleDeck system was chosen. It is a new technology, around 20 years on the market, but becomes more popular thanks to its advantages.

The difference between BubbleDeck and classic slab is that Bubbledeck has plastic balls which are replacing the concrete in the middle of a classic slab, which does not contribute to its structural performance. As a result the slab is lighter and can work in wider spans.

The wider spans were the main reason why this solution is used. The building is designed as an open plan, so the number of columns were limited to minimum.

Moreover, the Bubbledeck slab is much more sustainable than classical. According to producer, 35% less concrete is used in the slab compared to the traditional floor system. It has the impact on the whole structure, as the total weight of the construction is lighter.

Furthermore the balls for the slab are made from recycled plastic and all materials used can be reused upon demolition.

In the structure the prefabricated version of the slab is used, which works as a one-way slab. The slab is supported by beams hidden in the thickness of the slab and by bearing walls.

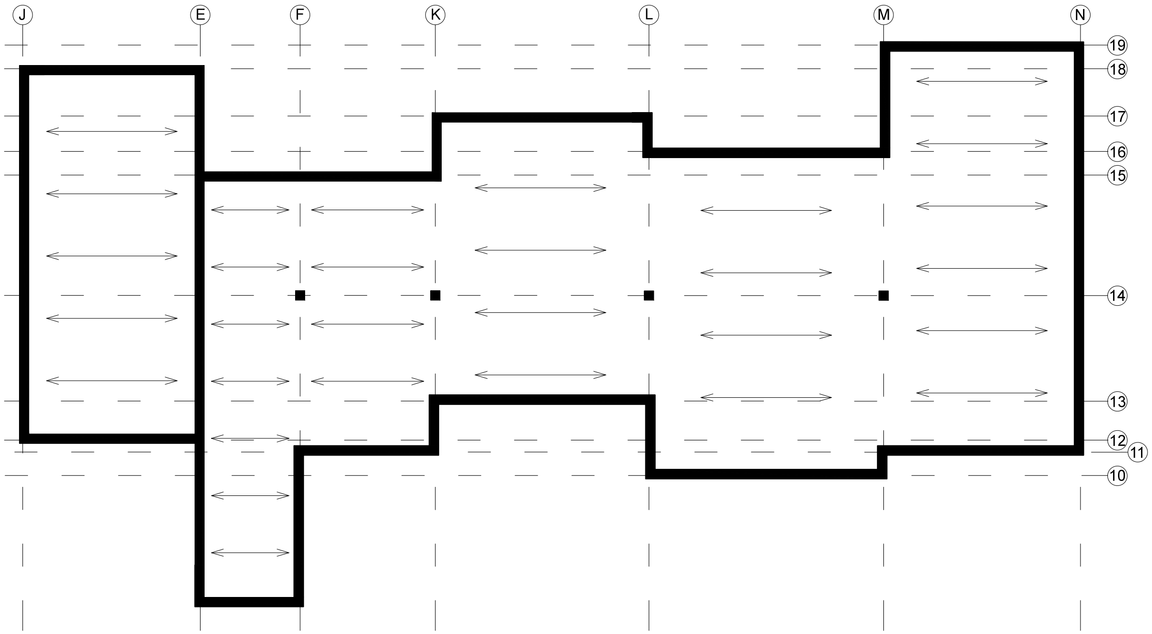


Fig. 5.9. Construction scheme.

The prefabricated BubbleDeck slab needs to be supported by bearing walls or beams. However beams are in the thickness of the slab, which means that slab creates a flat ceiling and thickness of the slab is the final thickness.

To calculate the accurate thickness of the slab, the bending-strenght design for a rectangular cross section was performed - according to producer recommendations.
The calculations where based on the part of a slab between axis 'L' and 'M', where the span is the biggest.
To calculate the maximum bending moment the model of bearing walls and columns were build in Robot. Calculations of the roof loads were made manual and implemented in Robot. The maximum bending moment for the slab is 122,6 kNm.
After calculations, taking into account the span of the slab, the thickness of 280mm was chosen.

Furthermore the beam in the axis 'M' was calculated, to get the reactions in the point of connection with the column.
For the calculations the prefabricated beam from concrete C25 was used.
Robot Structural Analysis was used to calculate the reactions on the beam. Two separate calculations were made, for a beam under the roof and under the slab.
As a result the maximum force on the beam from roof is 681kN, while 970kN for the beam under the slab.

The next step was to calculate the dimensions of the column. The columns of 400mm x 400mm are dimensioned to take forces of 2508kN. The applied force for the column on the first floor, extracted from Robot, is 1651kN, so the column will hold. Unfortunately, the column of the same dimensions was not able to hold the forces in the ground floor. Hence, the dimensions were changed into 450mm x 450mm. As a result, the applied force is 2653kN while the column can hold 3318kN.

All of the calculations were made according to Eurocodes and can be found in Appendix.

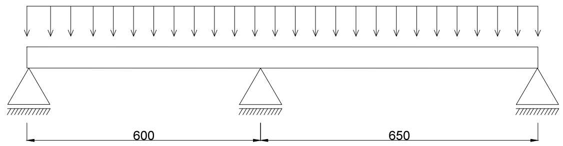


Fig. 5.10. Double span beam

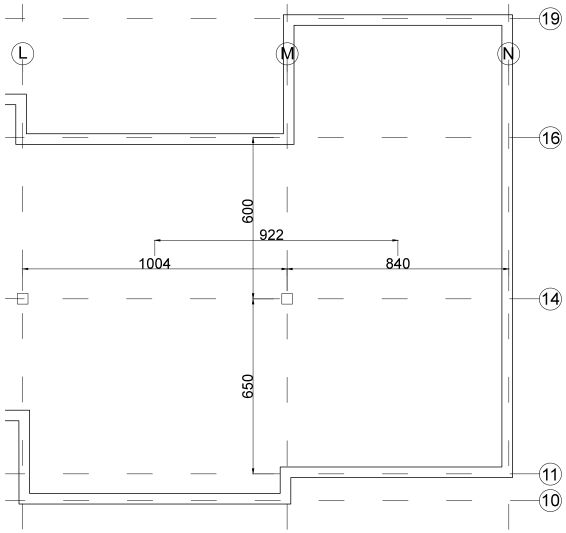


Fig. 5.11. Placement of the beam – in axis M

Fig. 5.12. Interior visualisation - competition version

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Slab

Loads

Layers:

- lightweight concrete $35mm$ – $21kN/m^3$ — $21kN/m^3 \cdot 0.035m = 0.735kN/m^2$
- installation $30mm$ – $0.45kN/m^3$ — $0.45kN/m^3 \cdot 0.03m = 0.0135kN/m^2$
- lightweight concrete $10mm$ – $21kN/m^3$ — $21kN/m^3 \cdot 0.01m = 0.21kN/m^2$
- wooden floor $15mm$ – $19kN/m^3$ — $19kN/m^3 \cdot 0.015m = 0.285kN/m^2$

safety factor (dead load) — 1.35

$(0.735 + 0.0135 + 0.21 + 0.285) \cdot 1.35 = 1.2435 \cdot 1.35 = 1.68[kN/m^3]$

total dead load: $1.68kN/m^2$

Function of the building: office.
According to Eurocodes, live load for office buildings: $3kN/m^2$

safety factor (live load) — 1.5

$3kN/m^2 \cdot 1.5 = 4.5kN/m^2$

partition walls — $1.2kN/m^2$

$1.2kN/m^2 \cdot 1.5 = 1.8kN/m^2$

$1.8kN/m^2 + 4.5kN/m^2 = 6.3kN/m^2$

total live load: $6.3kN/m^2$

Chosen slab

Type of slab used: Bubbledeck BD280, ball size $\oslash 225mm$

$$\mu_{sds} = \frac{m_{sd} \cdot D_{BD} \cdot 1.96}{({d_B}^3 \cdot f_{ck})} \leq 0.2$$

where:
μ_{sds} — relative bending moment in the ball zone
m_{sd} — max bending moment $[MNm]$
D_{BD} — ball diameter $[m]$
d_B — static height of the BubbleDeck $[m]$
f_{ck} — characteristic strength according to DIN 1045-1 $[MN/m^2]$

$$\frac{m_{sd} \cdot D_{BD} \cdot 1.96}{{d_B}^3 \cdot f_{ck}} \leq 0.2$$

$$m_{sd} = 112.56kNm = 0.19765MNm$$

$$D_{BD} = 0.225m$$

$$d_B = 0.25m$$

$$f_{ck} = 45MN/m^2$$

$$\frac{0.11256MNm \cdot 0.225m \cdot 1.96}{(0.25m)^3 \cdot 45} \leq 0.2$$

$$\frac{0.049}{0.7} \leq 0.2$$

$$0.07 \leq 0.2$$

Beam

All calculations are done for the beam in the ”M” axis.

Calculations for the beam with slab load.

$5.17kN/m^2$ — slab load
$6.3kN/m^2$ — slab live load
$1.68kN/m^2$ — slab dead load

$$5.17kN/m^2 + 6.3kN/m^2 + 1.68kN/m^2 = 13.15kN/m^2$$

$$13.15kN/m^2 \cdot 9.22m = 121.6kN/m$$

$l = 12.5m$ — length of the beam

$25kN/m^3$ — concrete beam load C25
$w = 0.4m$ — width of the beam
$h = 0.28m$ — height of the beam

$0.28m \cdot 0.4m \cdot 25 = 2.8kN/m$

$q = 121.2kN/m + 2.8kN/m = 124kN/m$

To calculate reactions on the beam, the Robot Structural Analysis was used.

$F_z = 969.99kN \simeq 970kN$ — the value of the reaction in the point of connection of the slab with a column (from RSA). Slab load.

Calculations for the beam with roof load.

- snow load

  $s = \mu \cdot c_e \cdot c_t \cdot s_k$

  $s_k = 0.1kN/m^2$ — the characteristic value for the terrain
  $c_e = 1$ — the exposure factor
  $c_t = 1$ — the thermic factor
  $\mu = 0.8$ – the form of the roof factor

  $s = 0.8 \cdot 1 \cdot 1 \cdot 0.1kN/m^2 = 0.08kN/m^2$

  $0.08kN/m^2 \cdot 1.5 = 0.12kN/m^2$

- live load – roof $= 0.4kN/m^2$

  $0.4kN/m^2 \cdot 1.5 = 0.6kN/m^2$

  total live load – roof $= 0.72kN/m^2$

- dead load – roof

  insulation 150mm — $0.45kN/m^3$ — $0.45kN/m^3 \cdot 0.15m = 0.068kN/m^2$
  asphalt felt — $0.1kN/m^2$
  Bubbledeck slab — $6.25kN/m^2$

  $0.068kN/m^2 + 0.1kN/m^2 + 6.25kN/m^2 = 6.42kN/m^2$

  total dead load – roof $= 6.42kN/m^2$

  $(6.24kN/m^2 \cdot 1.35 + 0.72kN/m^2) \cdot 9.22m = 87.1kN/m$

$F_{z2} = 681kN$ — the value of the reaction in the point of connection of the slab with a column (from RSA). Roof load.

Column

Column on the 1st floor

$970kN \cdot 2 + 681kN = 2621kN$

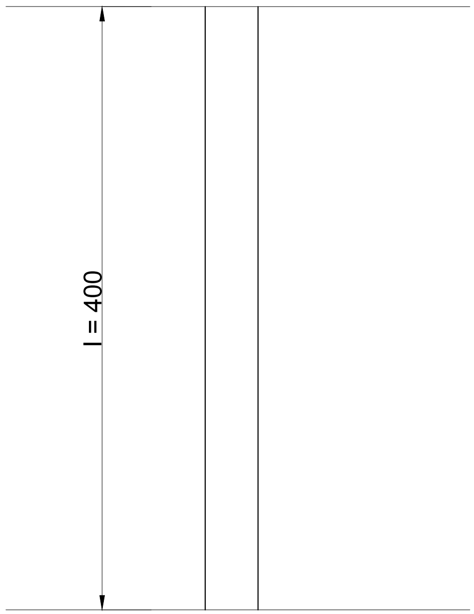
Column concrete C25

$h = 4m$
$w = 0.4m$
$l = 0.4m$

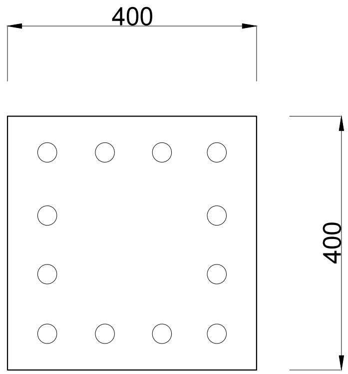
$4m \cdot 0.4m \cdot 0.4m = 0.64m^3$

$2 \cdot 0.64m^3 \cdot 25kN/m^3 = 32kN$

$2621kN + 32kN = 2653kN$



Dimensions of the column



Column 400mm × 400mm

Dimensions of the column:

$w = 400mm$
$h = 400mm$
$l = 4000mm$

Concrete 32 — $f_{ck} = 35MPa$
Steel ⌀25 — $f_{yk} = 550MPa$

Modulus of elasticity — $E_{sk} = 2 \cdot 10^5 MPa$ (for steel)

$$E_{sd} = \frac{E_{sk}}{\gamma_s} = \frac{2 \cdot 10^5 MPa}{1.2}$$

The concrete design compressive strength:

$$\gamma_c = 1.4 \qquad f_{cd} = \frac{f_{ck}}{\gamma_c} = \frac{35MPa}{1.4} = 25MPa$$

The steel design compressive strength:

$$\gamma_s = 1.2 \qquad f_{yd} = \frac{f_{yk}}{\gamma_s} \qquad f_{yd} = \frac{550MPa}{1.2} = 458.3MPa$$

Ultimate limit state

Slenderness ratio – λ:

$$\lambda = \frac{l}{\sqrt{\frac{I}{A}}} \qquad I = \frac{b \cdot h_3}{12} \qquad b \cdot h = A$$

$$\lambda = \frac{l \cdot \sqrt{12}}{h} = \frac{4000mm \cdot \sqrt{12}}{400mm} = 34.6$$

The reinforcement ratio – ρ:

$$\rho = \frac{A_{sc}}{A_c} = \frac{8 \cdot 25^3 * \frac{\pi}{4}}{400 \cdot 400} = 0.024 = 2.4\% \qquad \{0.2\% \leq 2.4\% \leq 4.0\%\}$$

Beginning modulus of elasticity – $E_{0,crd}$:

$$E_{0,crd} = \left\{ \begin{array}{l} 1000 \cdot f_{cd} \;\; for \;\; f_{cd} \leq 25MPa \\ 0.75 \cdot E_{0d} \;\; for \;\; f_{cd} > 25MPa \end{array} \right\}$$

$$E_{0,crd} = 1000 \cdot f_{cd} = 1000 \cdot 25MPa = 25000MPa$$

Critical tension – σ:

- concrete

  $$\sigma_{crd} = \frac{f_{cd}}{1 + \frac{f_{cd} \cdot \lambda^2}{\pi^2 \cdot E_{0,crd}}} = \frac{25MPa}{1 + \frac{28900MPa}{24674MPa}} = 11.52MPa$$

  The relationship between reinforcement and the concrete modulus of elasticity – λ:

  $$E_{c,eff} = \frac{E_{cm}}{1 + \varphi}$$

  $E_{cm} = 34000MPa$ (concrete class)

  $\varphi = 1.5$

  $$E_{c,eff} = \frac{34000MPa}{1 + 1.5} = 136000MPa$$

  $$\lambda = \frac{E_{sk}}{E_{c,eff}} = 14.7$$

- steel

  $\sigma_s = \lambda \cdot \sigma_{crd} = 14.7 \cdot 11.52MPa = 169.34MPa$

  $\sigma_s < f_{yd} \Rightarrow 169.34MPa < 458.3MPa$

Column load capacity

$N_c = A_c \cdot \sigma_{crd} = 400mm \cdot 400mm \cdot 11.52 \cdot 10^3 Pa = 1843.2kN$

$N_s = A_{sc} \cdot \sigma_s = 490.9mm^2 \cdot 8 \cdot 169.34 \cdot 10^3 Pa = 665kN$

$N_{cr} = N_c + N_s = 1843.2kN + 665kN = 2508.2kN$

The force extracted from Robot on the column on 1st floor is:

$970kN + 681kN = 1651kN$

$2508.2kN > 1651kN$

Thus, the column is dimensioned to hold.

Column in the ground floor

Column 450mm × 450mm

Dimensions of the column:

$w = 450mm$
$h = 450mm$
$l = 4000mm$

Concrete 32 — $f_{ck} = 35MPa$
Steel ⊘25 — $f_{yk} = 550MPa$

Modulus of elasticity — $E_{sk} = 2 \cdot 10^5 MPa$ (for steel)

$$E_{sd} = \frac{E_{sk}}{\gamma_s} = \frac{2 \cdot 10^5 MPa}{1.2}$$

The concrete design compressive strength:

$$\gamma_c = 1.4 \qquad f_{cd} = \frac{f_{ck}}{\gamma_c} = \frac{35MPa}{1.4} = 25MPa$$

The steel design compressive strength:

$$\gamma_s = 1.2 \qquad f_{yd} = \frac{f_{yk}}{\gamma_s} \qquad f_{yd} = \frac{550MPa}{1.2} = 458.3MPa$$

Ultimate limit state

Slenderness ratio – λ:

$$\lambda = \frac{l}{\sqrt{\frac{I}{A}}} \qquad I = \frac{b \cdot h_3}{12} \qquad b \cdot h = A$$

$$\lambda = \frac{l \cdot \sqrt{12}}{h} = \frac{4000mm \cdot \sqrt{12}}{450mm} = 30.8$$

The reinforcement ratio – ρ:

$$\rho = \frac{A_{sc}}{A_c} = \frac{8 \cdot 25^3 * \frac{\pi}{4}}{450 \cdot 450} = 0.019 = 1.9\% \qquad \{0.2\% \leq 1.9\% \leq 4.0\%\}$$

Beginning modulus of elasticity – $E_{0,crd}$:

$$E_{0,crd} = \begin{Bmatrix} 1000 \cdot f_{cd} \;\; for \;\; f_{cd} \leq 25MPa \\ 0.75 \cdot E_{0d} \;\; for \;\; f_{cd} > 25MPa \end{Bmatrix}$$

$E_{0,crd} = 1000 \cdot f_{cd} = 1000 \cdot 25MPa = 25000MPa$

Critical tension – σ:

- concrete

  $$\sigma_{crd} = \frac{f_{cd}}{1 + \frac{f_{cd} \cdot \lambda^2}{\pi^2 \cdot E_{0,crd}}} = \frac{25MPa}{1 + \frac{23716MPa}{24674MPa}} = 12.75MPa$$

  The relationship between reinforcement and the concrete modulus of elasticity – λ:

  $$E_{c,eff} = \frac{E_{cm}}{1 + \varphi}$$

  $E_{cm} = 34000MPa$ (concrete class)

  $\varphi = 1.5$

  $$E_{c,eff} = \frac{34000MPa}{1 + 1.5} = 136000MPa$$

  $$\lambda = \frac{E_{sk}}{E_{c,eff}} = 14.7$$

- steel

  $\sigma_s = \lambda \cdot \sigma_{crd} = 14.7 \cdot 12.75MPa = 187.4MPa$

  $\sigma_s < f_{yd} \Rightarrow 169.34MPa < 458.3MPa$

Column load capacity

$N_c = A_c \cdot \sigma_{crd} = 450mm \cdot 450mm \cdot 12.75 \cdot 10^3 Pa = 2581.9kN$

$N_s = A_{sc} \cdot \sigma_s = 490.9mm^2 \cdot 8 \cdot 187.4 \cdot 10^3 Pa = 736kN$

$N_{cr} = N_c + N_s = 2581.9kN + 736kN = 3318kN$

The force extracted from Robot on the most exposed and critical column (on the ground floor) is $2621kN$.

$2621kN < 3318kN$

Thus, the column is dimensioned to hold.

Additional informations about BubbleDeck.

“Two variants of BubbleDeck were entered into the comparison.
The result was clear – the BubbleDeck building was significant less expensive than the traditional system. The total savings was in the order of 20 %.

Report from AEC Consulting Engineers Ltd. / Professor M.P. Nielsen - The Technical University of Denmark – Enclosure H2.

Comparisons are made between BubbleDeck and solid decks.

Only differences in materials concerning the slabs are considered. Advantages in the building design and building process are not taken into account.

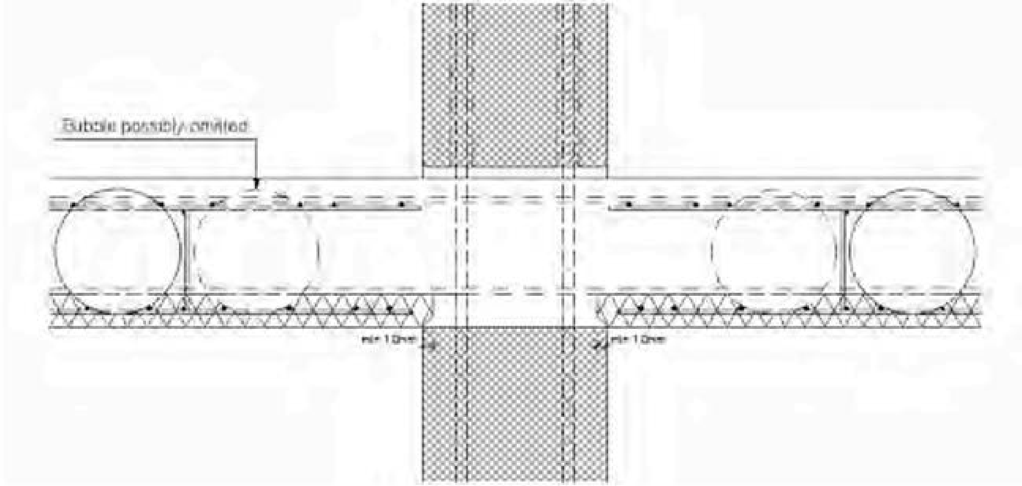
For the same amount of steel and concrete, BubbleDeck has 40 % larger span and is furthermore 15 % cheaper.
For the same span, BubbleDeck reduces the amount of concrete with 33 %, and reduces the price with 30 %.”

“Parts of the floor construction are pre-fabricated. There are three alternatives:
- Reinforcement Modules in which the bubbles are trapped between the upper and lower reinforcement mesh;
- Filigree Elements as above, but also with a pre-fabricated concrete biscuit cast onto the bottom reinforcement mesh (permanent formwork);
- Pre-cast Finished Planks in which the reinforcement modules have been cast into concrete to full finished depth.”

Reference: BubbleDeck. (2013) BubbleDeck Voided Flat Slab Solutions. [Online] Available from: http://www.bubbledeck-uk.com/pdf/2-BDTechManualv1a.pdf. [Accessed: 11.05.2015]

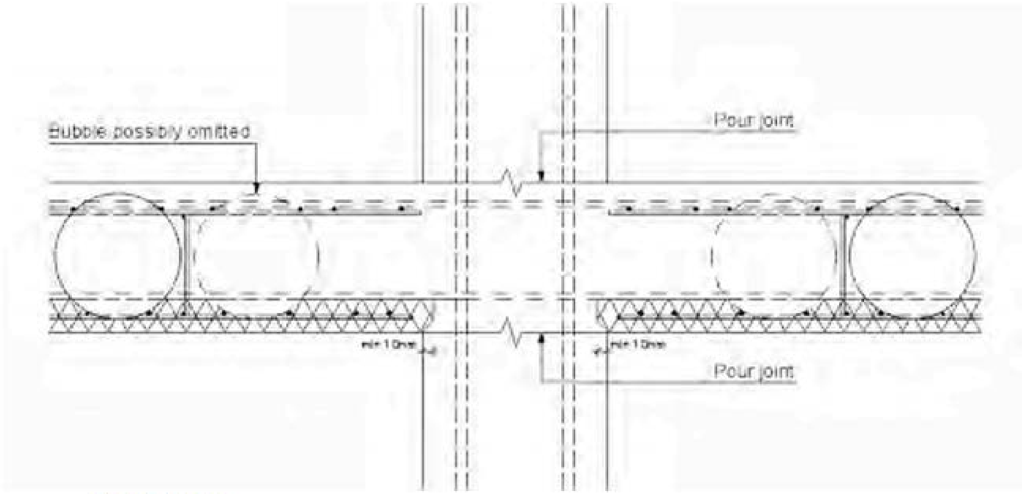
The beams can be hidden in the deck by spreading the reinforcement to make a space for a beam. Then the concrete is poured to connect parts together.

The stability of the building:
– the slab is placed on a bearing walls and columns+beams and connected with fixed joint
– prefabricated beam (double span) placed on bearing walls and columns, connected with fixed joint
– column – divided in three parts which are connected in-between by the extension of the reinforcement from one part into the next one of the whole column
– the bearing walls and columns are connected with fixed joint with the foundation plate



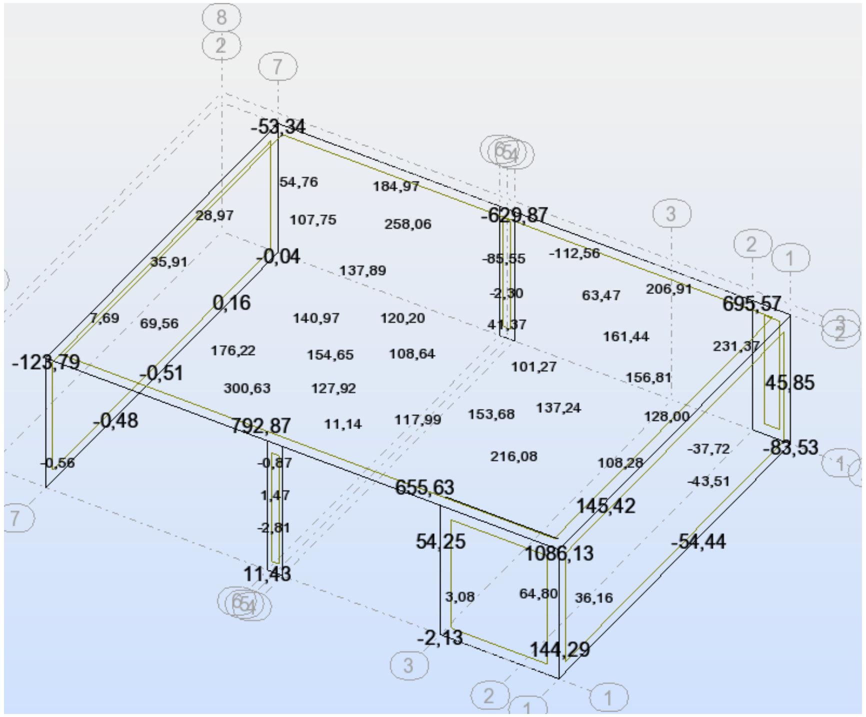
Detail 7

Connection to pre-cast concrete wall

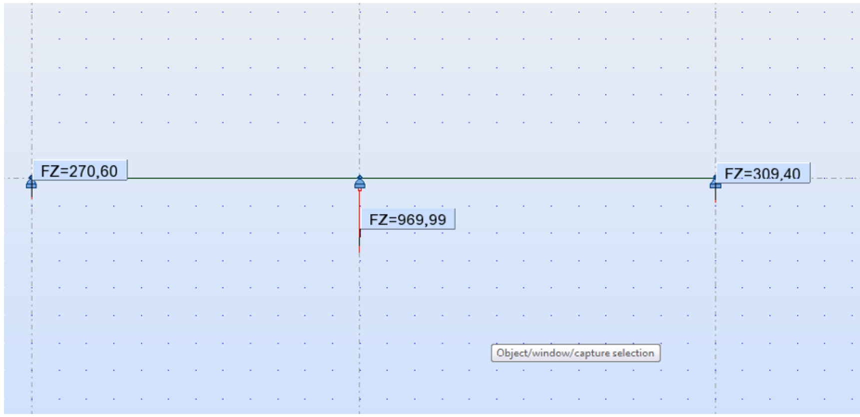


Detail 7a

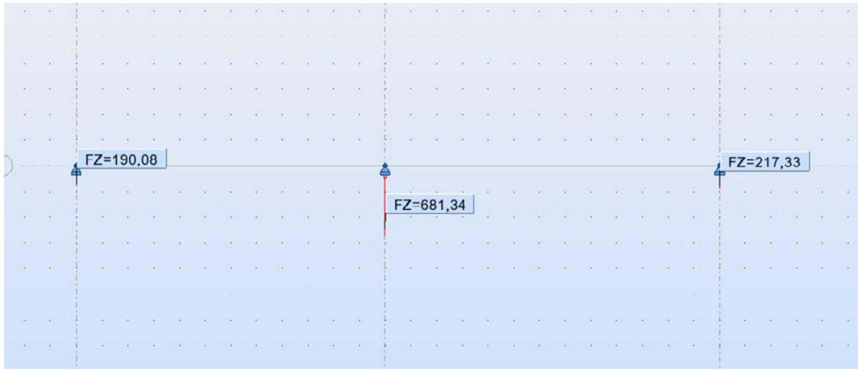
Connection to in-situ concrete wall.



Screenshot from Robot Structural Analysis. Model of the slab with bearing walls and columns.



Screenshot from Robot Structural Analysis. Double span beam, reactions.



Screenshot from Robot Structural Analysis. Beam with the additional load of the roof.