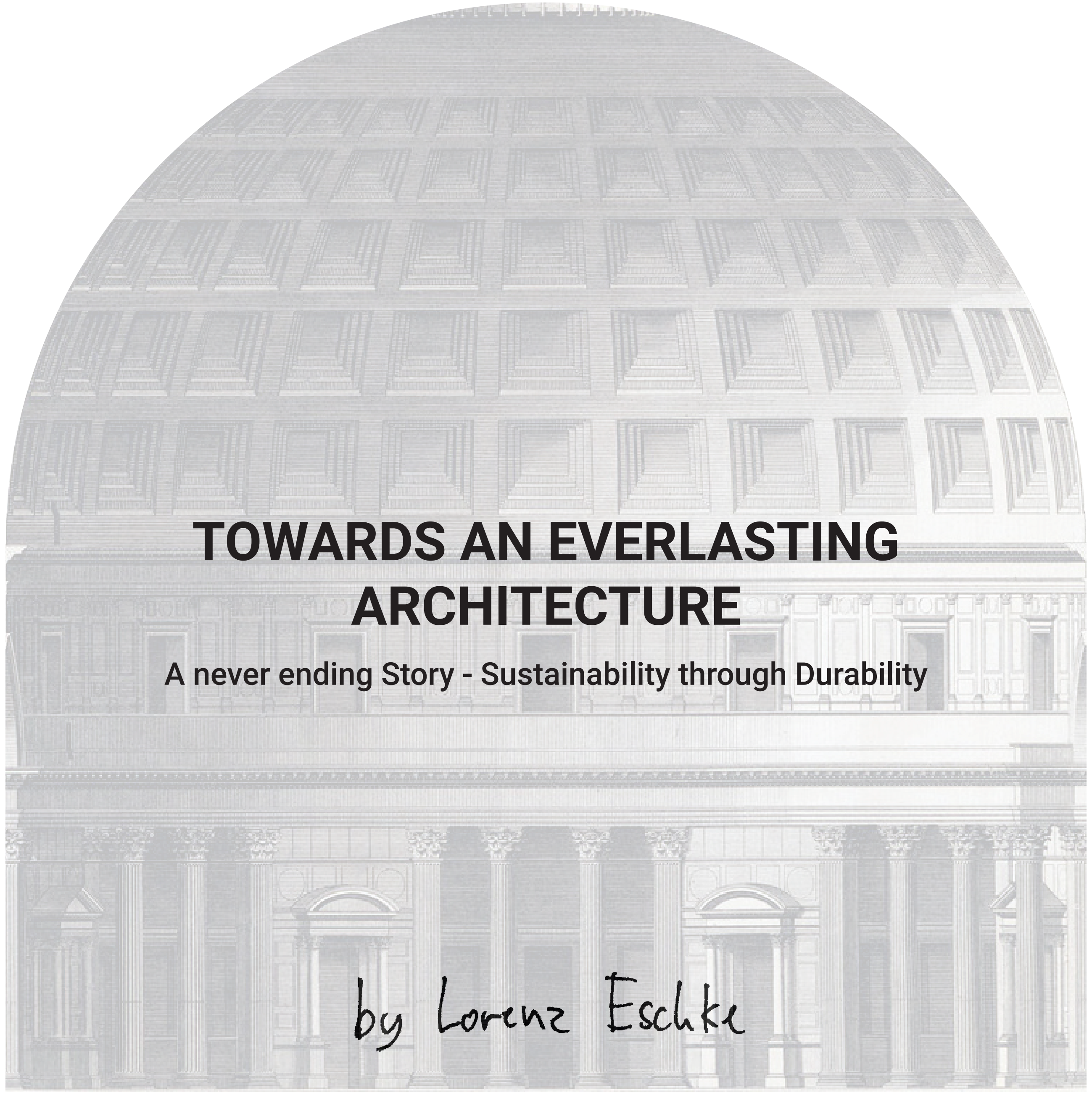
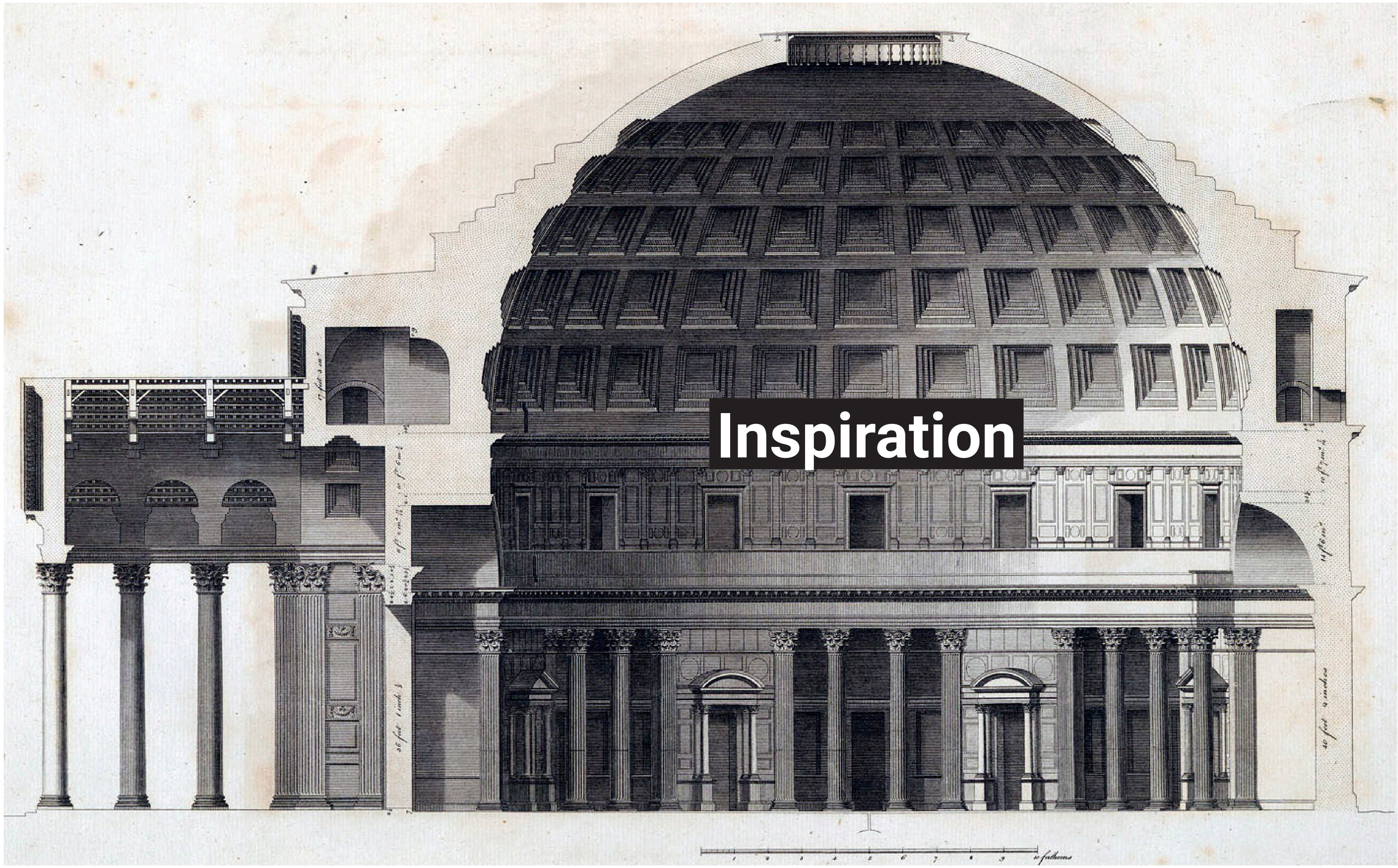


TOWARDS AN EVERLASTING ARCHITECTURE

A never ending Story - Sustainability through Durability

by Lorenz Eschke



Inspiration

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Introduction + Relevance

Research

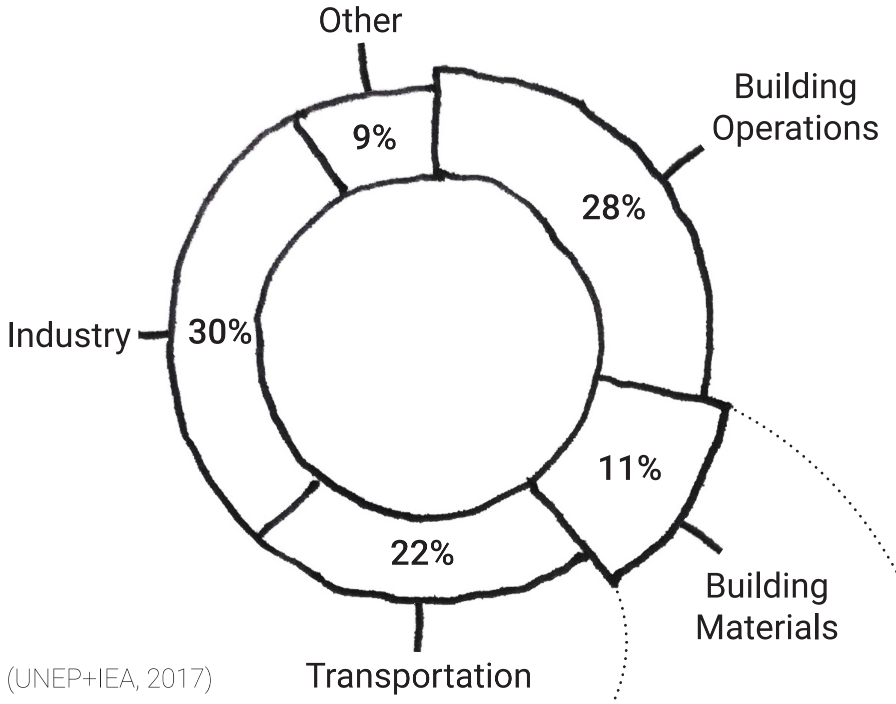
Design principle

Application of the design principle

Detailing + Climate

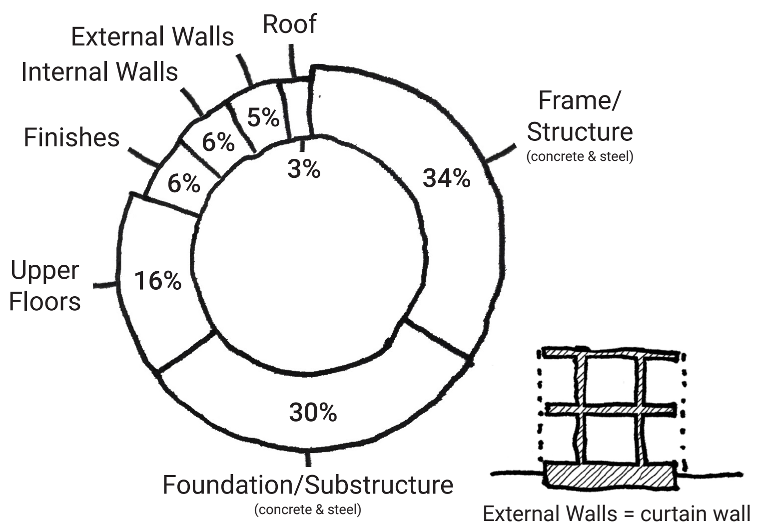
Embodied Carbon

Distribution of the EC among the different Building Components



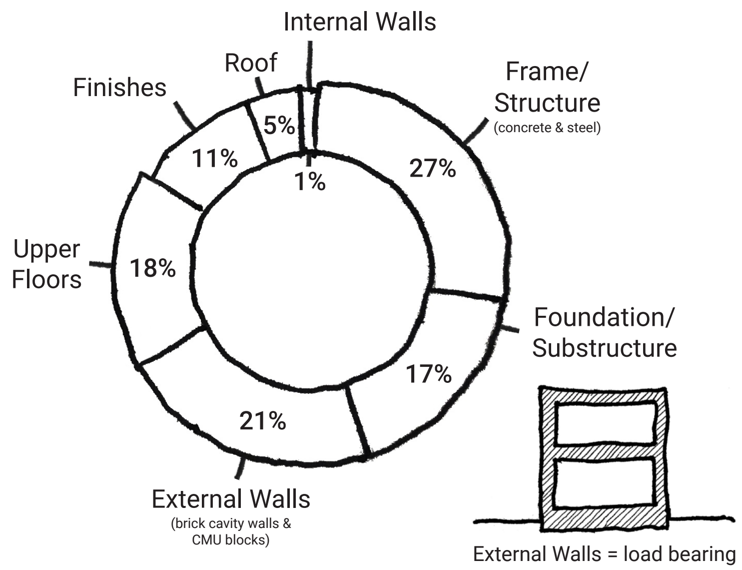
(UNEP+IEA, 2017)

Case Study 1 - Office Building



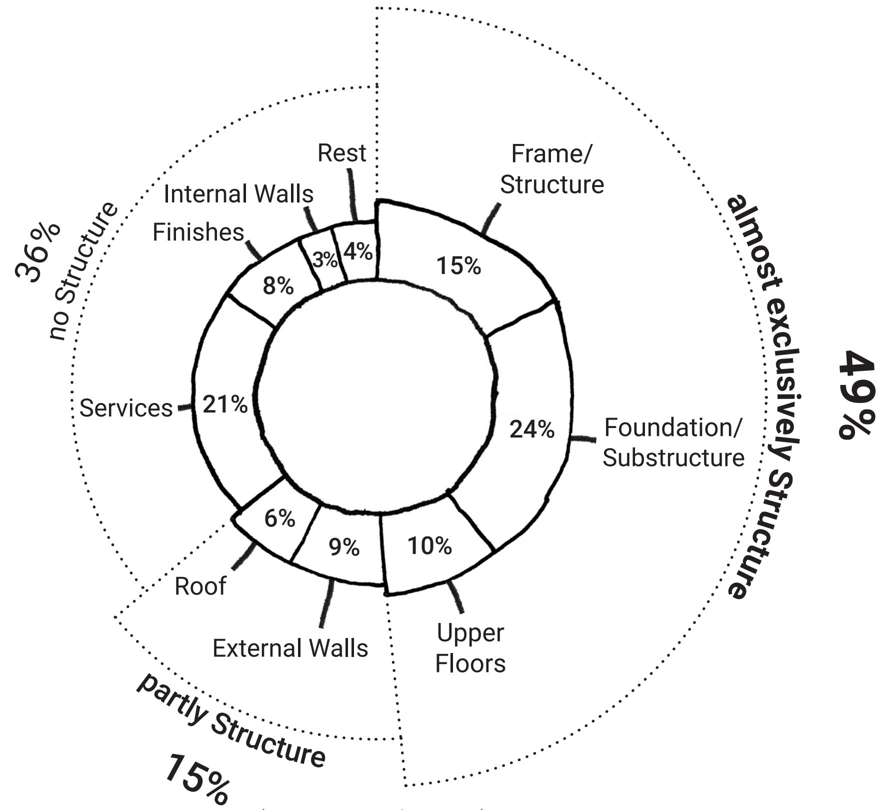
(Fernando et al., 2018)

Case Study 2 - Apartment Building



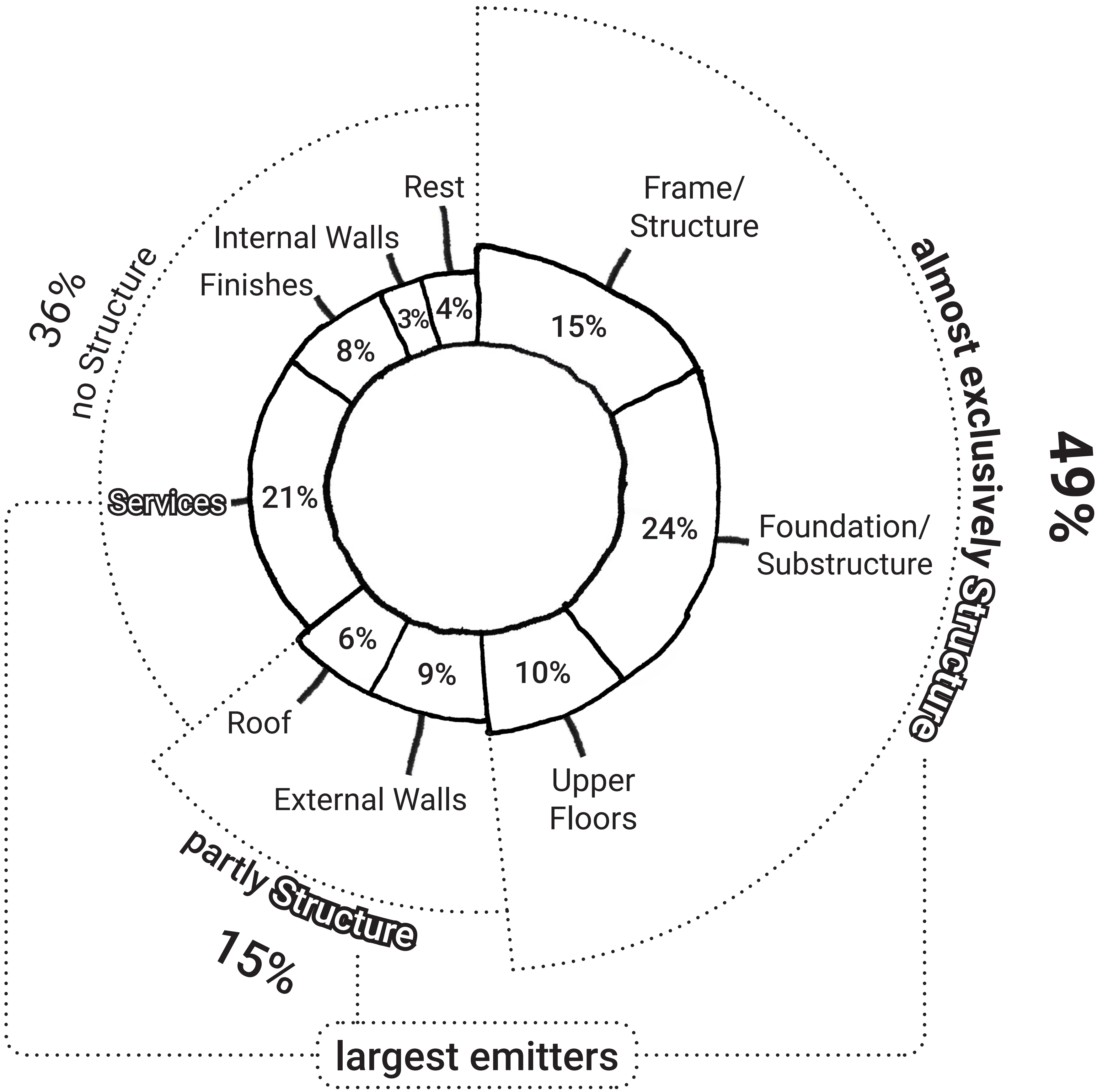
(Fernando et al., 2018)

Case Study 3 - 41 Office Buildings



(Victoria et al., 2018)

Case Study 3 - 41 Office Buildings



(Victoria et al., 2018)

Pain 1

Lifespan of Buildings

End-of-Life in the Netherlands

When?

Most buildings in the Netherlands are demolished in the age between **75** and **120** years.

Mooiman & Van Nunen, 2012

Why?

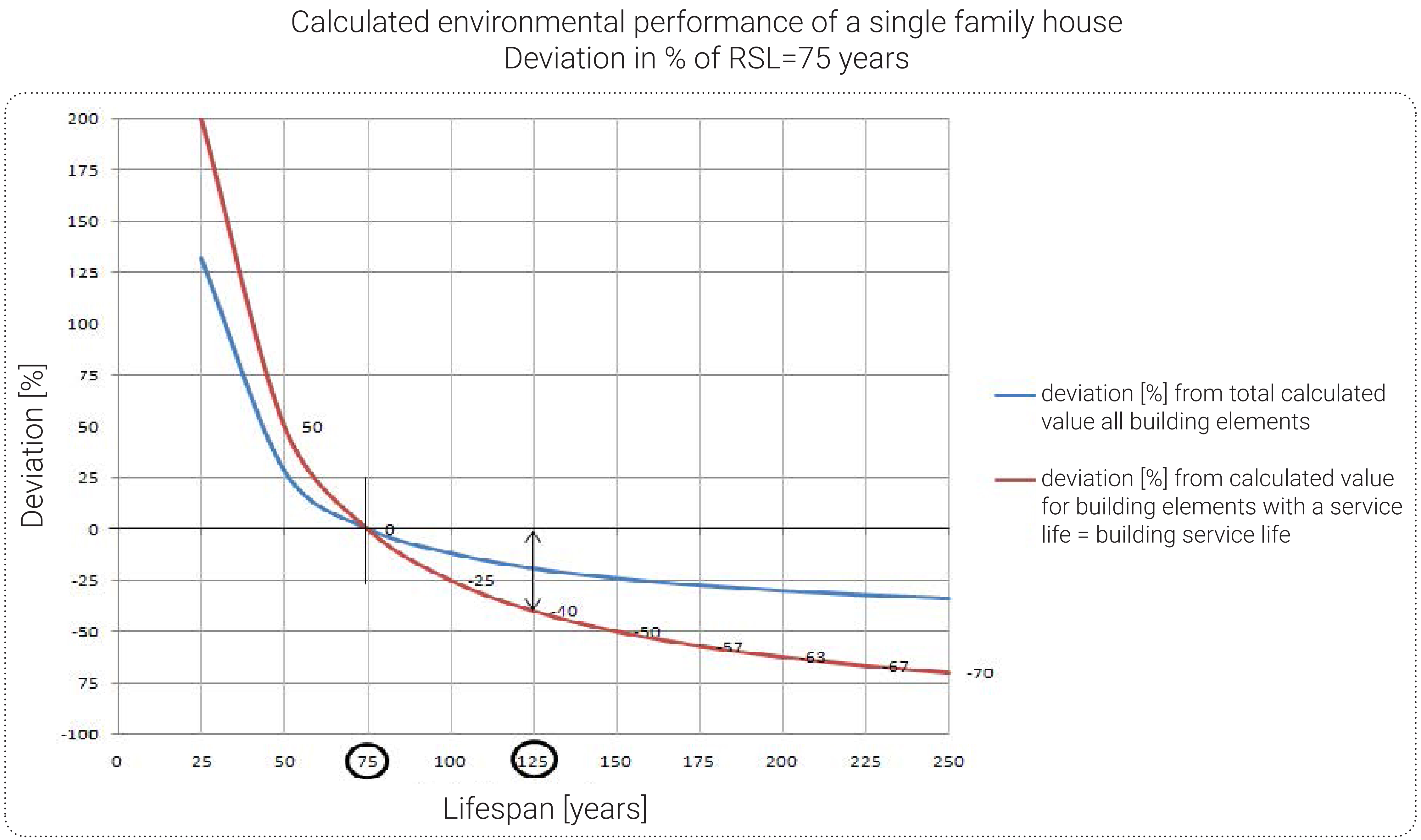
Due to **physical**, **social** or **economic decay** --> in the Netherlands "**physical durability** turned out to be the **least decisive reason** for the end-of-life of buildings"

Thomsen & Straub, 2018

Most buildings are demolished even though they are **not yet physically obsolete**. This causes **additional carbon emissions** when a new building is constructed as a substitute.

Pain 2

Relation of Lifespan and EC footprint



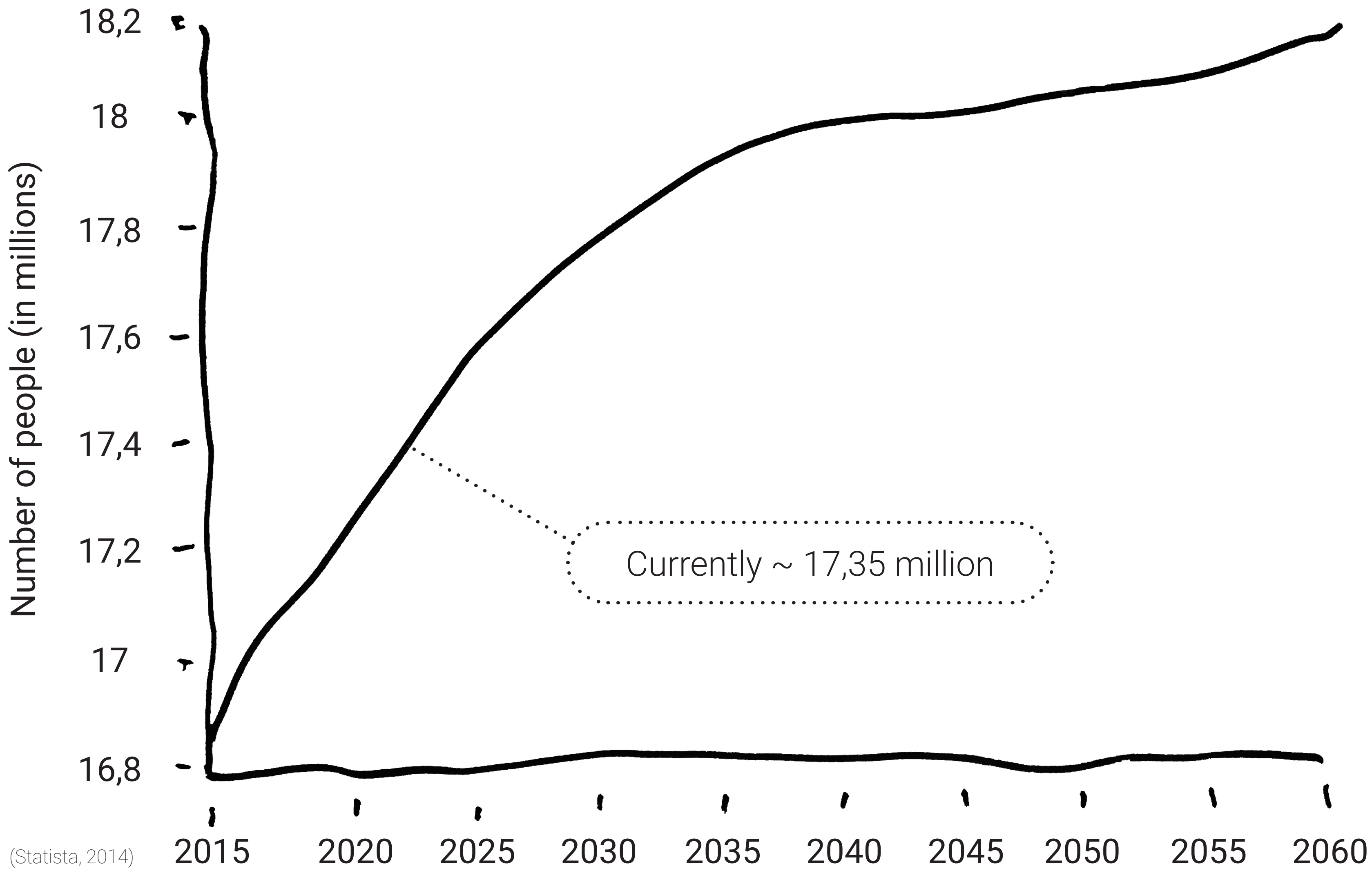
Mooiman & Van Nunen, 2012

"If a material **lasts ten times longer** than other materials, then the **environmental impact** of such material in principle counts, **only for one tenth**."

Mooiman & Van Nunen, 2012

Housing Shortage in the Netherlands

Forecast of the population in the Netherlands



Housing Shortage Numbers

2021: **279.000** missing units
2024: **316.000** missing units expected

low annual net addition of dwellings, well below 1% in the Netherlands

Pain 3.1

Student Population in Delft

City Population

Delft population increase:
2010: 96,760 to
2023: 106,086
--> growth of about **10%**

Allcharts.info, 2023

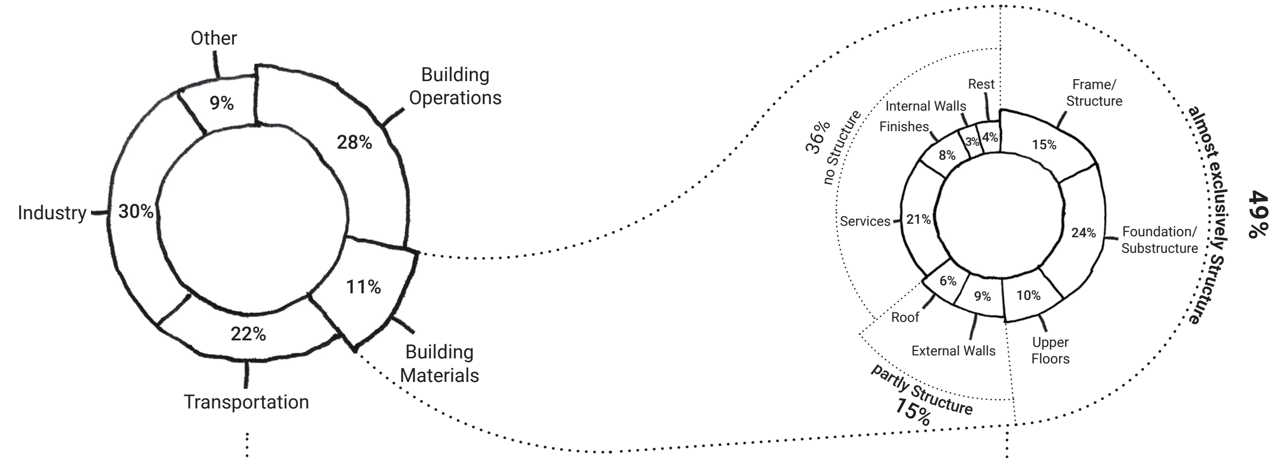
Student Population

TU Delft student population increase:
2010: 17,039
2022: 27,080
--> growth of **60%**
Future Ambition: **40,000**?

TU Delft, 2012
TU Delft, 2022
Bonger, 2022

In the city of Delft, with a rapidly growing student population, there is **not enough housing for students**. However, this is necessary to meet the ambitions of the TU Delft to grow to the size of 40,000 students.

Pain 3.2



Embodied carbon in buildings makes a significant contribution to **climate change**, accounting for 11% of total carbon emissions.

The building elements frame, substructure, upper floors and external walls, which largely consist of the building's **load-bearing structure**, as well as the **technical services** contribute to a **large part of the initial embodied carbon** (in the study by Victoria et al., 2018 it is over 80%).

Pain 1: Embodied Carbon

Most buildings in the Netherlands are demolished even though they are **not yet physically obsolete**, but are socially or economically bad performing. This causes **additional carbon emissions** when a new building is constructed as a substitute. Studies have shown that the **environmental impact of long-lasting buildings is much lower**, as the initial embodied carbon invested is used for longer.

The growing **housing crisis** in the Netherlands makes it difficult to find affordable housing, especially in the big cities and the Randstad. In the city of Delft, with a **rapidly growing student population**, there is **not enough housing** for students. However, this is necessary to meet the ambitions of the TU Delft to grow to the size of 40,000 students.

Experts also recommend a **longer service life** of dwellings in EU countries, as the **annual net addition** of new buildings is **too small** to meet the demand for housing.

Pain 2: Lifespan of Buildings

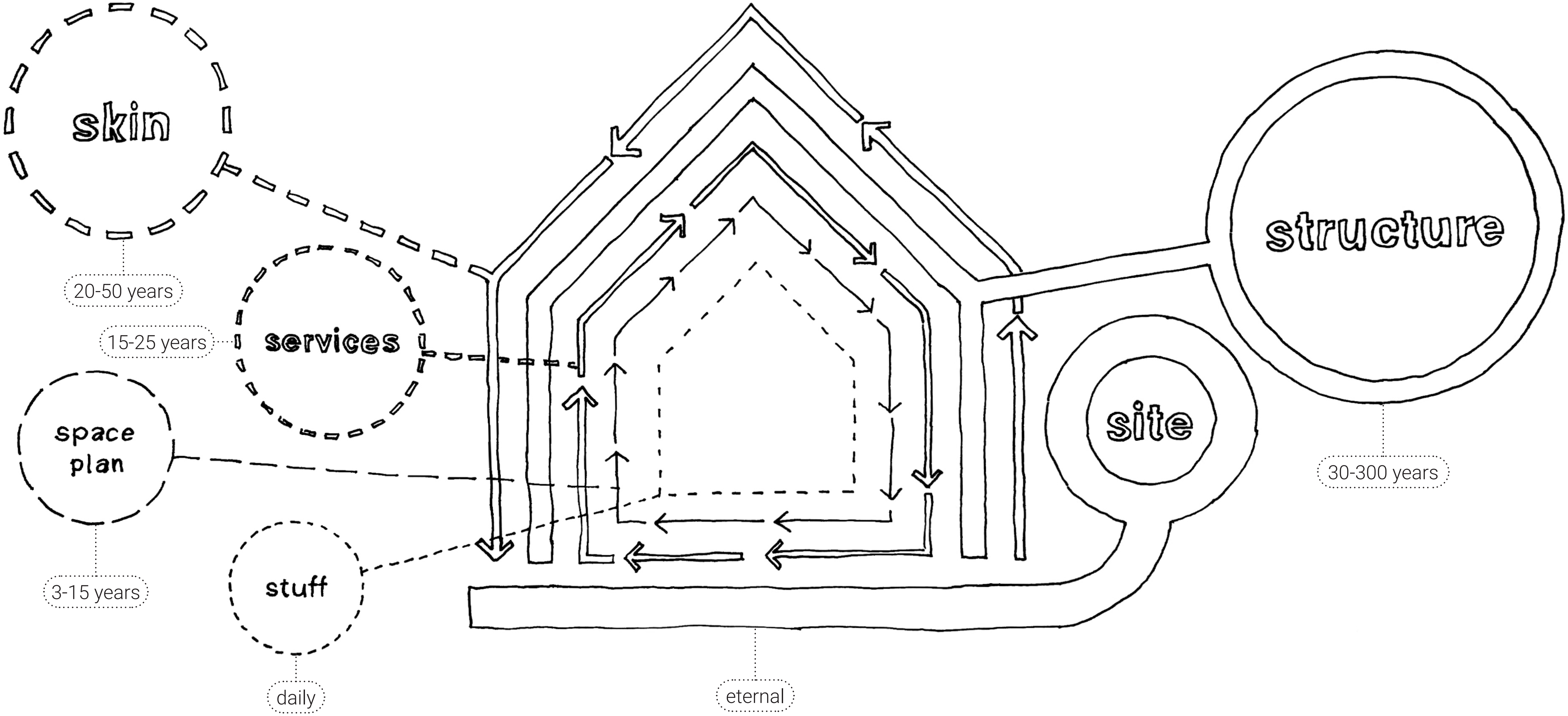
Pain 3: Housing Shortage

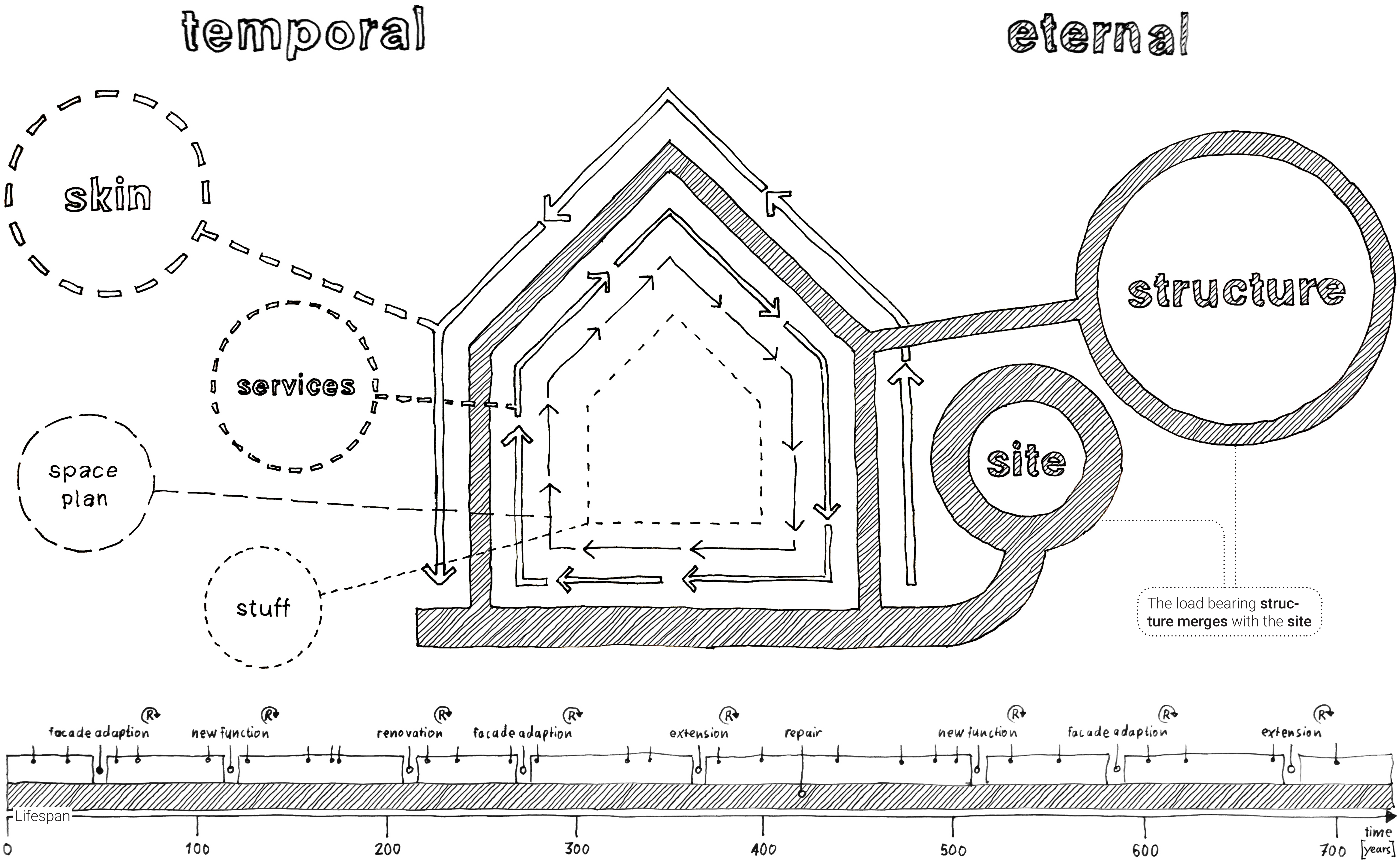
The **construction industry** is a **major contributor** to **climate change**. To create sustainable and resilient architecture **longevity** should play a **major role**, as the **initial embodied carbon** could be **used for longer**. Furthermore, the **lifespan** of Dutch dwellings needs to be **extended** to **counteract** the **low annual net addition** of new buildings and the **housing shortage**.

Problem Statement

Strategy

Shearing Layers - Steward Brand

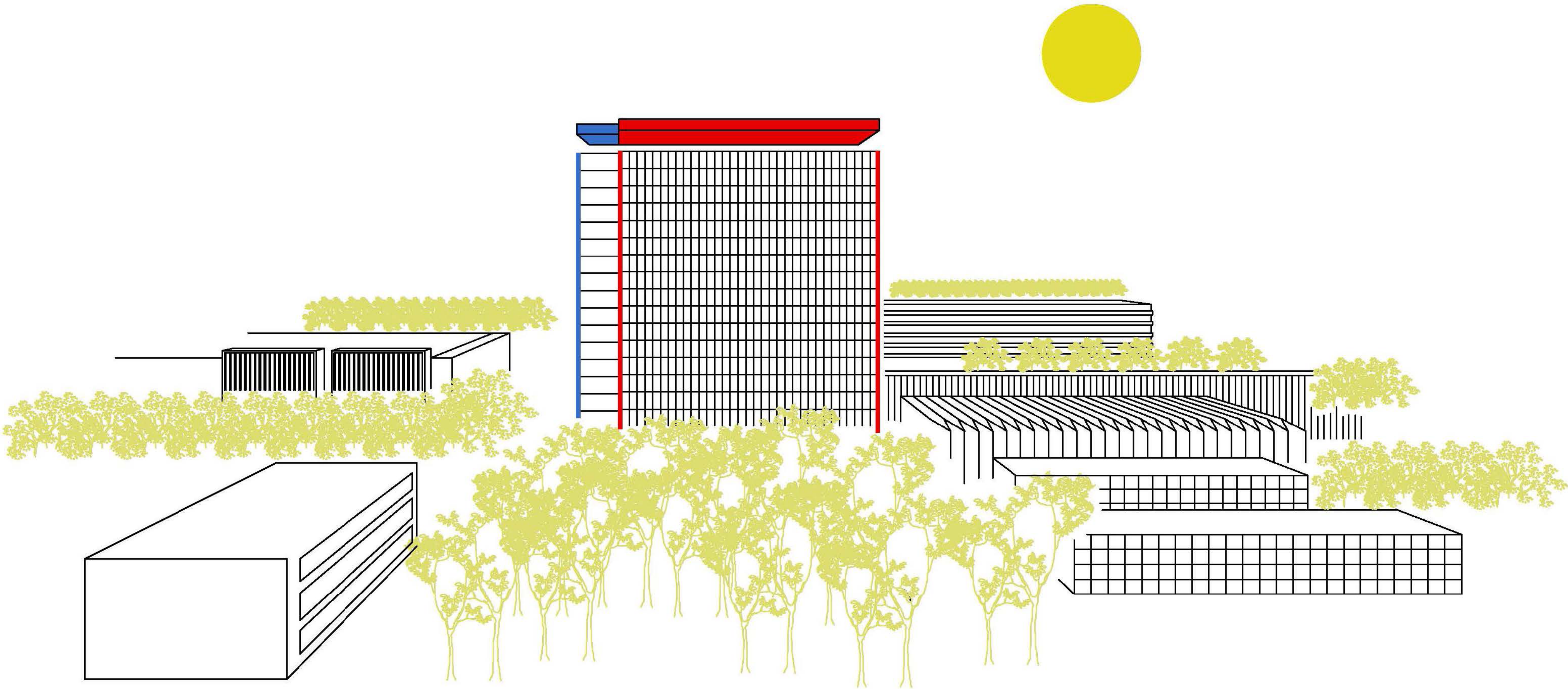



temporal
eternal
skin
services
space plan
stuff
structure
site
The load bearing structure merges with the site
facade adaption
new function
renovation
facade adaption
extension
repair
new function
facade adaption
extension
Lifespan
0
100
200
300
400
500
600
700
time [years]

Context

LIVING LAB

NATURE & TECHNOLOGY



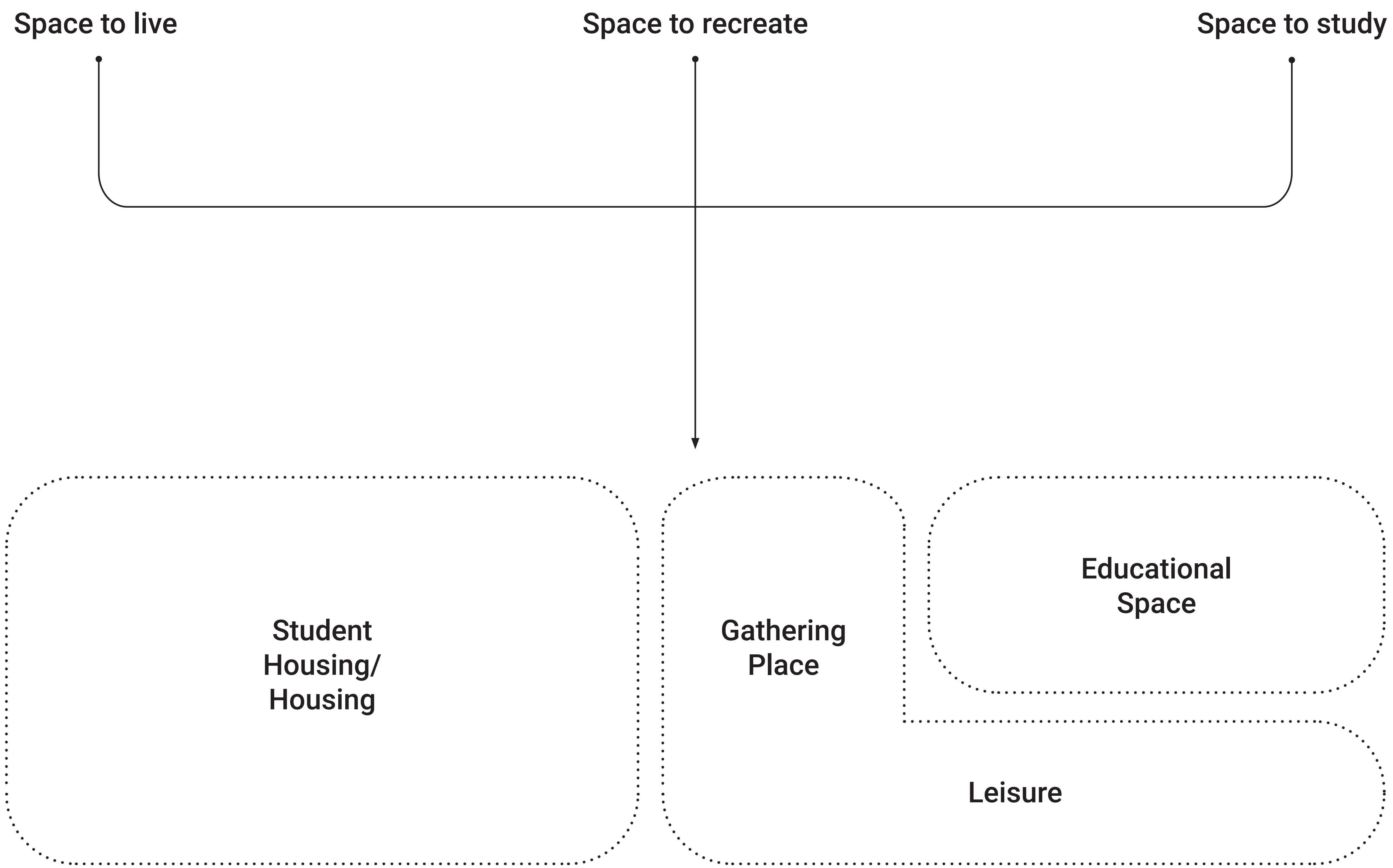
TU Delft Sustainability Goals

The TU Delft has the ambition to be **carbon neutral**, **climate-adaptive** and **circular**, with contribution to the **quality of life** and **biodiversity**, by **2030**.


Site

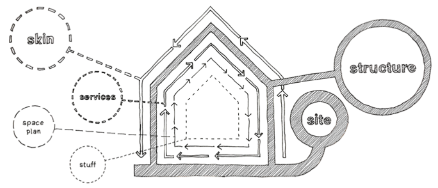
Program

Project is dedicated to Students - What do students need?



1. Strategy

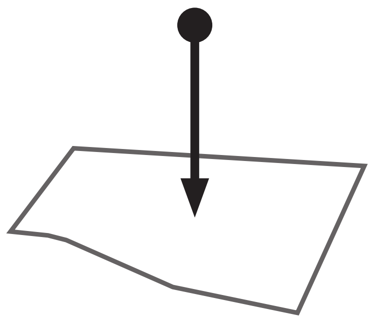
The focus, as explained in the previous chapters, lies on the design of a very durable building through the combination of long-lasting building elements that form the structure and temporal ones. This should simultaneously achieve a low environmental impact and the greatest possible adaptability for the future.



2. Context

This project can be considered a major experiment. Therefore, a university context is ideally suited to monitor and analyze the results that accumulate over time and eventually incorporate them into the teaching of future generations of engineers and architects.

Since the TU Delft in particular has the ambition "to be carbon neutral, climate-adaptive and circular, with contribution to the quality of life and biodiversity, by 2030", the campus in Delft was chosen as the context for this project. It is also considered as a "Living Lab" where new innovative ideas can be tested to contribute to this goal.



3. Program

As this project is dedicated to students, it is primarily about meeting their needs. As shown in the problem statement, there is too little accommodation for students in Delft. Therefore, a part of the building will be used for student housing in different unit sizes. Furthermore, with the growing number of students, new educational space is needed. Since the campus is immensely large and there is not really a recreational offer besides the sports facility X, a public leisure function will be integrated into the project, so that students from all faculties can be attracted.

Student Housing/ Housing

Gathering Place

Educational Space

Leisure

Design Question

How to design a **multifunctional building** on campus that **rethinks the typical timescales** of architecture and provides a **sustainable alternative** to construction methods with a low initial carbon footprint (such as timber construction) by using a **durable structure** and **passive measures** while remaining **highly adaptable** to future changes in its requirements?

Research

Research Question

Which **material** is best suited to create a **durable** and therefore sustainable **structure** for the design?

Sub question:

Which **material** is the best for integrating **passive measures** to **minimise active services** and the embodied carbon associated with them?

Methodology - Definition of Requirements/Disciplines

Physical Requirements

- **Durability**: The structure very durable and needs minimal maintenance.
- **Repair options**: It is easily possible to repair the structure in case of damage.

Environmental Requirements

- **Environmental impact**: The GWP of the structural material is considered and put into perspective with the possible lifespan.
- **Passive measures:** Possibilities for passive measures for instance thermal mass and transmittance of the material are considered.

Methodology - Case Studies

Historical Case Studies

Pantheon
Rome, Italy
Concrete
Built ~128 AD
~1896 years old

Aula Palatina
Trier, Germany
Brick Masonry
Built ~312 AD
~1712 years old

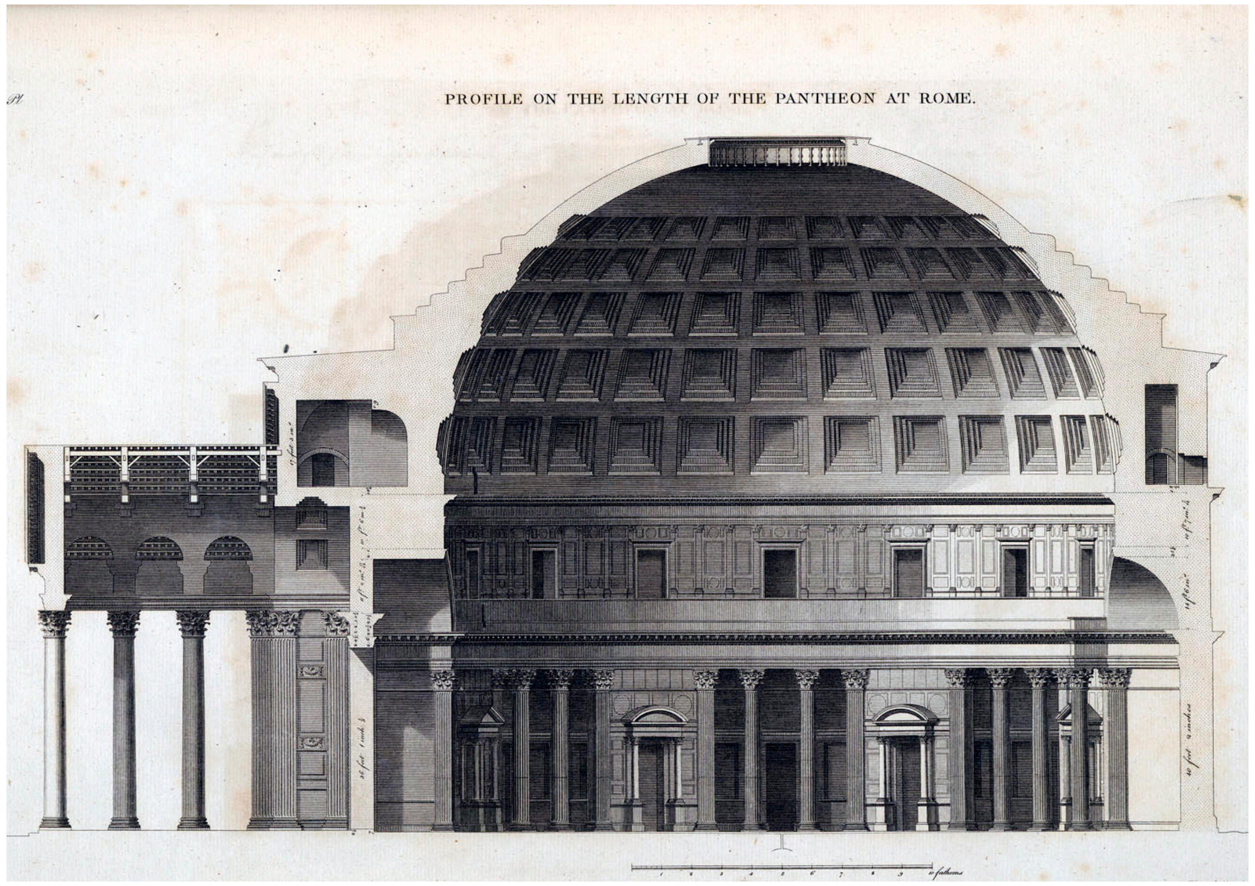
Horyuji Temple
Ikaruga, Japan
Wood
Built ~670
~1354 years old

Contemporary Case Study

Buidling Simply, Florian Nagler
Bad Aibling, Germany
Concrete, Brick Masonry, Wood
Built 2019-2020
~3 years old

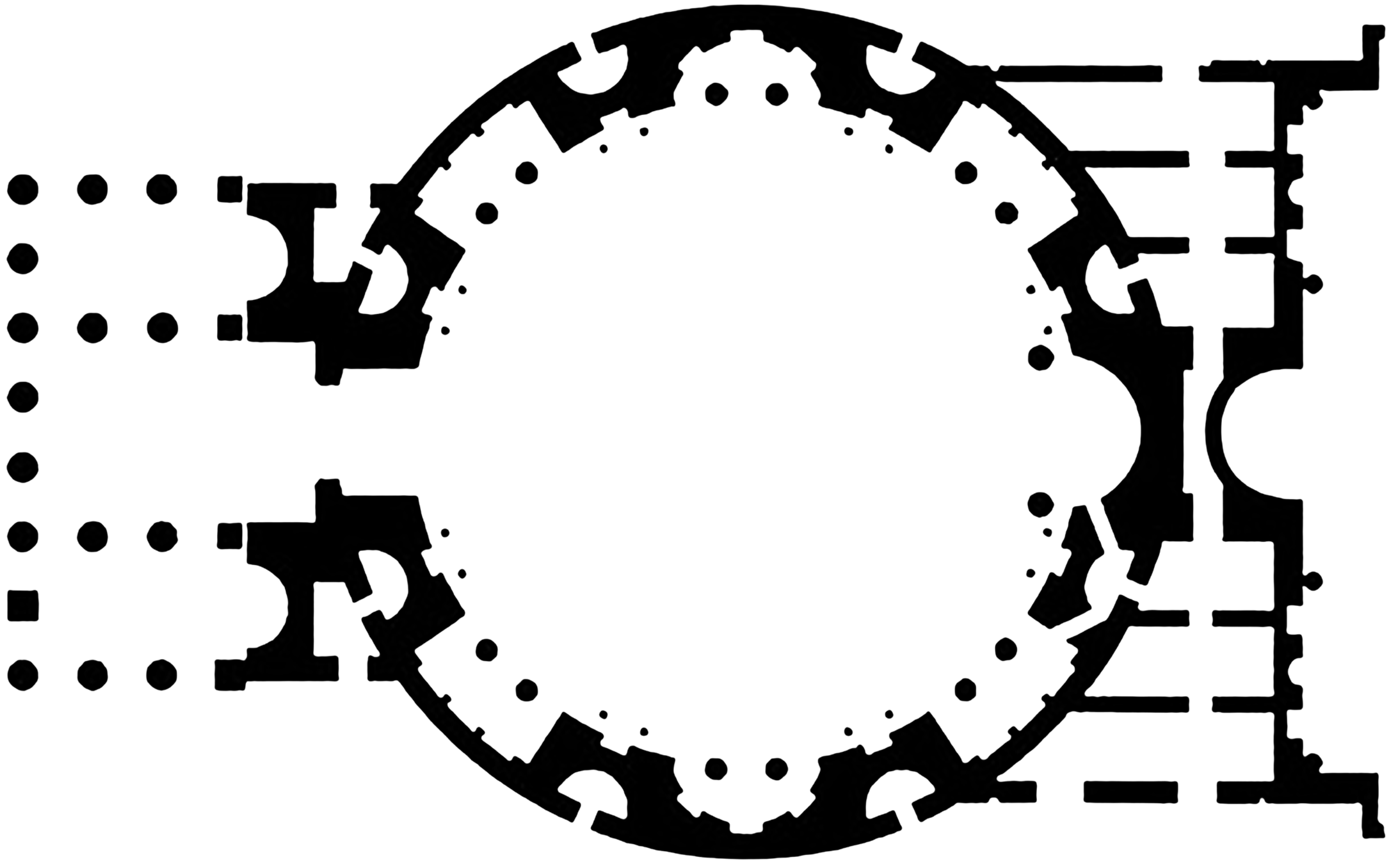
Pantheon

Rome, Italy
Concrete
Built ~128 AD
~1896 years old



Pantheon Section

Pantheon, Rome



Pantheon Floor Plan

Pantheon Dome

Damages

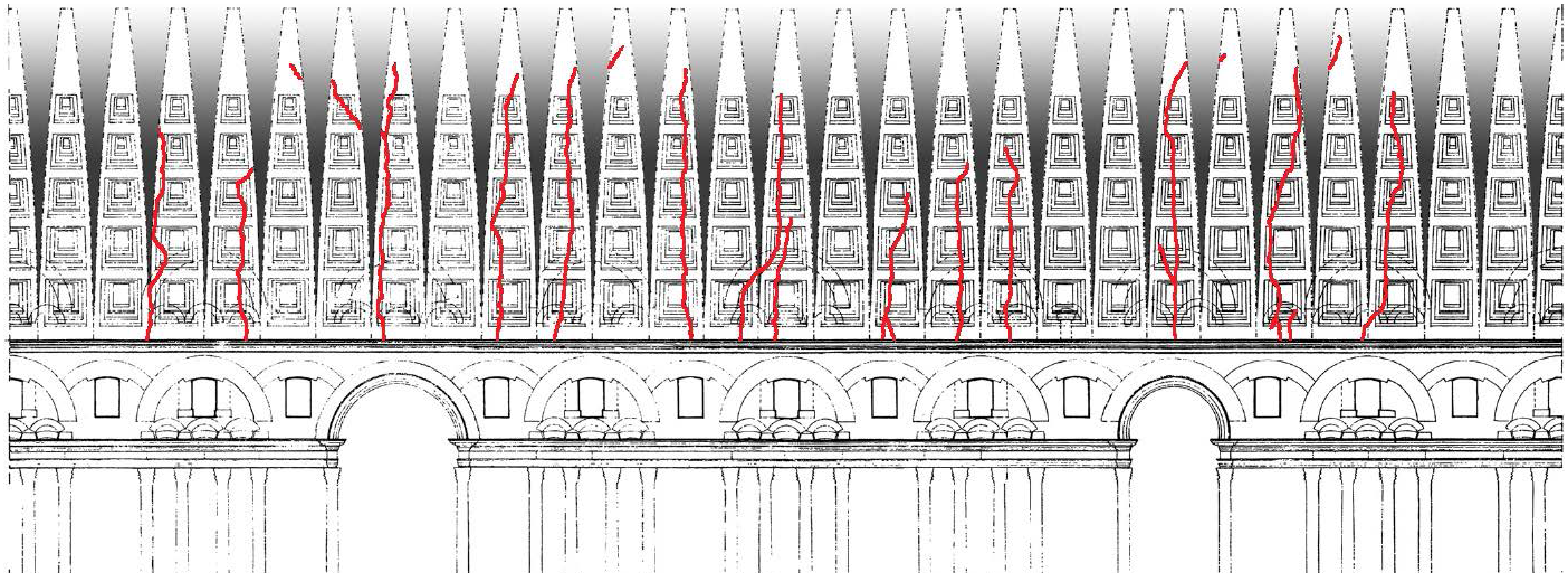
- damages and replacements in brick envelope of opus latericium

- cracks in dome (probably soon after construction, so almost as old as the building itself)

- despite the cracks the structure is in very good condition

Pantheon external Wall

Damages 'opus latericium'



Display of Cracks in Pantheons Dome

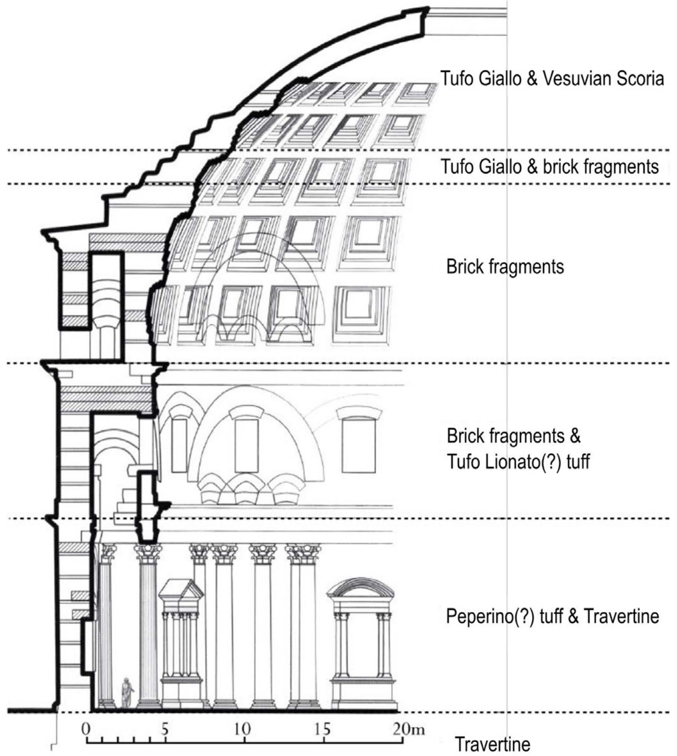
Opus Caementicium
+ modern equivalents

- opus caementicium has self-healing abilities

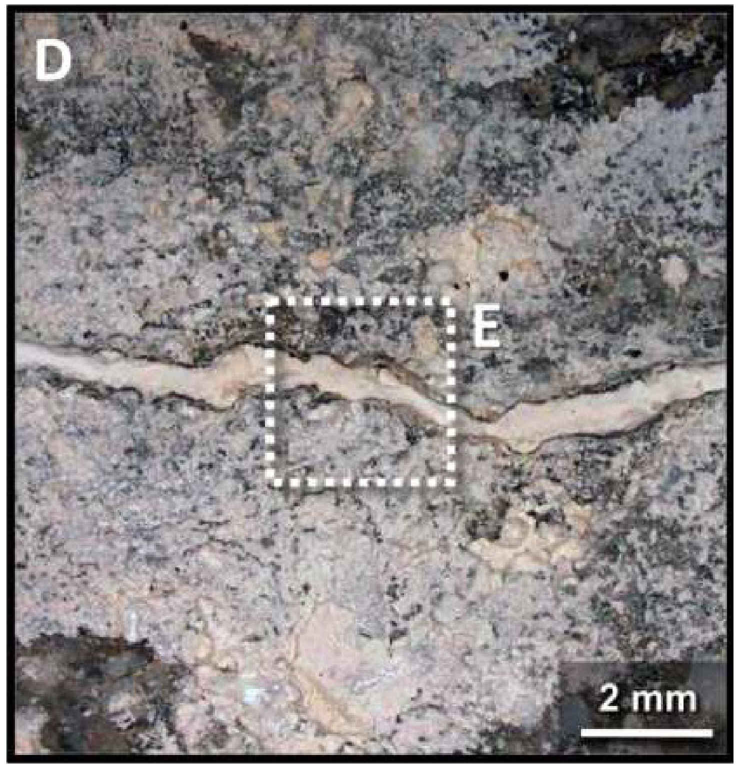
- small lime clasts in matrix that don't fully react initially

- in case of crack, the lime reacts with water and 'heals' the crack

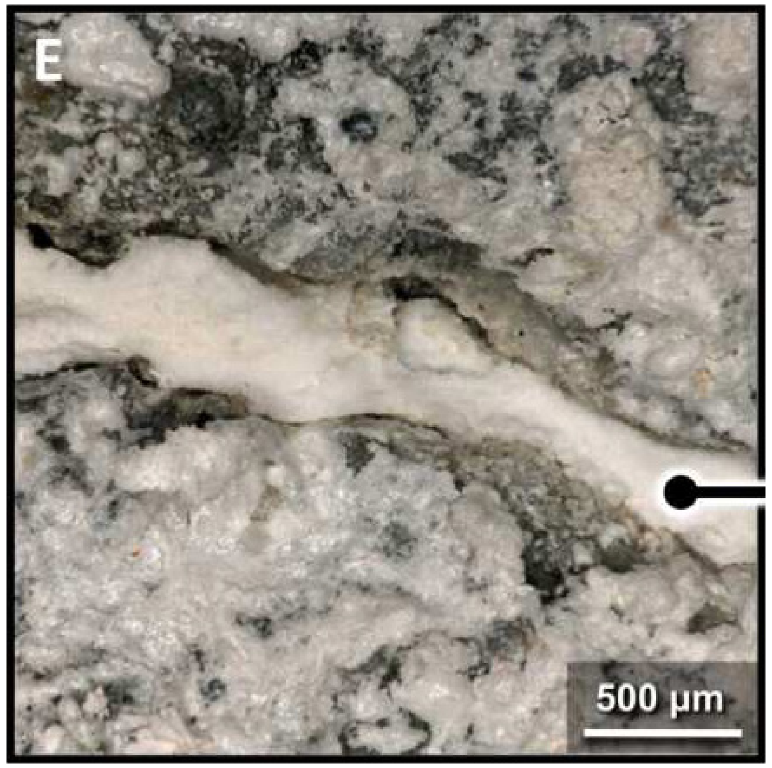
- renaissance of opus caementicium --> companies develop modern form of it (e.g. D-Mat --> D-Lime)



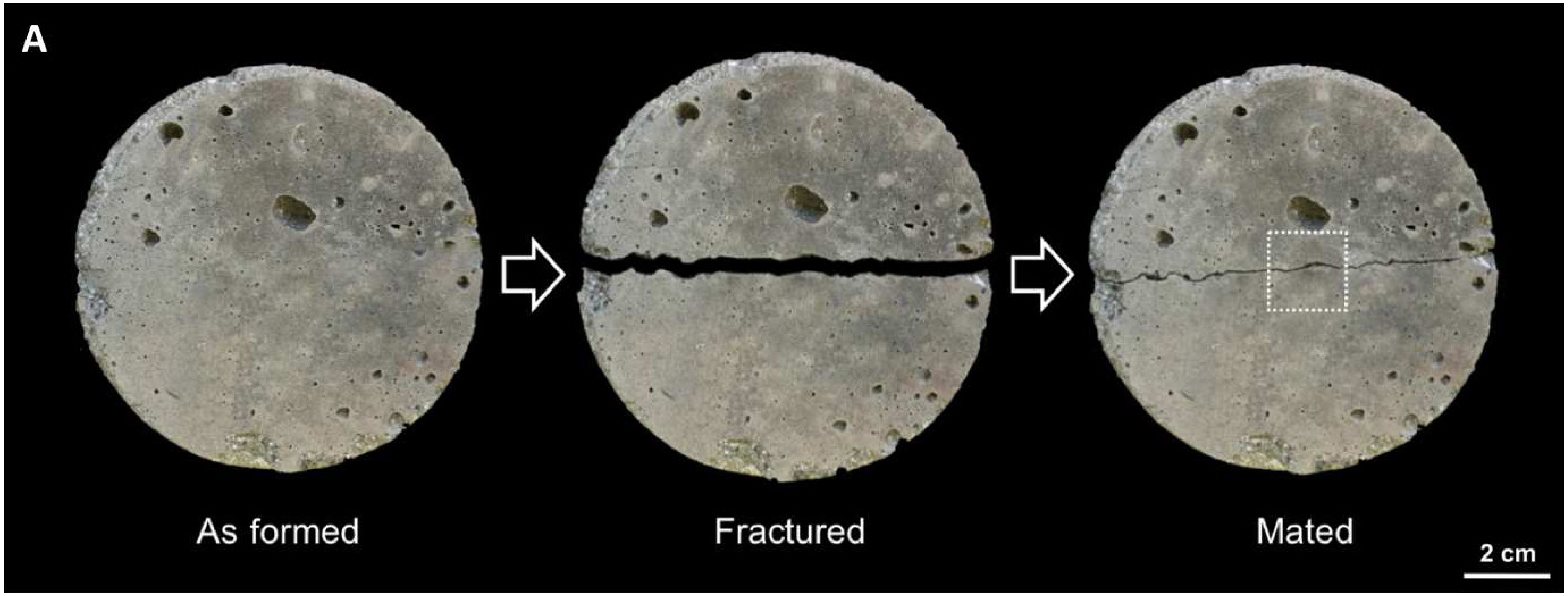
Different Aggregates



Healed Crack



Healed Crack



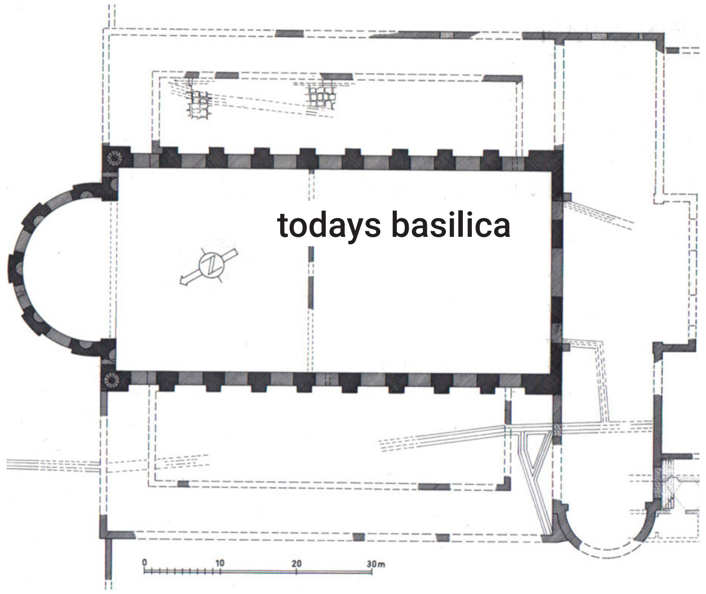
Healing Process

Aula Palatina

Trier, Germany
Brick Masonry
Built ~312 AD
~1712 years old

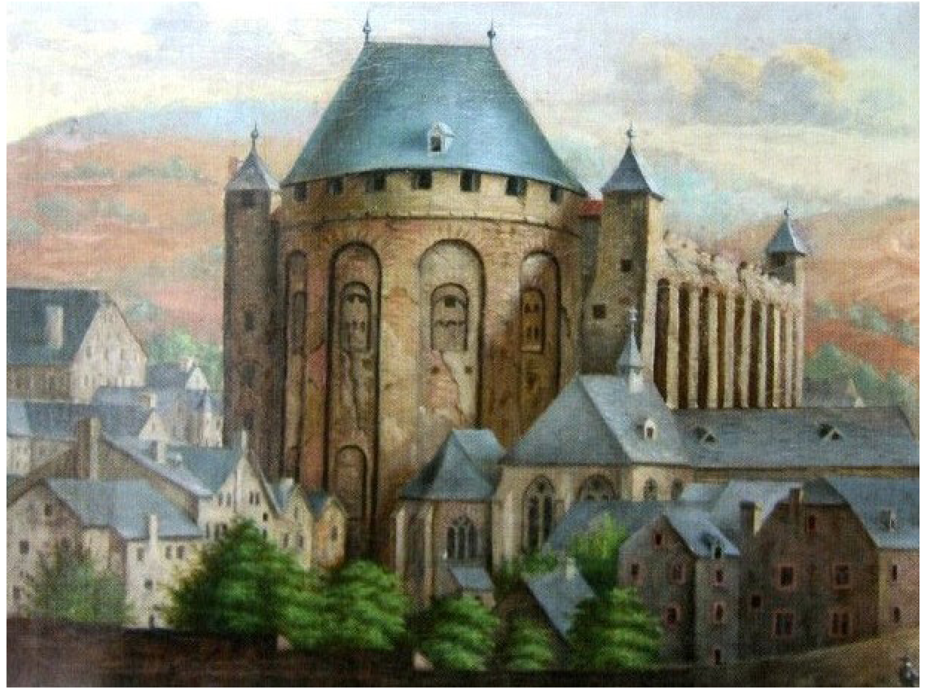
Aula Palatina, Trier

Interior Space

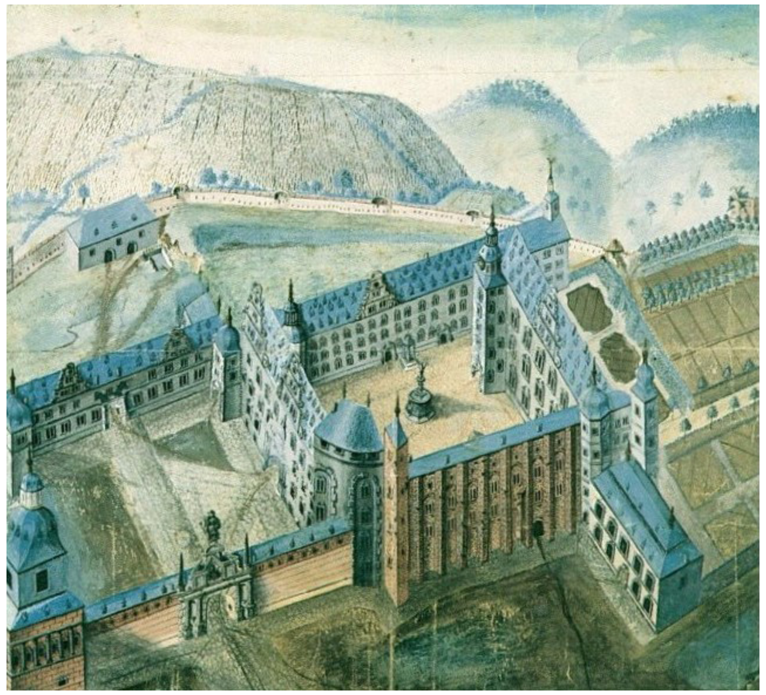


Ancient Complex

Basilica, Antiquity



Fortress, Middle Ages



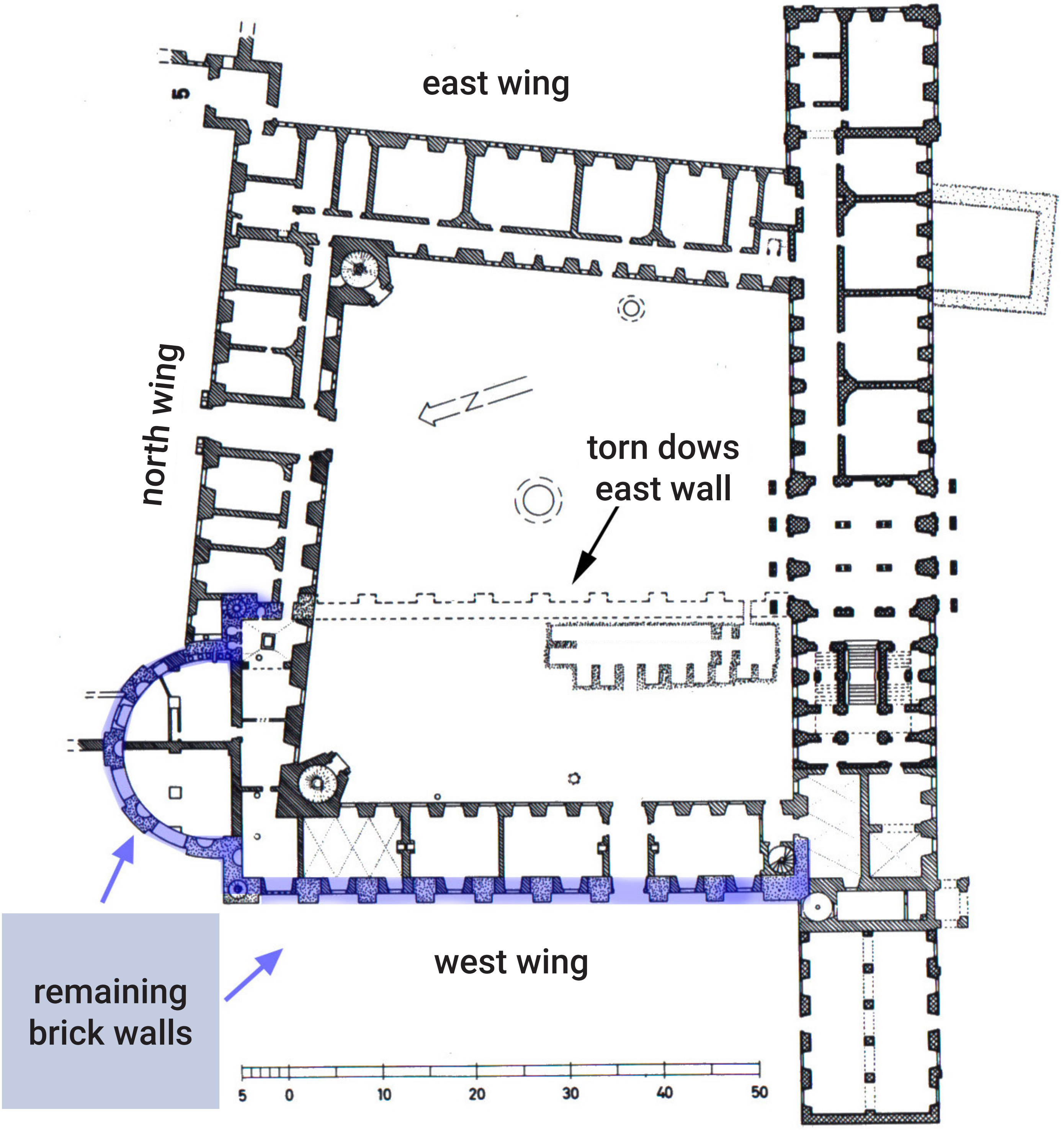
Palace Complex, Renaissance

Damages

- demolition of east and south wall in Renais-sance

- only half of original brick walls remained

- bomb attack in WWII but the structure sur-vived with smaller dam-ages



Remaining Walls

Destruction by WWII Bomb Raid

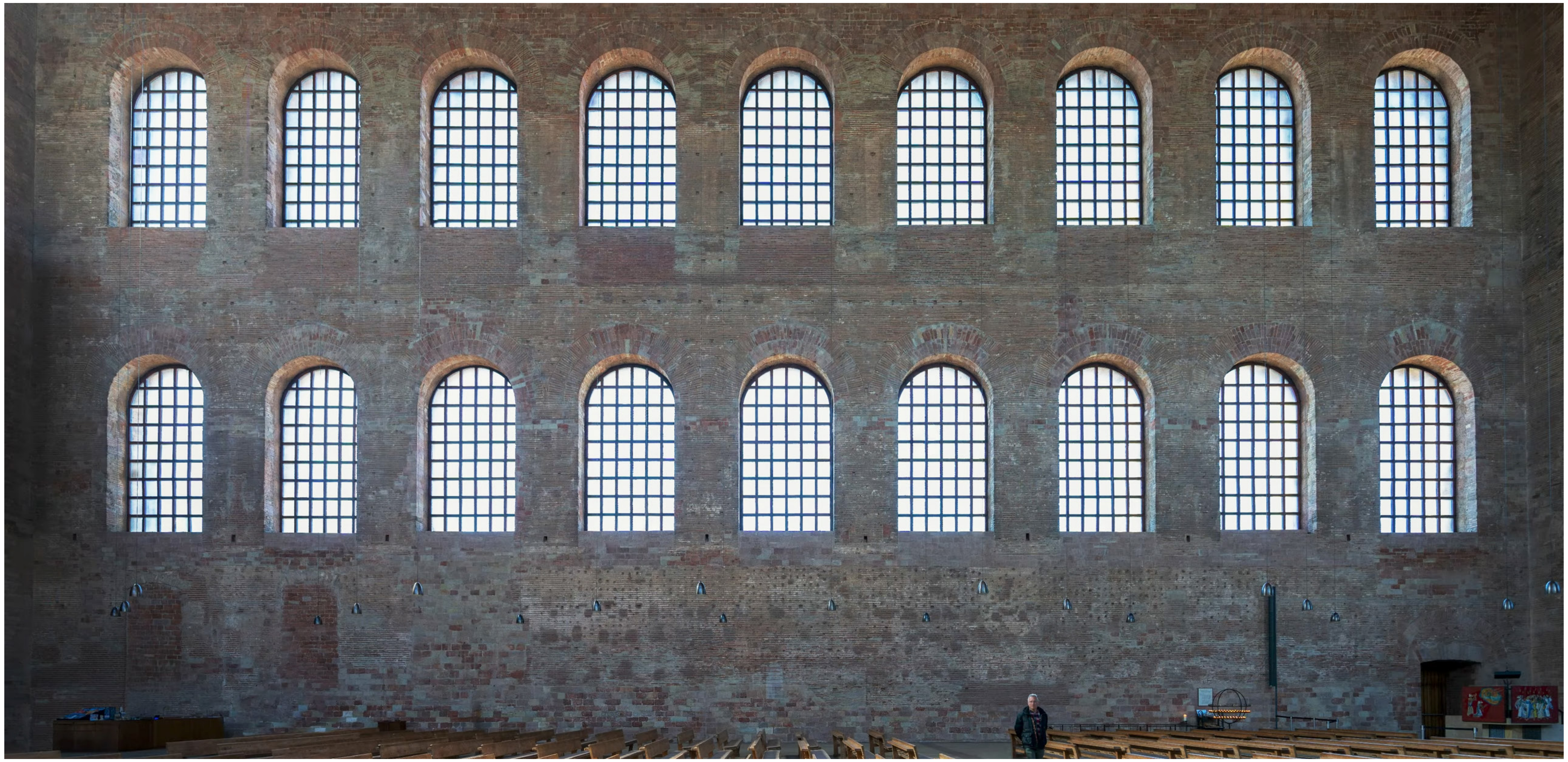
Destruction by WWII Bomb Raid

“A Reconstruction of a Reconstruction of a Re-construction”

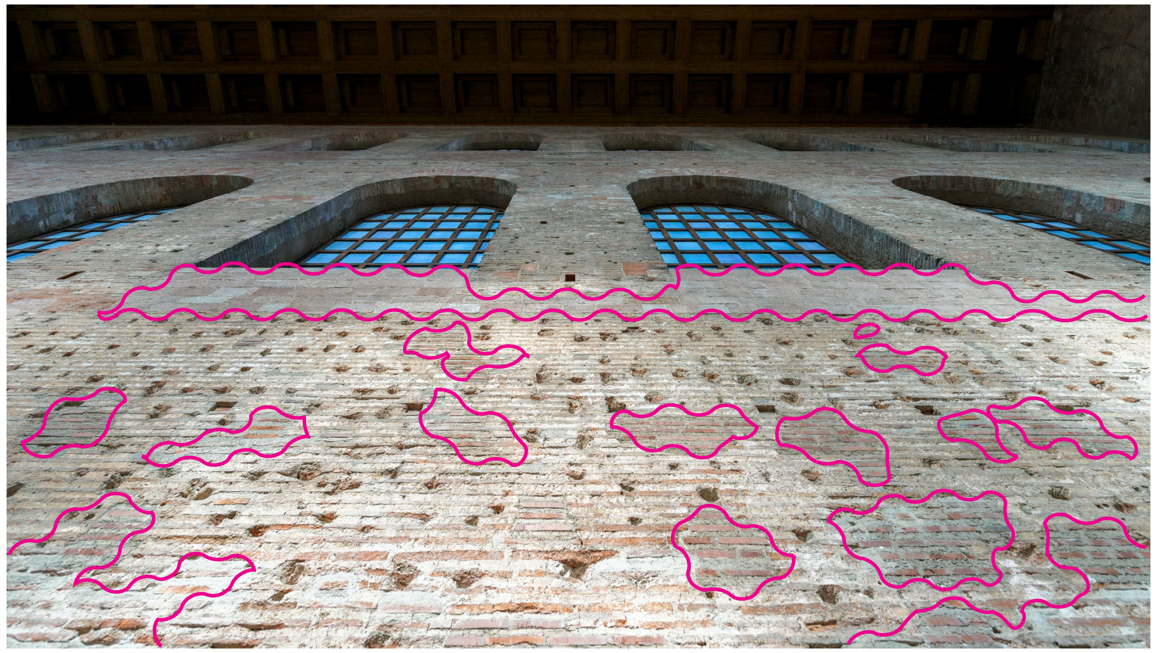
- repairs over the centuries resolve in patchwork as some bricks and mortar joint have definitely been replaced

- today’s structure is in good condition but only due to constant repair

- although most damages were man-made so probably the structure would not have needed the repairs



Original West Wall



Repairs

Repairs

Horyuji Temple

Ikaruga, Japan
Wood
Built ~670
~1354 years old

- complex partly burned down multiple times (vulnarability against fire)

-> high fire protection standards

West District

Damages

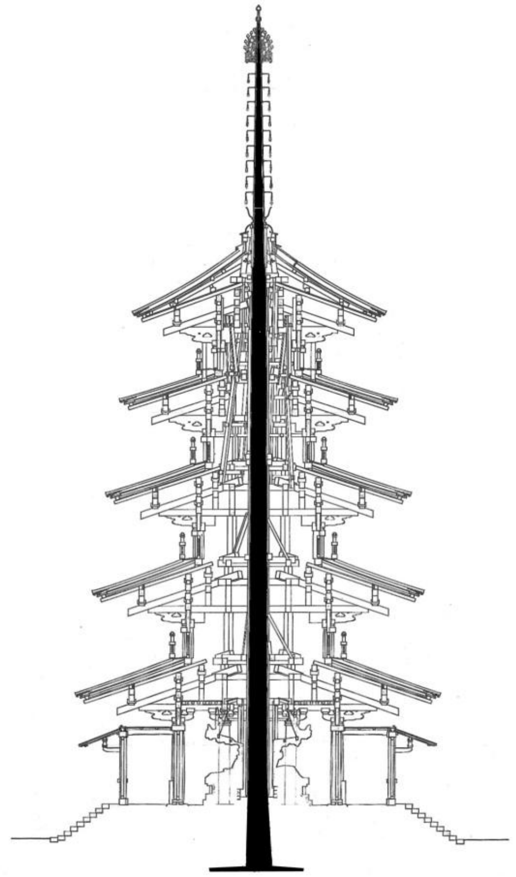
- central trunk of pagoda is rotten (vulnerability against moisture)

- the replacement of damaged wooden parts is completely natural and planned from the initial stage -> replacement more often but also very easily doable

- the structure of the pagoda is despite the rotten central trunk in good condition although it is hard to say to which extent the wood has been replaced in the past

Pagoda

Pagoda Structure



Wrong Assumption of Trunk since its rotten and not load-bearing

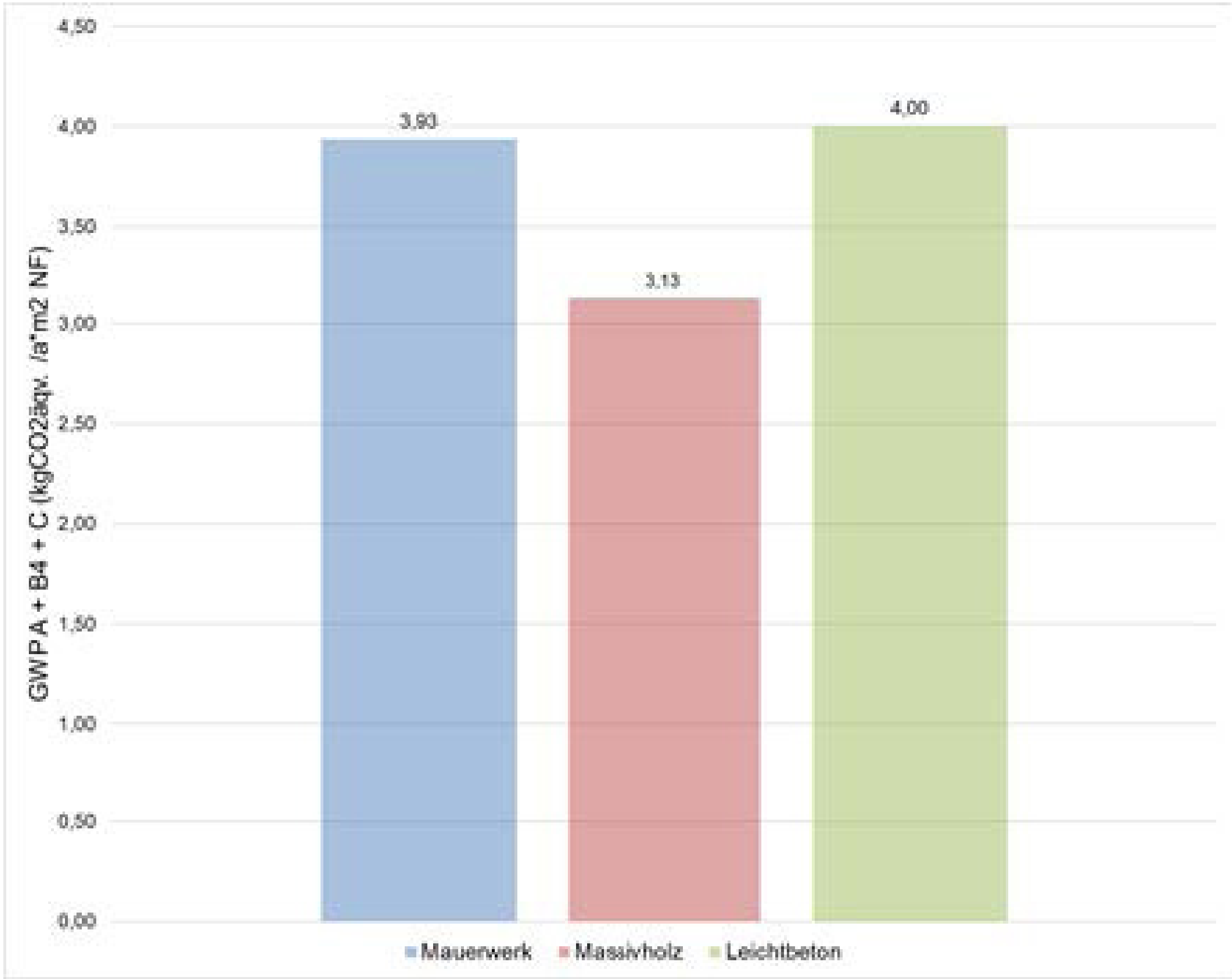
Arcade, worn out Wood

Buidling Simply, Florian Nagler - Research Houses Bad Aibling

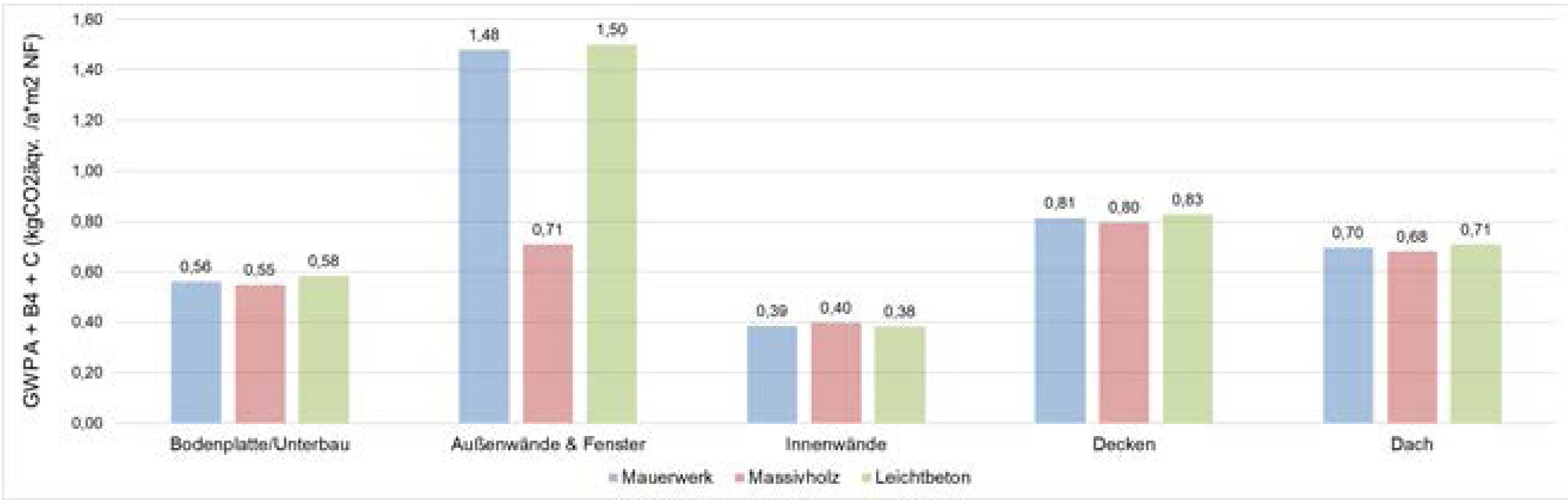
Bad Aibling, Germany
Concrete, Brick Masonry, Wood
Built 2019-2020
~3 years old

Arcade, worn out Wood

Global Warming Potential



GWP total



GWP per Building Element

Solid Walls

Thickness **30** cm + Skin
U-Value **0,22** W/m²*K
Thermal Mass **3300** [Wh/K per room]

Thickness **42,5** cm + Plaster
U-Value **0,25** W/m²*K
Thermal Mass **4400** [Wh/K per room]

Thickness **50** cm
U-Value **0,35** W/m²*K
Thermal Mass **5600** [Wh/K per room]

U-Value + Thickness

Final Matrix

Conclusion

Which **material** is best suited to create a **durable** and therefore sustainable **structure** for the design?

Answer: Concrete is best suited, especially the modern **equivalent** to **Opus Caementicium** (D-Lime) is promising because of its self-healing abilities.

Which **material** is the best for integrating **passive measures** to **minimise active services** and the embodied carbon associated with them?

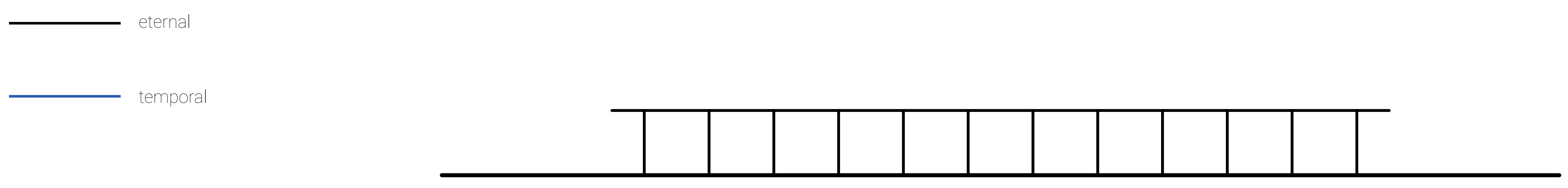
Answer: Since **thermal mass** is most relevant in terms of passive measures for this project, **concrete** is best suited.

	Concrete	**Masonry**	**Wood**
Historical Case Studies	**Pantheon**	**Aula Palatina**	**Horyuji Temple**
Age [years]	- built 128 AD - 1896 years old	- built 312 AD - 1712 years old	- built 670 - 1354 years old
History (changes, destruction, repair, replacement on structure)	- crack in foundation (during construction) - damages and replacements in brick envelope of opus latericium - cracks in dome (probably soon after construction, so almost as old as the building itself) - small manmade passage trough load-bearing wall - potentially self-healing because of the lime clasts in the cementitious matrix	- destroyed by Germanics but structure remained - conversion into fortress - demolition of east and south wall in Renaissance - bomb attack in WWII but the structure survived with smaller damages - repairs over the centuries resolve in patchwork as some bricks and mortar joint have definitely been replaced	- complex partly burned down multiple times (vulnarability against fire) -> high fire protection standards - central trunk of pagoda is rotten (vulnarability against moisture) - the replacement of damaged wooden parts is completely natural and planned from the initial stage -> replacement more often but also very easily doable - major restoration works in 1374 AD, 1603 AD, and in the mid-20th century
Condition of Structure	- despite the cracks the structure is in very good condition	- todays structure is in good condition but only due to constant repair - although most damages were manmade so probably the structure would not have needed the repairs - „reconstruction of a reconstruction of a reconstruction“ - 2 of the 4 walls remain the roman original as well as some plaster	- the structure of the pagoda is despite the rotten central trunk in good condition although it is hard to say to which extent the wood has been replaced in the past - assumption that most of the wood is original
Contemporaly Case Study	**Building simply concrete house**	**Building simply masonry house**	**Building simply solid timber house**
GWP/surface area [kg CO^2eq/m²]	4,00	3,93	3,13
Thermal Mass [Wh/K per room]	5600	4400	3300
U-Value [W/m²K]	0,35	0,25	0,22
Wall Thickness [cm]	50	42,5	30

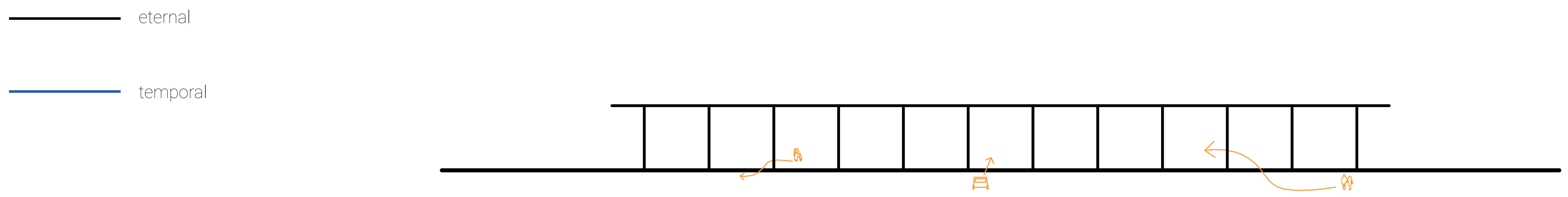
Design principle

eternal

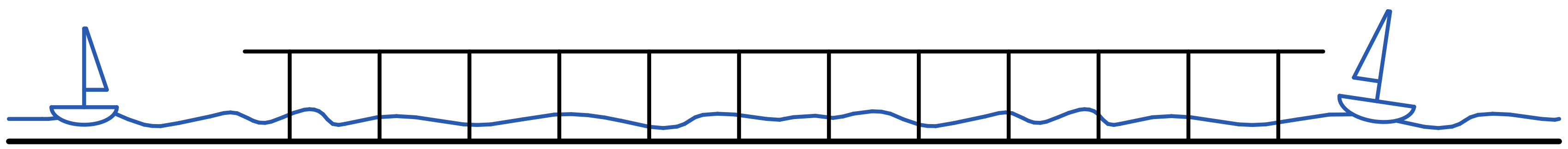
temporal

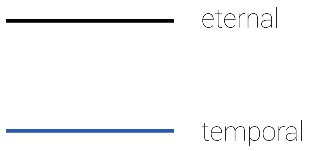


eternal concrete table

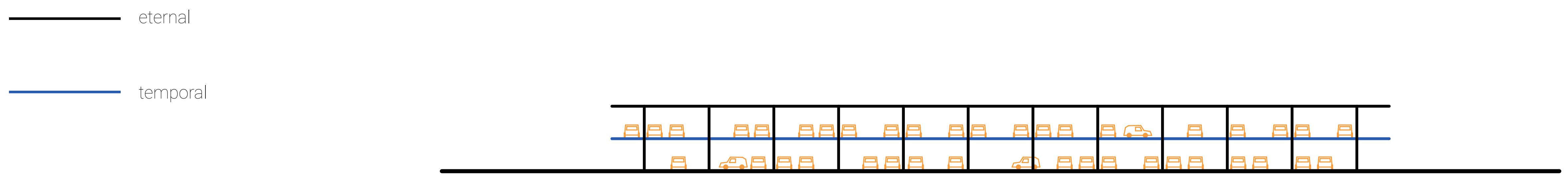


permeability





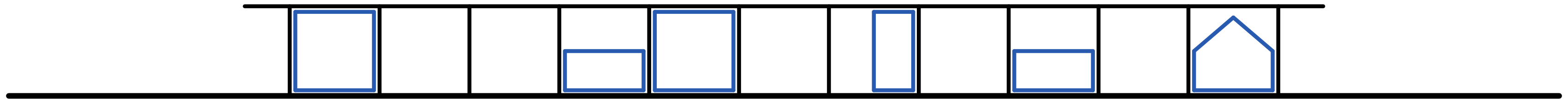
could be flooded



parking underneath

eternal

temporal



independent volumes underneath

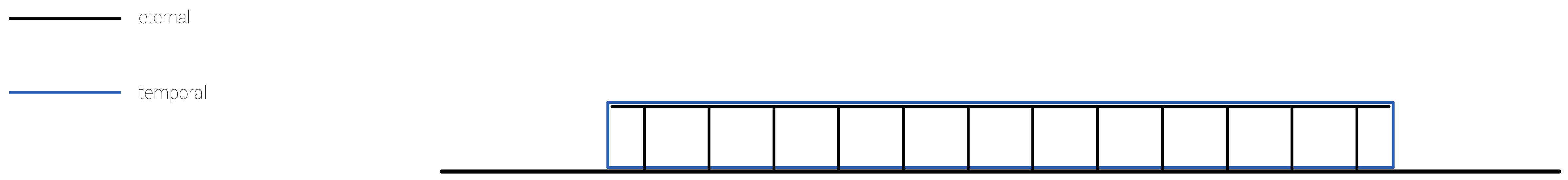
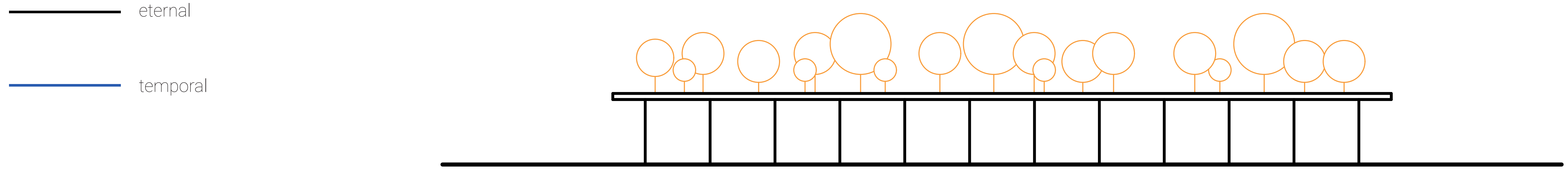
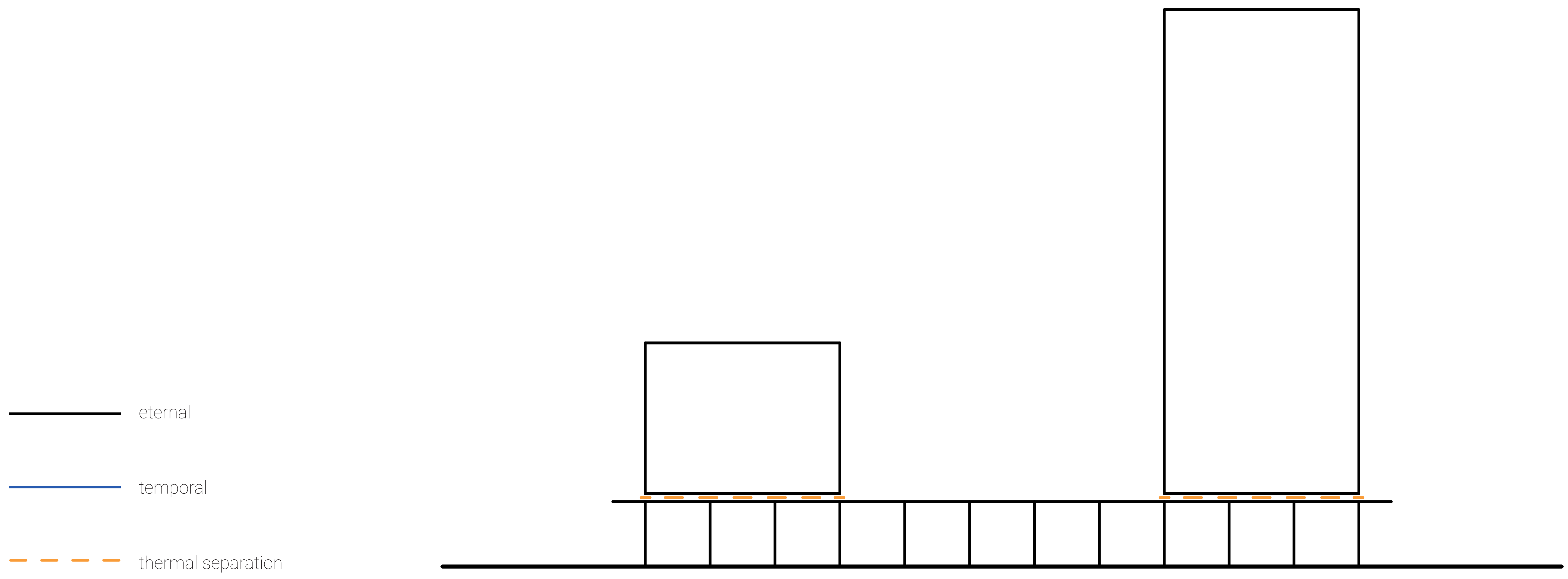


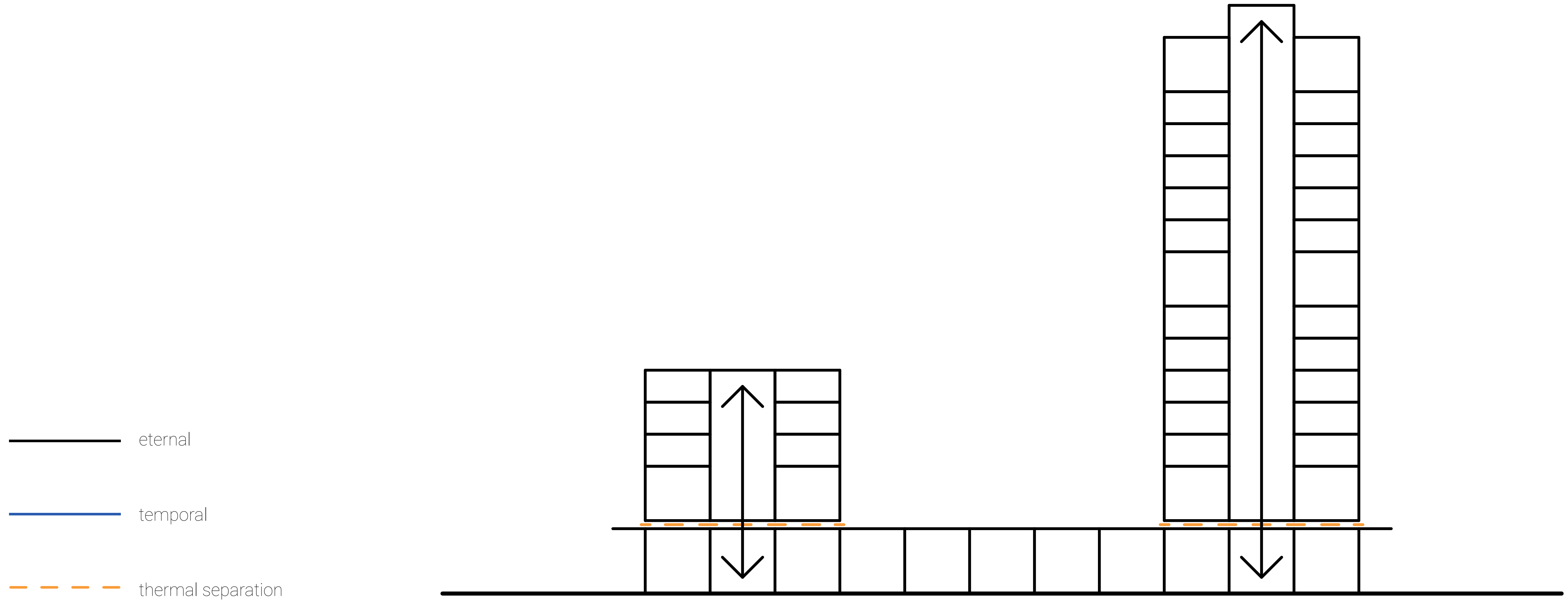
table as one volume



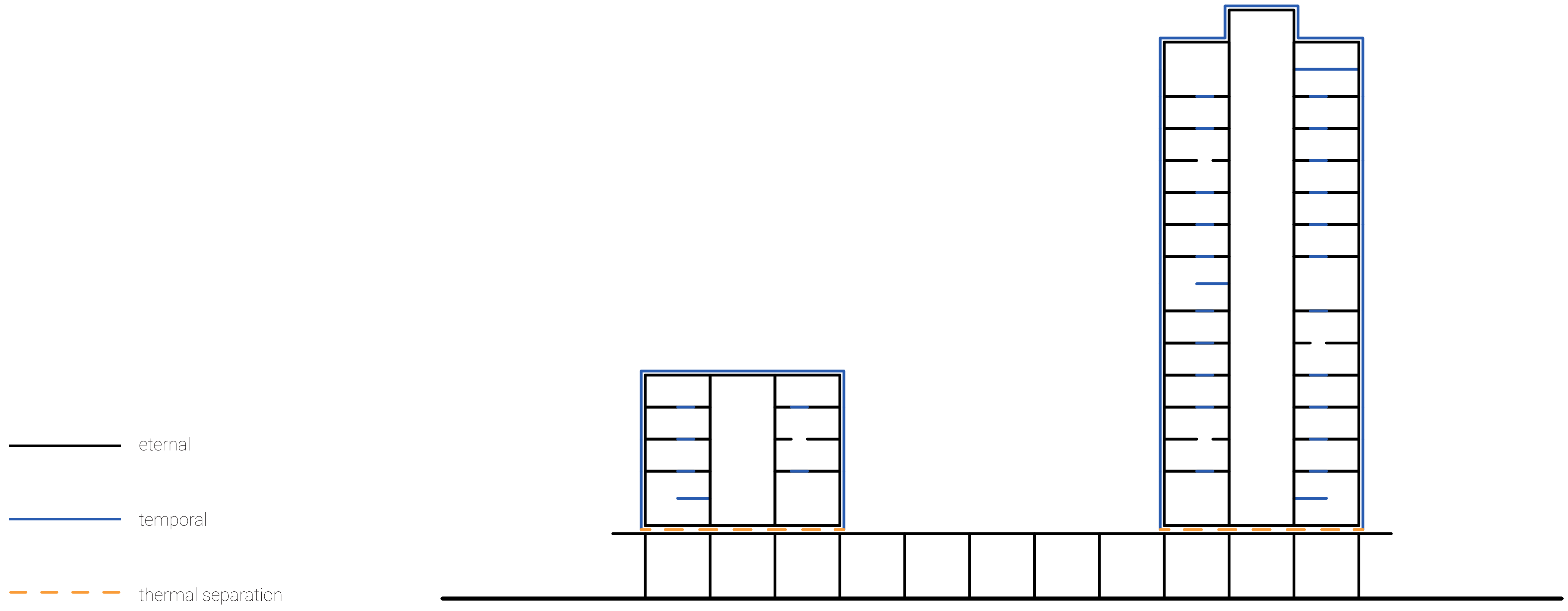
park on top



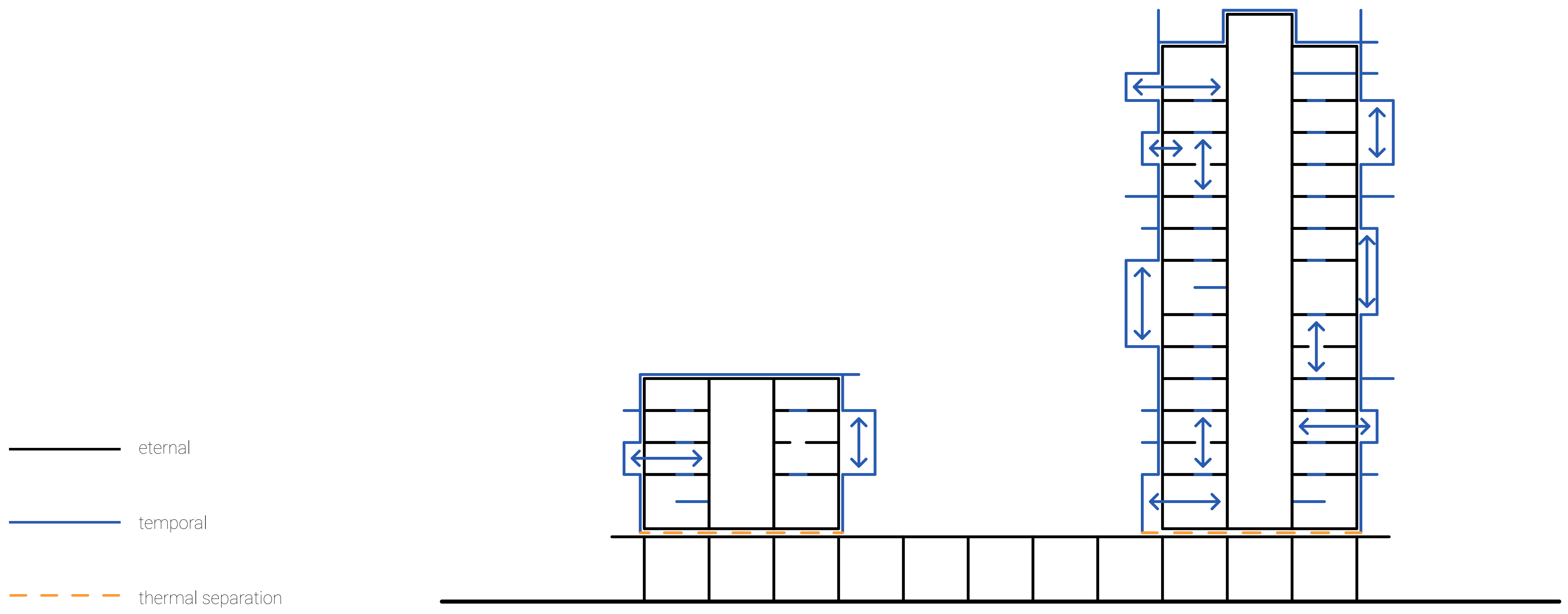
insulated volumes on top



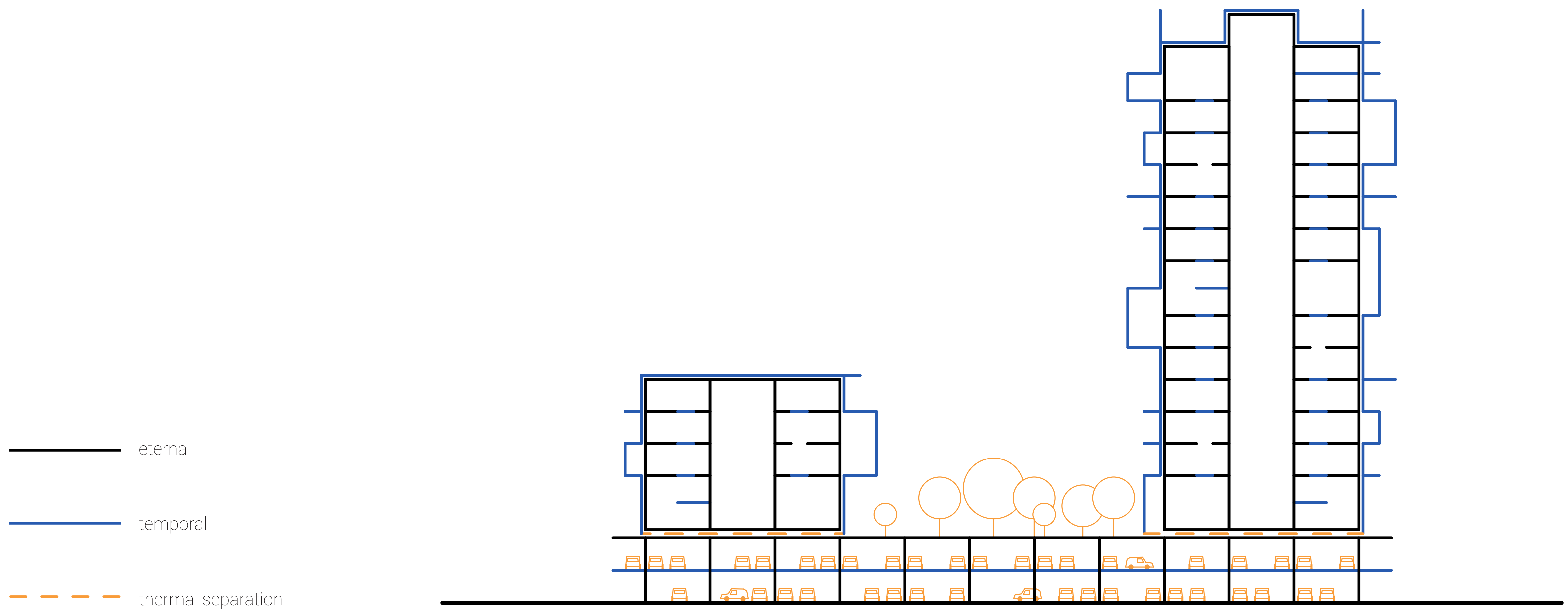
connected through cores



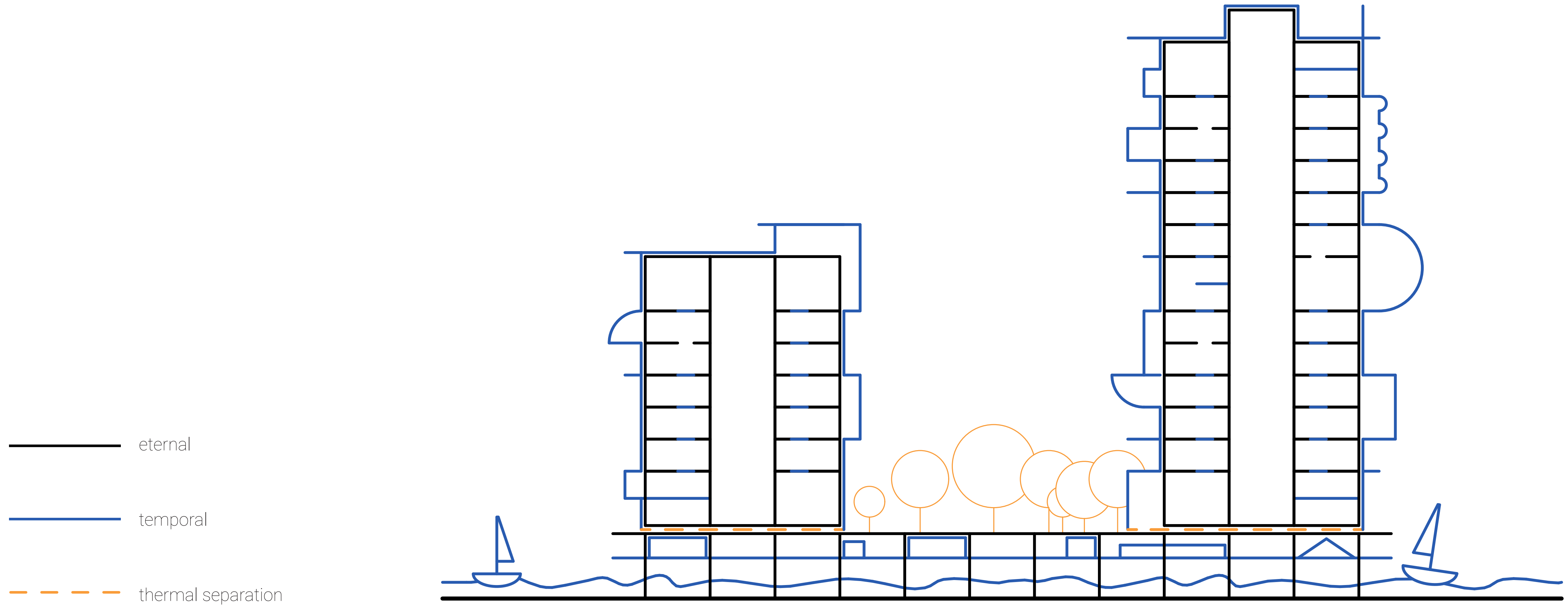
temporal skin + slabs, vertical flexibility



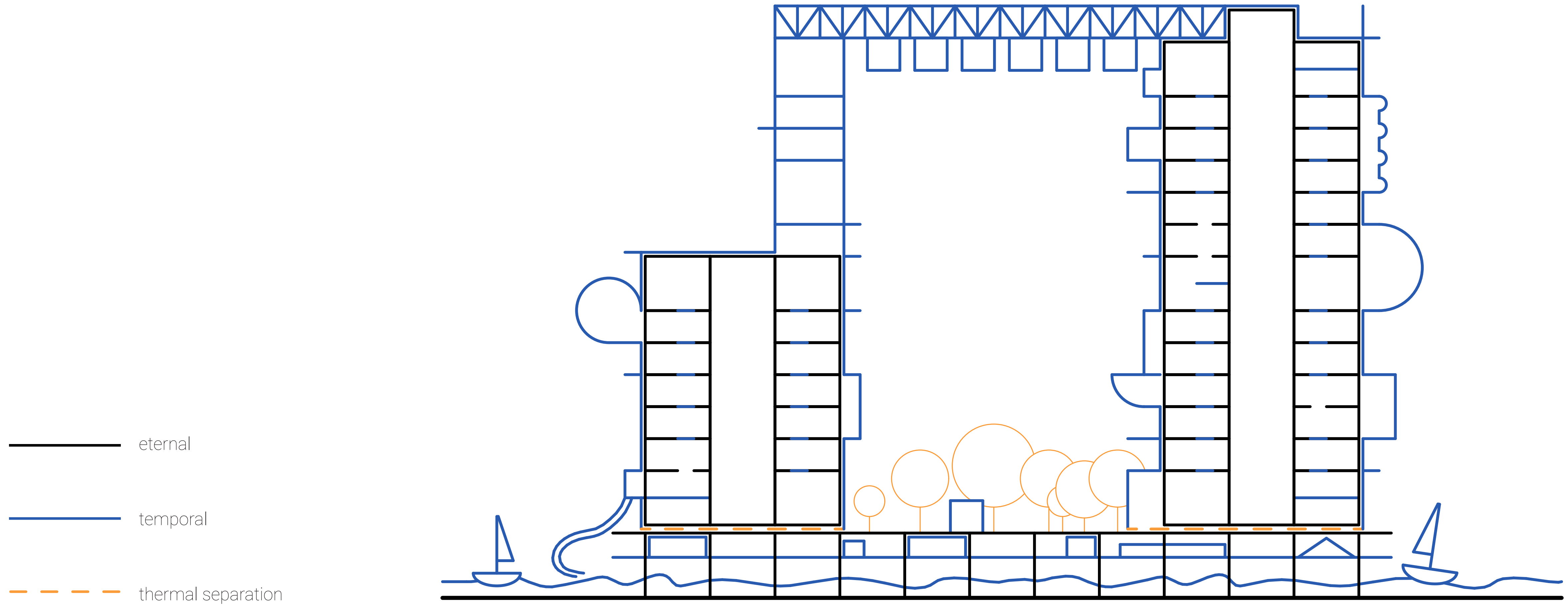
horizontal extensions and vertical connections



initial design

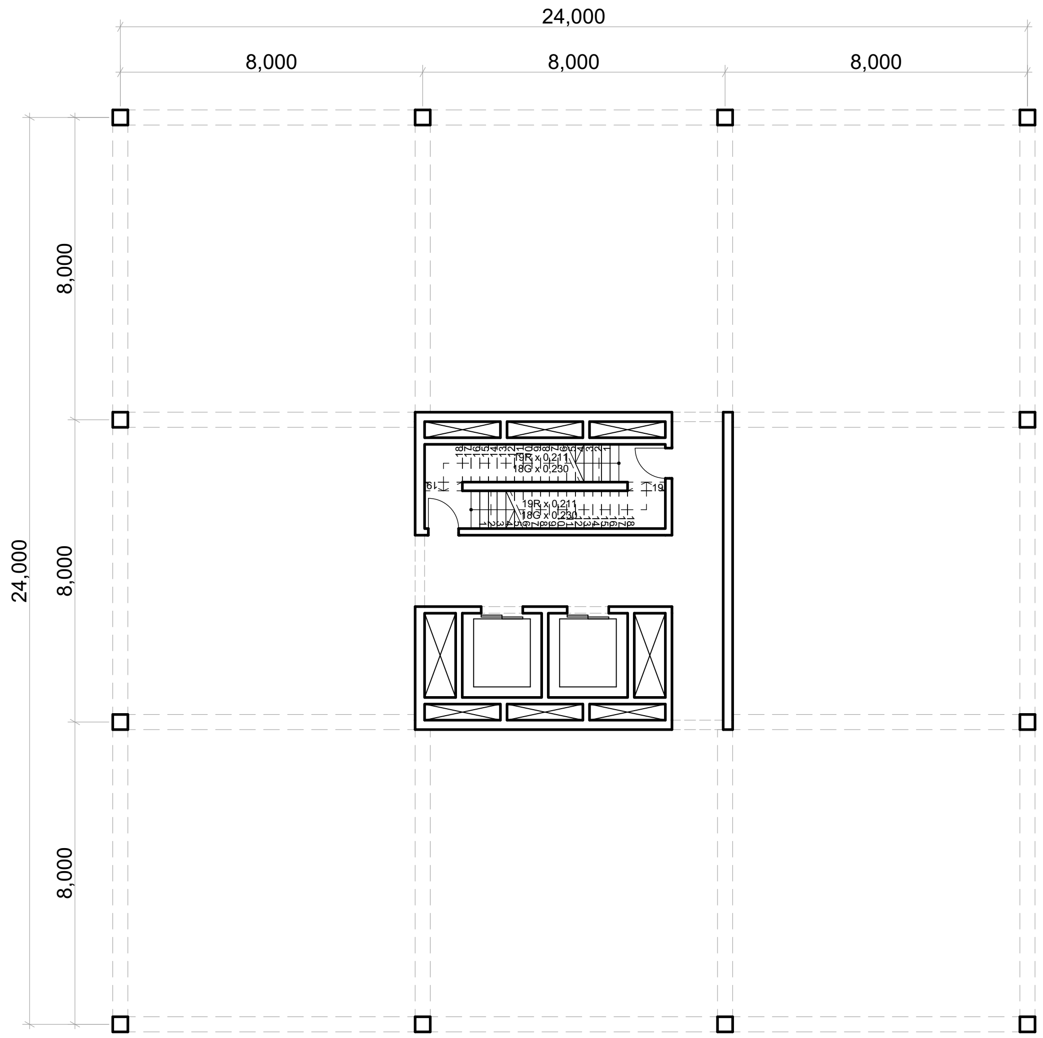


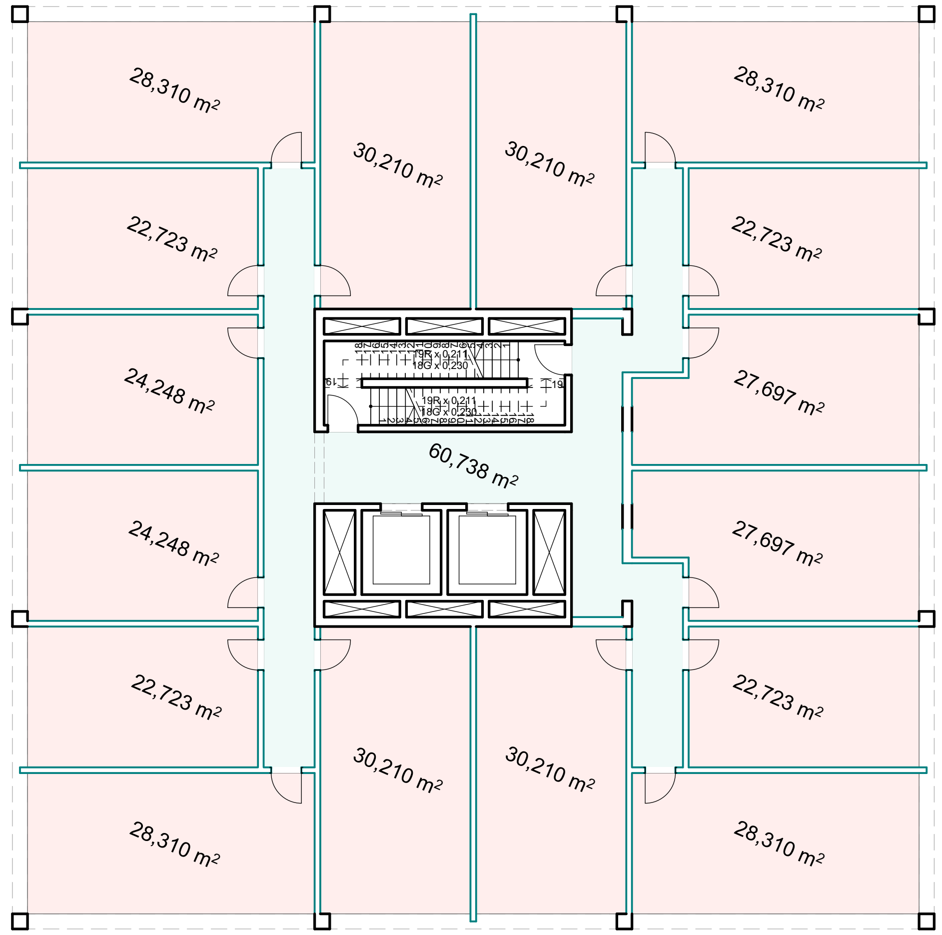
potential development in 75 years



potential development in 150 years

Generic Space



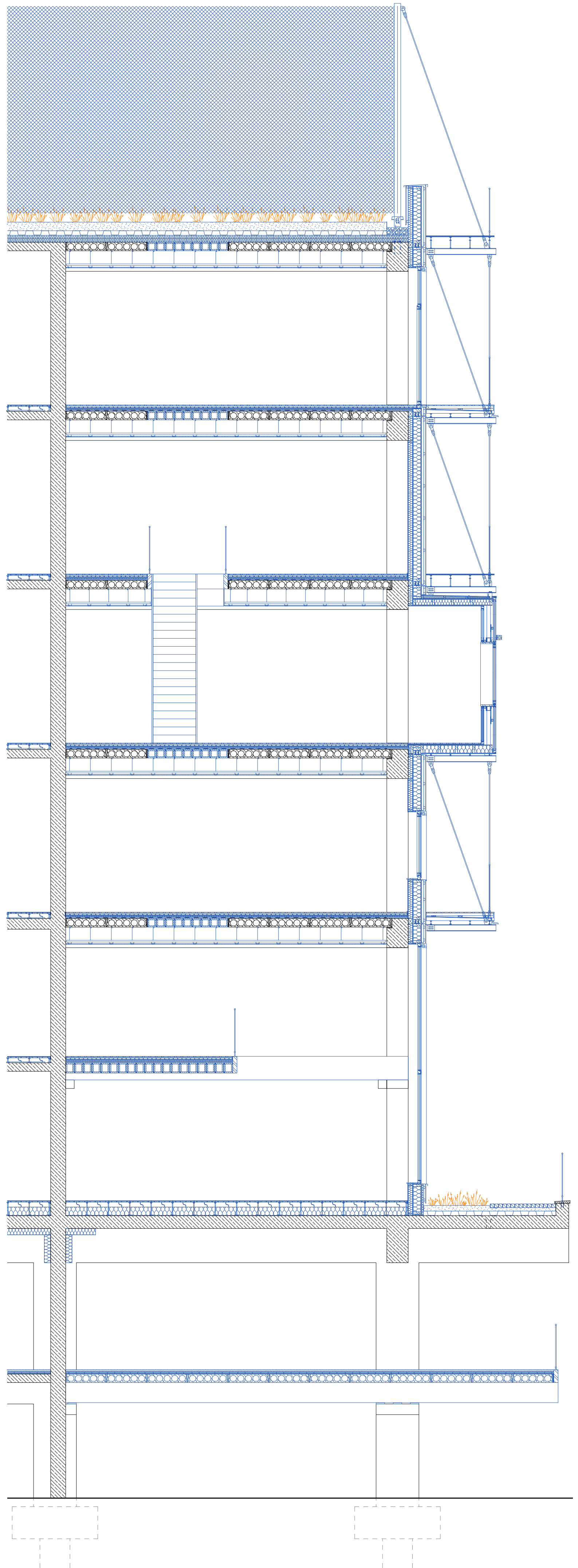


generic space between core and columns

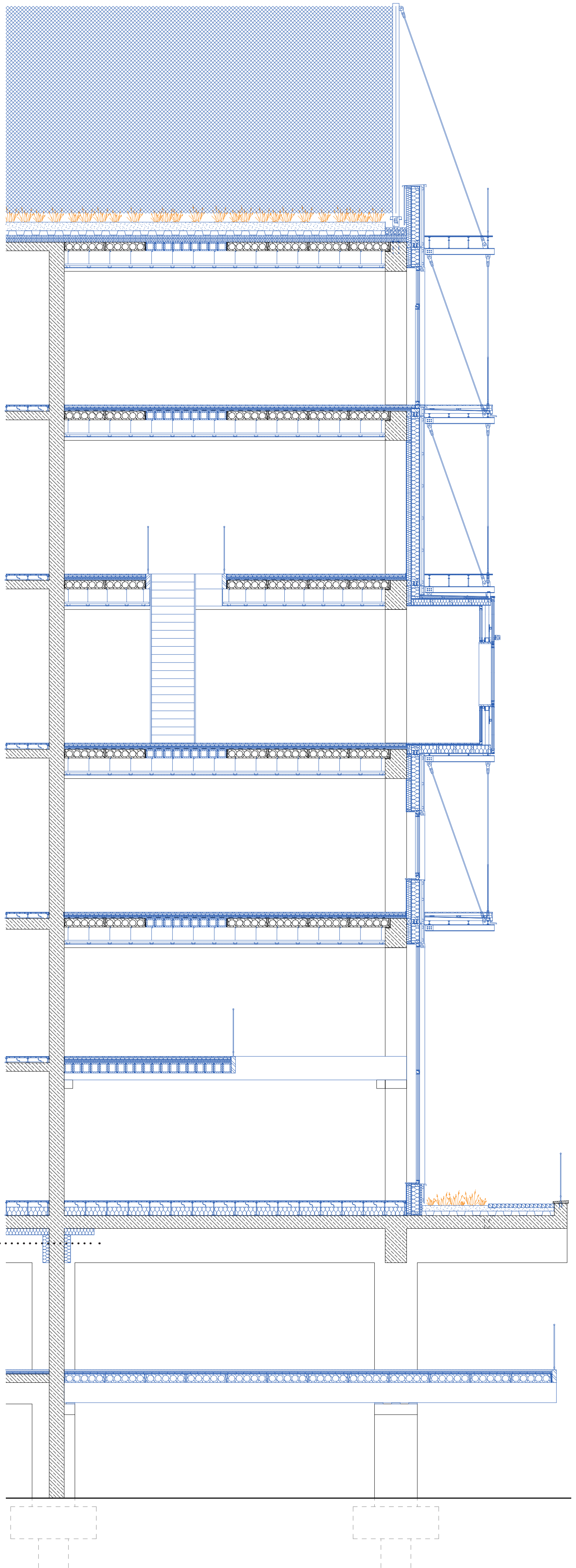
smallest possible division into 16 units

eternal

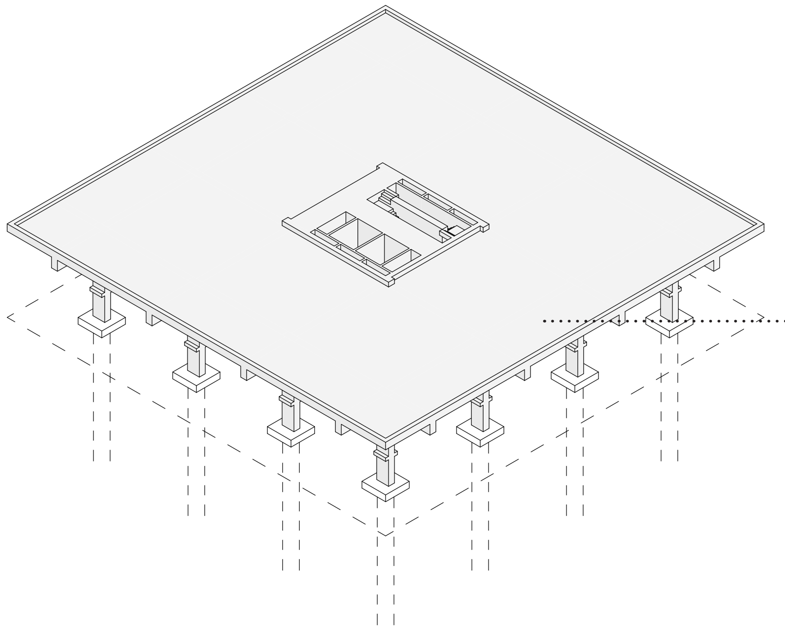
temporal



eternal



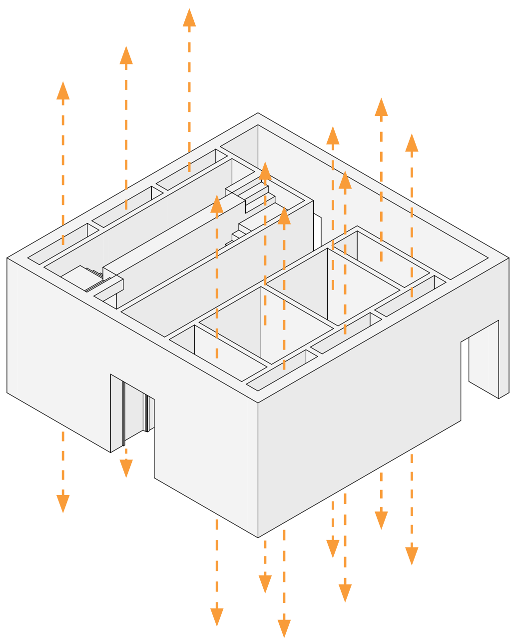
temporal



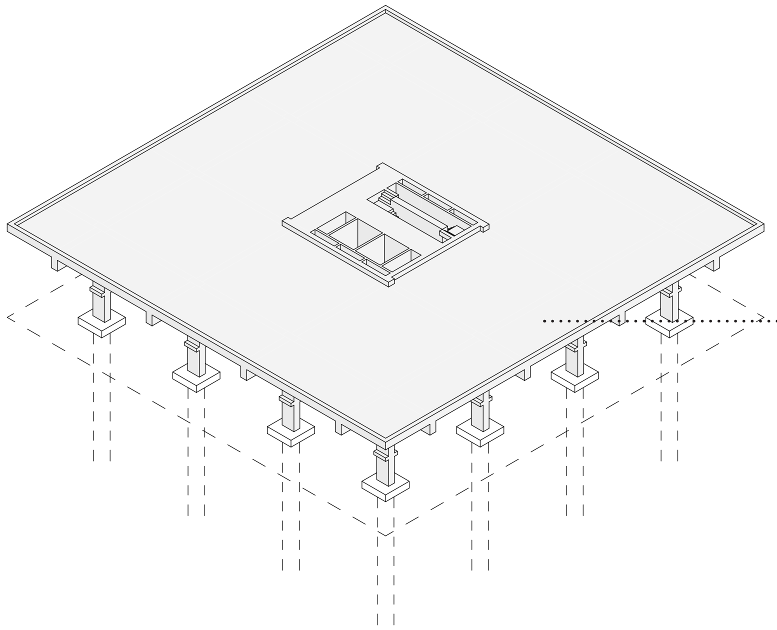
casted concrete table/foundation

eternal

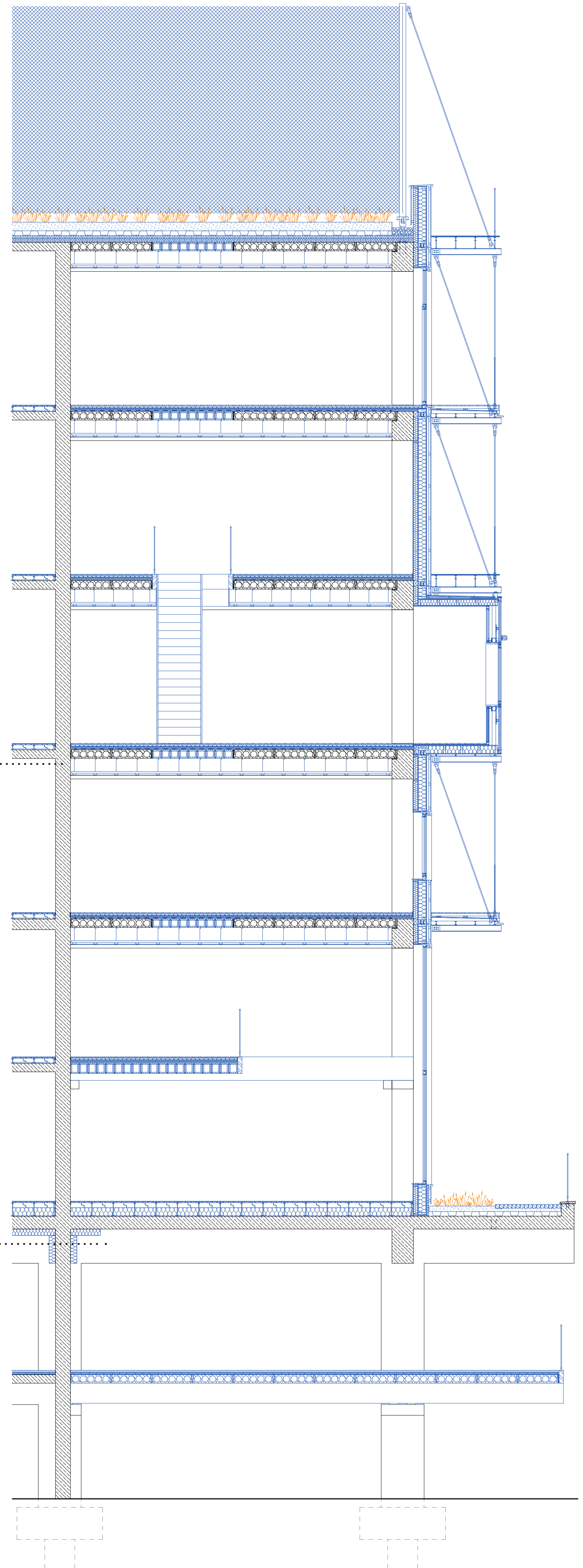
temporal



casted concrete core

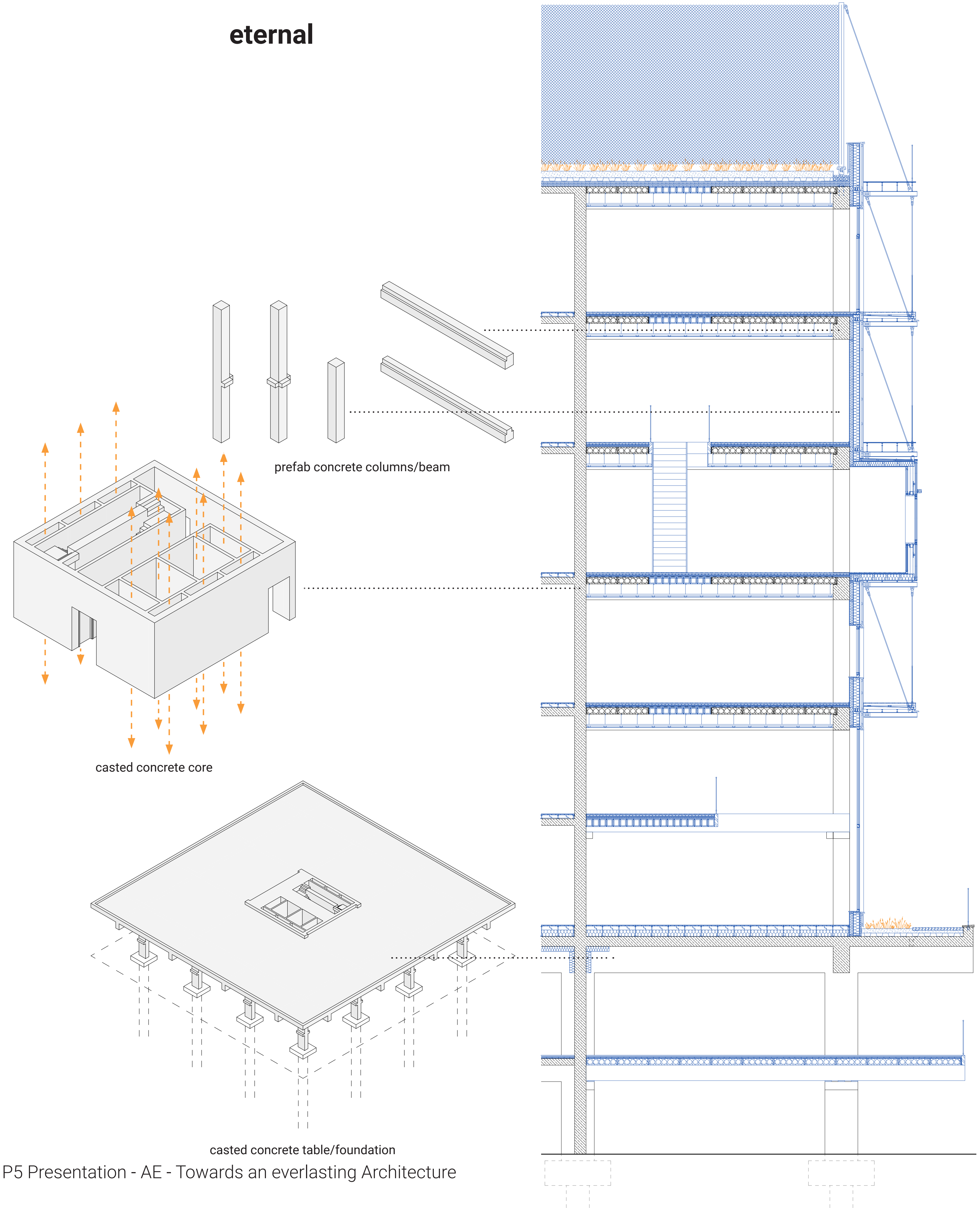


casted concrete table/foundation



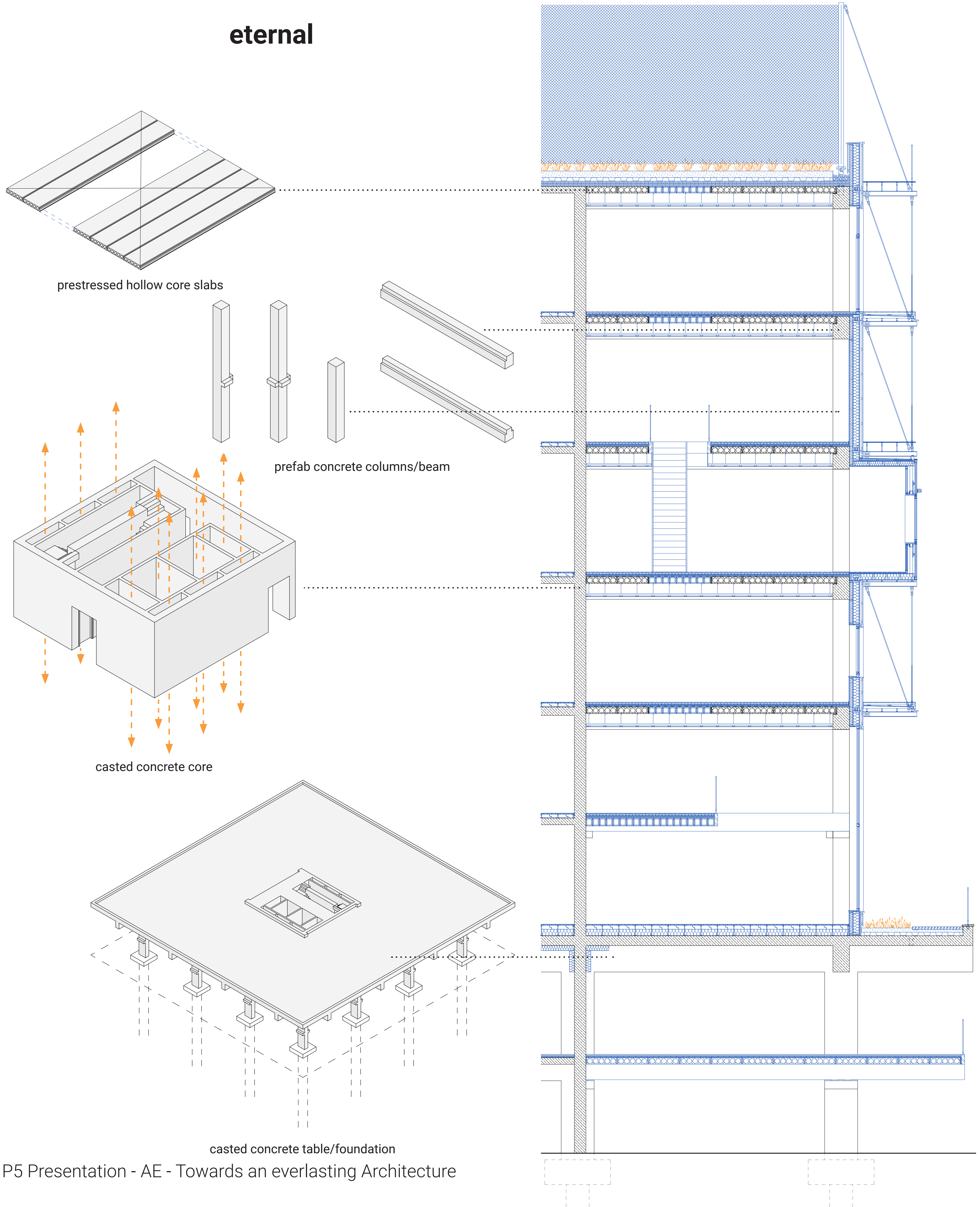
eternal

temporal



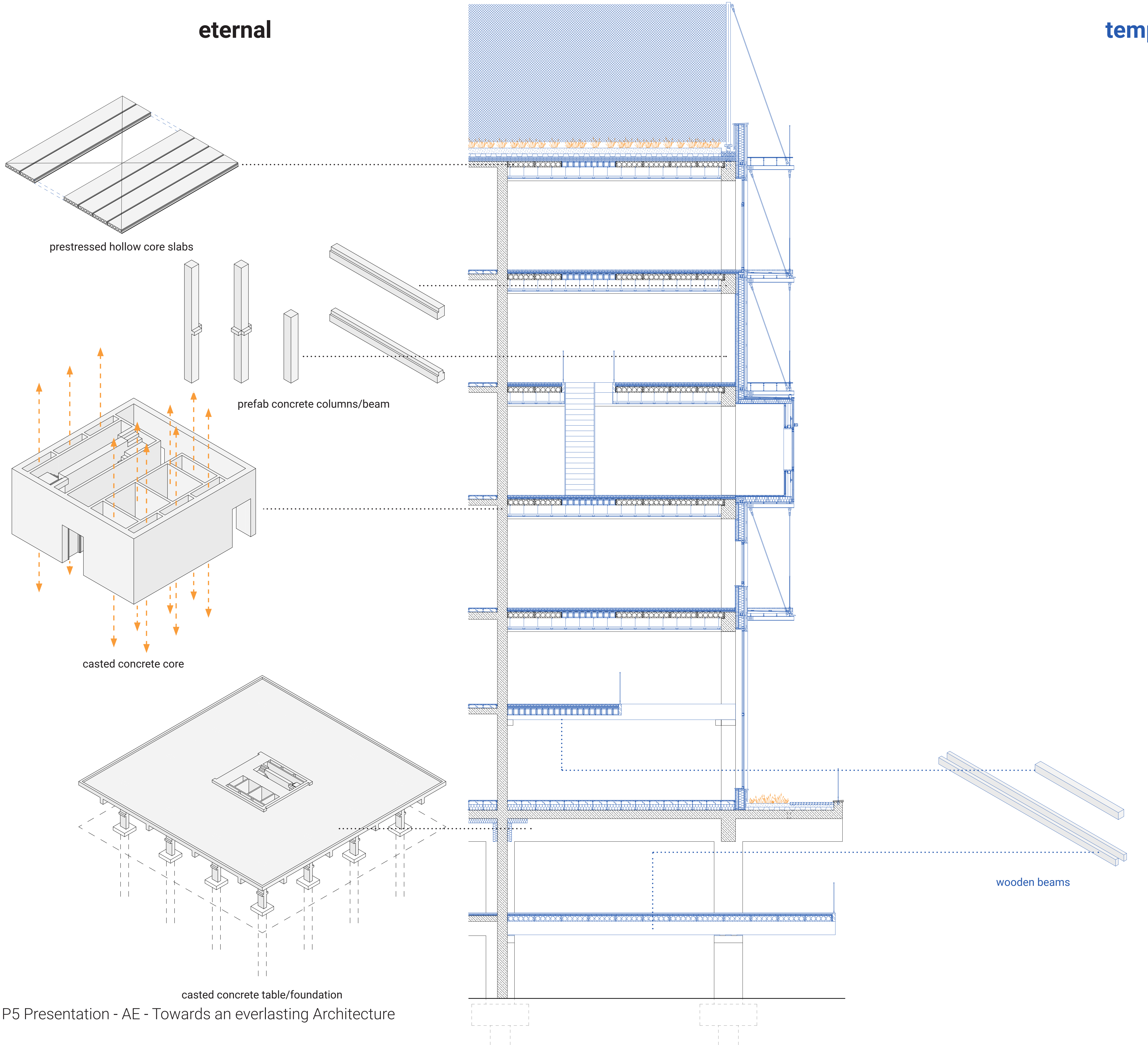
eternal

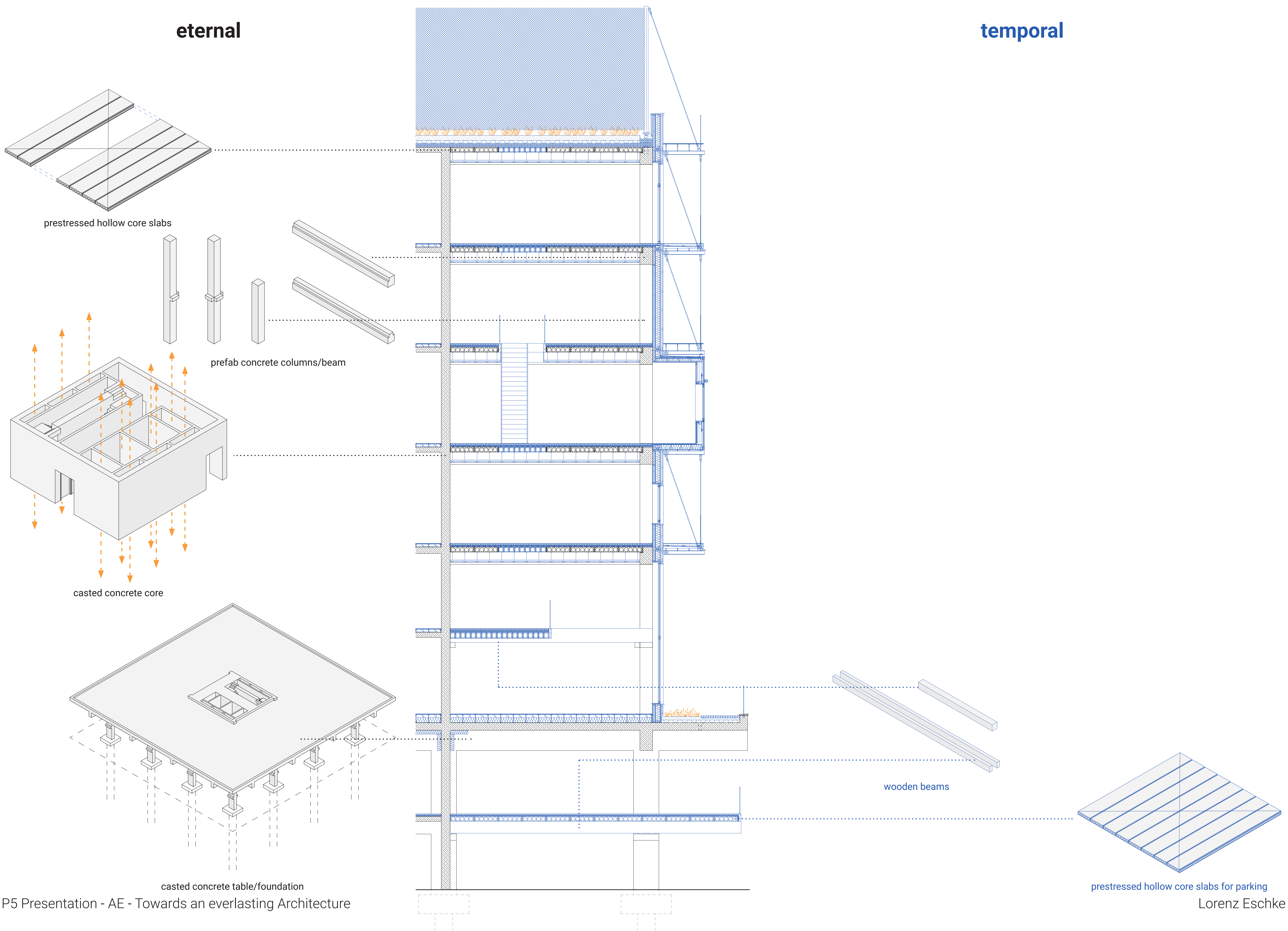
temporal

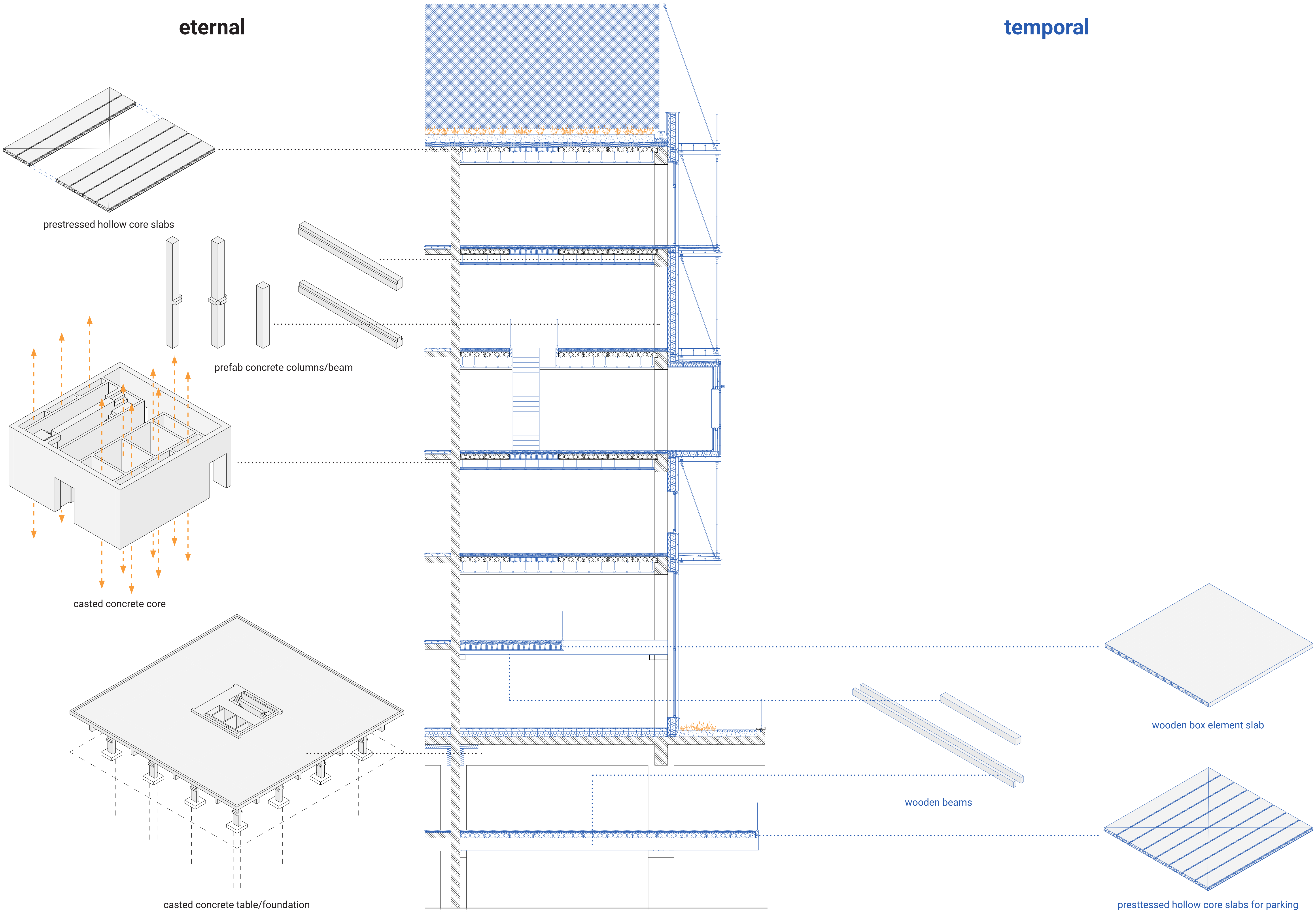


eternal

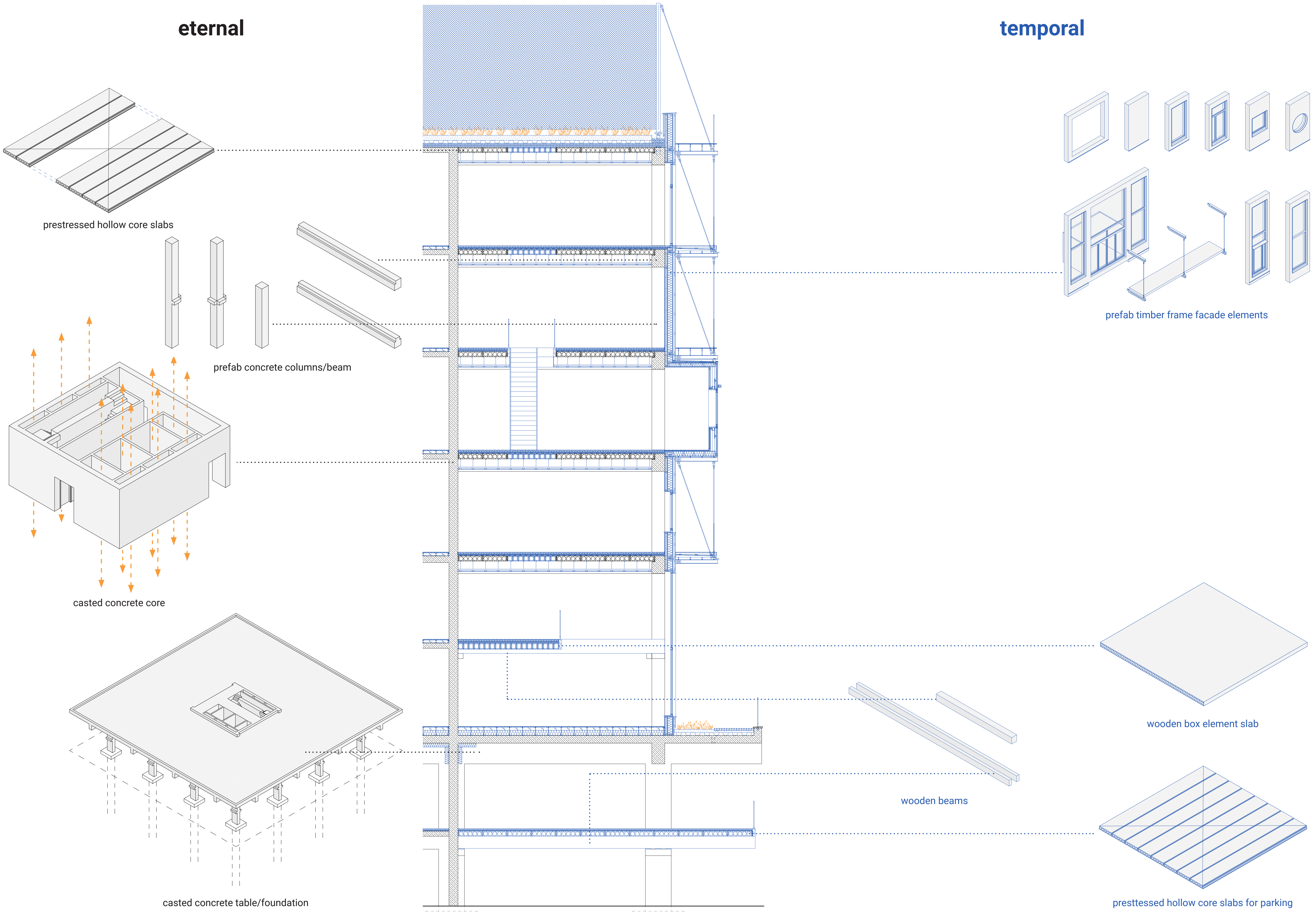
temporal



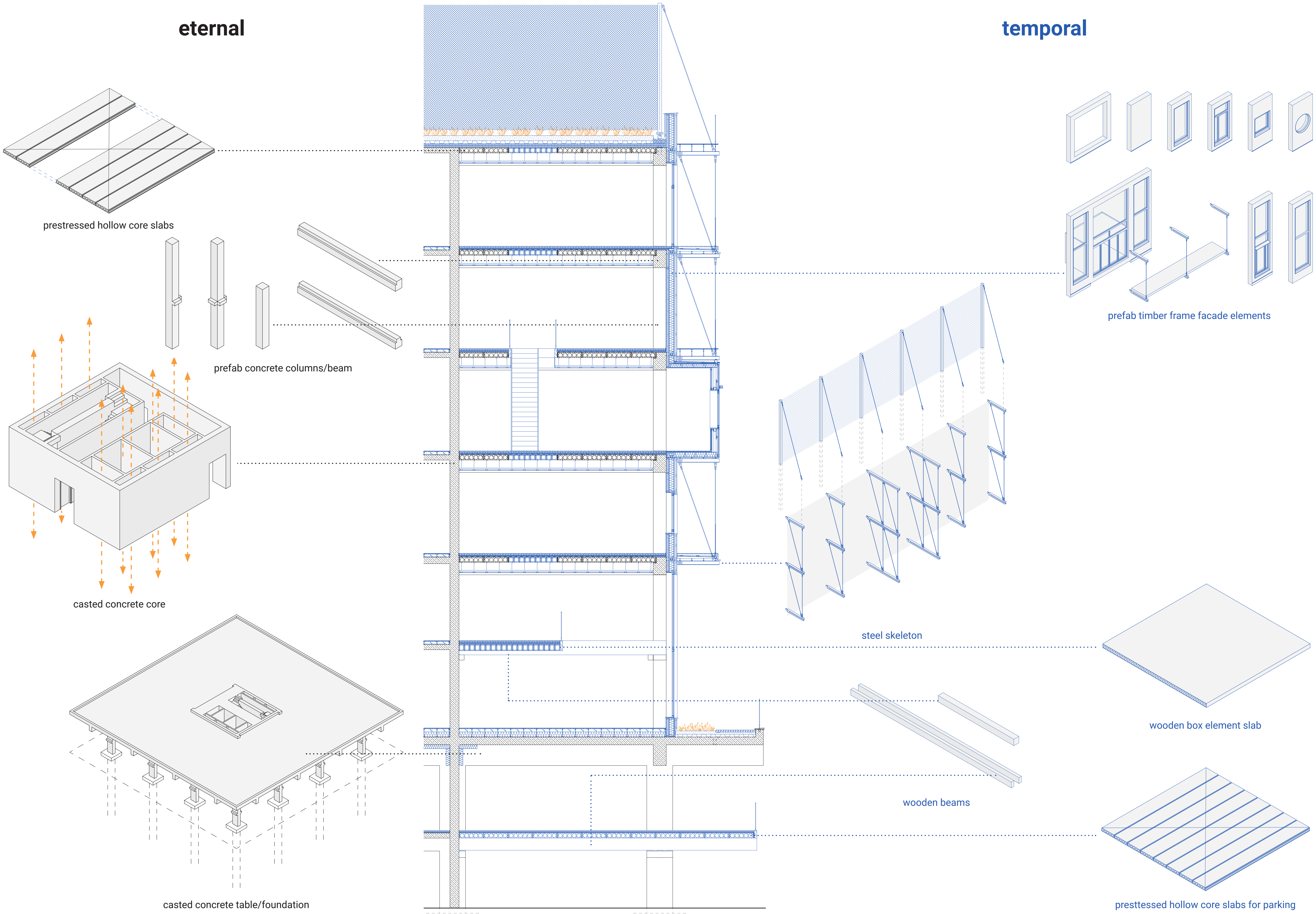

eternal
temporal
prestressed hollow core slabs
prefab concrete columns/beam
casted concrete core
casted concrete table/foundation
wooden beams
prestressed hollow core slabs for parking

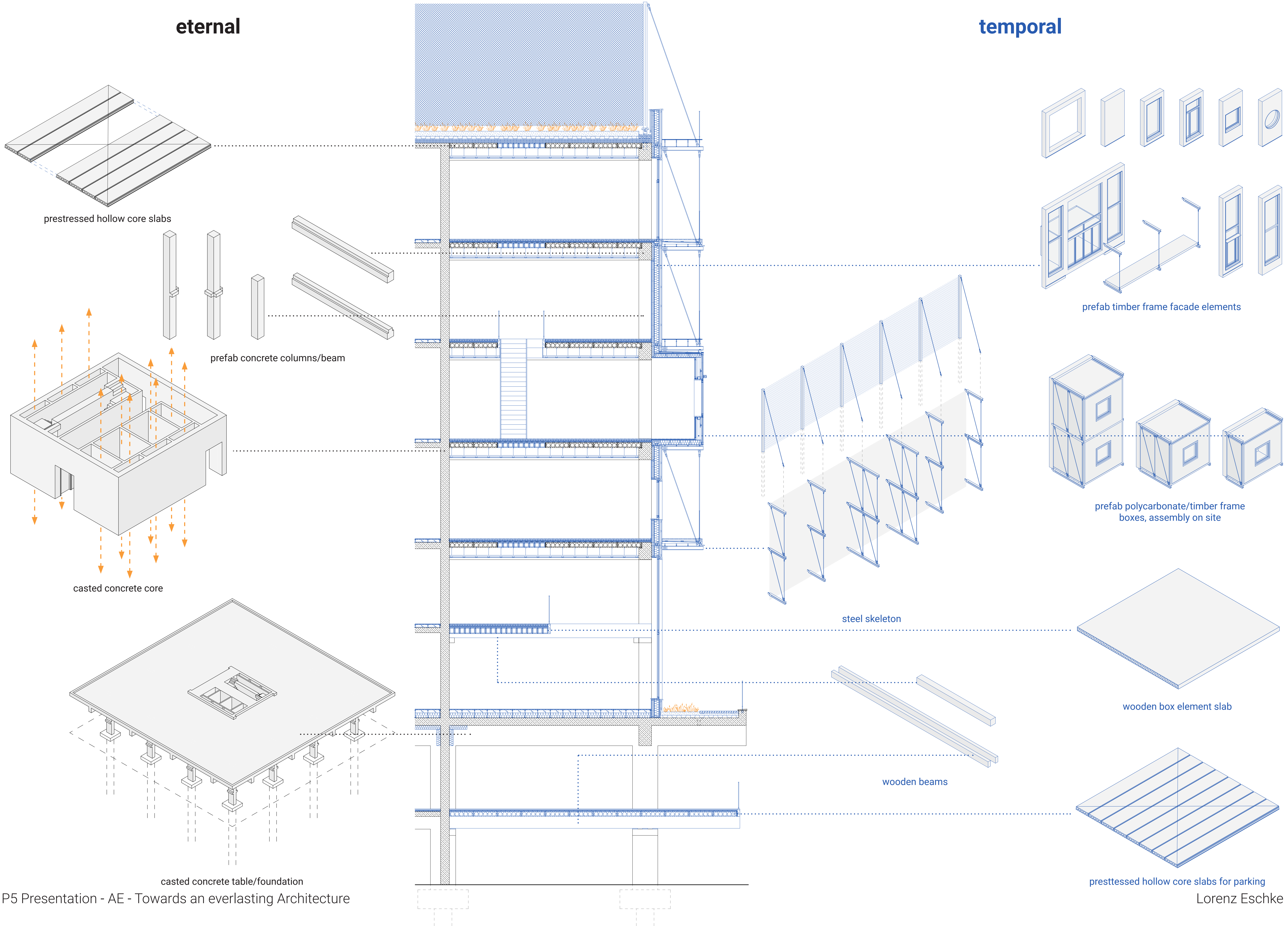


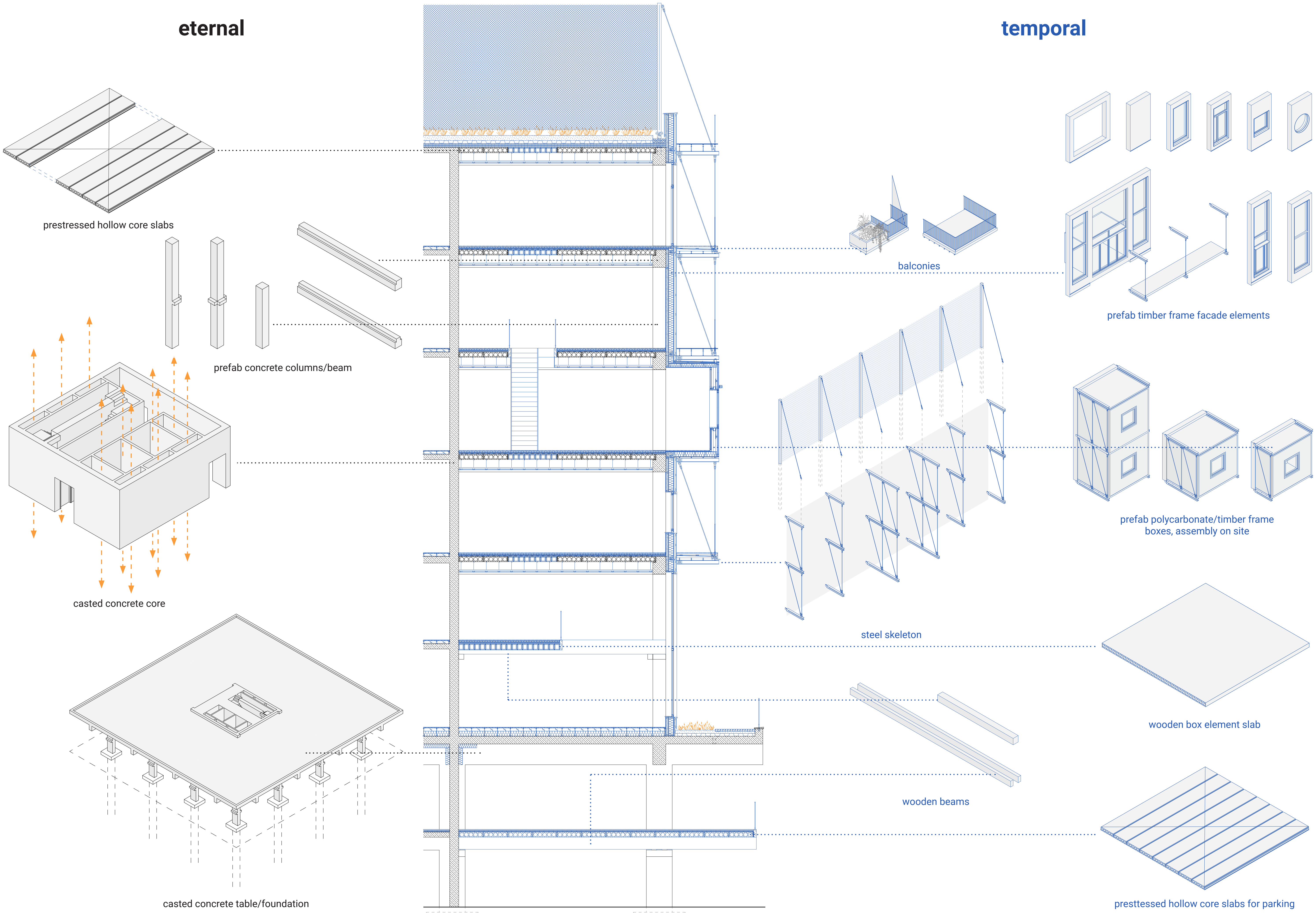
eternal
temporal
prestressed hollow core slabs
prefab concrete columns/beam
casted concrete core
casted concrete table/foundation
wooden box element slab
wooden beams
presttessed hollow core slabs for parking

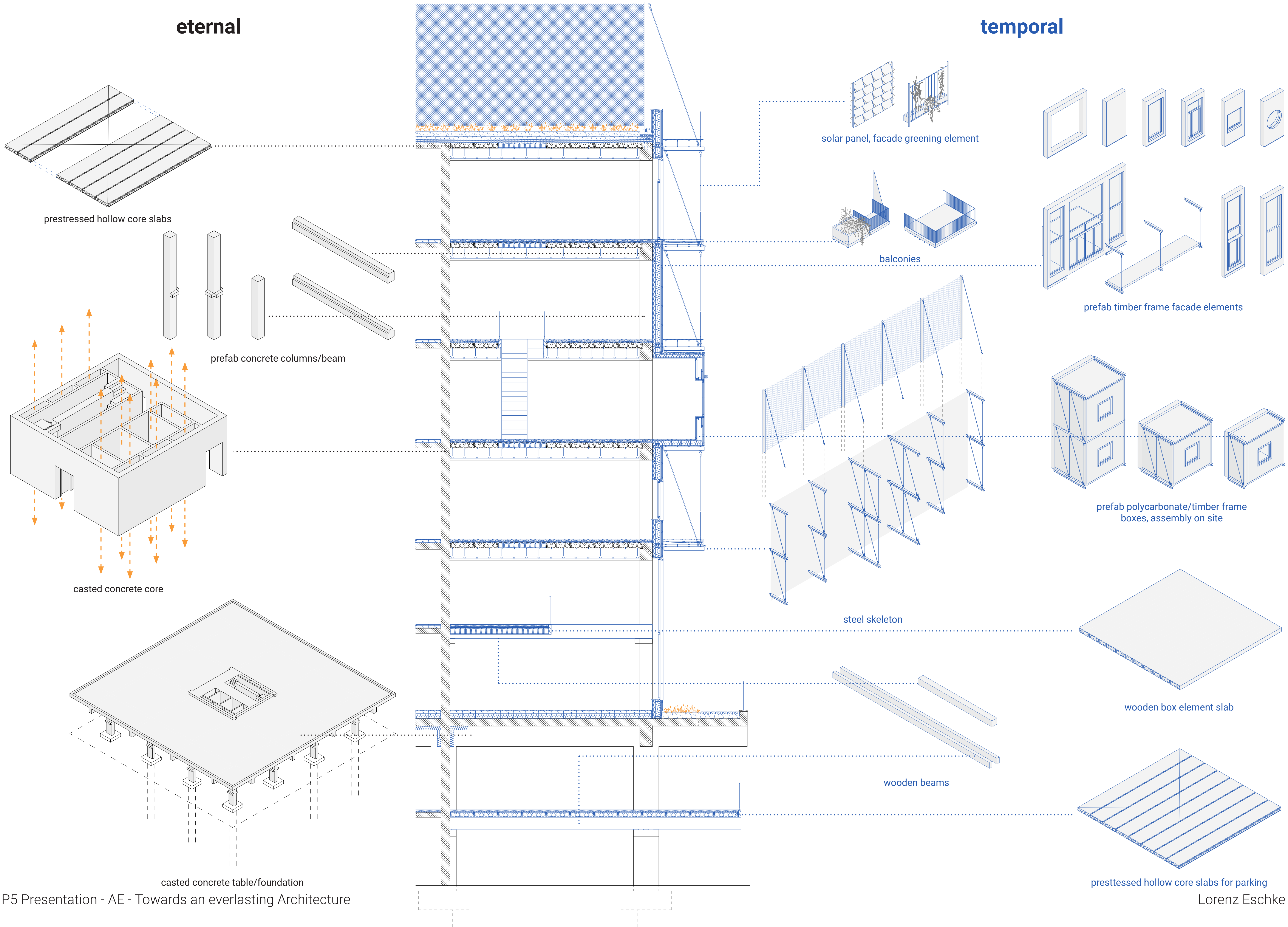


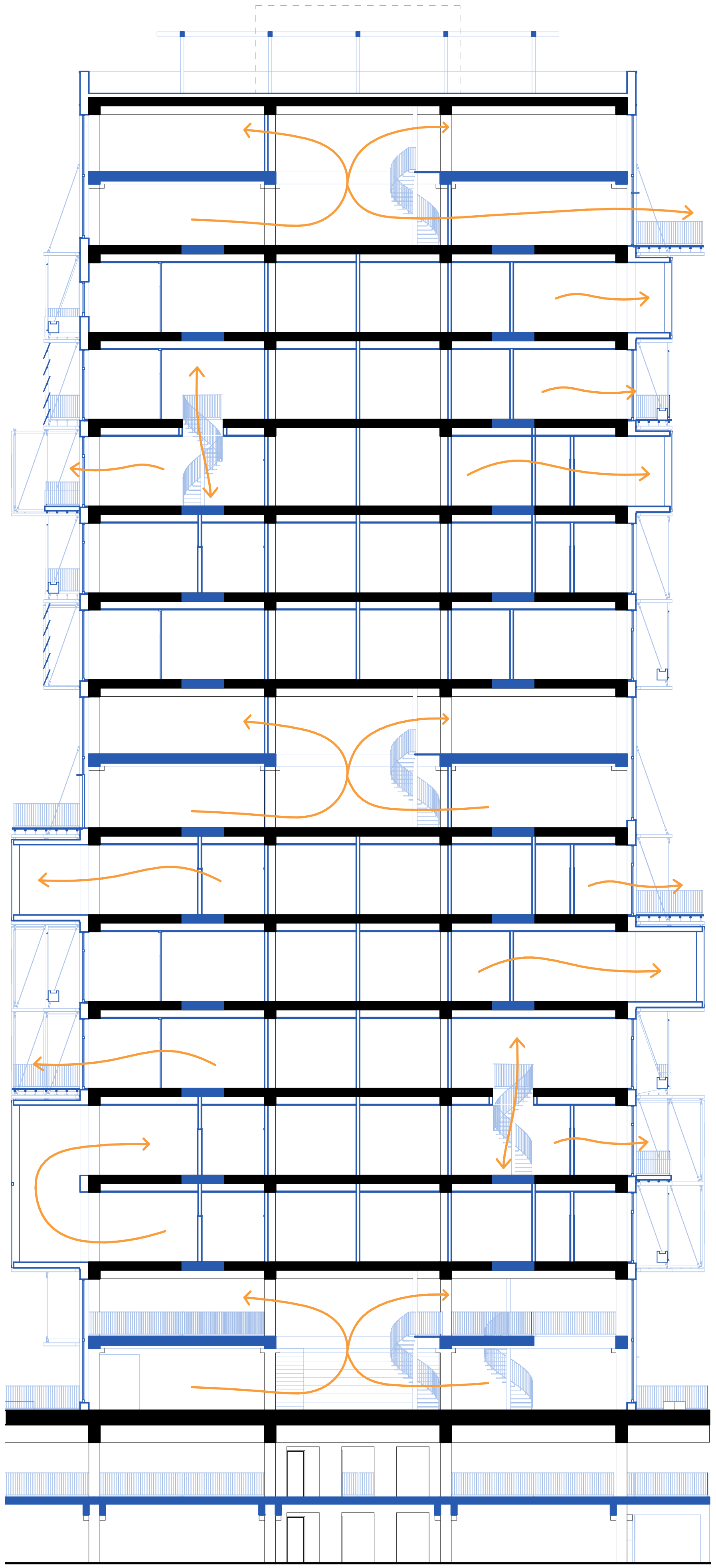
eternal
temporal
prestressed hollow core slabs
prefab concrete columns/beam
casted concrete core
casted concrete table/foundation
prefab timber frame facade elements
wooden box element slab
wooden beams
presttessed hollow core slabs for parking


eternal
temporal
prestressed hollow core slabs
prefab concrete columns/beam
casted concrete core
casted concrete table/foundation
prefab timber frame facade elements
steel skeleton
wooden box element slab
wooden beams
presttessed hollow core slabs for parking

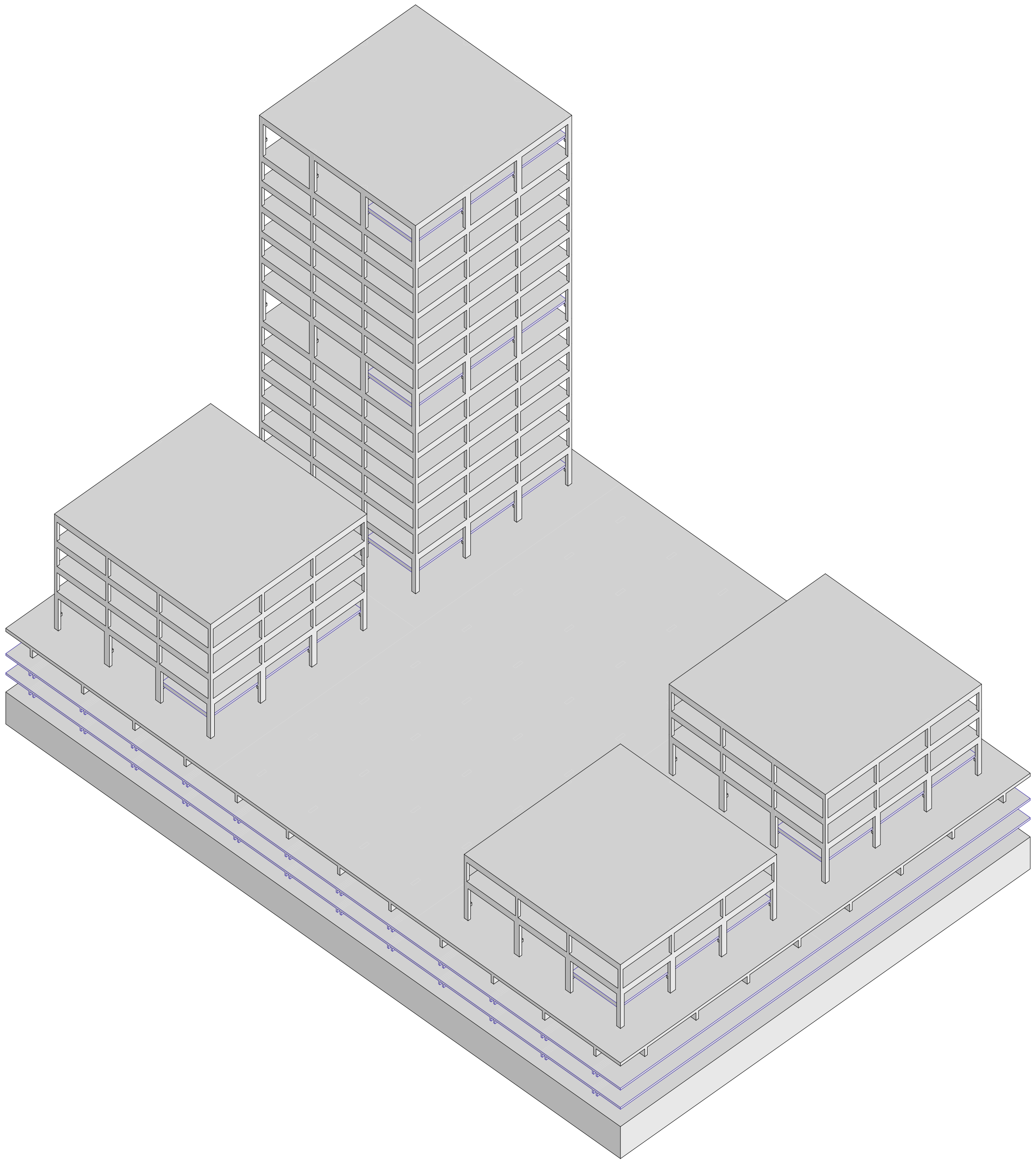

eternal
temporal
prestressed hollow core slabs
prefab concrete columns/beam
casted concrete core
casted concrete table/foundation
prefab timber frame facade elements
prefab polycarbonate/timber frame boxes, assembly on site
steel skeleton
wooden box element slab
wooden beams
presttessed hollow core slabs for parking

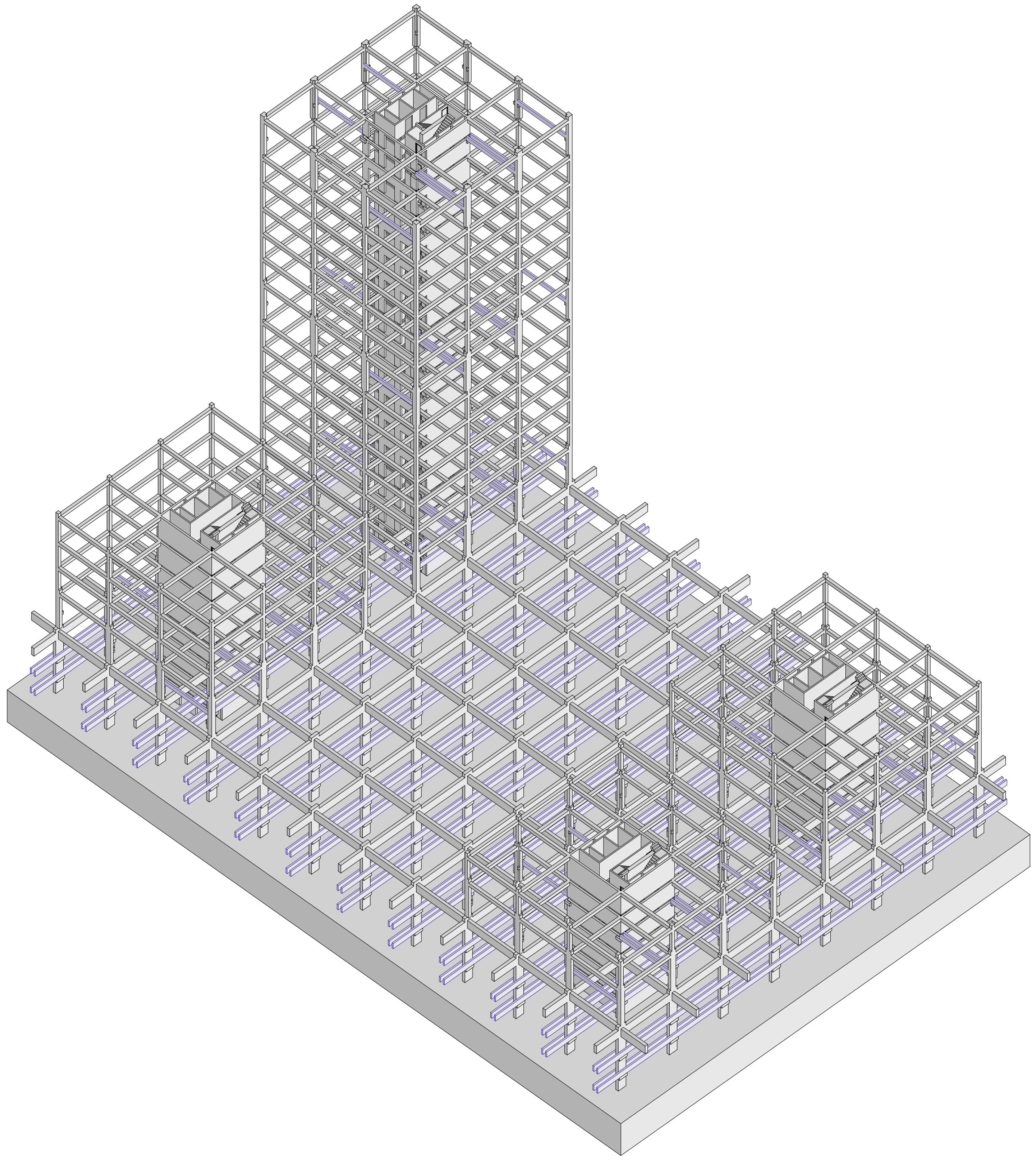

eternal
temporal
prestressed hollow core slabs
prefab concrete columns/beam
casted concrete core
casted concrete table/foundation
balconies
prefab timber frame facade elements
steel skeleton
prefab polycarbonate/timber frame
boxes, assembly on site
wooden box element slab
wooden beams
presttessed hollow core slabs for parking


eternal
temporal
prestressed hollow core slabs
prefab concrete columns/beam
casted concrete core
casted concrete table/foundation
solar panel, facade greening element
balconies
prefab timber frame facade elements
steel skeleton
prefab polycarbonate/timber frame boxes, assembly on site
wooden box element slab
wooden beams
presttessed hollow core slabs for parking

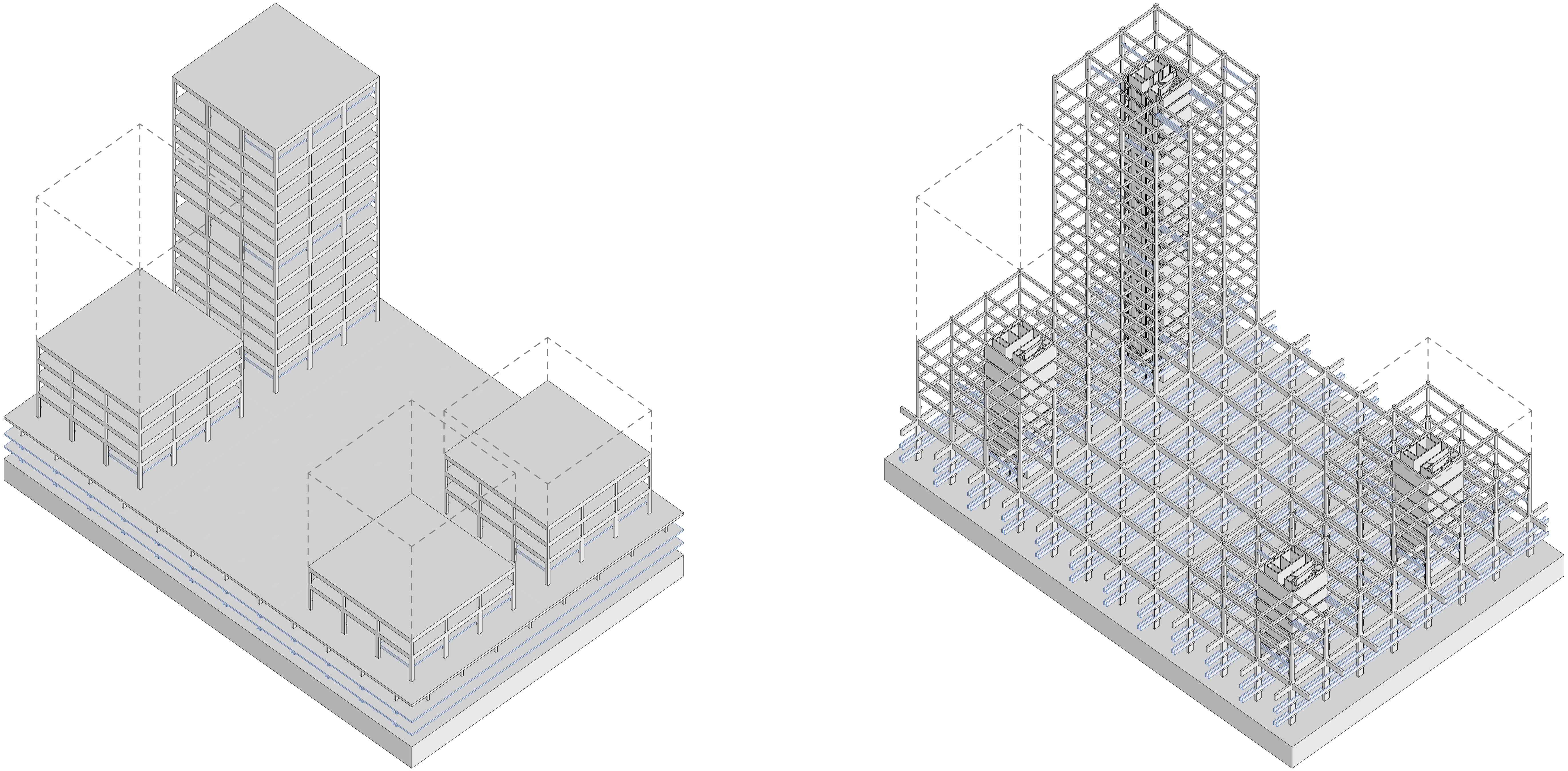


horizontal extensions/vertical connections

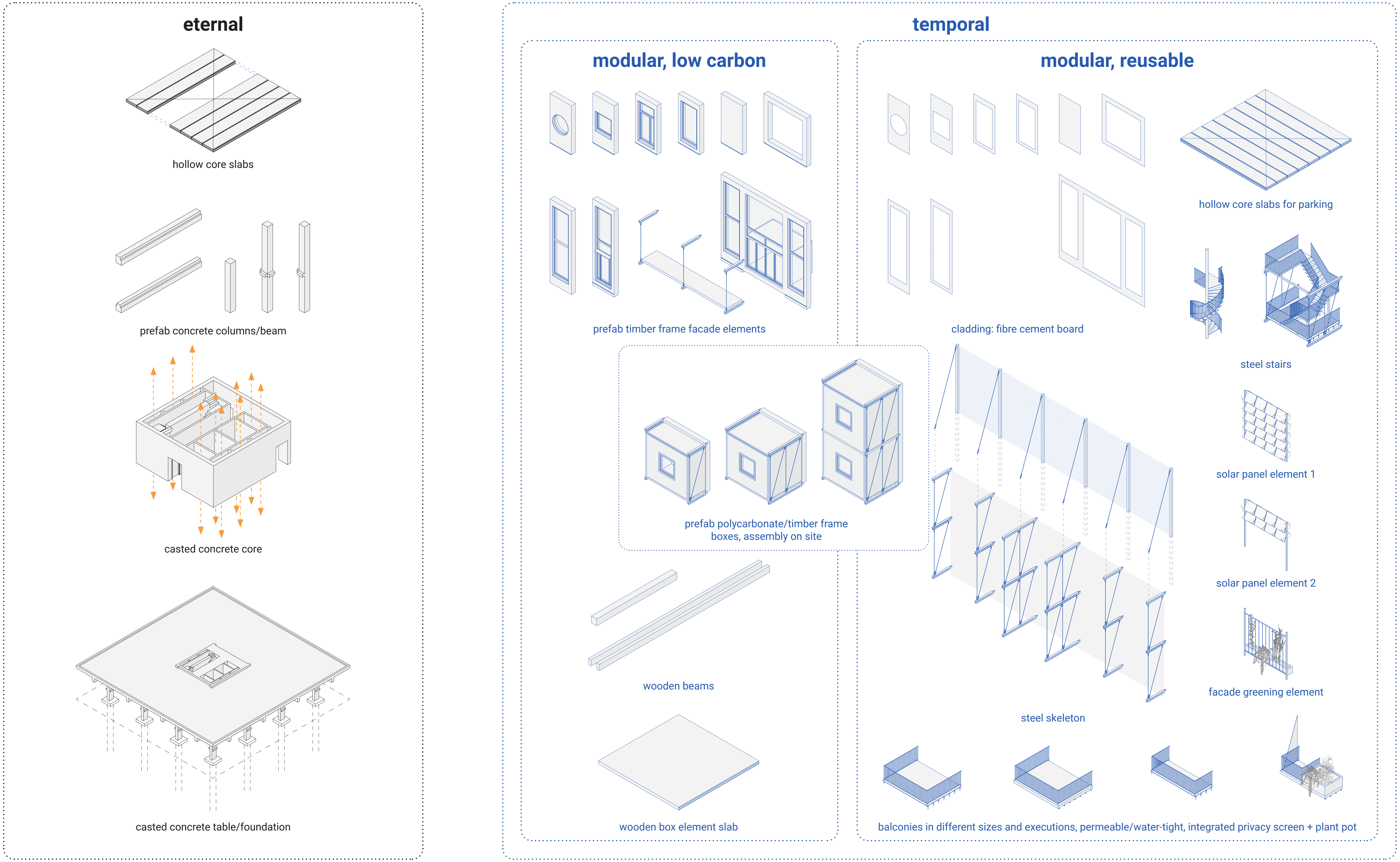




eternal table with 4 towers - urban system in itself

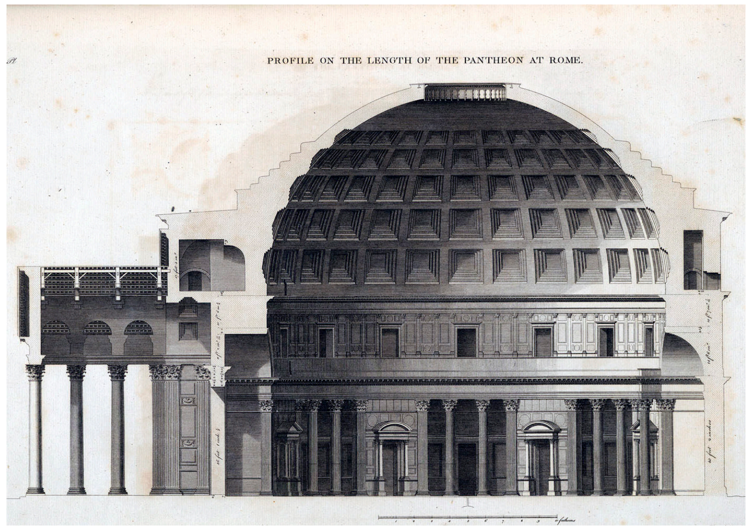


growable towers



categorization

eternal

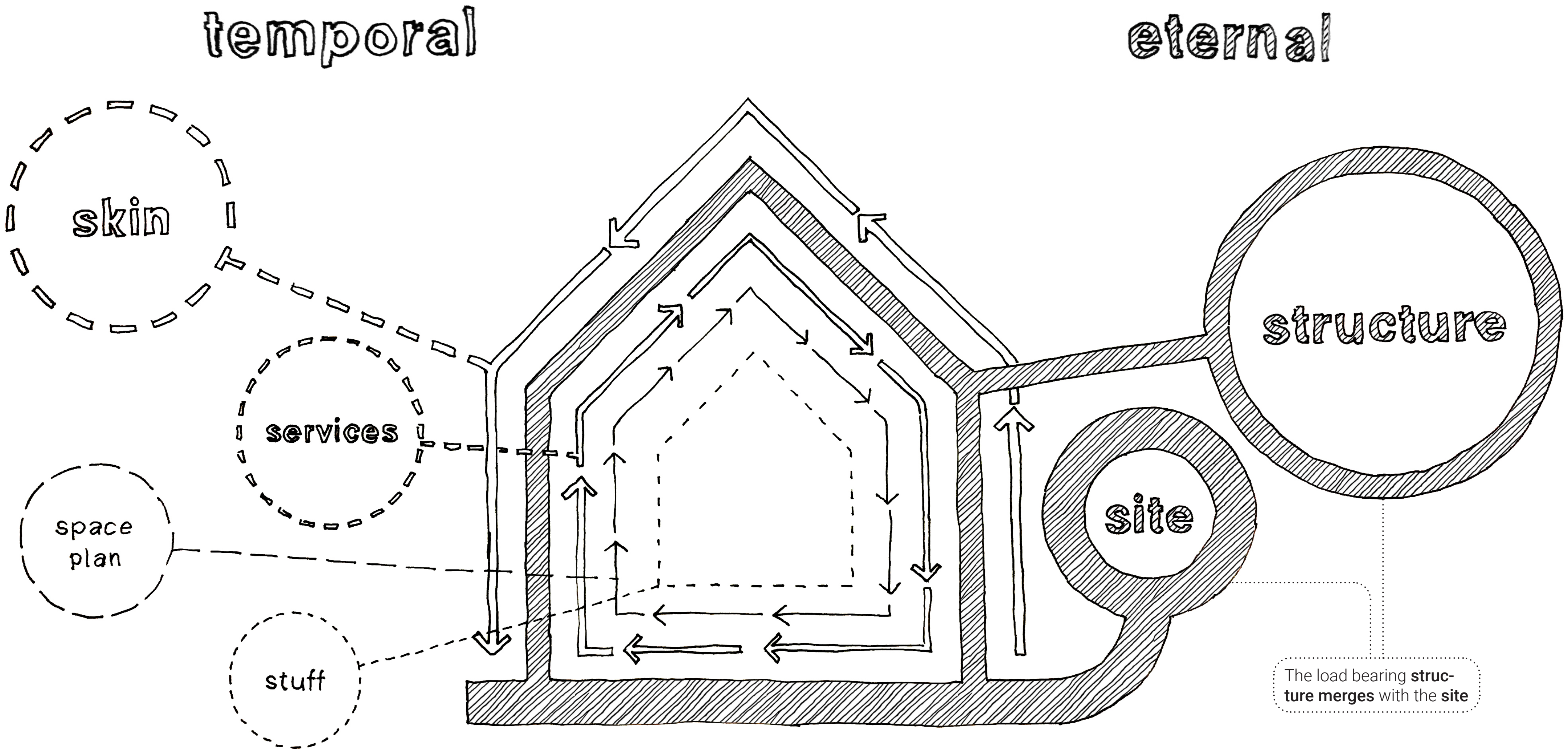


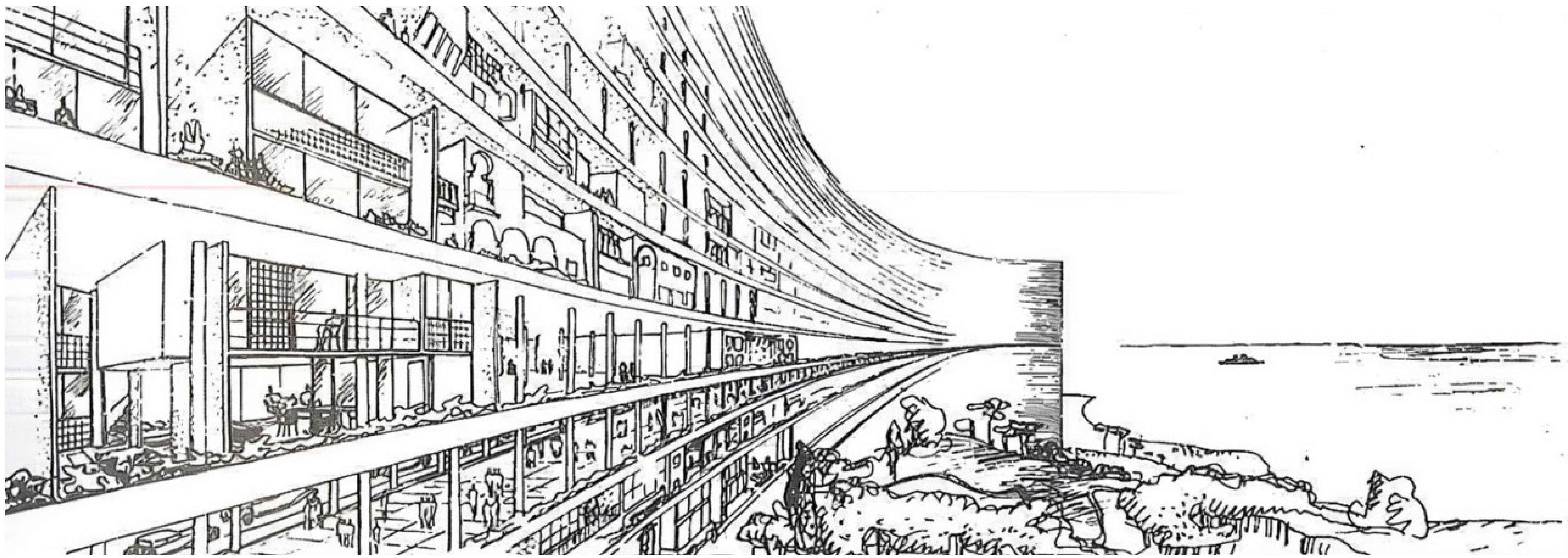
Pantheon
“eternal” concrete cast that does not
need to be repaired or changed
- use of roman concrete/modern equiv-
alent with self-healing abilities

temporal

Horyuji Temple
modular wooden construction in which parts can
be repaired, replaced or changed when needed

historical case studies as role models





Le Corbusiers Plan Obus, Algiers - structure becomes land

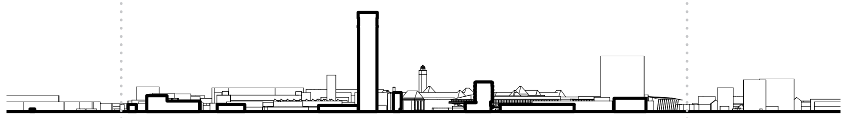
Application of the design principle

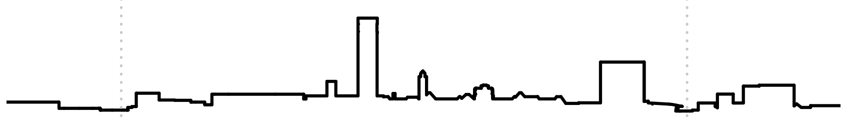
Figure Ground Plan

1|5000

Typologies and Heights

1|5000





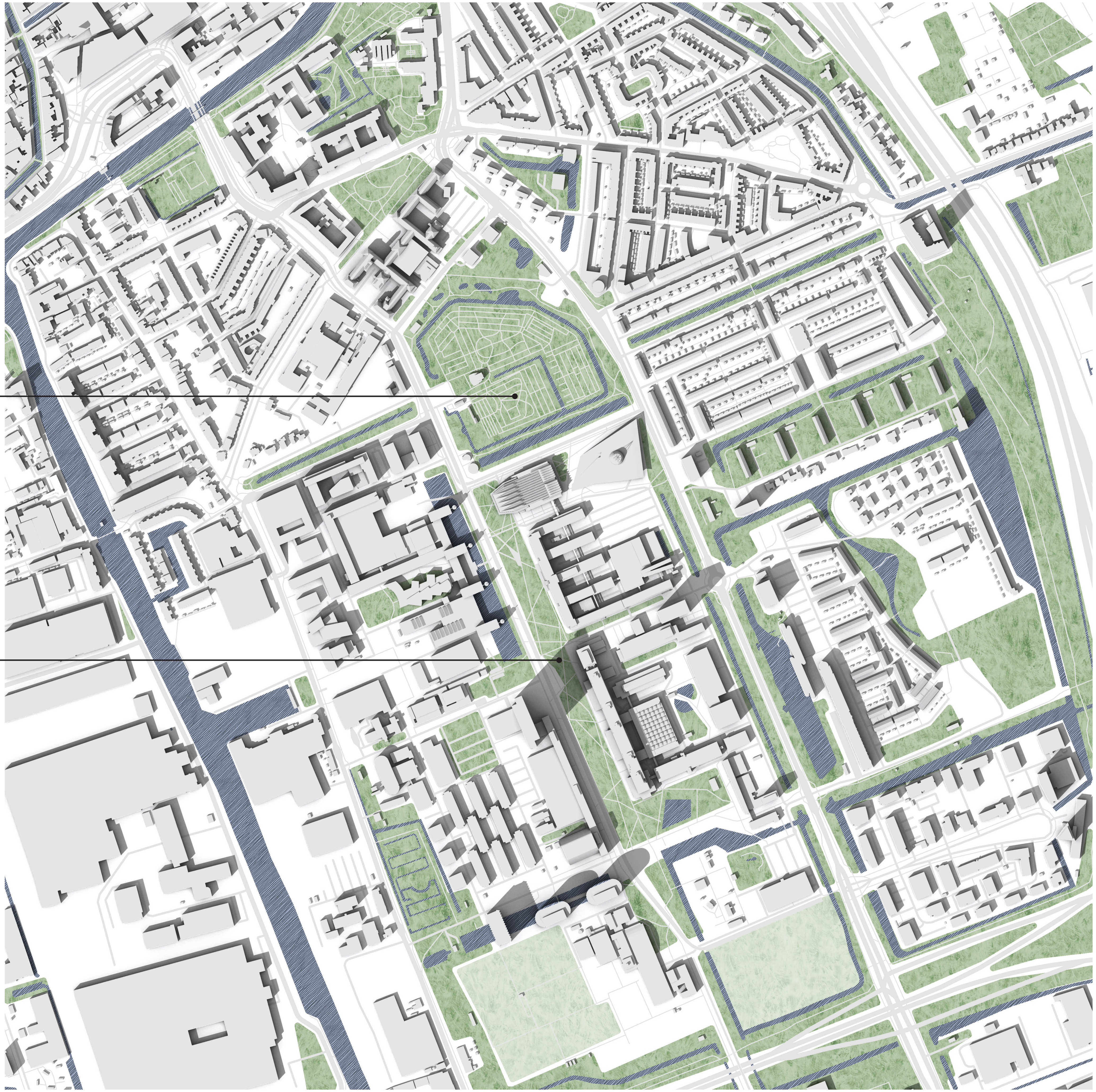
Campus

Green Spaces and Water

1|5000

Cemetery

Mekelpark



Campus Real Estate Vision for 2030

1|5000

Faculties + Gathering Spaces

1|5000

Gathering/Leisure Space for Everyone

Faculties + Gathering Spaces

Faculties + Gathering Spaces

1|5000

Gathering/Leisure Space for Everyone

Faculties + Gathering Spaces

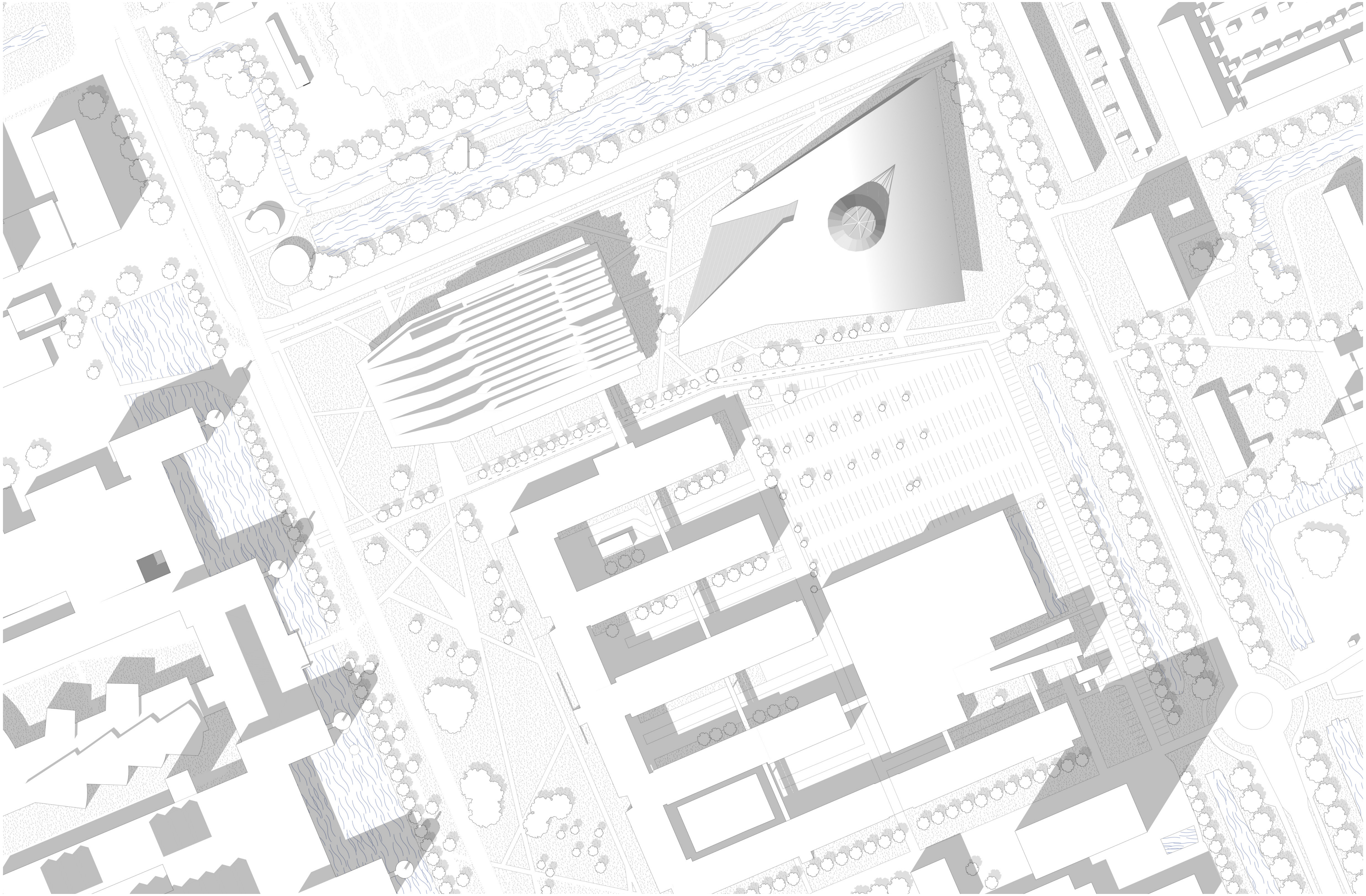
Personal Vision

1|5000

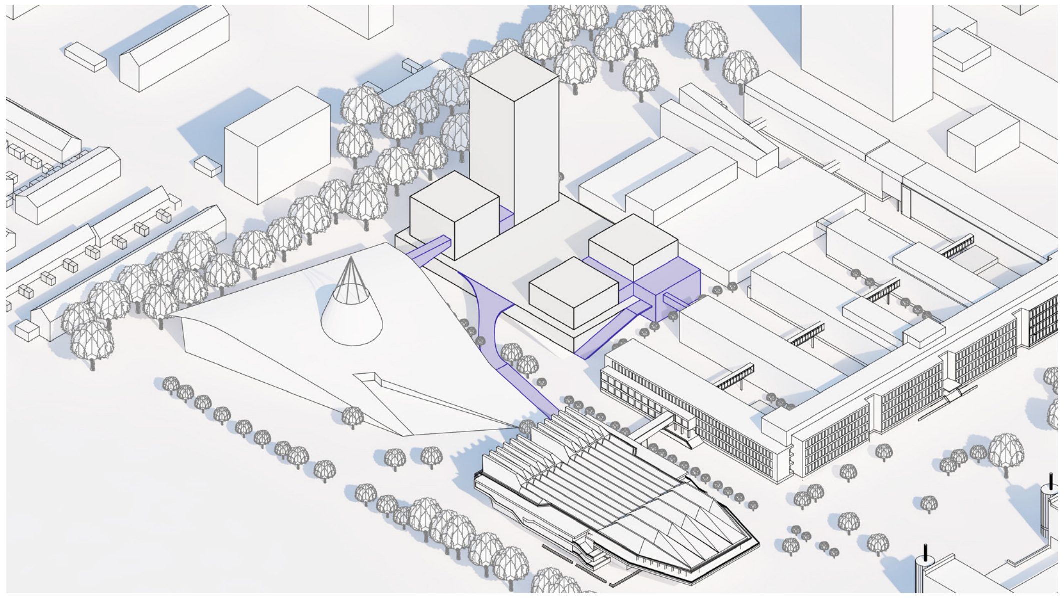
Gathering/Leisure Space for Everyone

Connection via Green Space

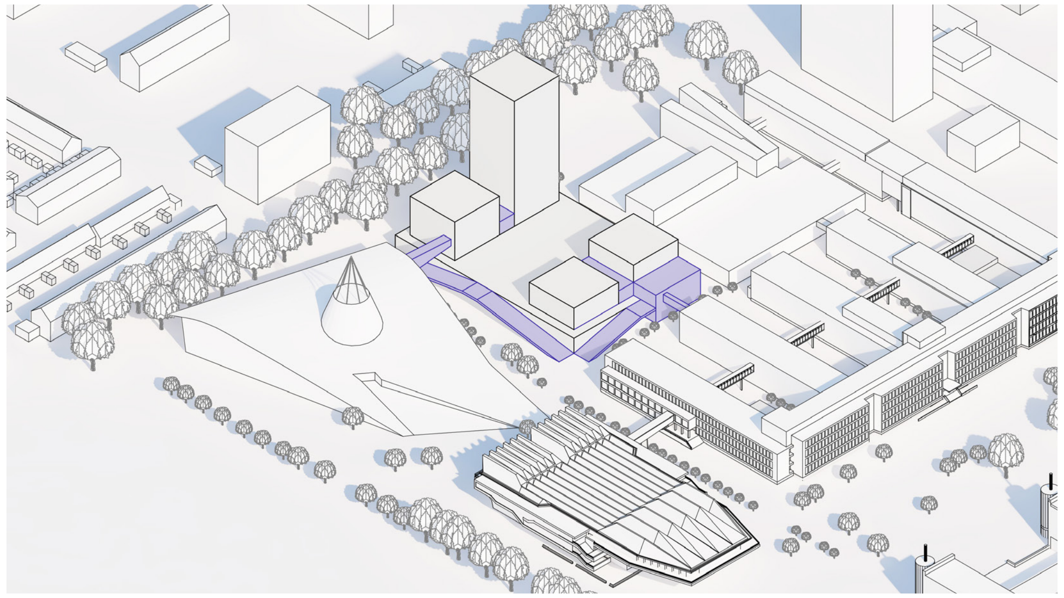
New Building that encloses Green Space



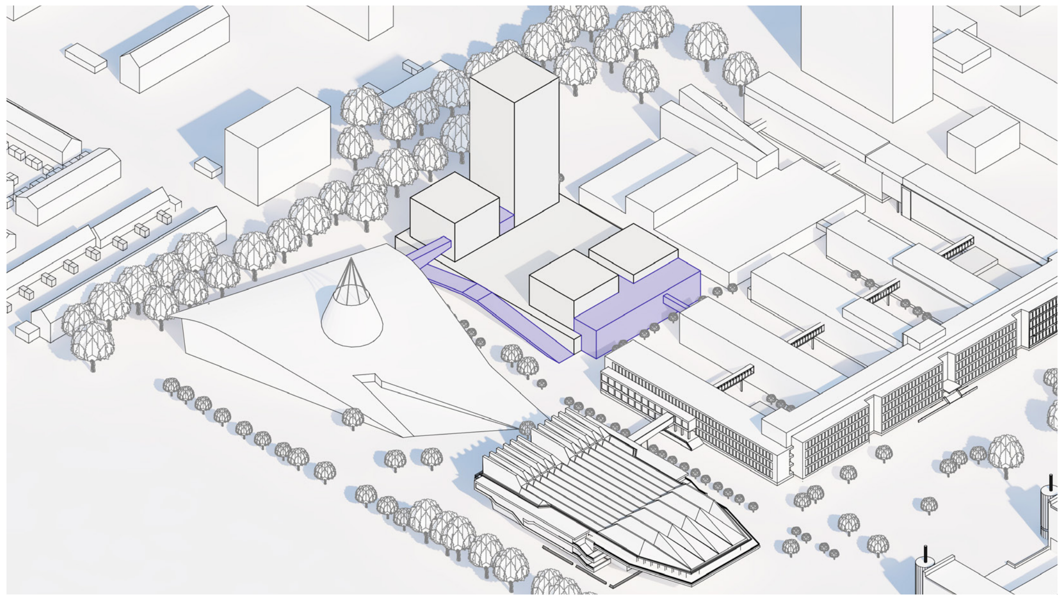
status quo



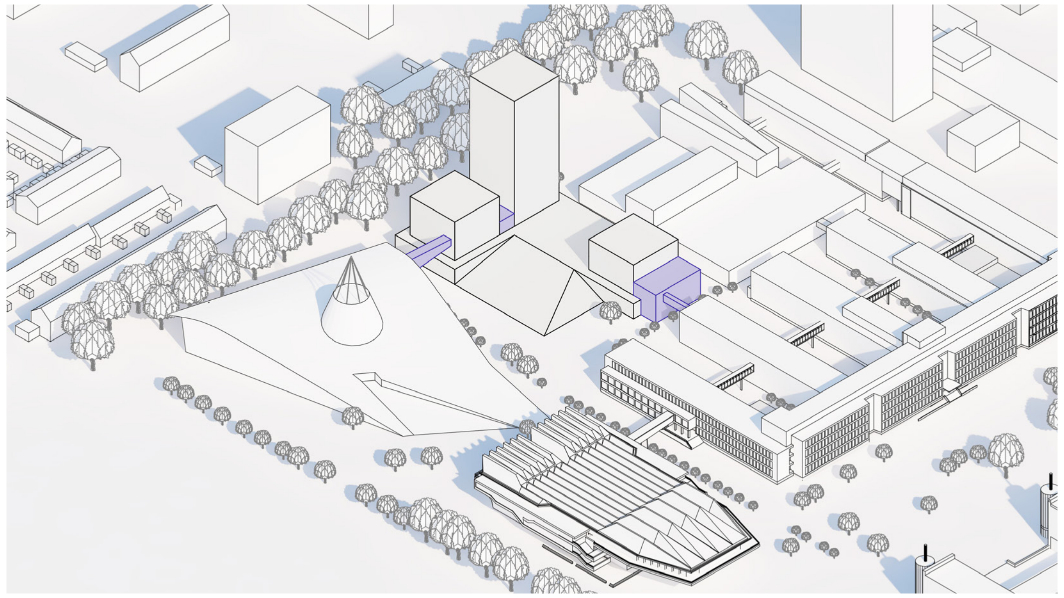
V1 - full table



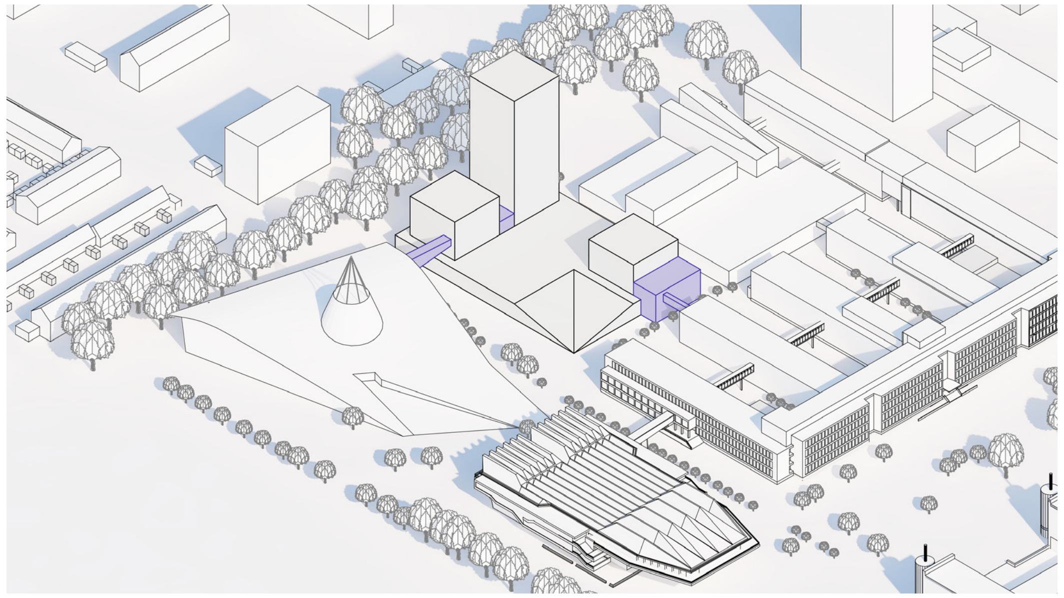
V2 - full table



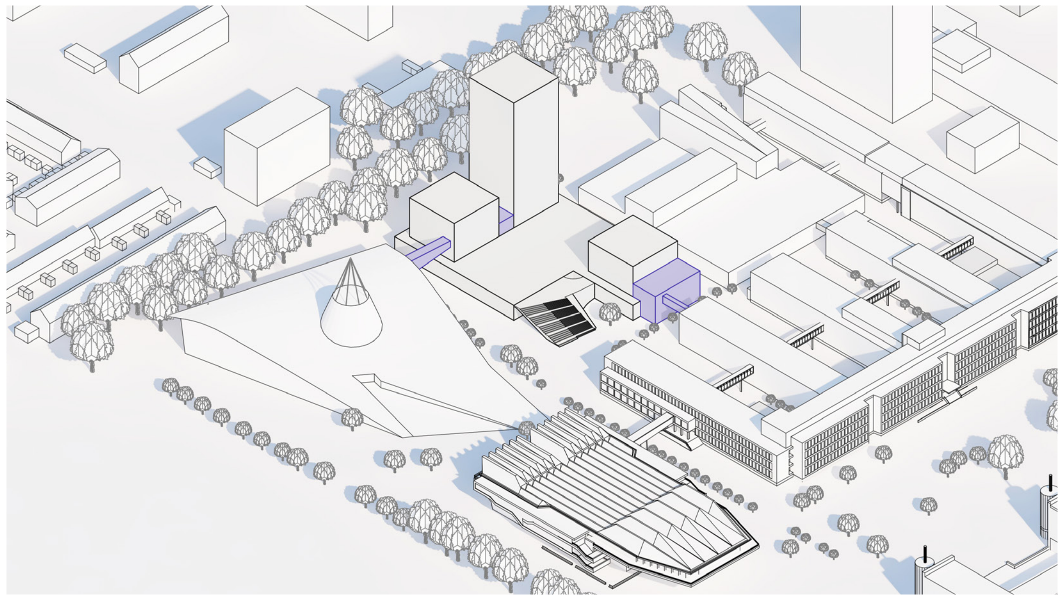
V3 - full table



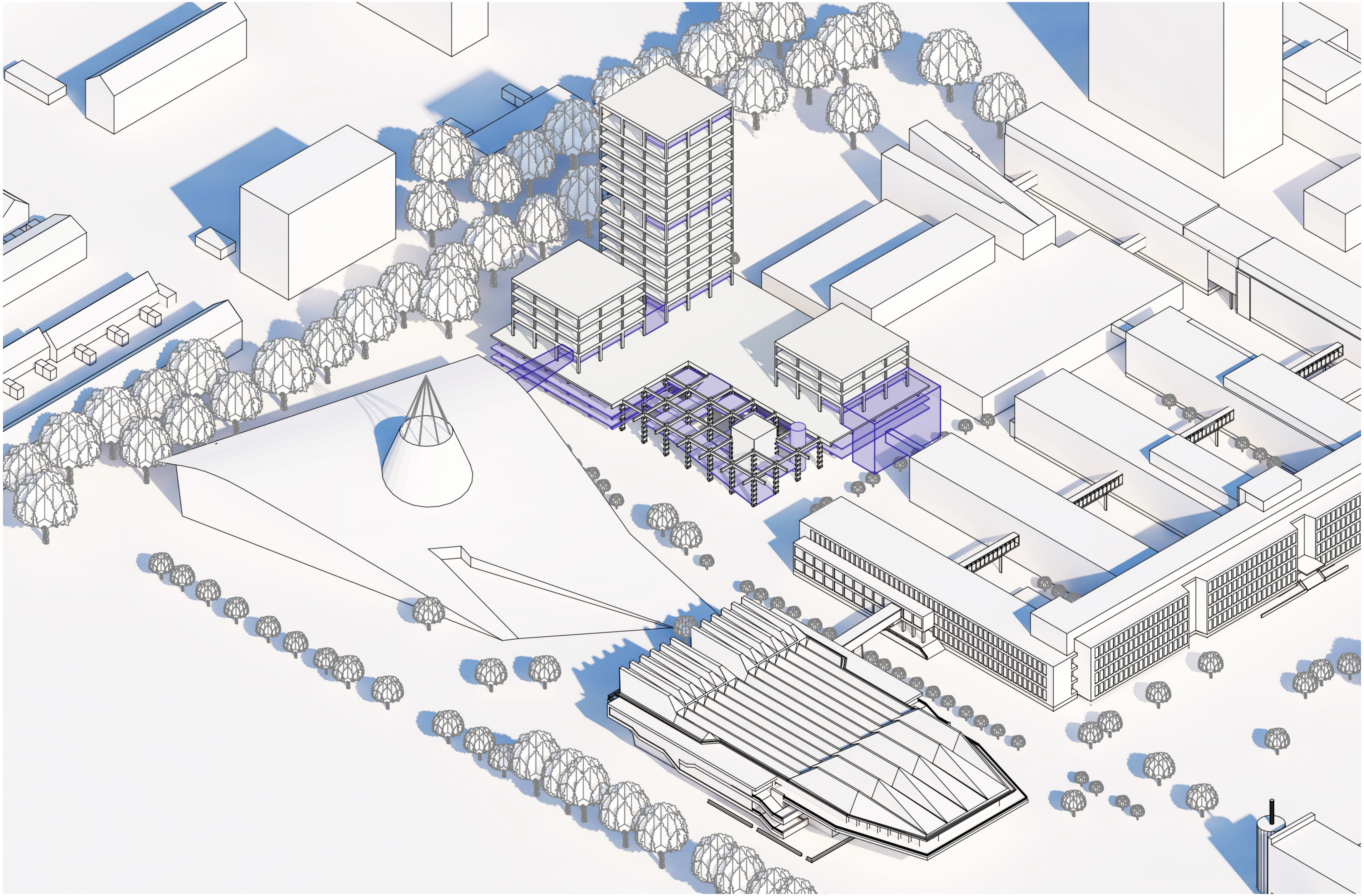
V4 - incomplete table



V5 - incomplete table

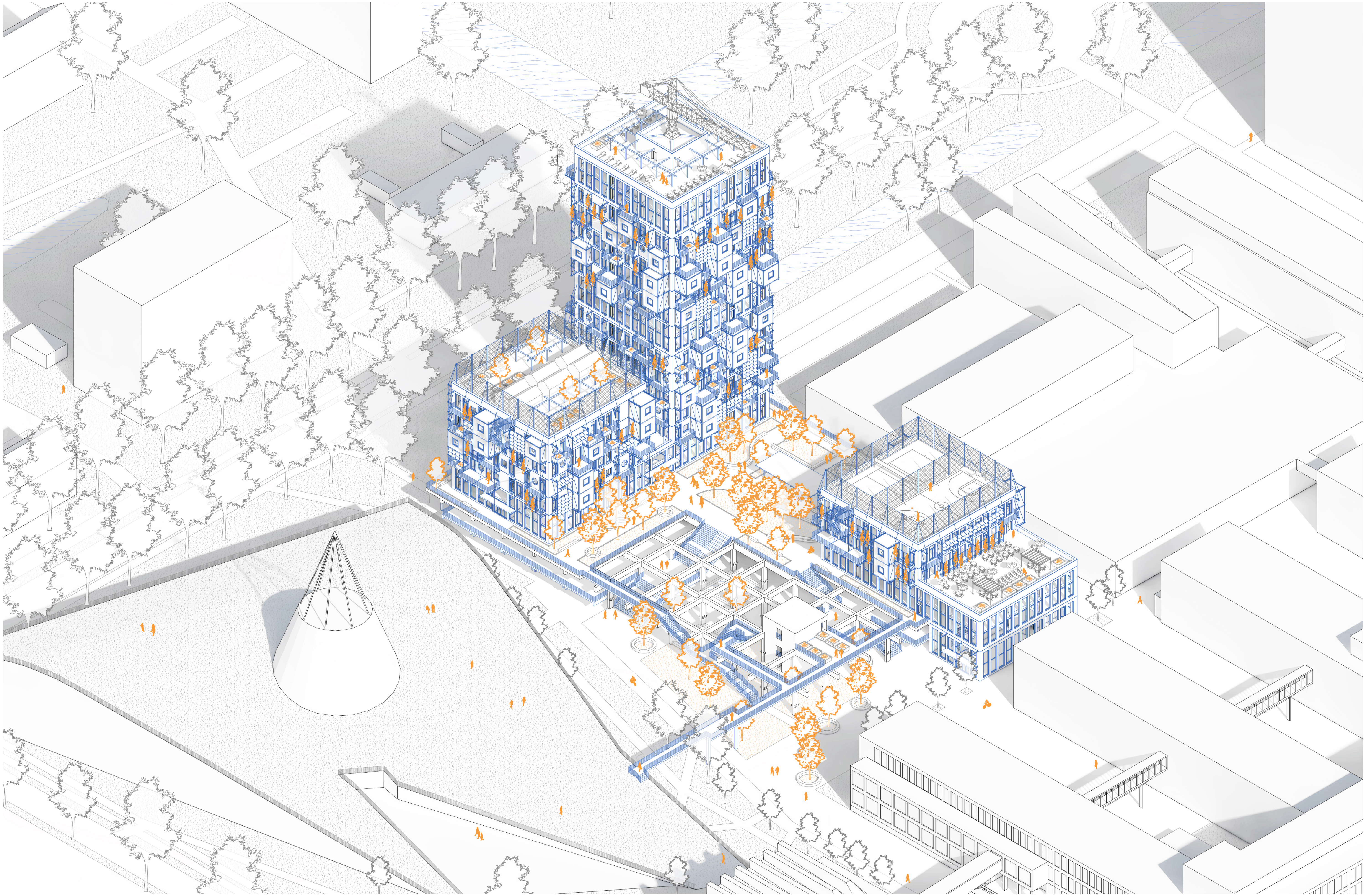


V6 - incomplete table



incomplete table

Lorenz Eschke



design proposal

Lorenz Eschke

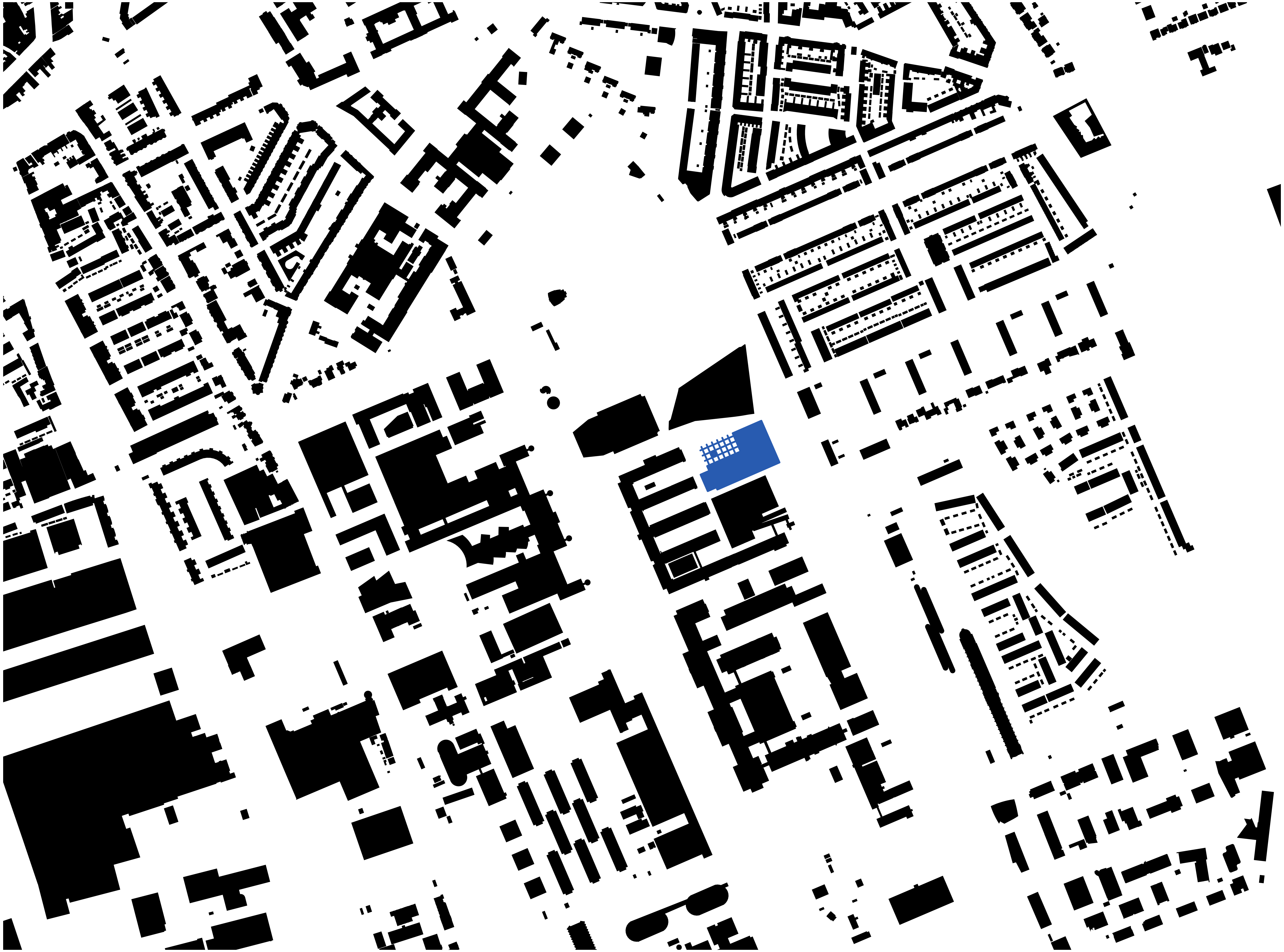
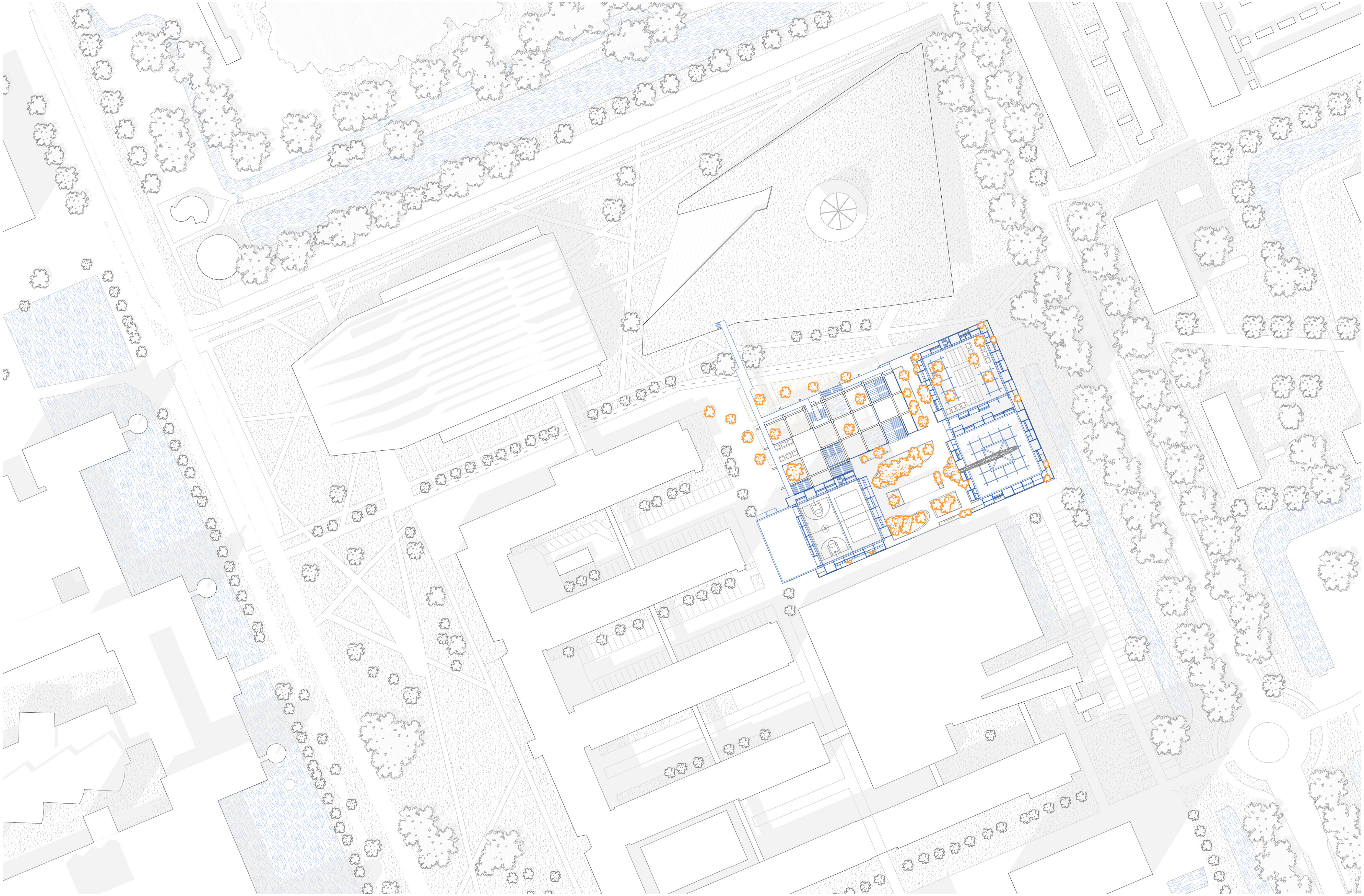
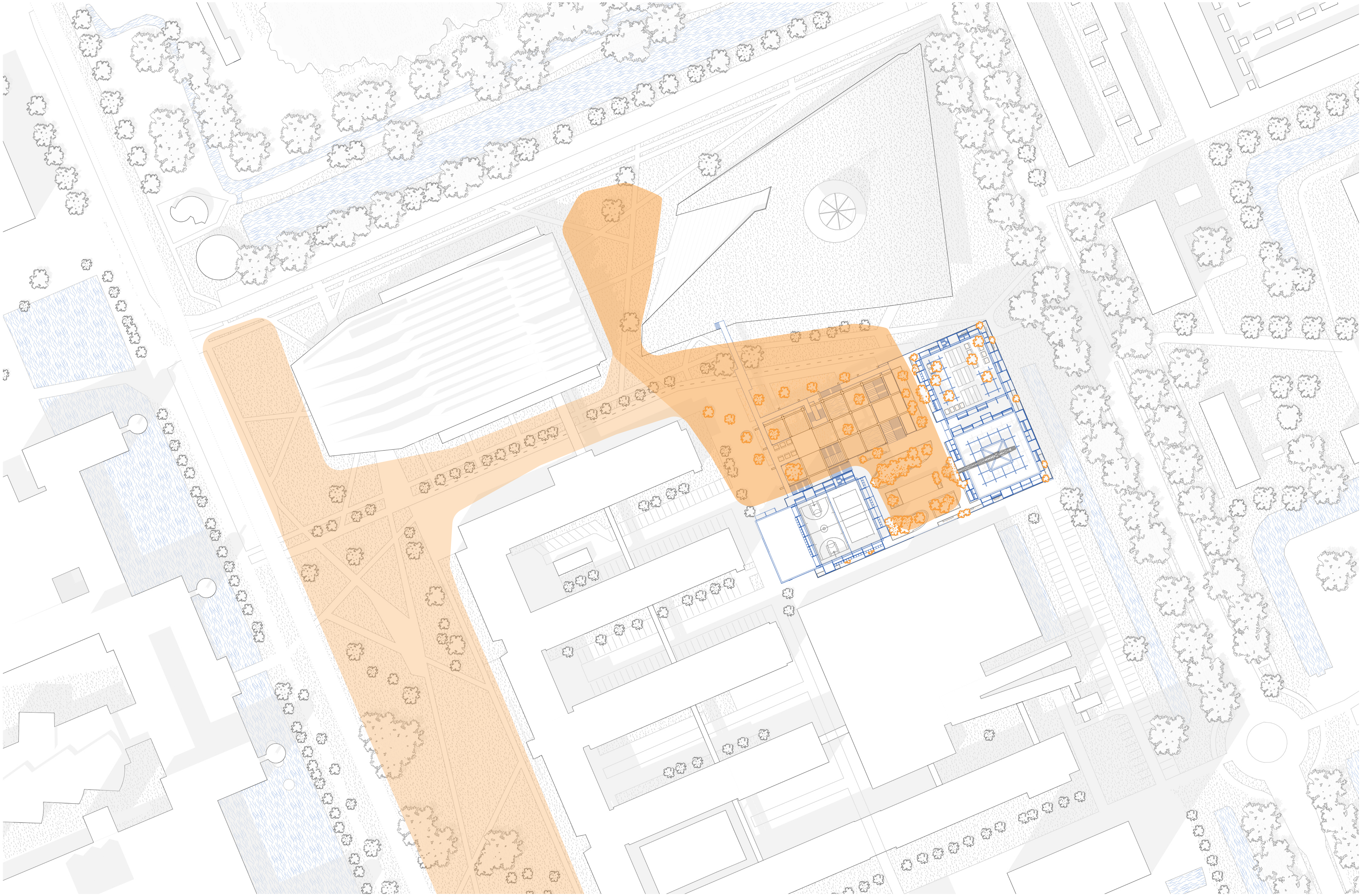


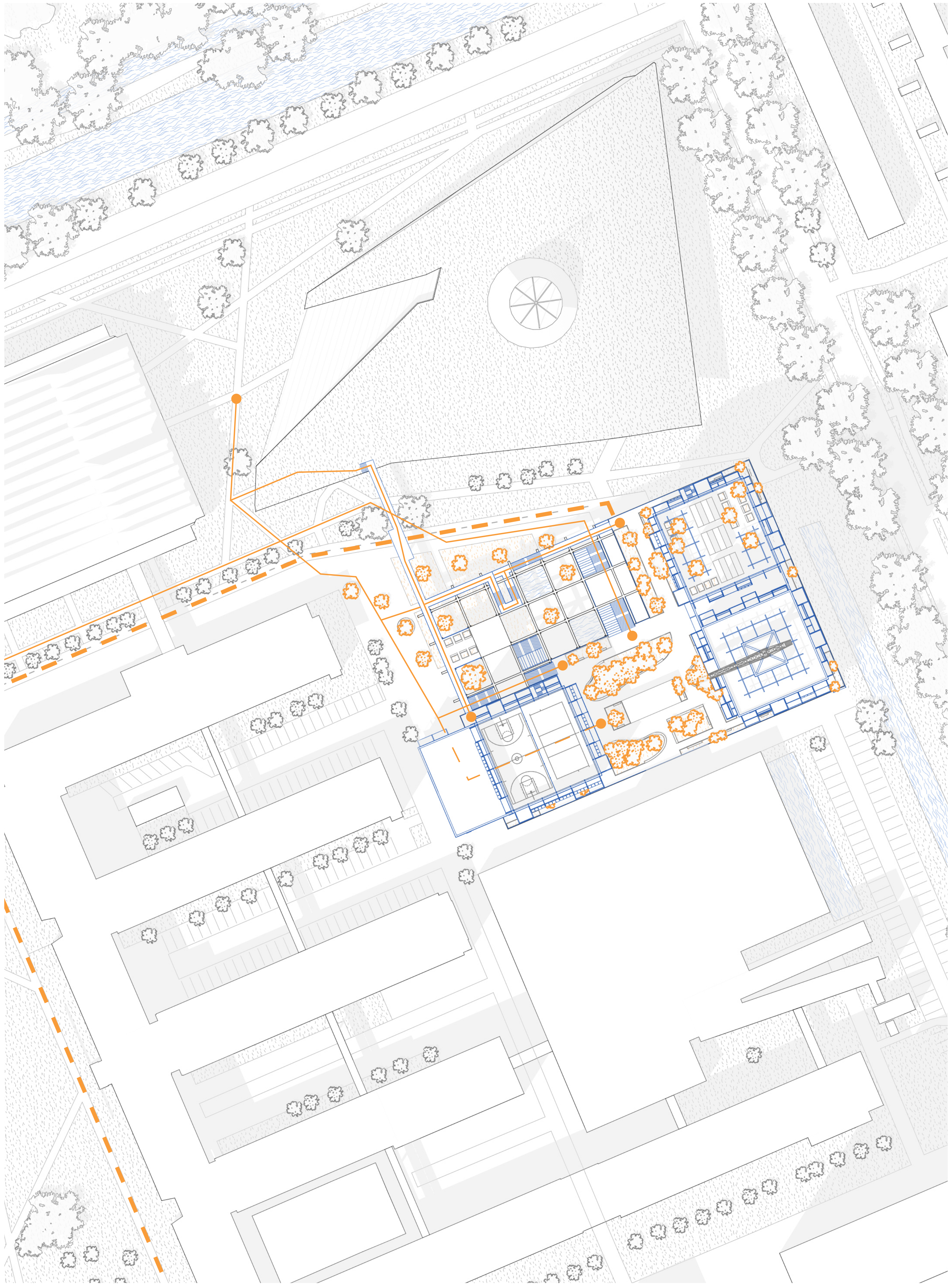
figure ground plan



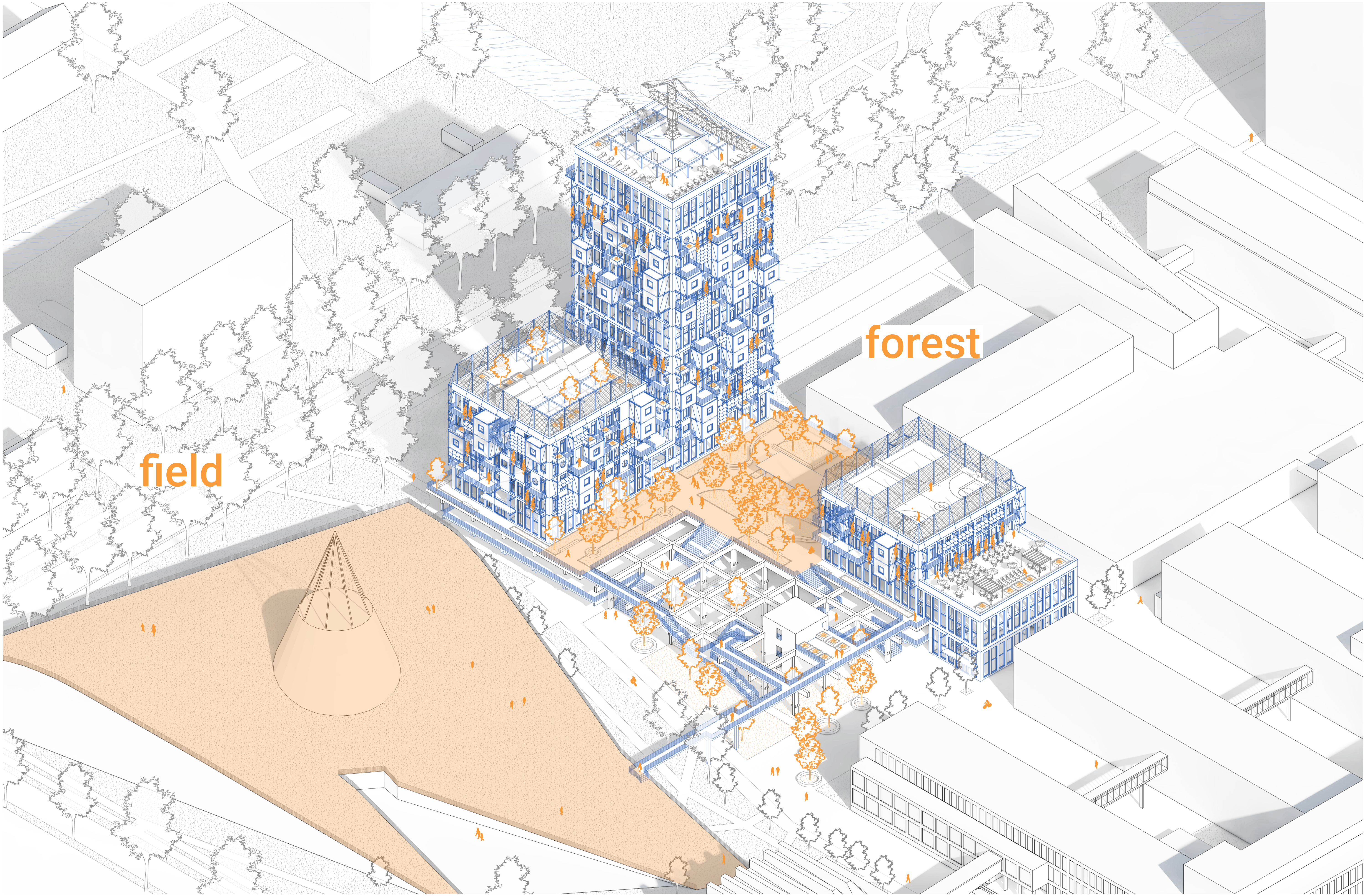
site plan



network of public space/green

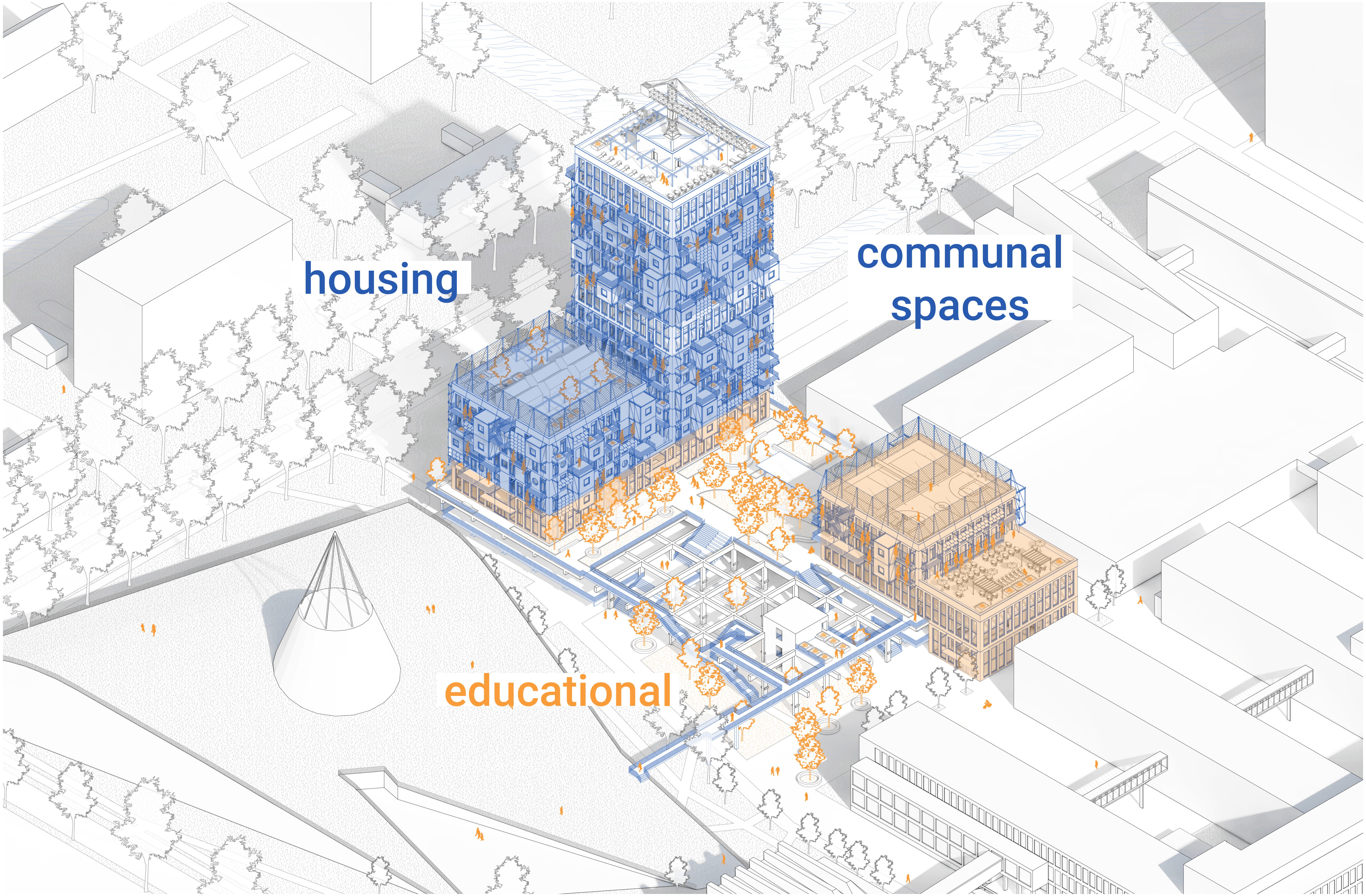


vertical connections

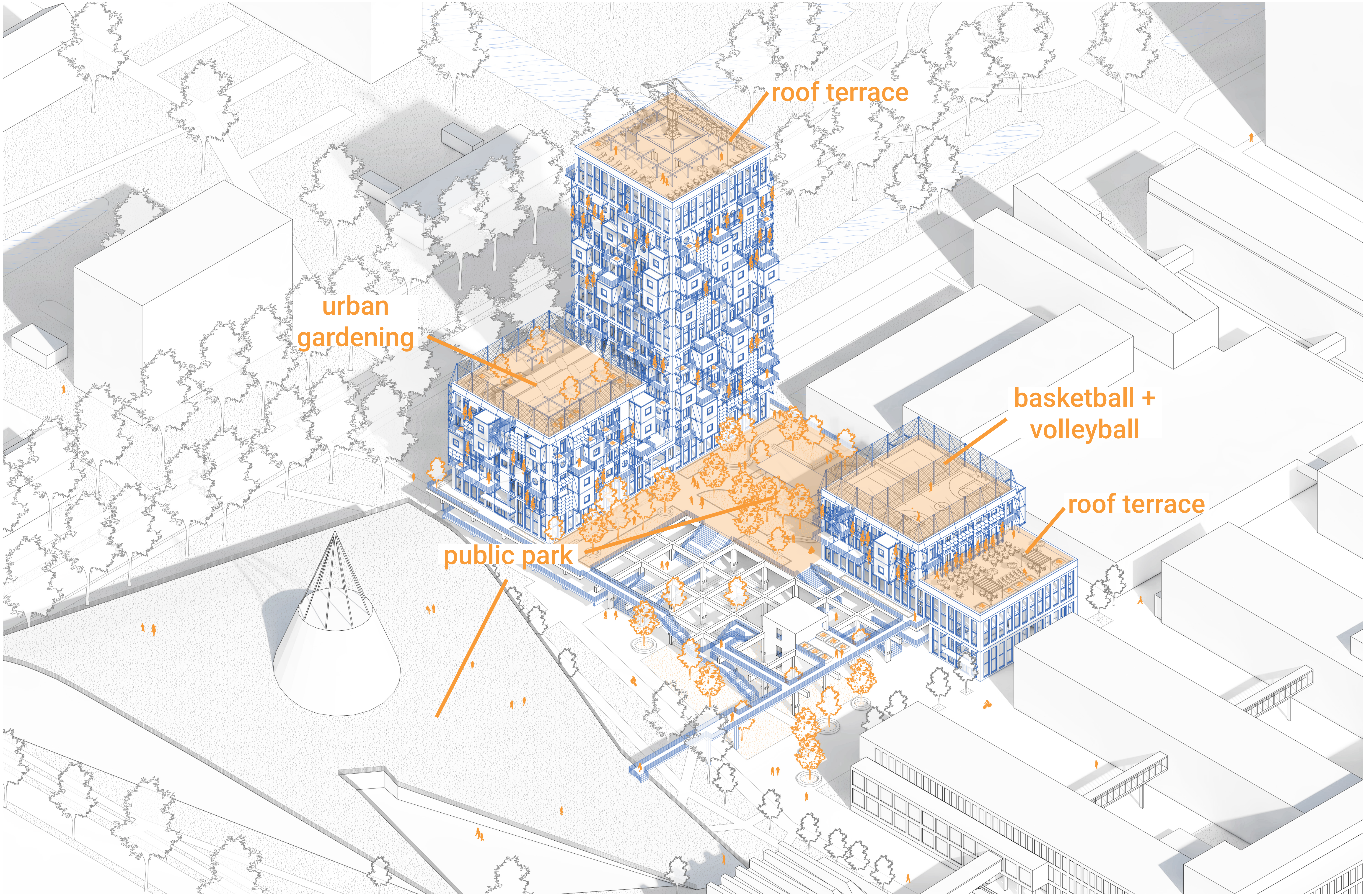


nature contrast

Lorenz Eschke



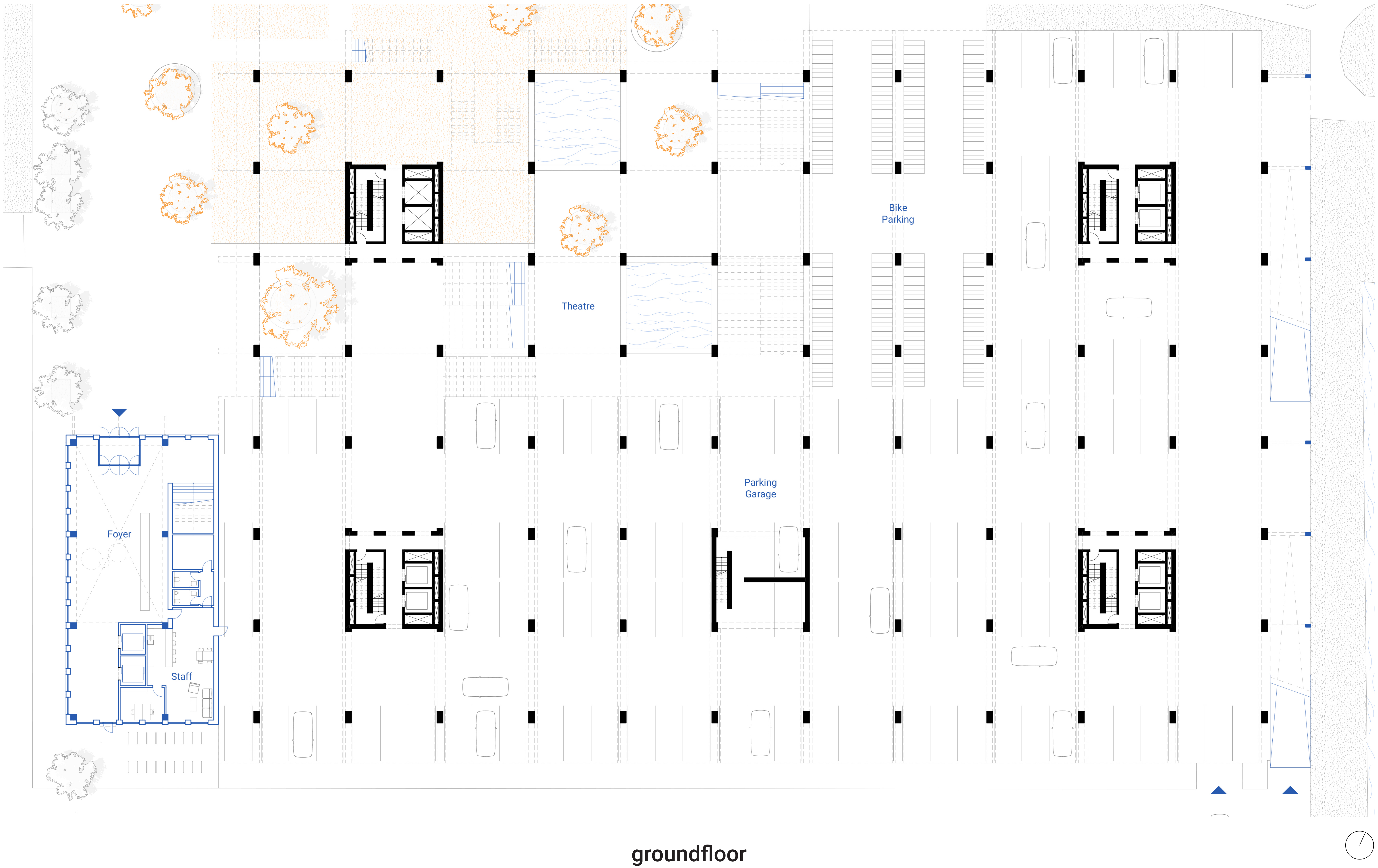
program



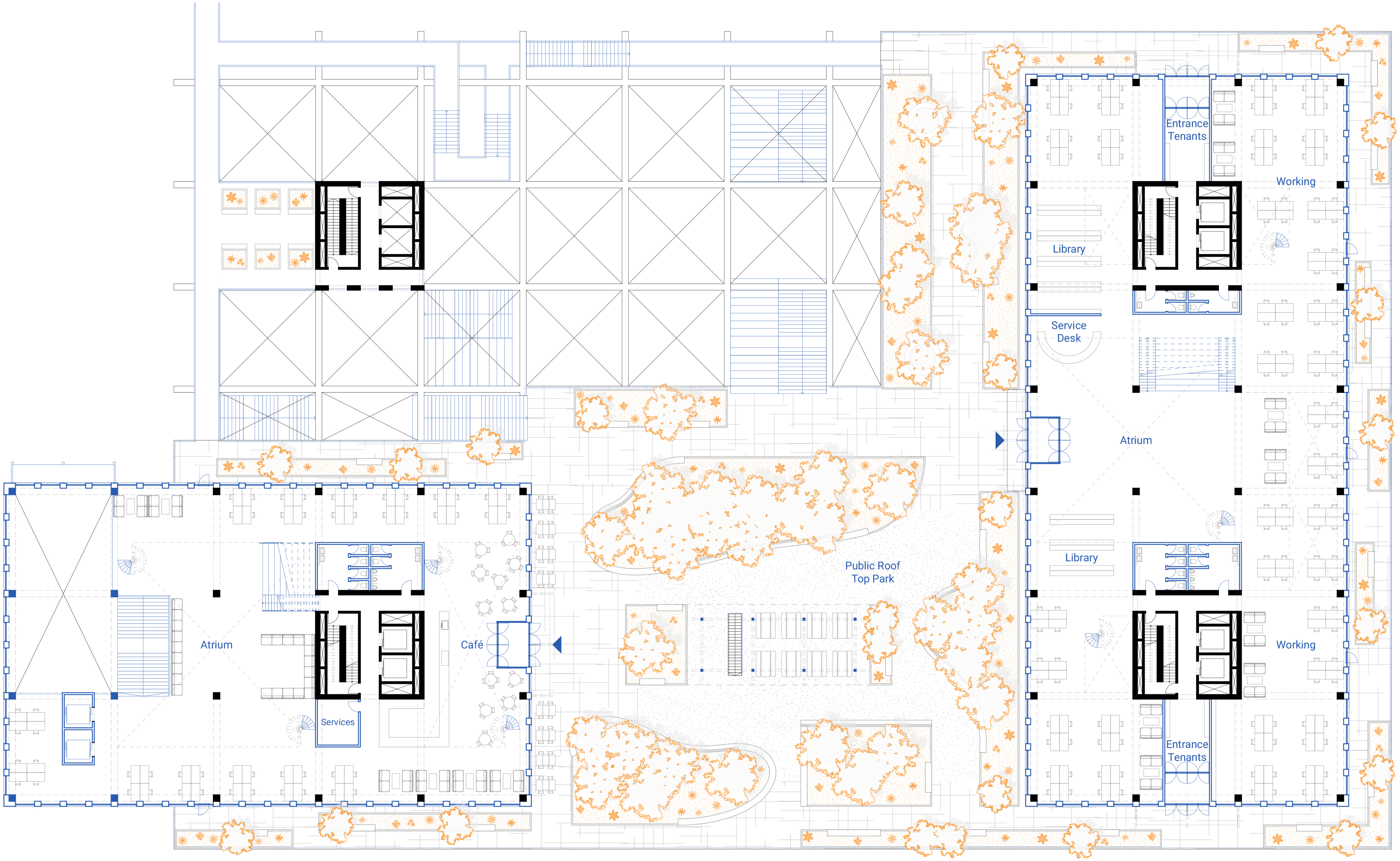
leisure spots

Lorenz Eschke

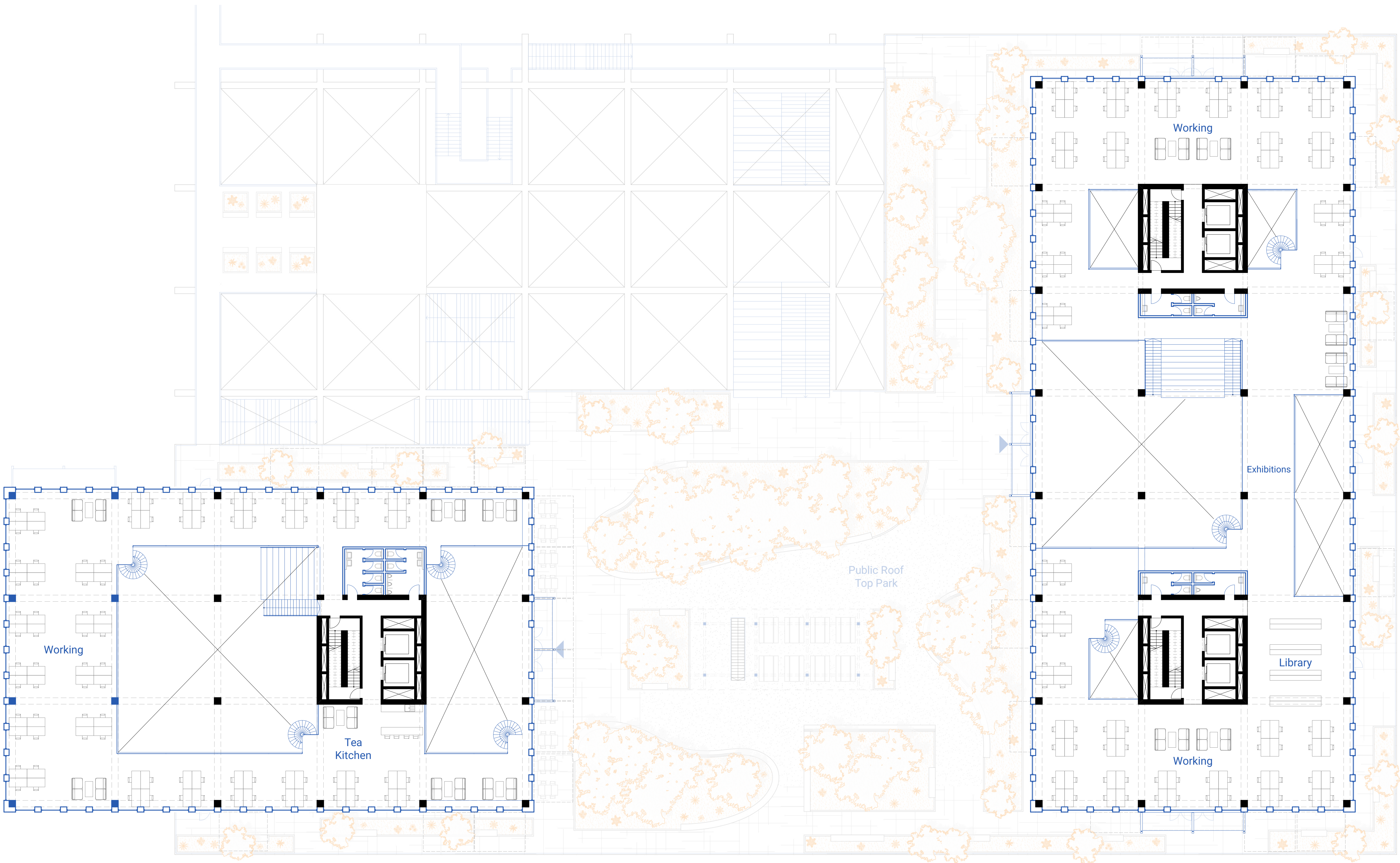
groundfloor with surroundings



groundfloor

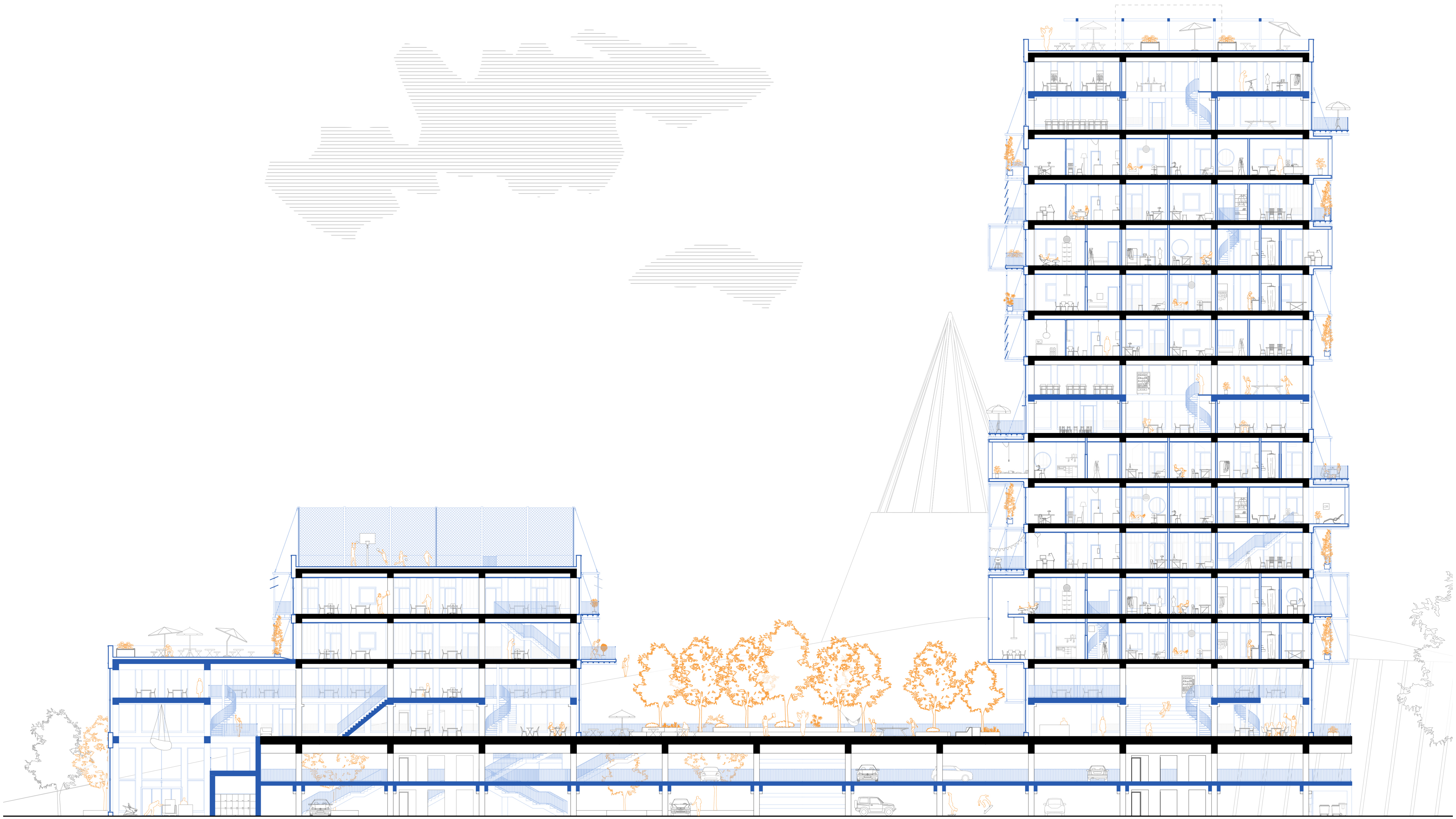

Entrance
Tenants
Working
Library
Service
Desk
Atrium
Public Roof
Top Park
Library
Atrium
Café
Services
Working
Entrance
Tenants

2nd floor

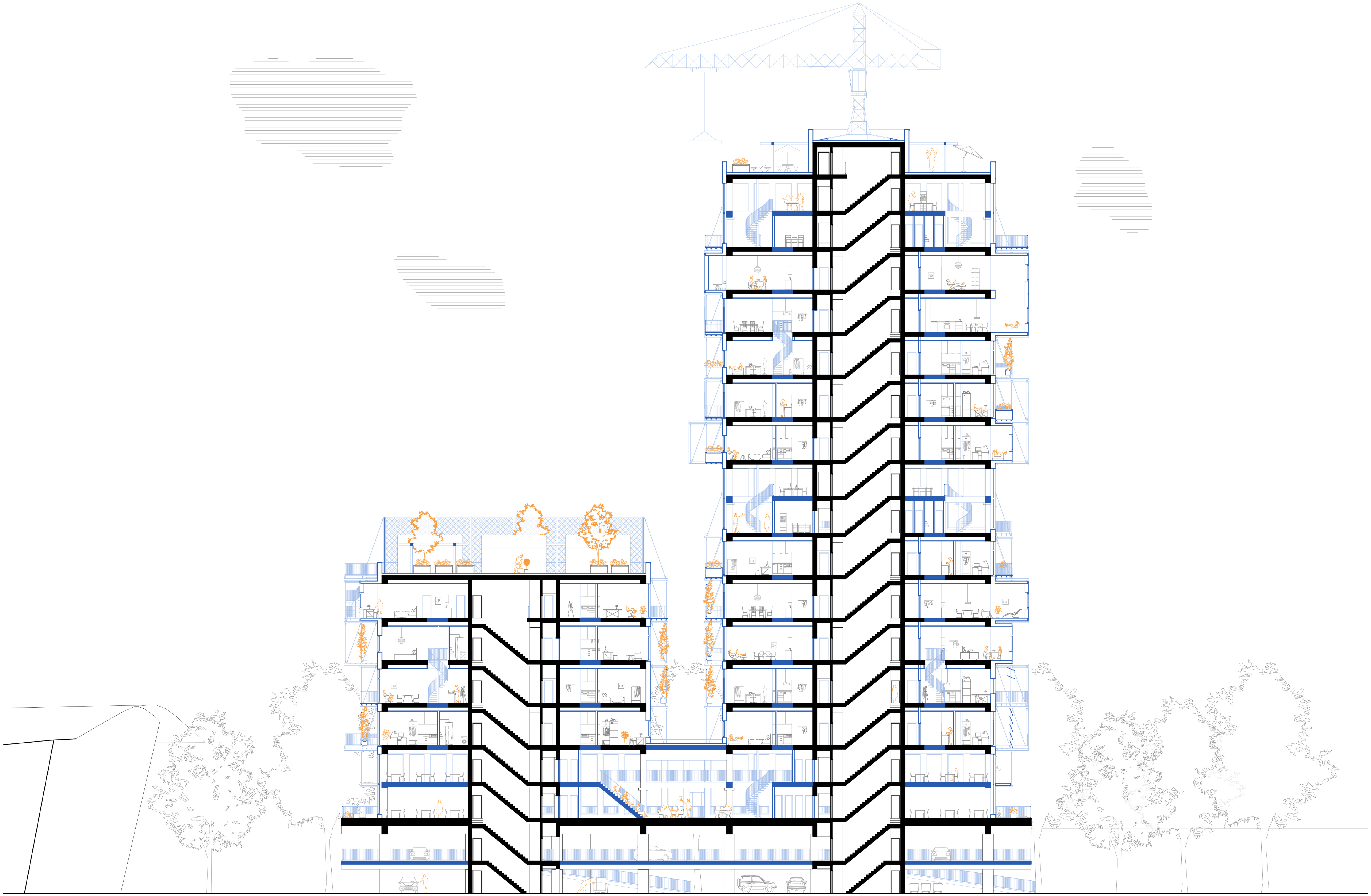


3rd floor

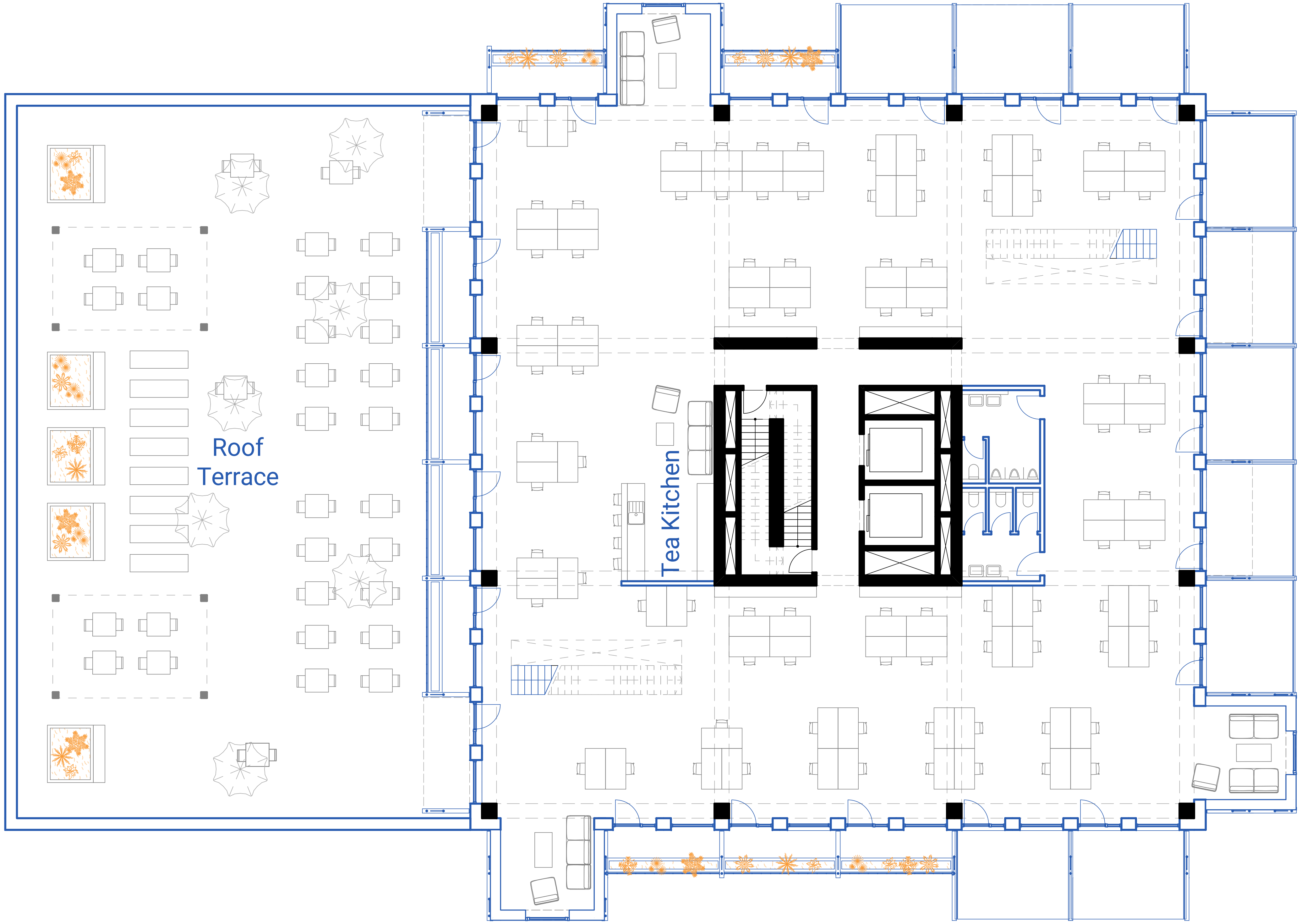
Lorenz Eschke

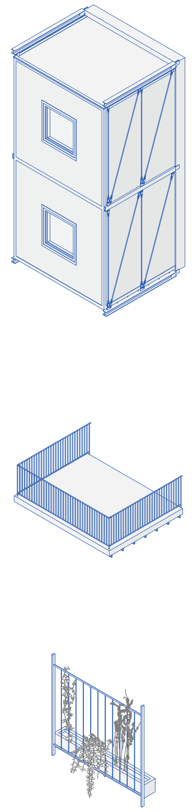


section A-A

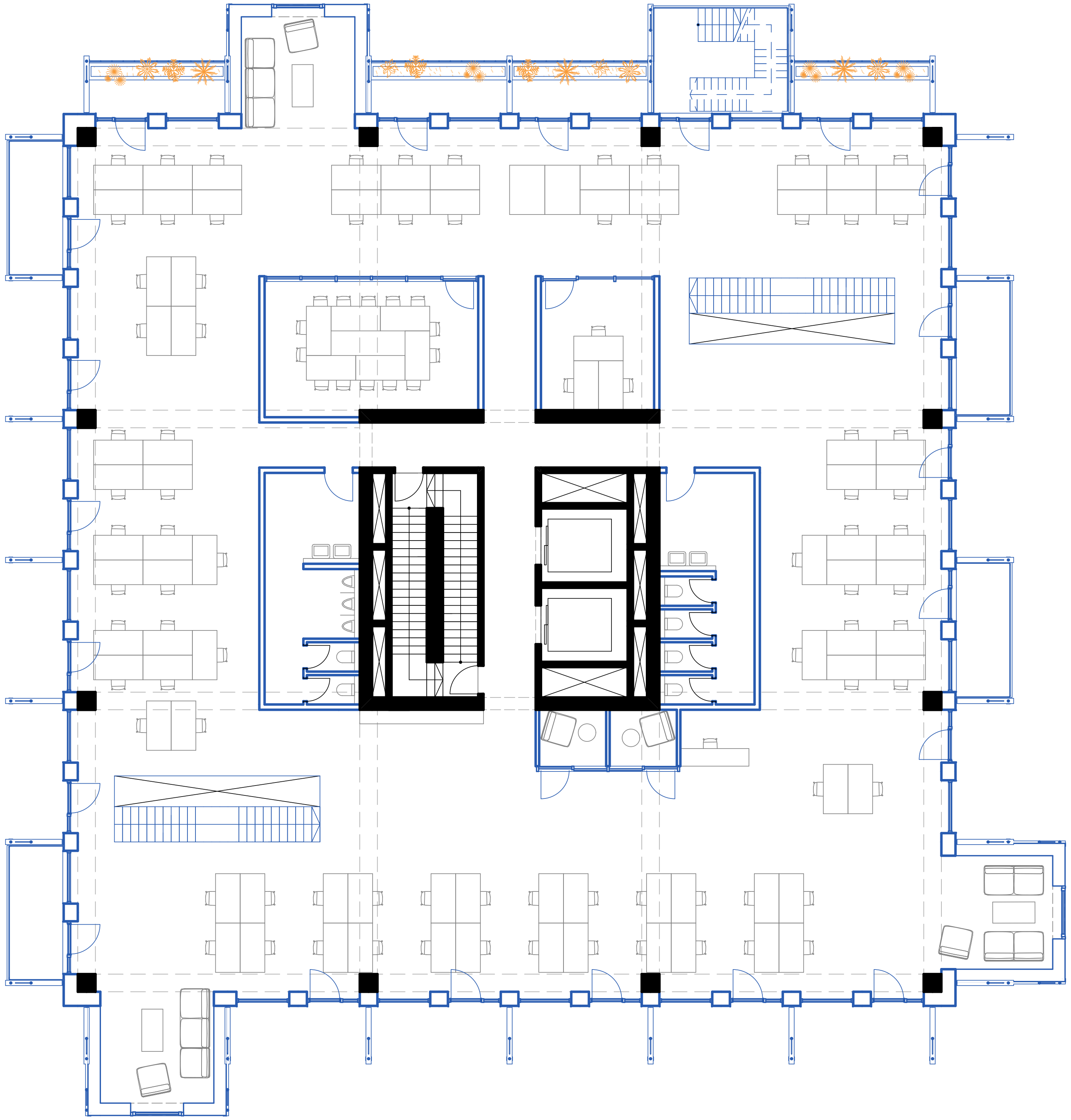


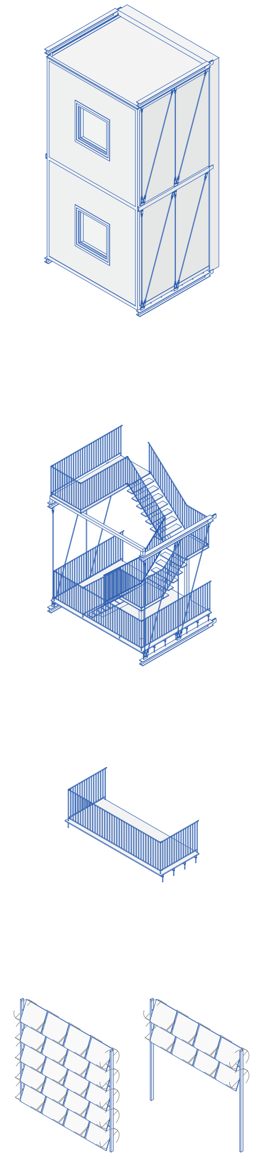
section B-B



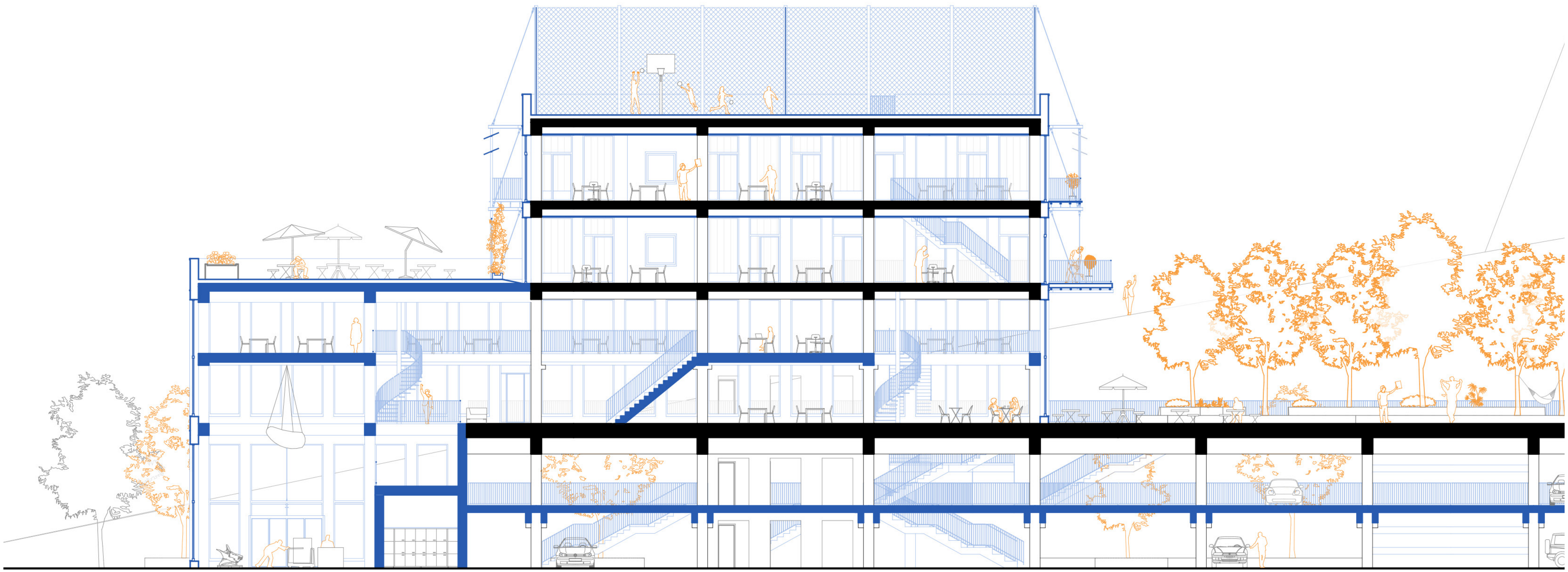


4th floor, educational with roof terrace



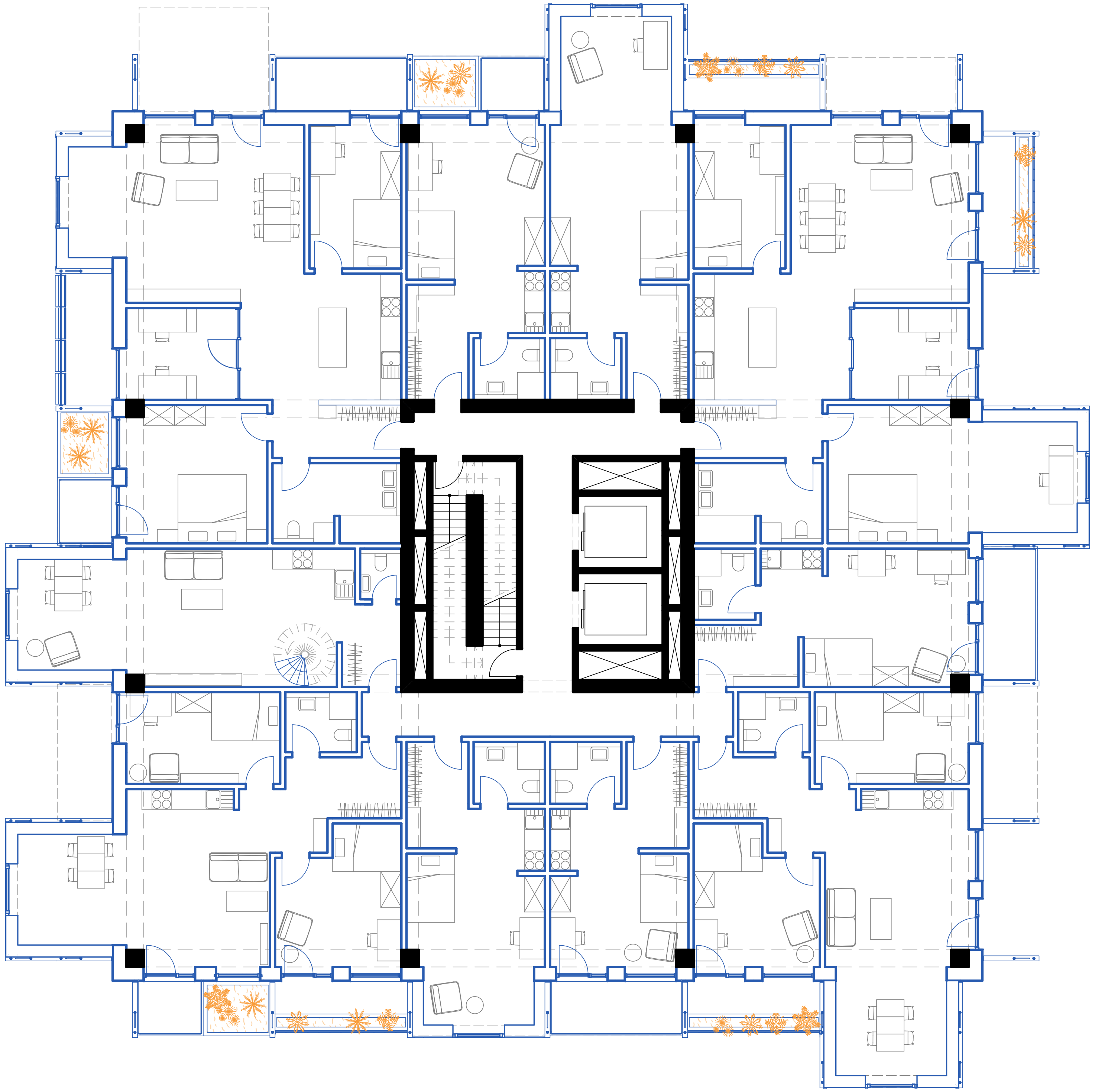


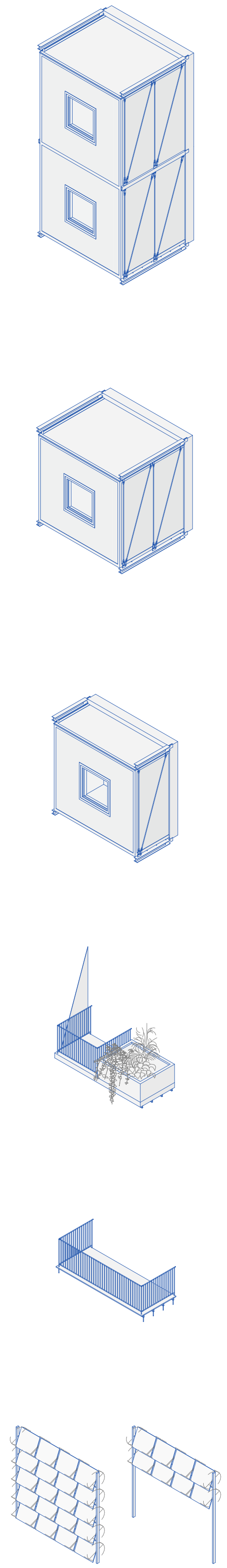
5th floor, educational/potentially office



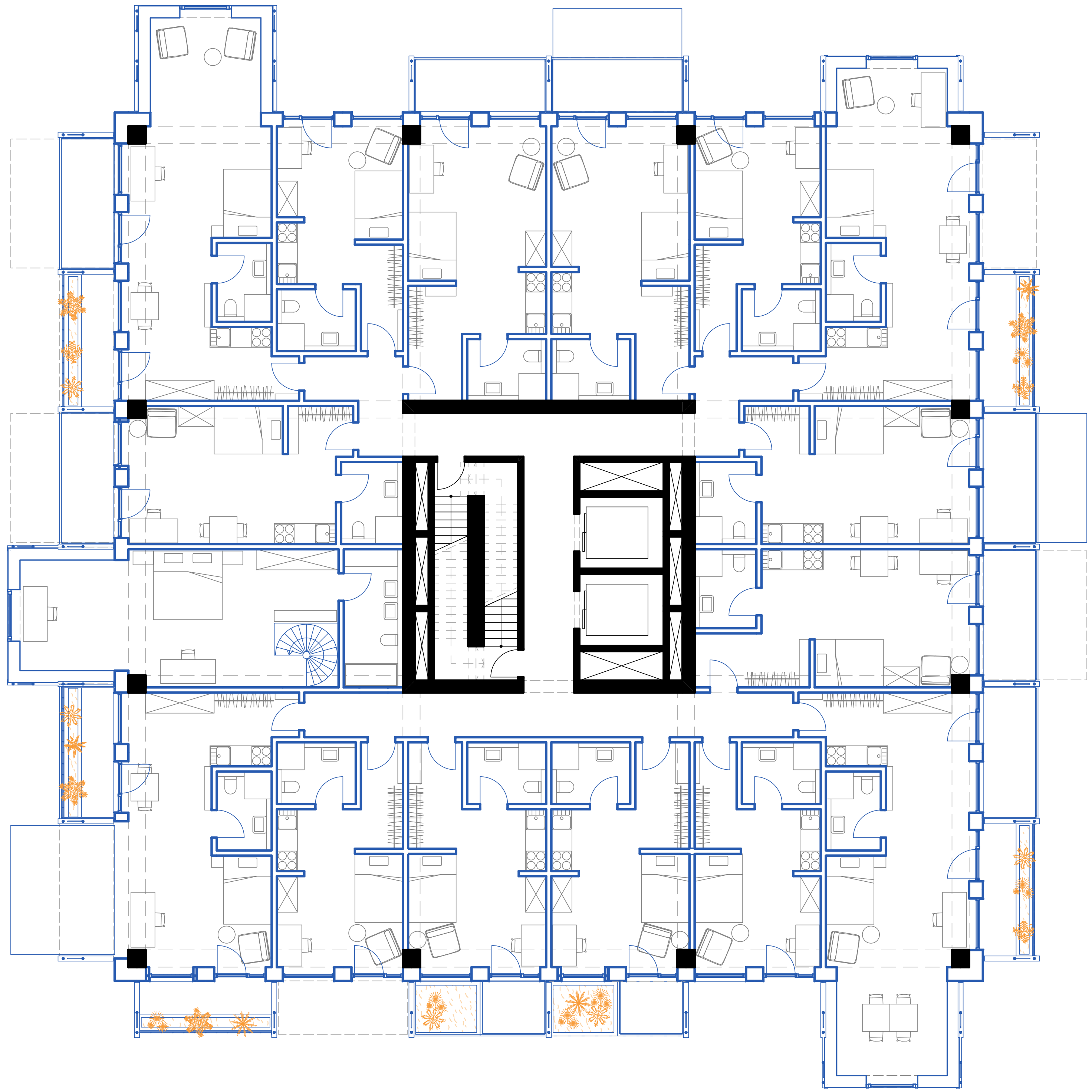
section A-A

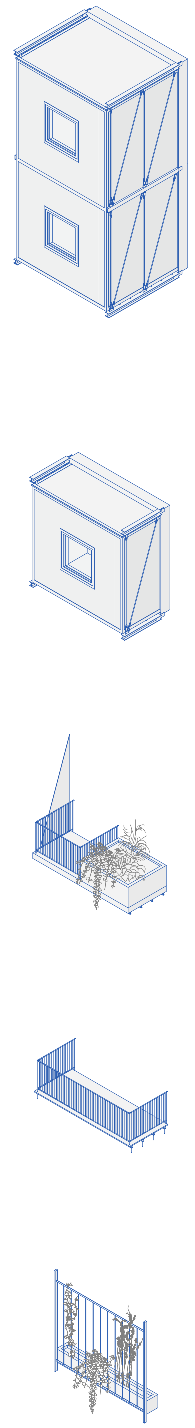
Lorenz Eschke

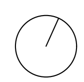




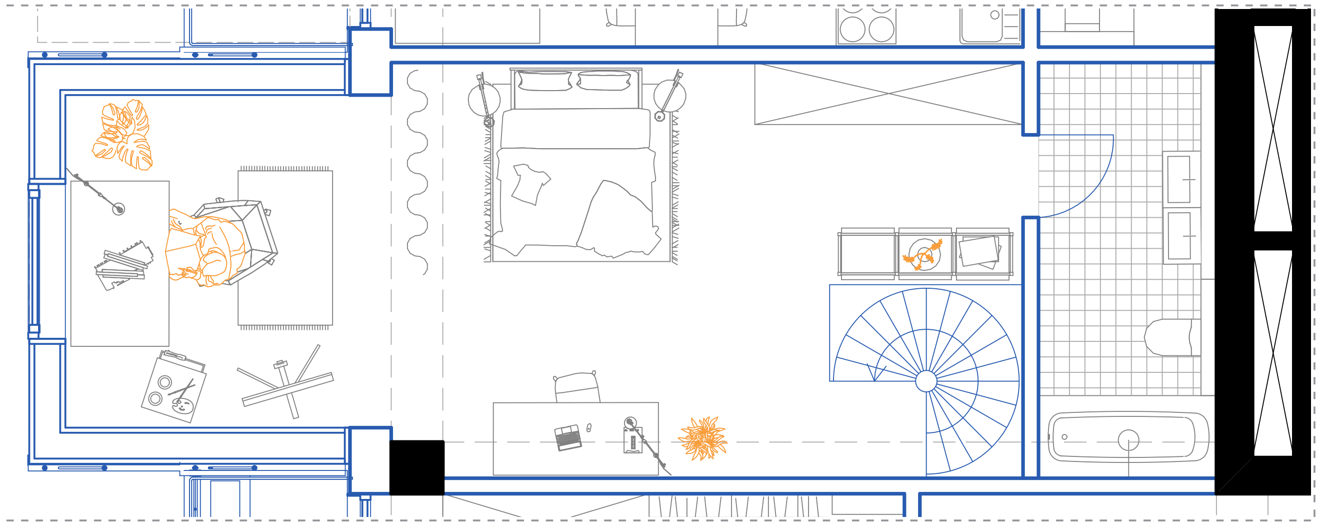
11th floor, 10 units different sizes



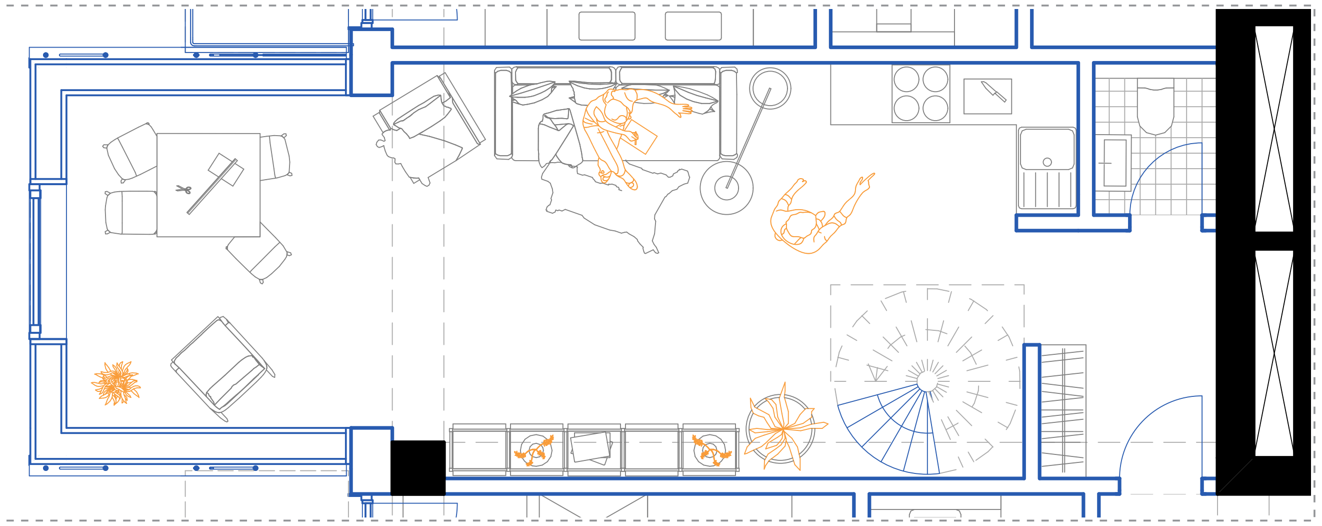




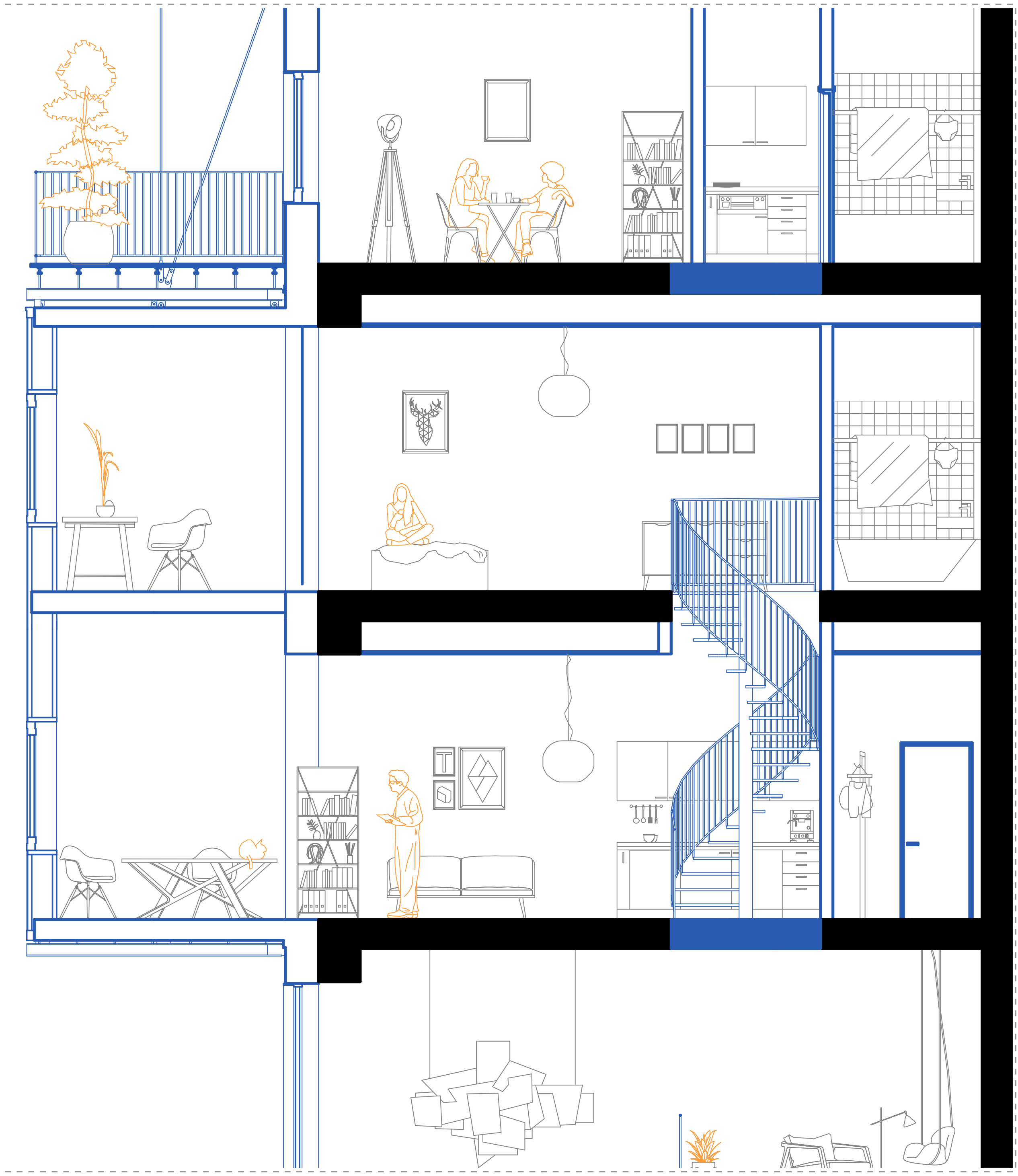
12th floor, 16 units same size



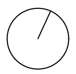
12th floor, maisonette flat 1|100

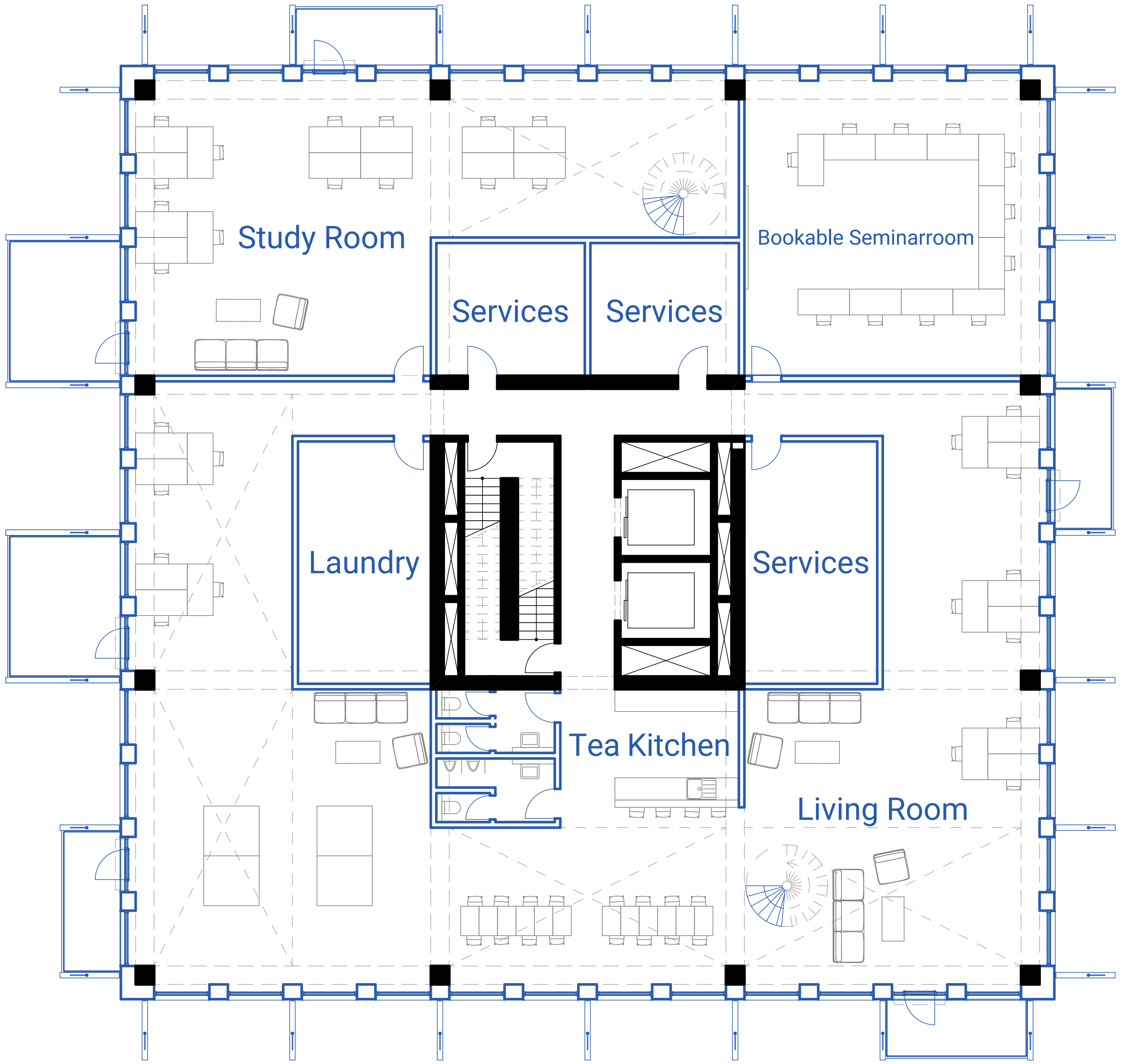


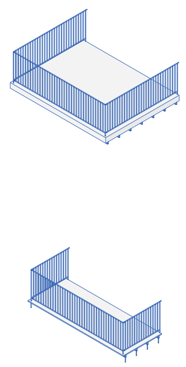
11th floor, maisonette flat 1|100



section C-C

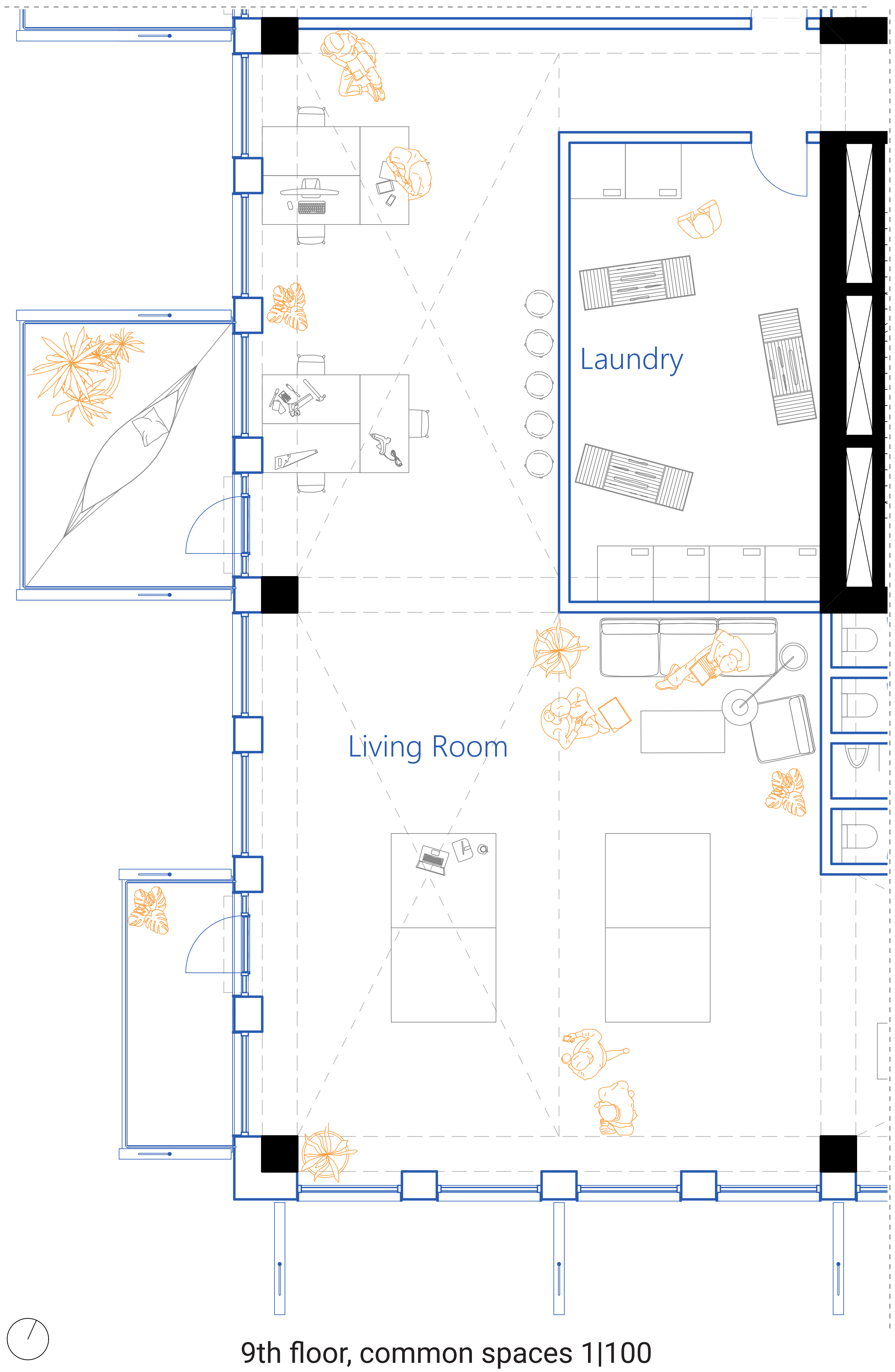




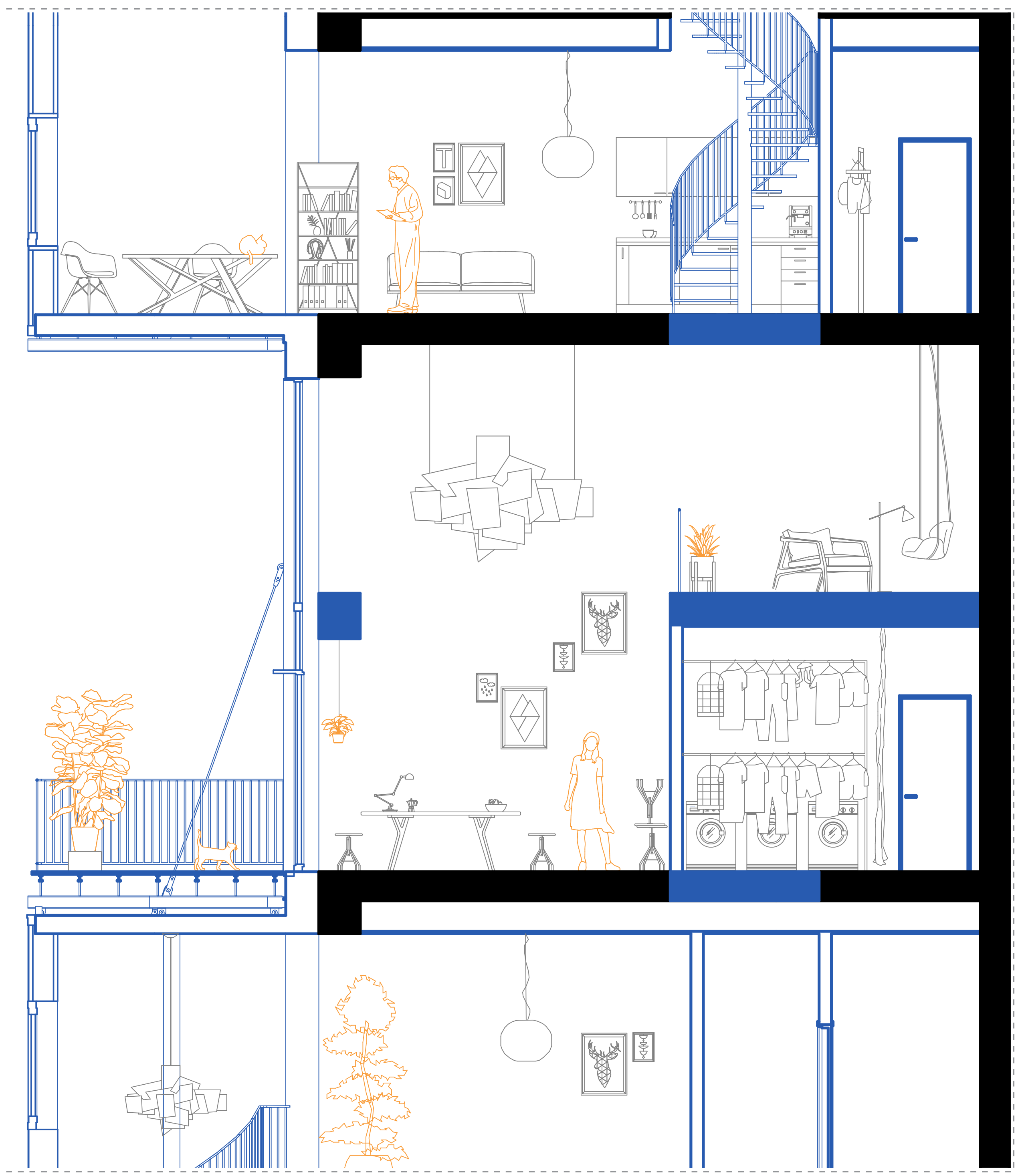


9th floor, communal space

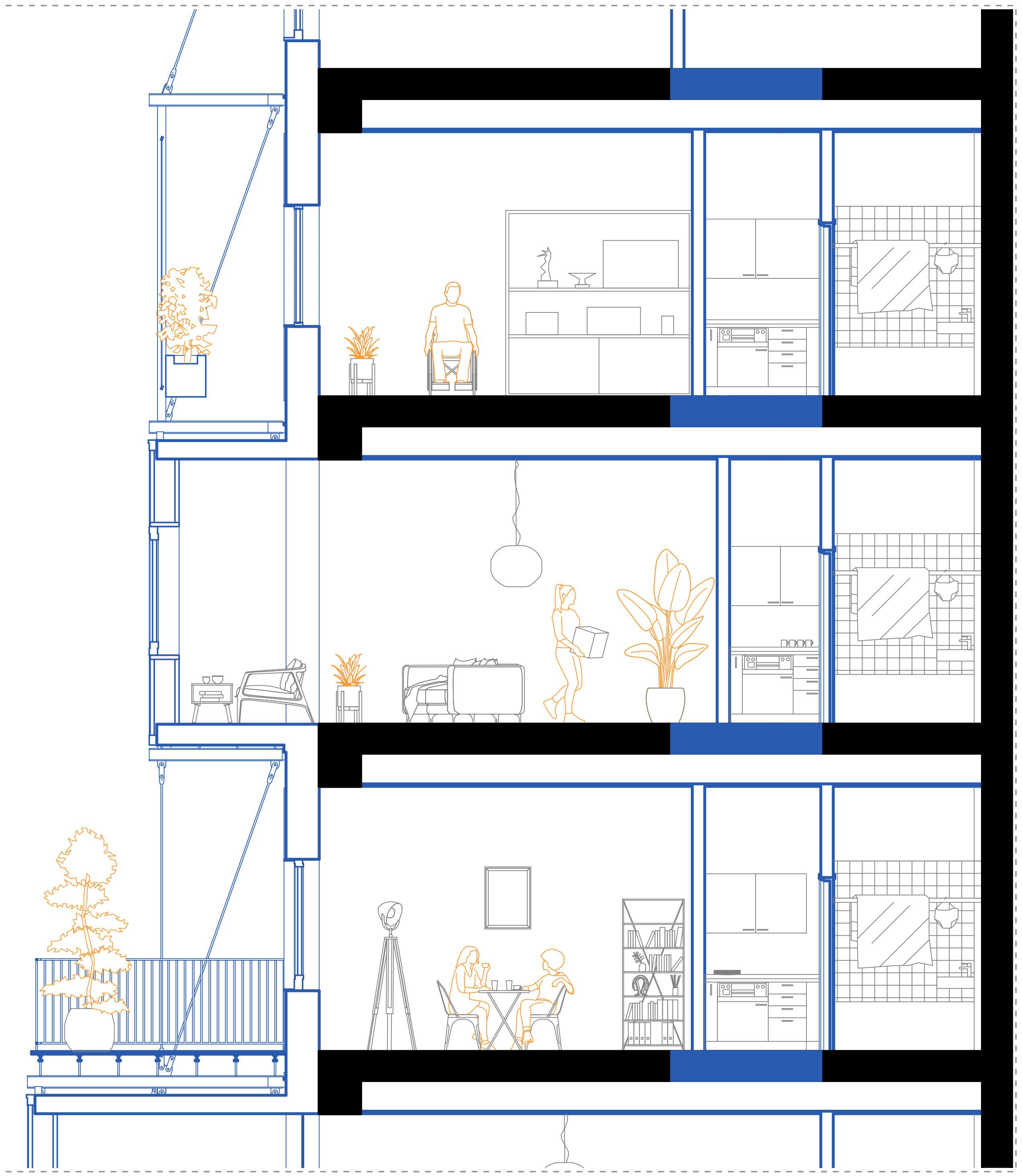
Lorenz Eschke



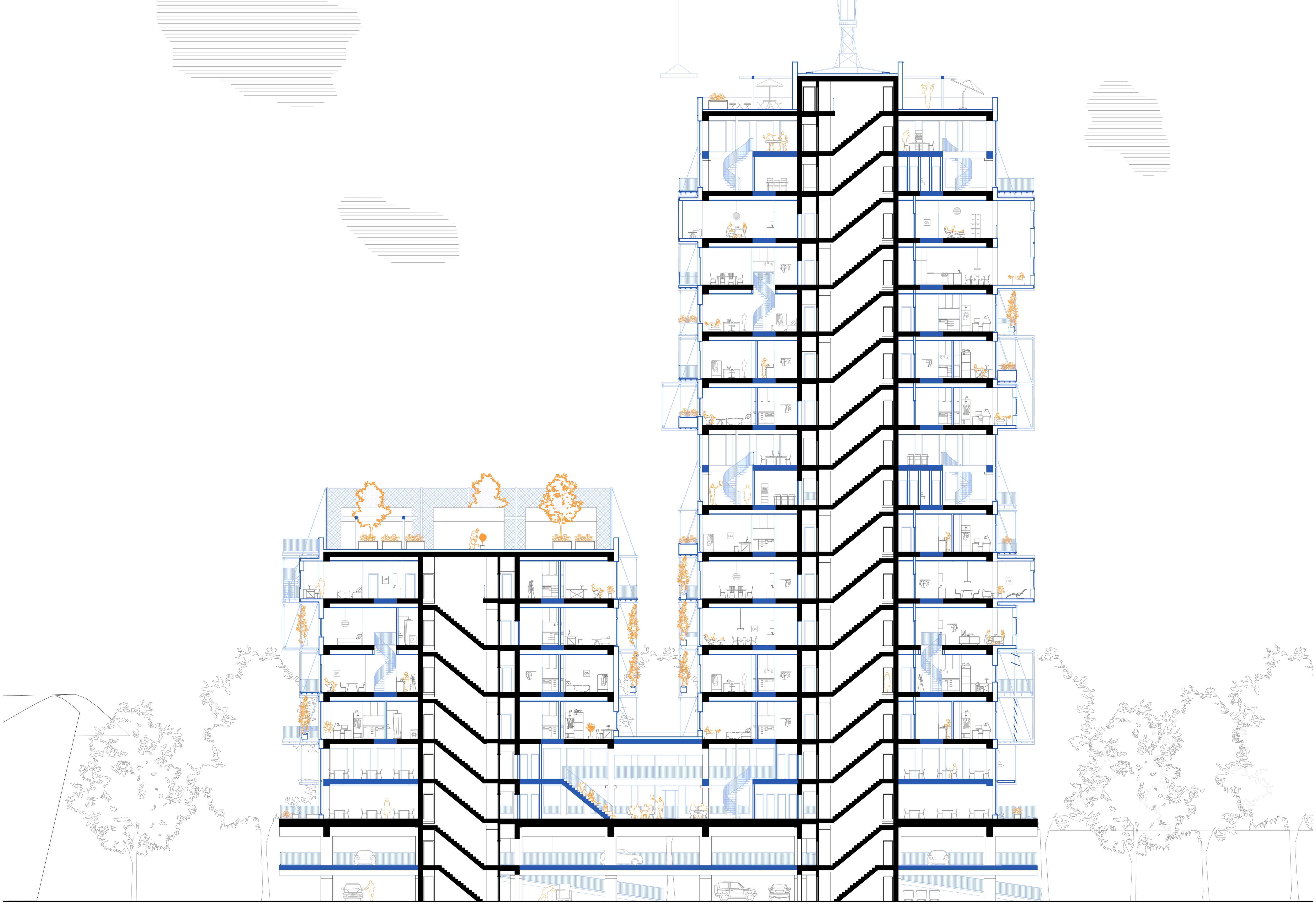
9th floor, common spaces 1|100



section C-C

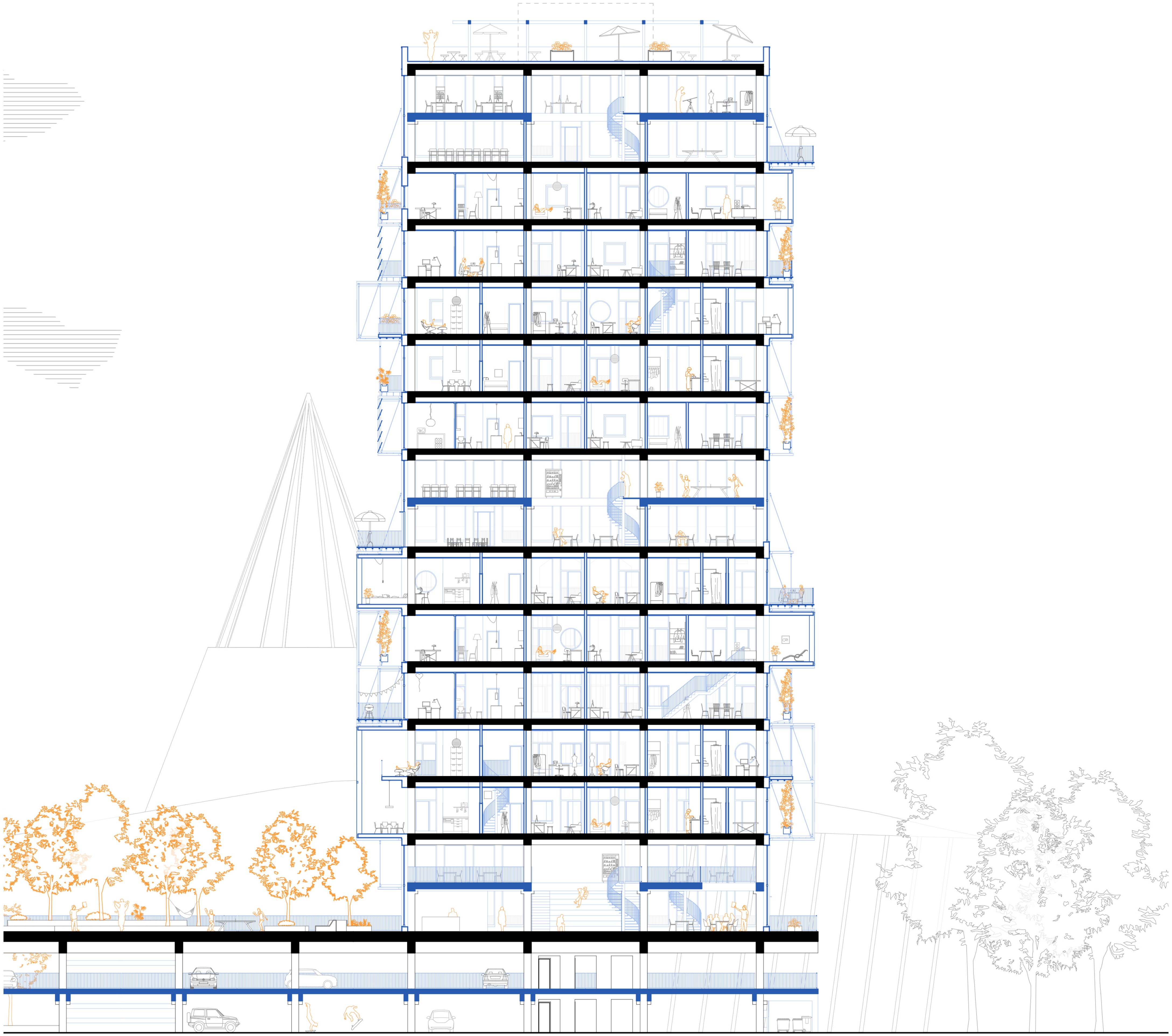


section C-C



section A-A

Lorenz Eschke



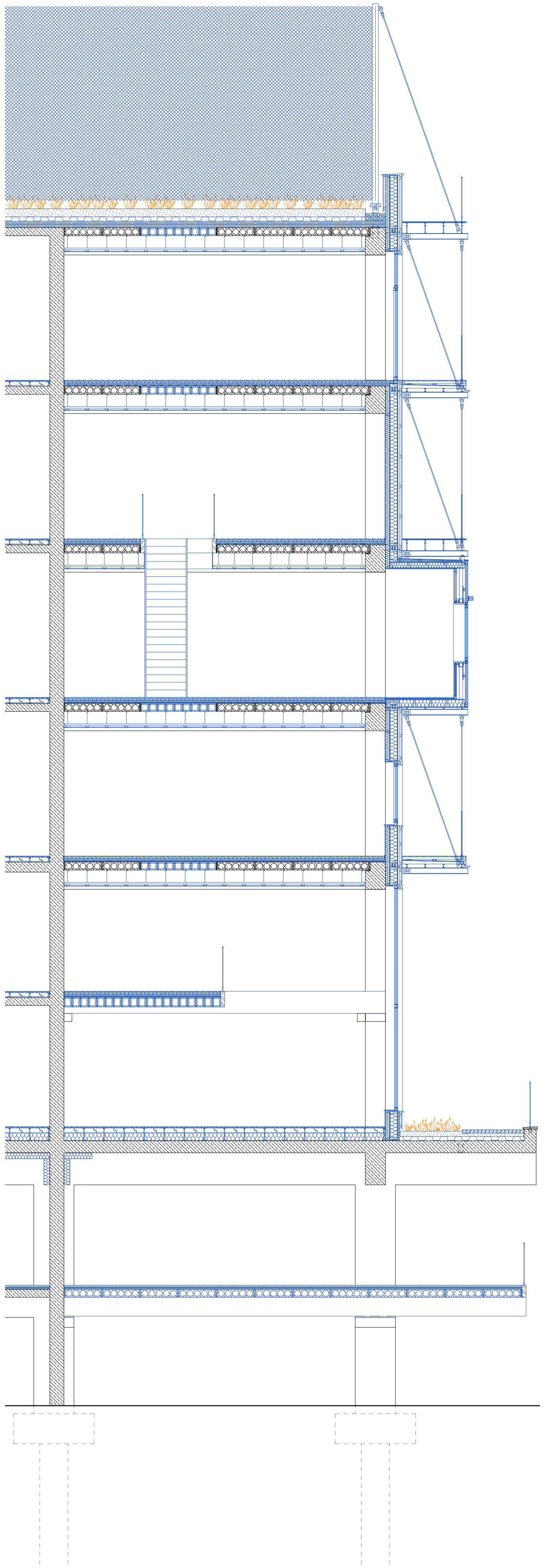
section A-A

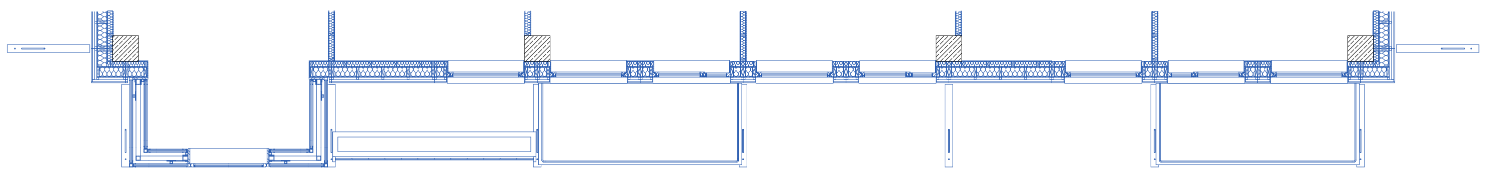
Facade

elevation north - west

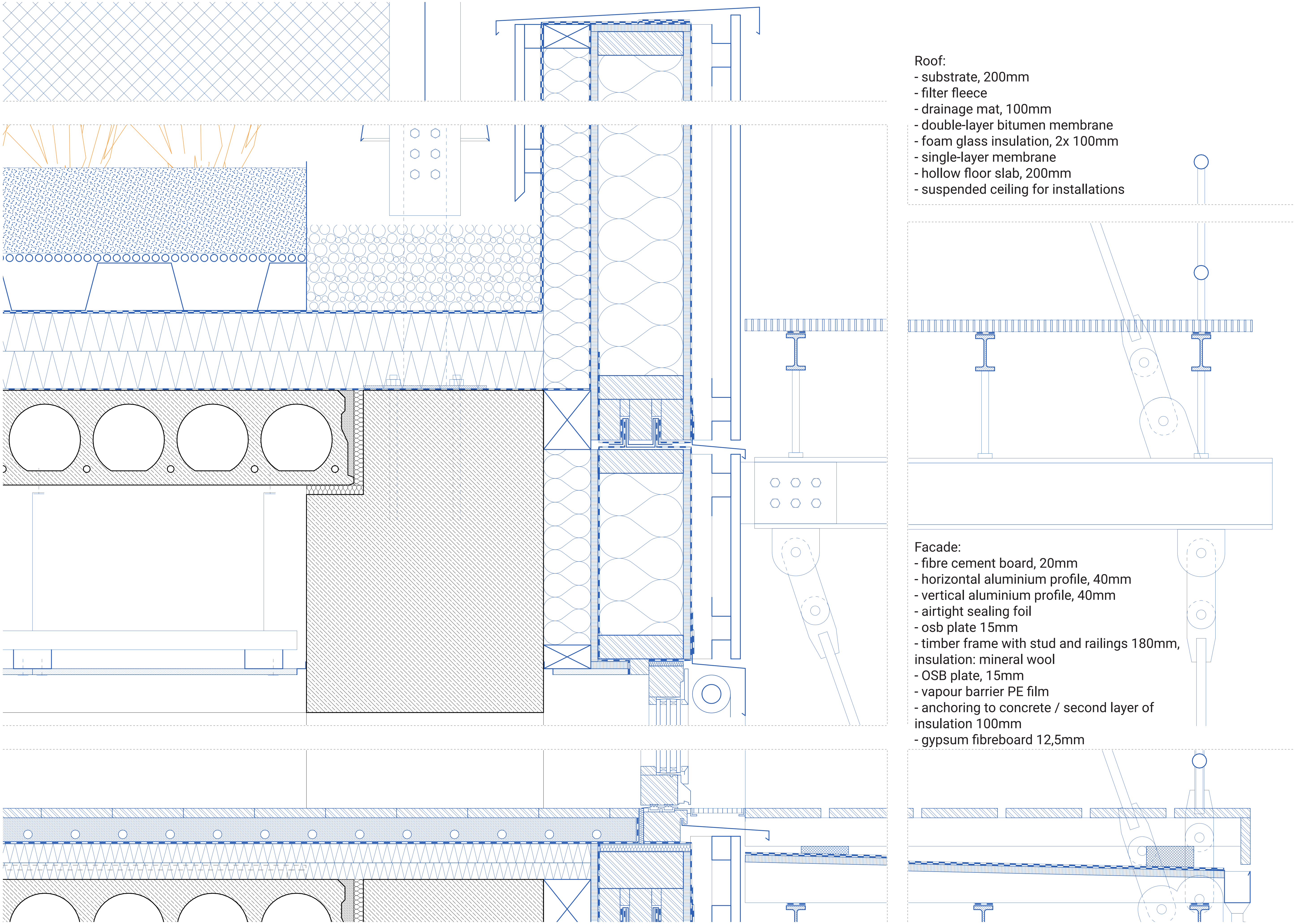
elevation south - west

Lorenz Eschke





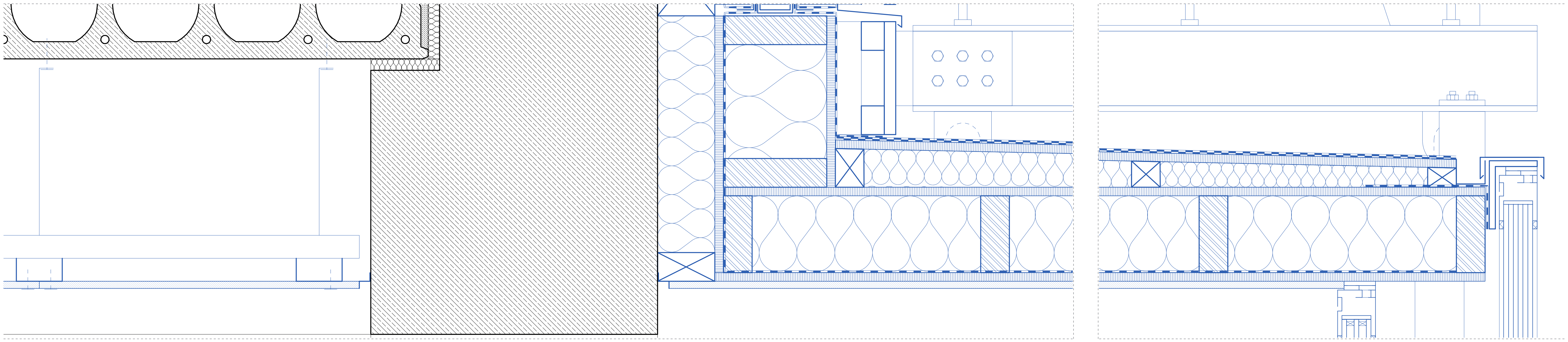
Detailing



Roof:
- substrate, 200mm
- filter fleece
- drainage mat, 100mm
- double-layer bitumen membrane
- foam glass insulation, 2x 100mm
- single-layer membrane
- hollow floor slab, 200mm
- suspended ceiling for installations

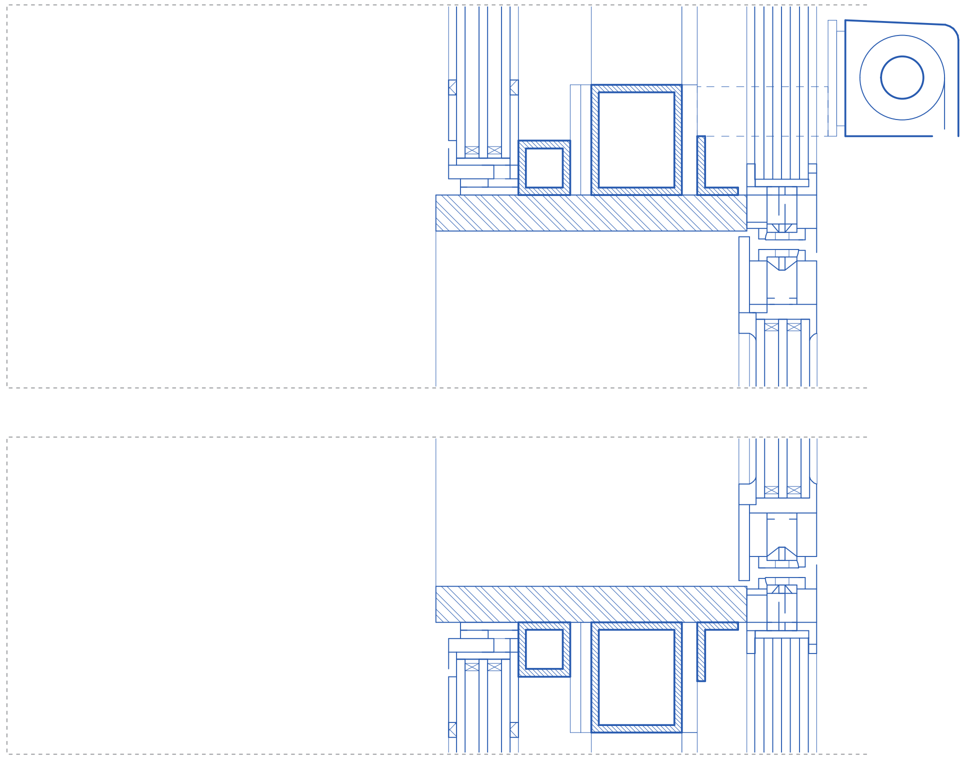
Facade:
- fibre cement board, 20mm
- horizontal aluminium profile, 40mm
- vertical aluminium profile, 40mm
- airtight sealing foil
- osb plate 15mm
- timber frame with stud and railings 180mm, insulation: mineral wool
- OSB plate, 15mm
- vapour barrier PE film
- anchoring to concrete / second layer of insulation 100mm
- gypsum fibreboard 12,5mm

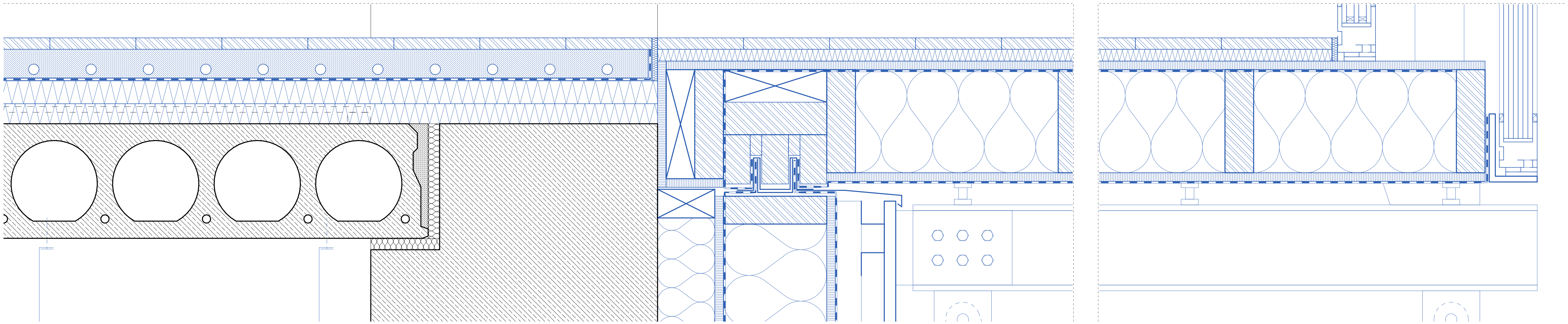
Lorenz Eschke

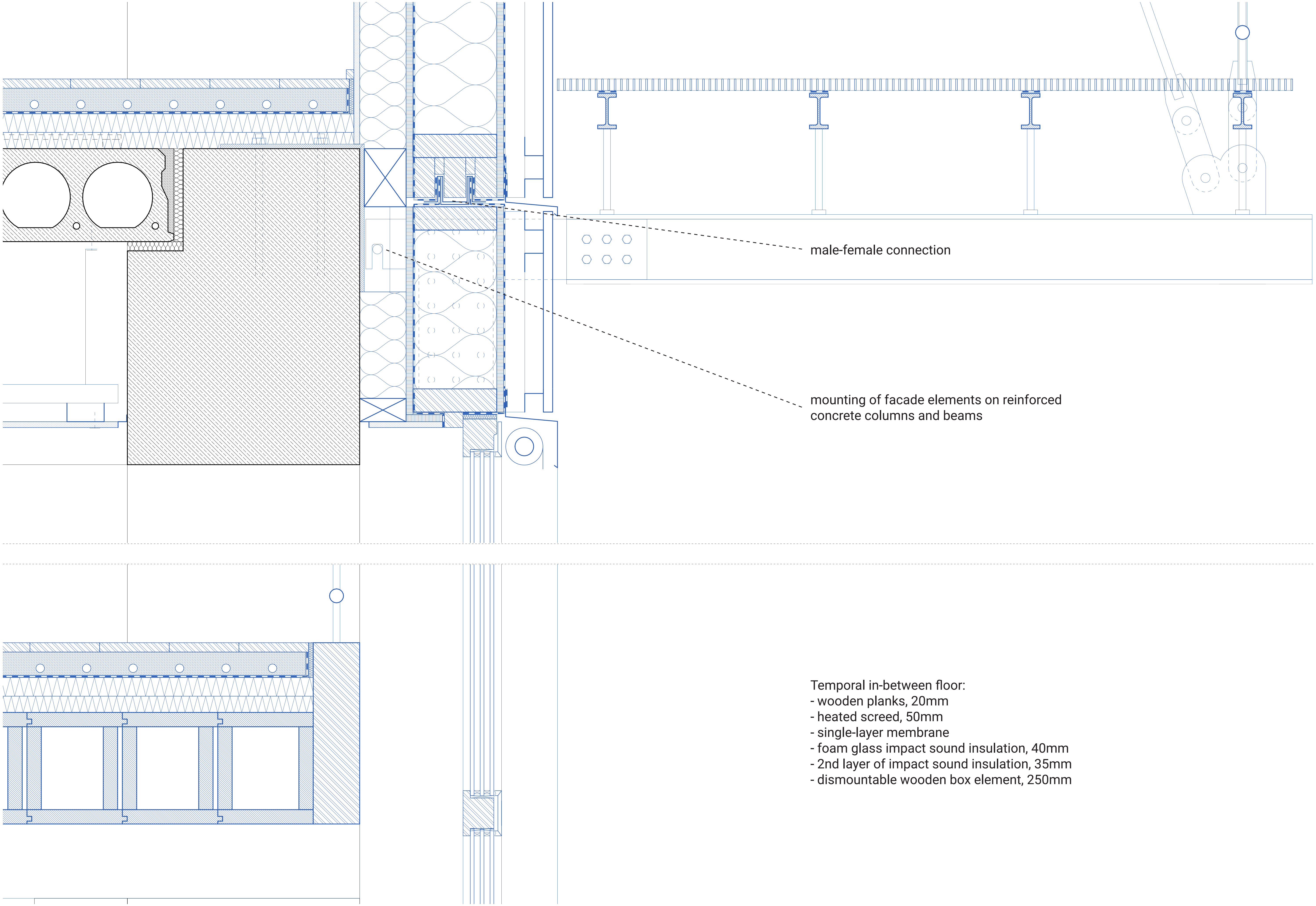


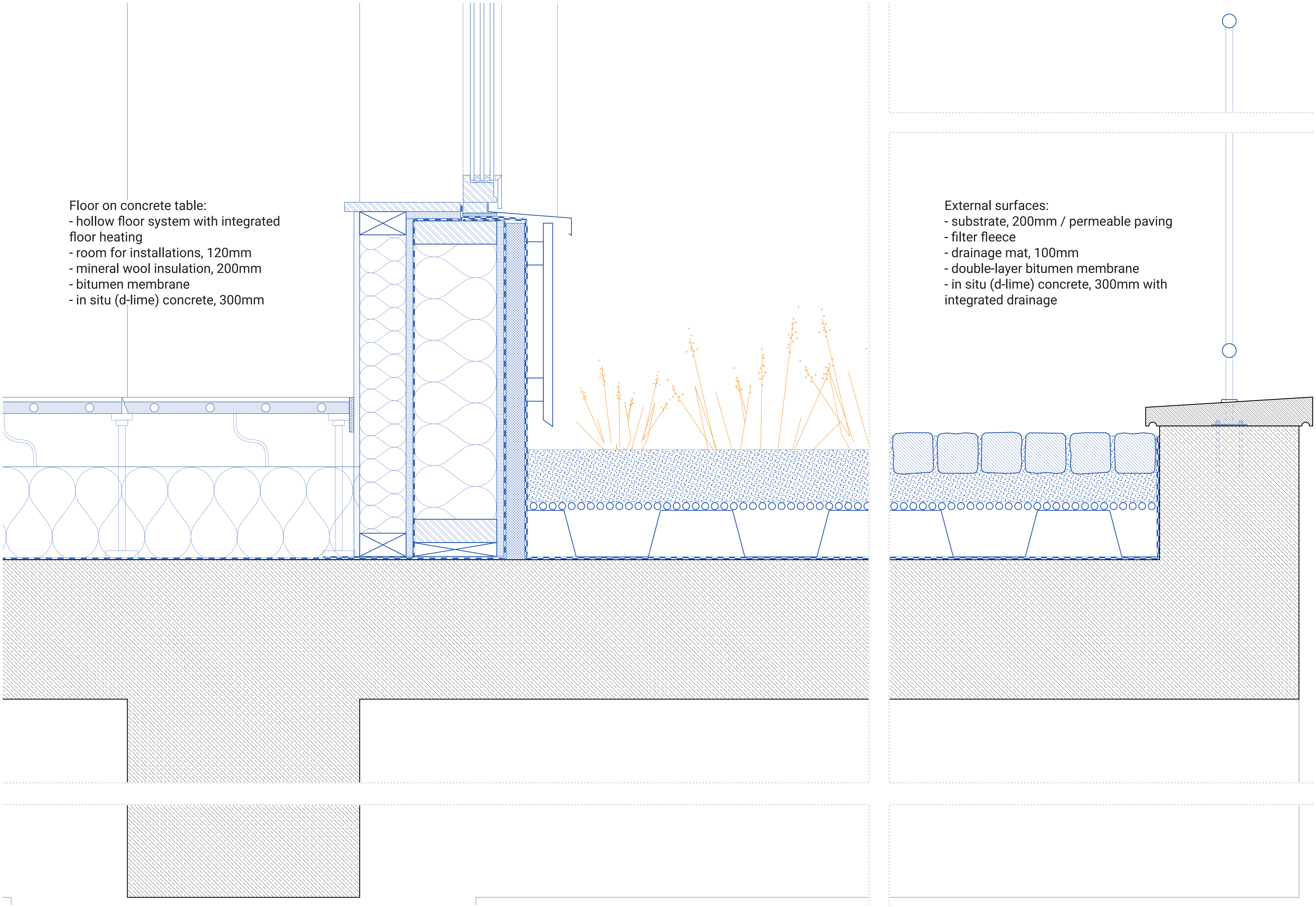
Floor flats:
- wooden planks, 20mm
- heated screed, 50mm
- single-layer membrane
- foam glass impact sound insulation, 40mm
- 2nd layer of impact sound insulation, 35mm + embedded stiffening for hollow core elements
- pre stressed hollow core concrete planks 200mm

Hung-in extension box:
- six-layer polycarbonate multi-wall sheeting with tonged + grooved joints 40 mm (1.1-1.2 W/m2K)
- square hollow-section aluminium supporting construction, 50/50/4 mm
- steel flat supports, 10 + 10 mm
- steel RHS column, 180/100 mm
- steel flat supports, 10 + 10 mm
- triple glazed Okatherm (by Okalux) fixed glazing, reduced UV transmission (0.5 W/m2K)

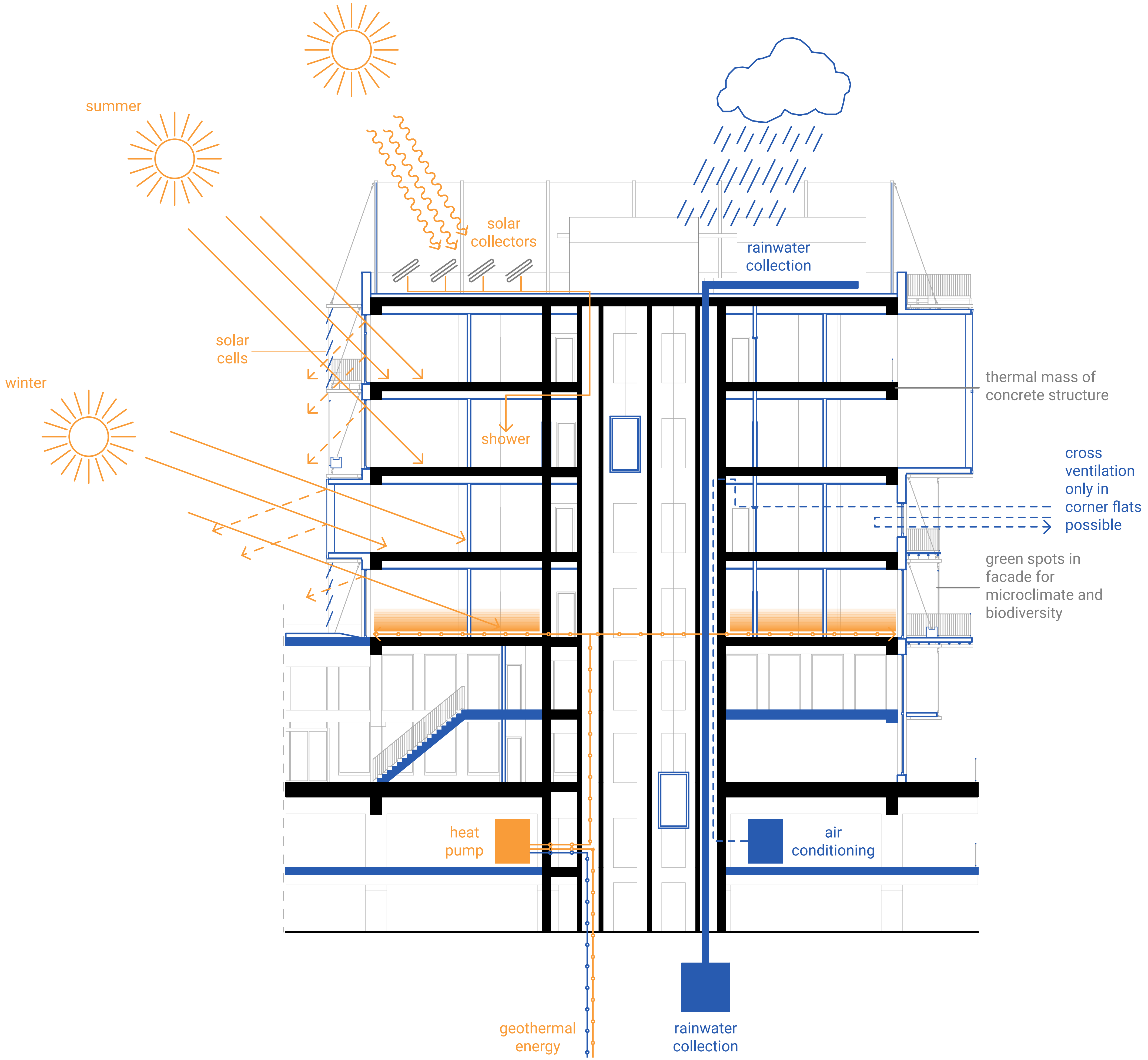





male-female connection
mounting of facade elements on reinforced concrete columns and beams
Temporal in-between floor:
- wooden planks, 20mm
- heated screed, 50mm
- single-layer membrane
- foam glass impact sound insulation, 40mm
- 2nd layer of impact sound insulation, 35mm
- dismountable wooden box element, 250mm


Floor on concrete table:
- hollow floor system with integrated floor heating
- room for installations, 120mm
- mineral wool insulation, 200mm
- bitumen membrane
- in situ (d-lime) concrete, 300mm
External surfaces:
- substrate, 200mm / permeable paving
- filter fleece
- drainage mat, 100mm
- double-layer bitumen membrane
- in situ (d-lime) concrete, 300mm with integrated drainage

Climate



climate diagram