LET'S BUILD A LANDFILL!

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or: How can we turn non-hazardous soil excavations into buildings?

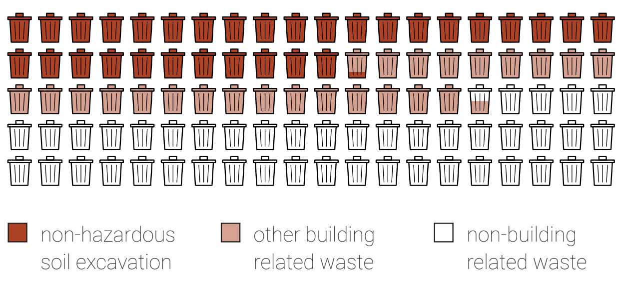
The currently mostly inefficient resource management neglects valuable existing stocks, and grey energy and emissions contribute to a building sector misaligned with climate goals. Amid these challenges, rammed earth, an ancient material, is experiencing a sustainable construction resurgence by transforming under-utilized non hazardous soil excavations into a building material. However, traditional on-site fabrication is expensive and labor-intensive. The investigation of four already existing methods of prefabrication combined with requirements in sub-urban residential housing generates a strategy of how the use of the material can be scaled up considering aspects of efficiency, circularity, and aesthetics. The aspect of efficiency is crucial since the product would otherwise have no real possibility of being available in the quantity needed and at different locations. Considering circularity as another factor comes naturally with the need to approach resources on a more efficient level to get closer to the set climate protection goals. Aesthetics eventually bridge the gap between industry and design by giving important indications of limitations related to each manufacturing method, which determine minimal and maximal dimensions of modules of the housing system, as well as possibilities to create a variation in shape.

A landfill site for the deposition of non-hazardous soil excavations in Weiach, Switzerland.

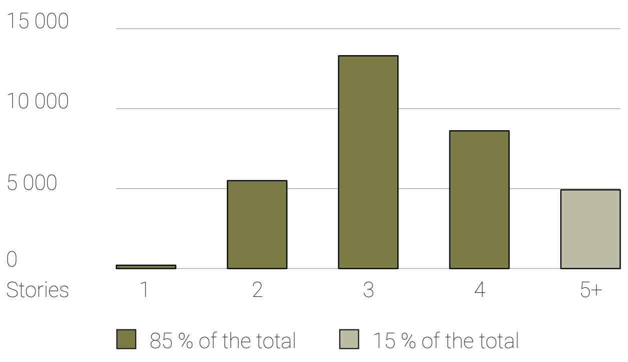
The Potential

Empirical data shows, that most newly erected multi-family residential buildings have four stories or less, underscoring the inherent potential of rammed earth, since the material readily accommodates the construction of load-bearing walls of this height. Generally, a minimum of 50% and up to 100% of all rammed earth structures can exist out of waste soil excavations, highlighting the potential of these, nowadays, waste streams.

The initial costs of sustainable alternatives, coupled with a lack of familiarity with environment-friendly and circular building methods amongst both professionals and clients, have led to the application of CO2-intensive and non-circular forms of building. A significant portion of these resources ultimately becomes waste, contributing to 55,4% building related waste of the total. Whilst there already are certain r-strategies in place to facilitate partial recycling, a substantial 56,3% of the building waste, which consists of non-hazardous soil excavations from building sites, remains largely underutilized.

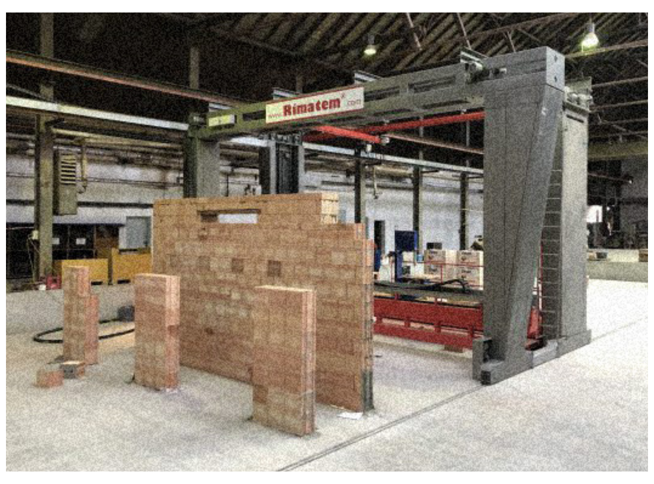


The waste balance of Germany in 2020, compared in weight.



Number of new multi-family residential houses in Switzerland 2022 in number of stories.

Case Studies



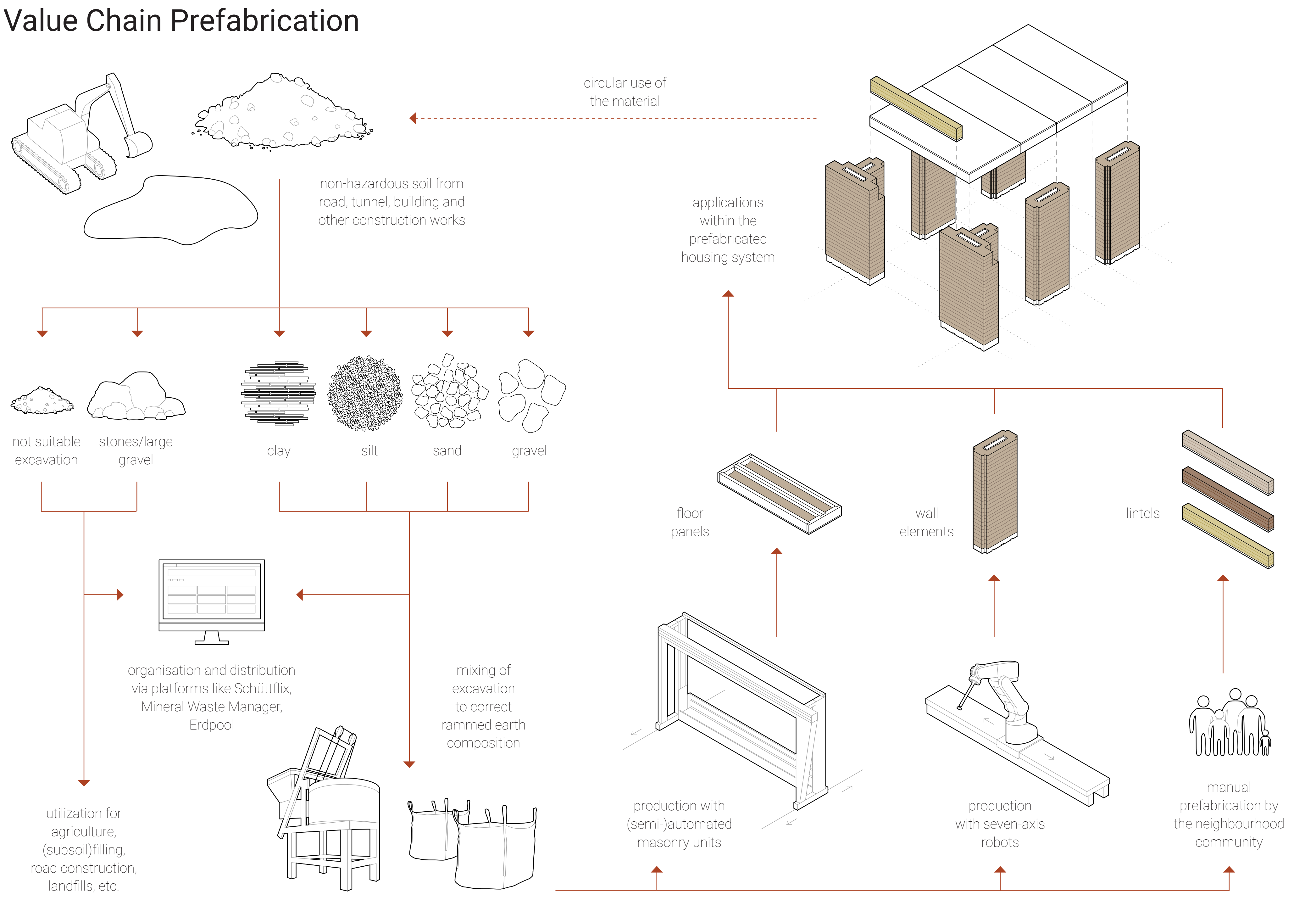
August Lücking GmbH & Co. KG (Warburg, DE)

The brick factory started producing and selling prefabricated rammed earth elements, intending to broaden the product palette towards more sustainable building solutions, whilst making use of the already existing factory infrastructure with only slight adjustments, centred around their semi-automatic masonry unit.

ERNE AG Holzbau (Laufenburg, CH)

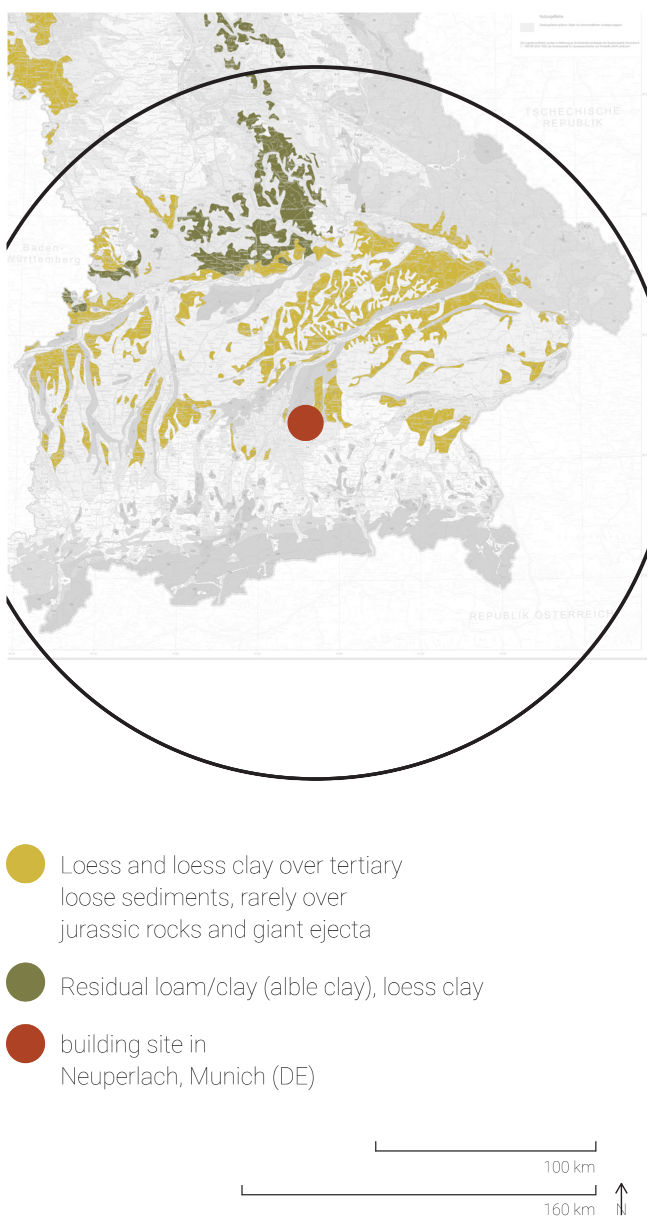
The timber specialized company produces individual wall elements with a seven-axis industrial robot with a pneumatic rammer on its end effector. The fabrication system followes a specific sequencing, involving three parallel production zones, between which the robot is able to vary by running on a rail, thus allowing for optimum fabrication without any idle time.

Value Chain Prefabrication



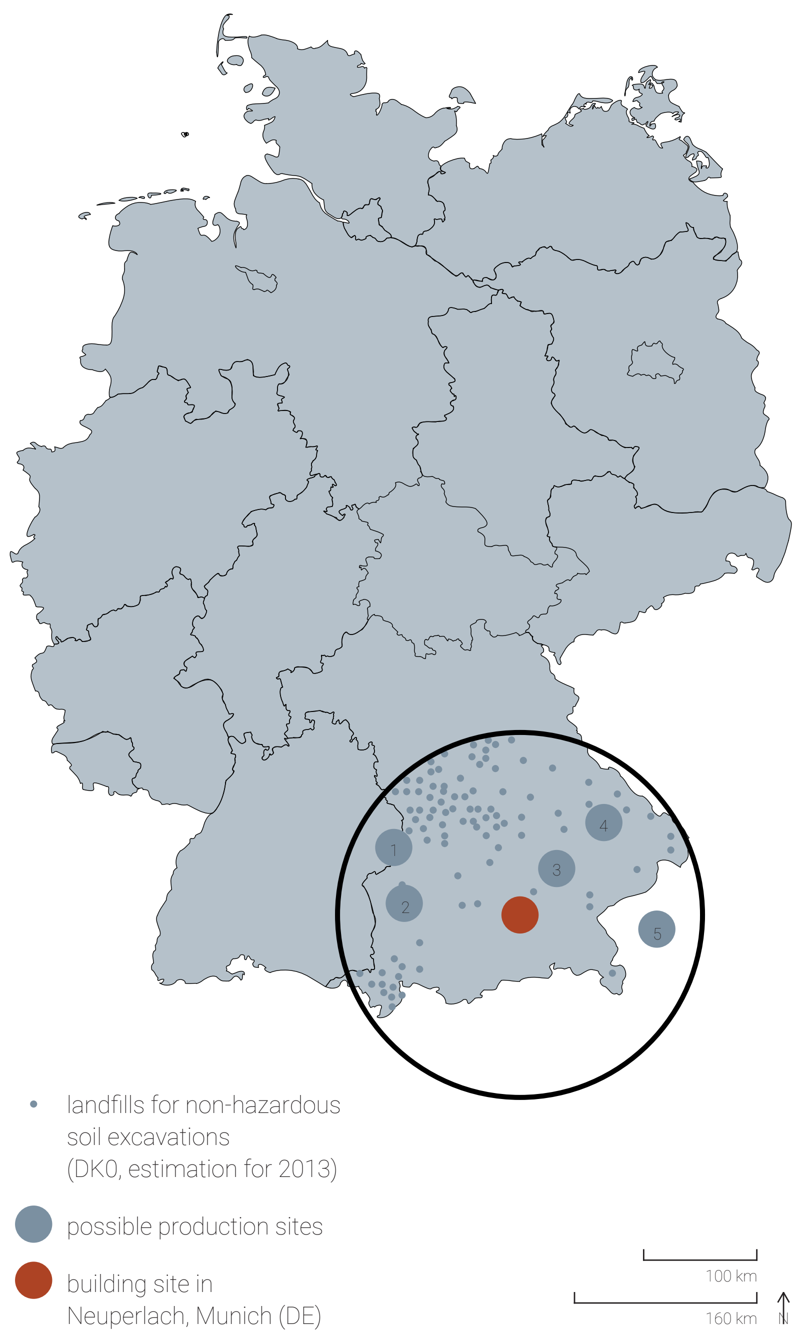
The evolved production strategy involves external stakeholders, like local landfills or construction companies, which already prefilter material, and thus contribute to more uniformity of the rammed earth mixture. More recently emerging distribution and organization platforms, such as Schüttflix, Mineral Waste Manager, or Erdpool, classify accruing mineral material and direct suitable charges. For the ramming process, the use of a seven-axis robot, like at Erne AG, presents an almost fully automated solution for an otherwise very labour-intensive work. In a reduced manner, this also applies to the utilization of semi-automated masonry units, as seen at August Lücking. Next to enhancing the consistency of raw rammed earth material, the already-mentioned distribution and organization platforms for mineral materials can also contribute to circularity by enabling a much more barrier-free availability and thus, utilization of the mostly as waste denoted, non-hazardous soil excavations. Applying the term of circularity also on the infrastructure needed to produce the rammed earth elements, the systems of fabricating with semi-automated masonry units, as well as with seven-axis robots, are the most promising due to their wide availability, thus preventing the need to construct more specialized production sites.

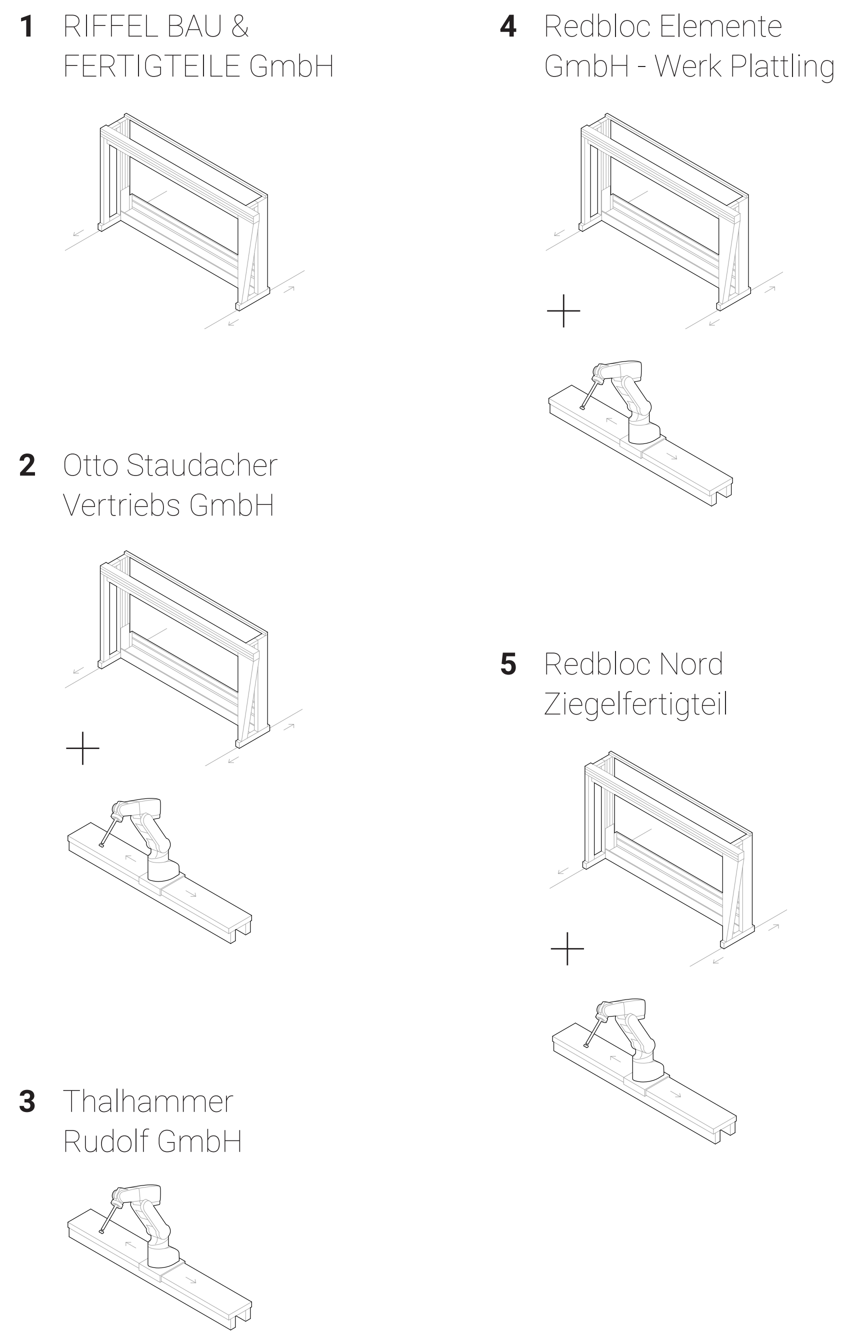
Available Clay Soils



Clayey soils can be found in most parts of the world. The map above visualizes that this is also the case for the surrounding regions in a distance of 160 km to the building site in Neuperlach, Munich.
Thus, the assumption can be taken that also the excavations that are executed on a day to day basis contain enough clay to utilize for the mixing of rammed earth. These can then be seperated, if evaluated as usable, and directly transported to contractors.

Local Production Infrastructure





Using the masonry prefabrication infrastructure of other already existing companies, or by building up fabrication lines with commonly available and in-use seven-axis robots in suitable locations, regional production can be reached.
An analysis of the surrounding of the building site in Neuperlach, Munich shows that there is a large number of possibly usable infrastructure already available. Especially landfill sites of the category DK0, meaning for non-hazardous soil excavations, are widely present.
Looking at existing infrastructure for the prefabrication of brick walls, similar to the example of August Lücking, five different producers were identified which offer possible machinery for the production of rammed earth.
Since especially seven-axis robots are widely used in other industries apart from brick wall prefabrication, the assumption can be taken that this type of machinery is available to a much higher number in the surround than what is displayed in the graphic.

Interior perspective of a double-height apartment.

Strategy for Materials

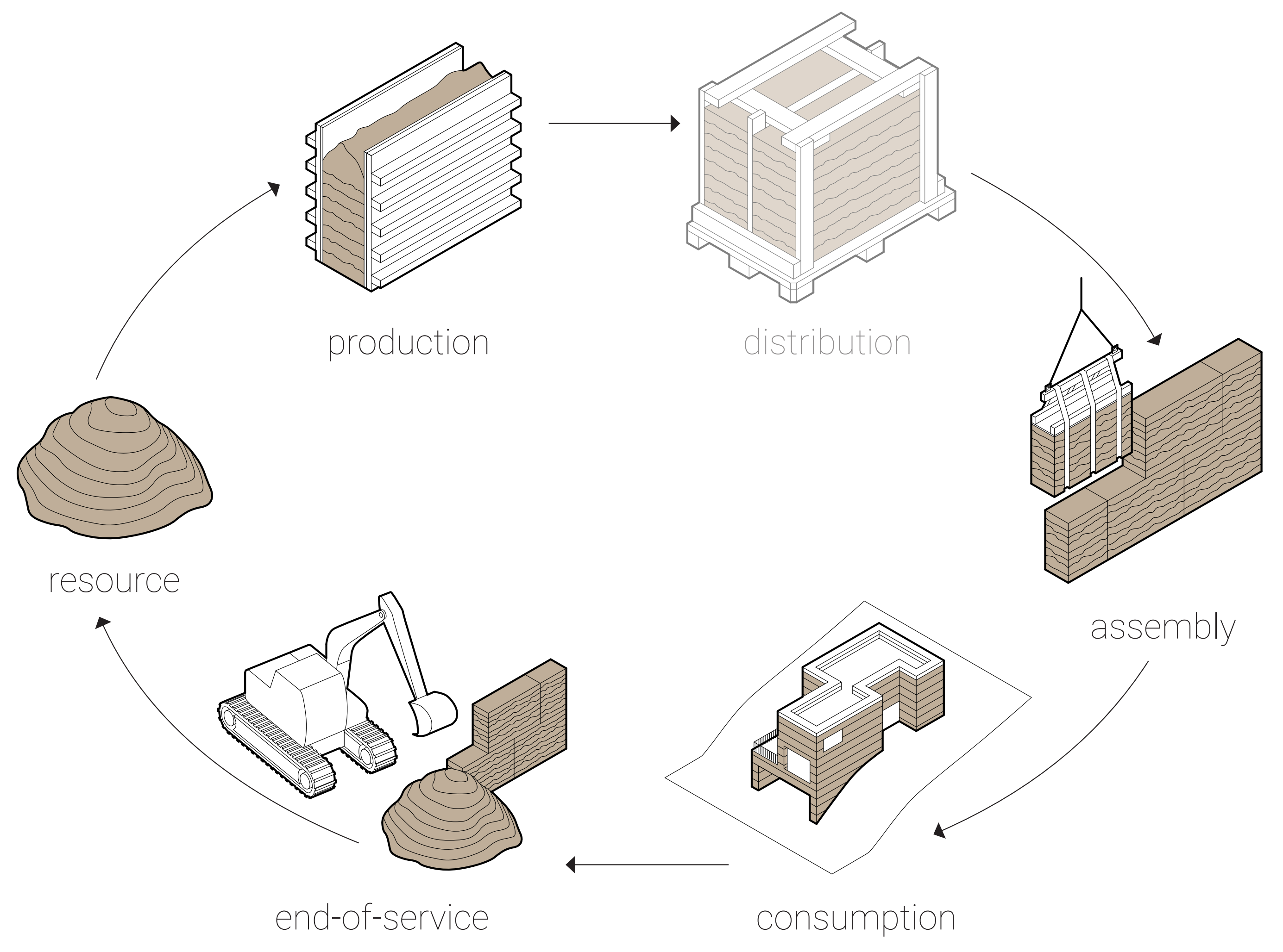
Within the broader framework of establishing a housing system, four distinct objectives arise: Firstly, the housing system shall incorporate elements of flexibility and adaptability, improving the irregular building occupancy to eventually lower the need for new construction. Building less already results in a more purposeful utilization of materials. Nevertheless, also a more affordable and practicable use of rammed earth within the housing system shall be achieved by reducing highly specialised labour and the time of construction, as second objective. Thirdly, the material's already inherited beneficial properties of thermal mass and vapour openness shall contribute to maximize passive climate control, thereby reducing the operational energy. Lastly, an advantage of rammed earth lies in its independence of primary resources. Accordingly, the objective encompasses the utilization of secondary resource soil excavations wherever feasible, extending to ensure that all materials used for the design are used in a way that enables a circular life-cycle.

Within the developed housing system, rammed earth stands out by having the highest occurrence. Next to that, the majority of the other mass consists of the bio-based materials timber and straw in differently processed states. The use of materials that inherently connect to high CO2 eq and more difficulty in circular utilization, concrete and steel, is kept to the indispensable minimum.

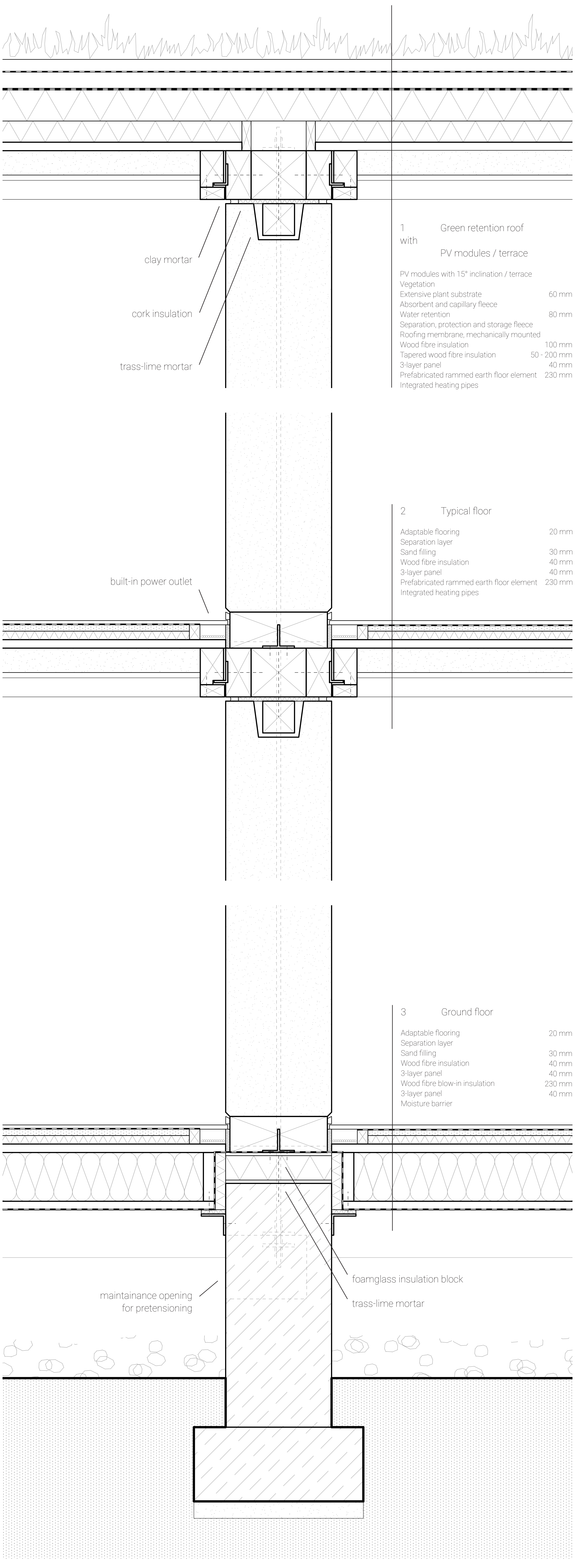
Approximate material use in one unit over three stories.

Circular Potential of Rammed Earth

Challenging the current issue of inefficiently deployed resources, rammed earth has the potential to make use of the abundant under-utilized, and mostly as waste denoted, non-hazardous soil excavations, which are widely available in almost all parts of the world. Furthermore, consisting of a purely mineral mix of compressed earth-moist loam, meaning sand, silt and clay, and gravel, it has optimum prerequisites for circular use, in which rammed earth elements can be crushed and re-moistened into the raw material in theoretically endless cycles.



Life-cycle of a typical prefabricated rammed earth module (Lehm Ton Erde).



Connection Floor to Wall 1:15

CUSTOMIZABLE HABITATS

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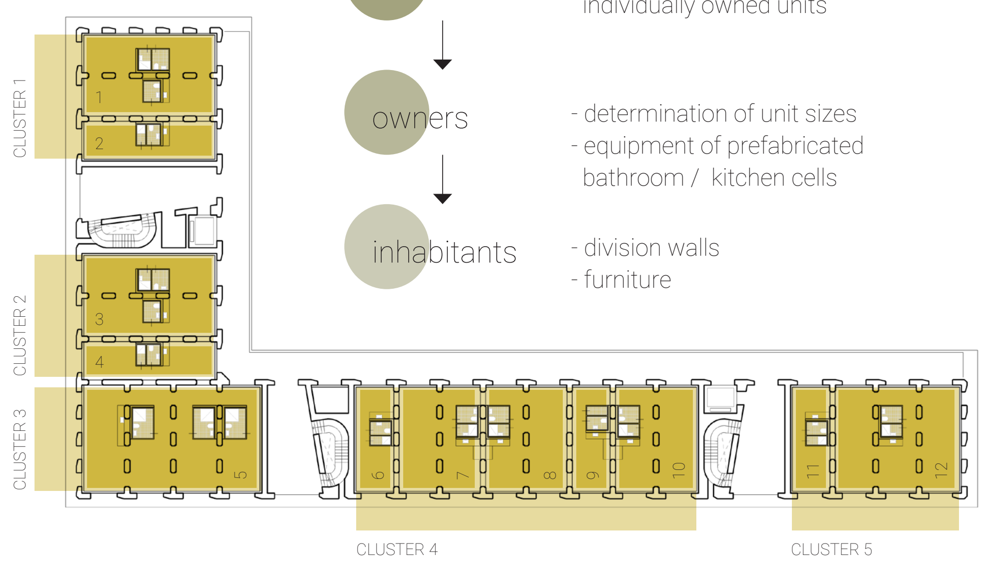
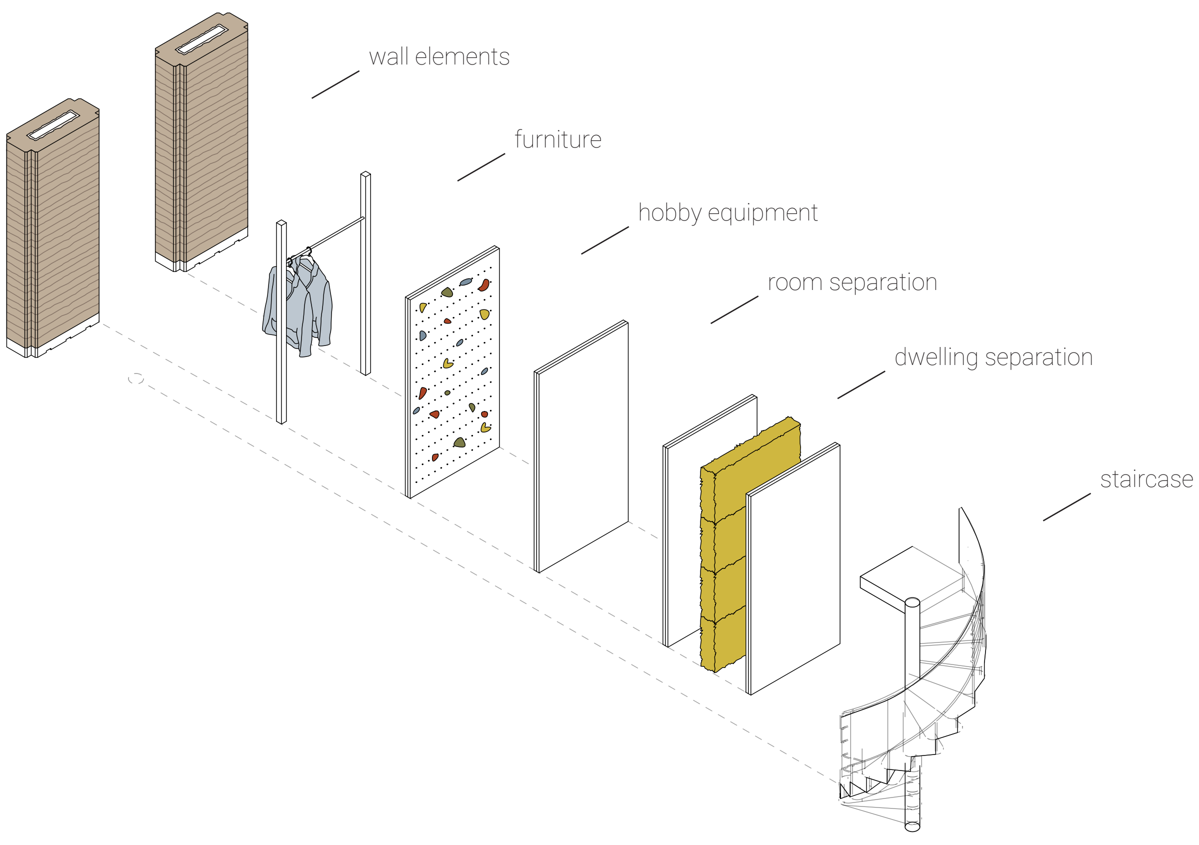
Interior perspective of a single-height apartment.

A new approach to ownership

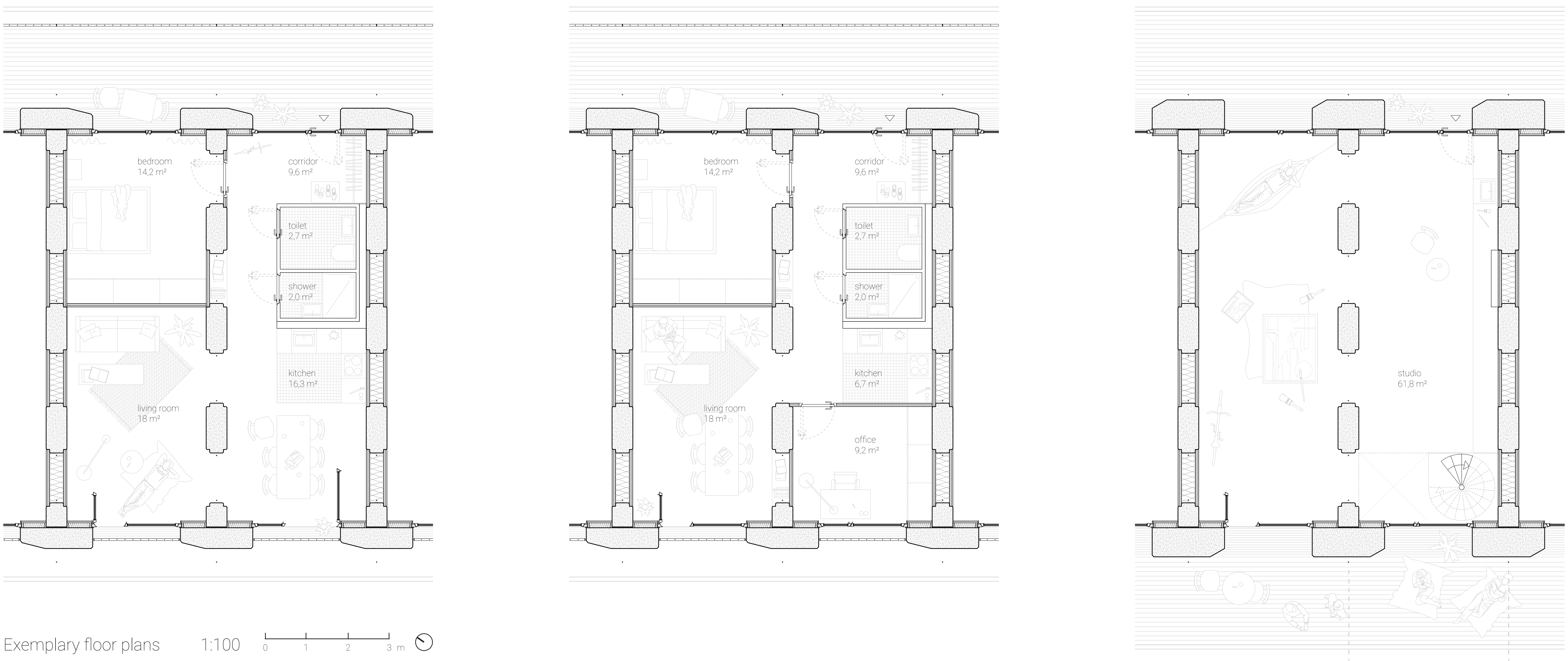
With the introduction of maximum flexibility, also the current approach to ownership has to adapt to actually facilitate the desired flexibility. To do so, the roles of the designer, the client, the owner, as well as the inhabitants change. The designer uses the building system as a tool, within which location specific aspects, such as entrances or facades are adjusted. The client decides on the cluster sizes of purchasable / rentable clusters. The owners define the individual unit sizes, and the inhabitants can customize their room separations.

- designer
  - general building layout
  - load bearing structure
  - facade
- client
  - division into clustered rental / individually owned units
- owners
  - determination of unit sizes
  - equipment of prefabricated bathroom / kitchen cells
- inhabitants
  - division walls
  - furniture

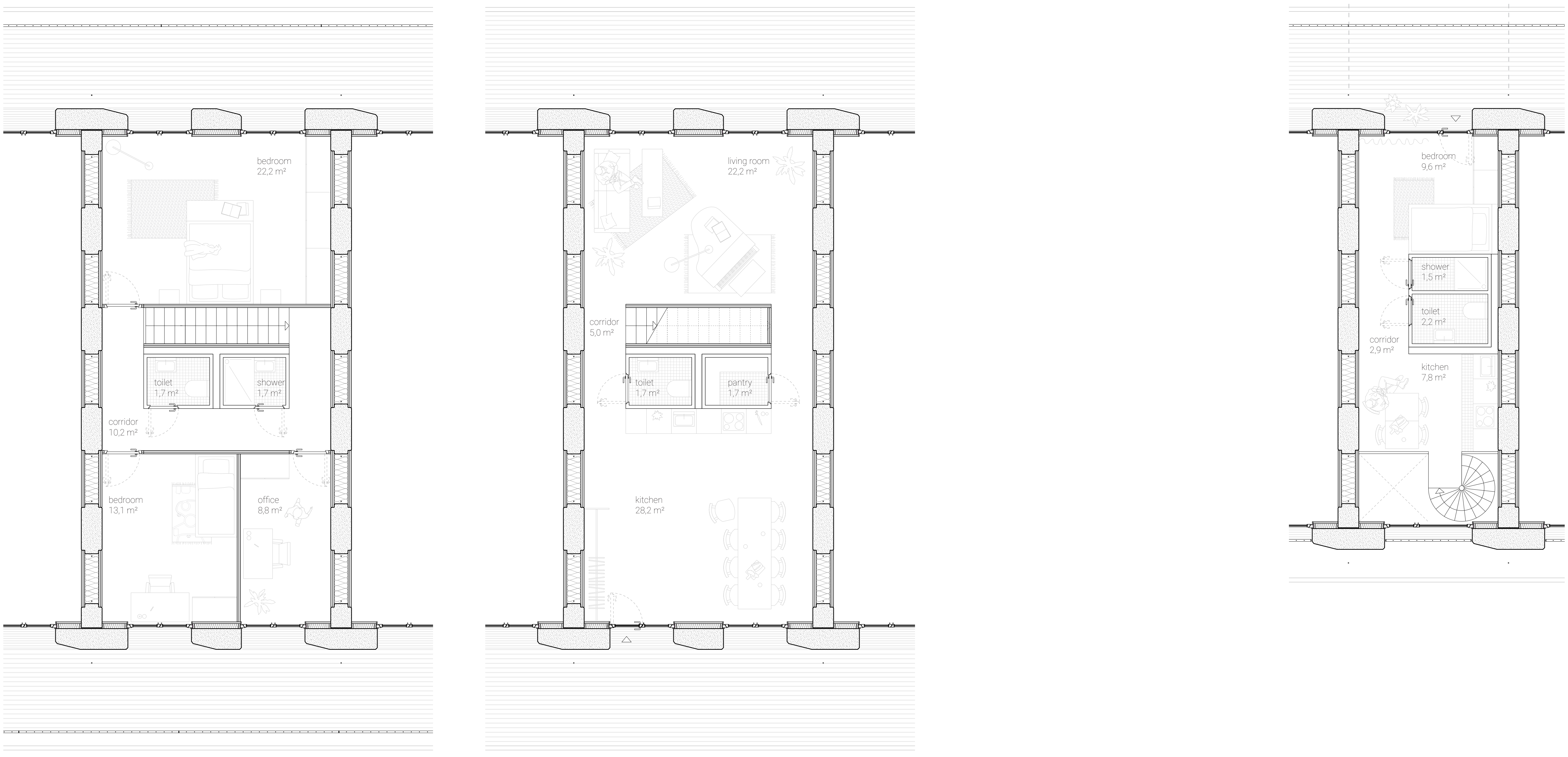




Interior Scheme



Exemplary floor plans 1:100



COMMUNITY-INVOLVED CONSTRUCTION

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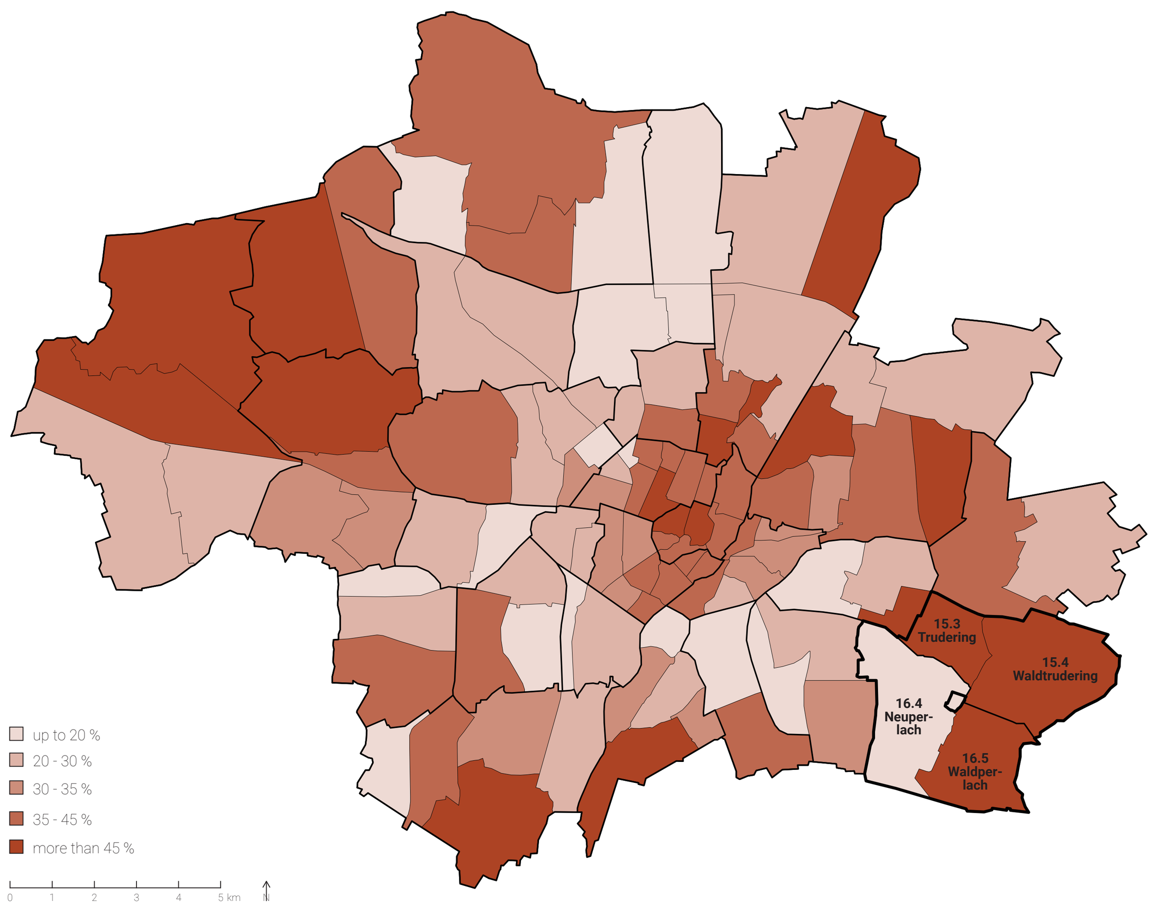
A new quarter to connect highly diverse neighbourhoods

Even though the advantages of the material rammed earth are very widely acknowledged, also amongst non-professionals, a scepticism towards the actual use remains, especially in load-bearing function and exposed to the weather.
To educate future inhabitants, but also the wider neighbourhood, workshops are offered which allow to partake in the actual construction process. For this, the non-structural lintel elements of the façades are prefabricated by the community themselves hyper-locally, meaning in direct proximity to the later construction site. This allows both for the community to build up trust in the material by actually getting their hands on it, but also for later identification with the buildings.
To carry the knowledge also to new residents and younger generations, selected workshop spaces remain active in the new areal. There, people are free to use offered tools, formwork, and raw material, to to bring their own ideas to life, such as interior and exterior furniture, or smaller objects and decoration.

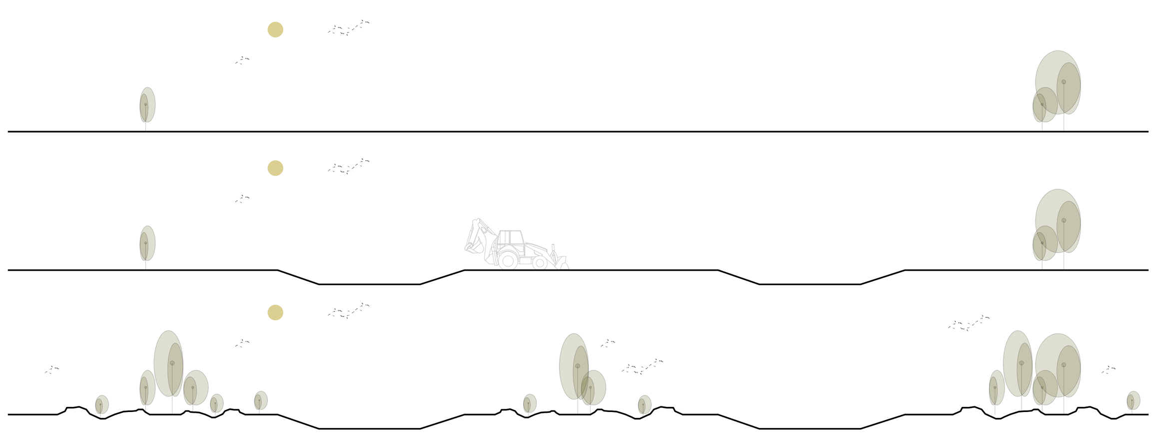


High-income households (>4000€/month) in Munich, 2015.

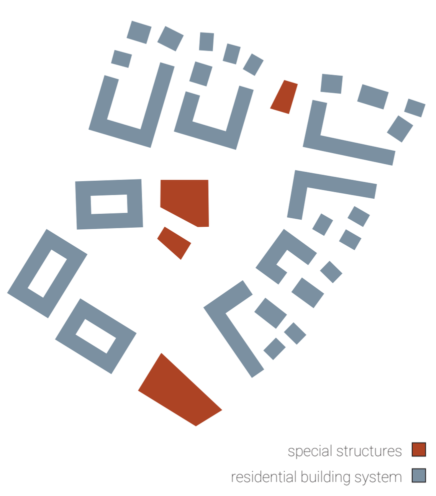
Exterior perspective of the building.

A more nature inclusive landscape

To allow for the whole new areal to be protected of weather and to maximise the surface which allows for water penetration, all buildings are elevated and built on strip foundations. The resulting excavated soil (approximately 13 950 m³) is filtered according to the prefabrication value chain model, and either used to prefabricate rammed earth modules or to renaturate the landscape.



Landscaping Scheme



Urban Plan 1:3000

1 — Connected Neighbourhood

The specific urban design is following the principles of implementing the developed rammed earth housing system on a large scale, whilst at the same time connecting the diverse surrounding neighbourhoods. Central to this idea is the outer neighbourhood route, which is car free, but accessible to all neighbours and invites to explore the area.

1 400 — Created Connectable Units

Within the new area a number of 1 400 units allows for new habitats. Following the new approach to ownership, these units are managed and arranged to dwellings as individually desired. Considering that one standard unit has a size of 31,2 m² and can easily facilitate one individual, it can be assumed that the area's use of space is much more efficient than the German average with 47,4 m² per individual in 2020.

40 950 — Tons of purposefully banked soil excavations

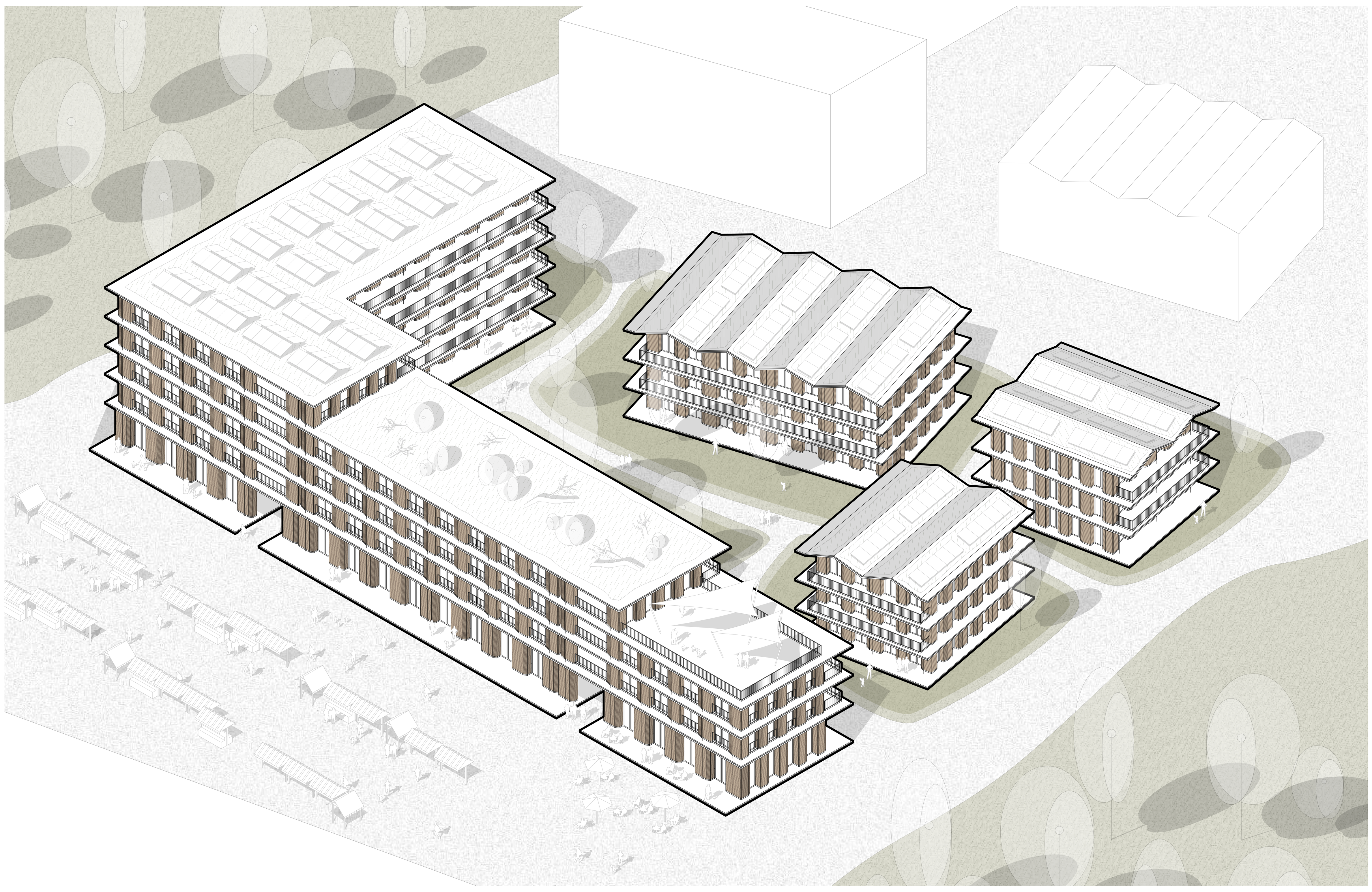
The large amount of processed rammed earth in the new area counteracts the currently quite common overburdened landfill sites. Furthermore, it allows for minimum environmental impact by using mostly 'waste'.
(exempting the special structures; calculations based on: https://www.erne.net/de/leistungen/technologien/stampflehm/)

88 — % less CO2 emmissions compared to concrete

Looking at guiding values to compare the CO2 eq of rammed earth and reinforced concrete (with 90kg steel/m³) shows that in the same amounts, the savings by using rammed earth are immense.
(calculations based on: https://www.erne.net/de/leistungen/technologien/stampflehm/)

17 100 — m2 of special structures

To diversify the neighbourhood, buildings which hold special functions, such as kindergardens or the community centre, do not follow the residential structural systems. This allows for having landmarks within the new areal that allow for better orientation but also identification.



Axonometric view on the building.

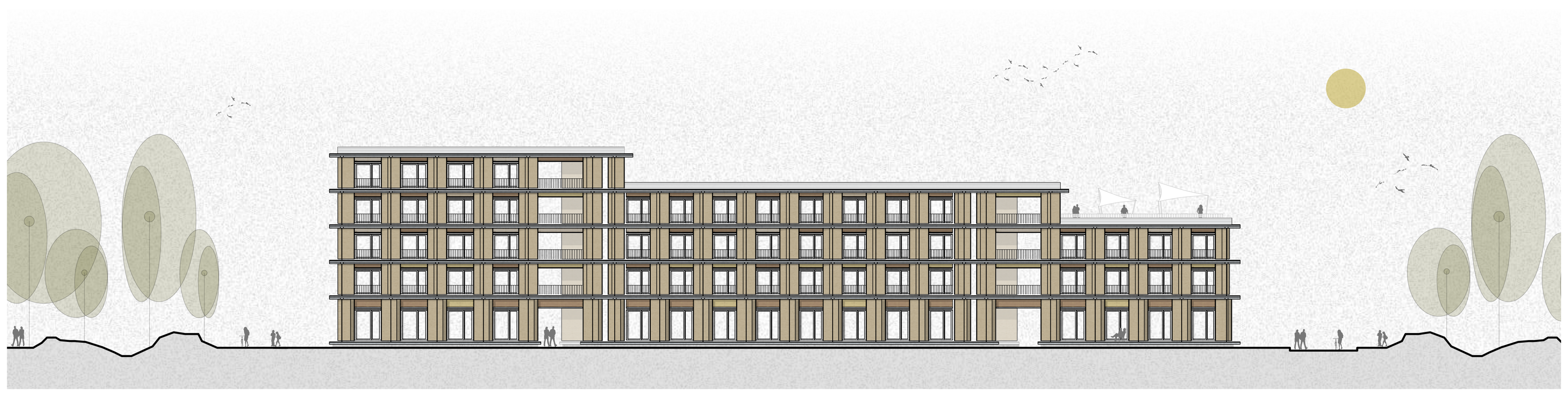
CLUSTERED DWELLINGS AS NEIGHBOURHOOD HUBS

Shared spaces for residents

Each clustered residential block contains not only residential functions but inherits a number of shared open spaces, available to all residents.
In the elaborated cluster, these shared spaces can be found on each storey. The ground floor mostly contains functions that are open not only to the residents but also to the public, responding to the buildings' very central location: a café nearby the outer neighbourhood route as well as the nature reserve, artist in residence studios which allow for a connection between activism and the disconnected neighbouring districts, pop-up stores that give opportunities to entrepreneurs for testing their ideas and products, as well as an open workshop which encourages residents to also include factors of sustainability in their daily life, e.g. by having access to tools that allow for repairing damaged goods.
The residents exclusively have access to a kids' playroom on the ground floor, multiple shared loggia spaces in the staircase halls, as well as a large roof terrace.

Climatic Strategy

The climate control within the building mostly focuses on activating the mass of the rammed earth to passively balance out temperature peaks. To do so, PV panels (with east and west orientation) are installed on the roof surface, on top of a green roof to allow for passive cooling and thus, a more efficient operation of the PV system. The gained energy primarily is used to run the air to water heat pump, which heats up or cools down water which is running through the ceiling elements. The pipes are located on top of the rammed earth and directly activate its mass. Furthermore, being aligned with the housing grid system of 1,20 m it also allows for heating / cooling of individual rooms or units. With the implementation in the ceiling, the system is also independent of chosen flooring types or furniture, which would cover up floor heating. Good ventilation is guaranteed by self-regulating, soundproof air inlets at the top of the window frames, and a decentralised ventilation unit in the bathroom modules, which exhausts air and recovers heat.
The rain and sun shields are dimensioned to block off sun in summer, and let it inside the apartments in winter.



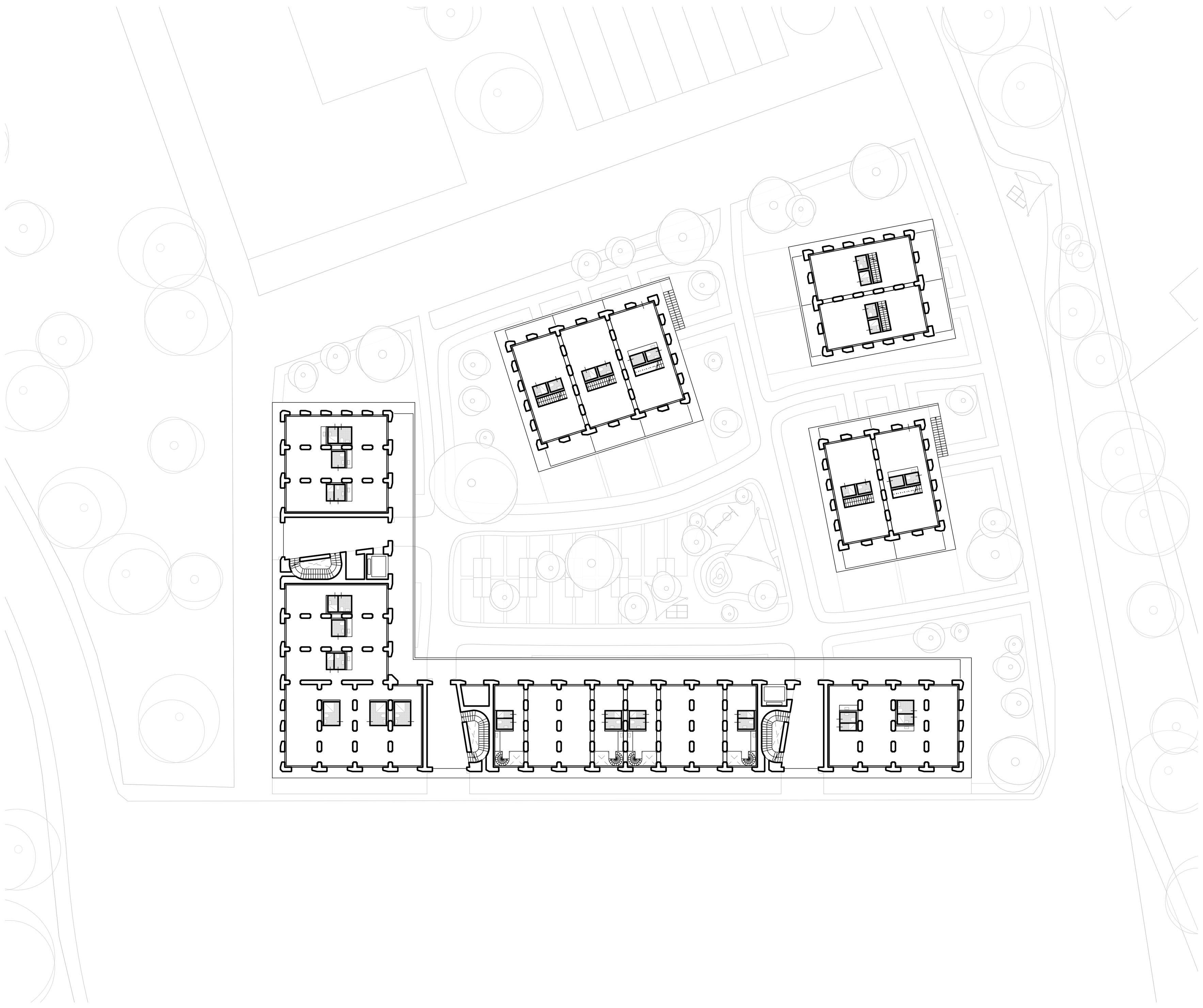
West Elevation 1:500

North Elevation 1:500

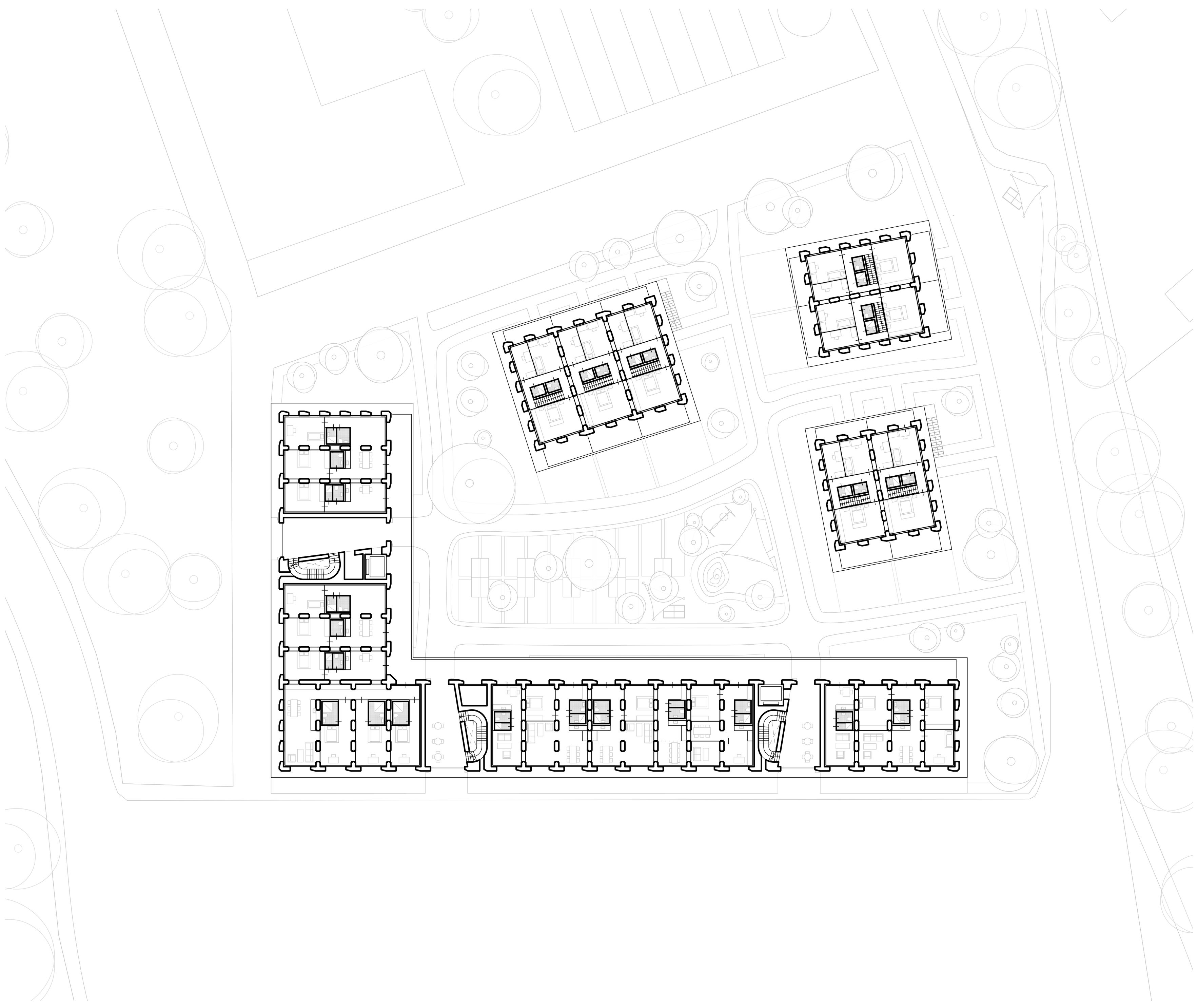
East Elevation 1:500

South Elevation 1:500

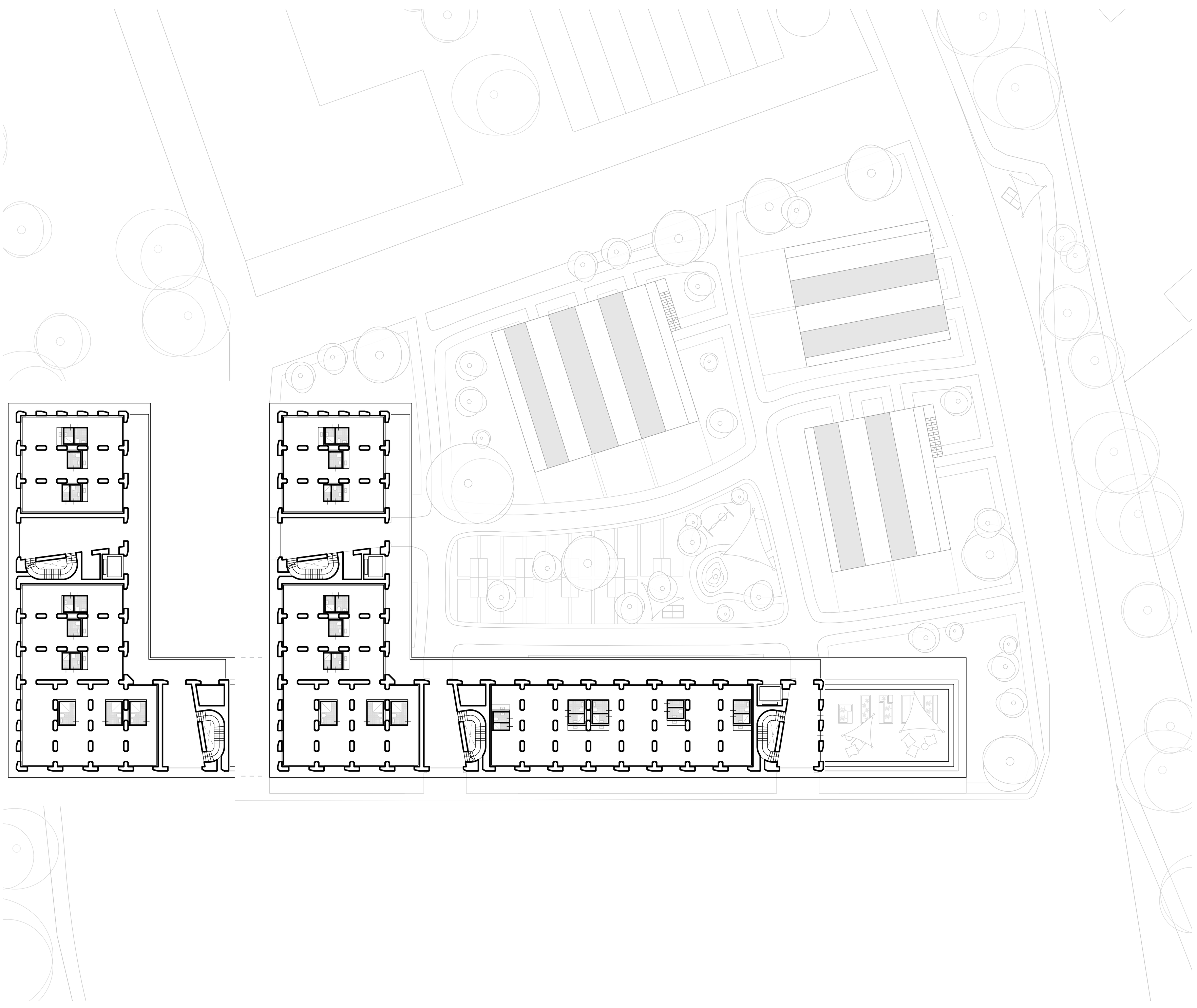
Ground Floor 1:500



First Floor 1:500



Second Floor 1:500



Fourth Floor 1:500 Third Floor 1:500

FUTURE-PROOF CLIMATE CONTROL

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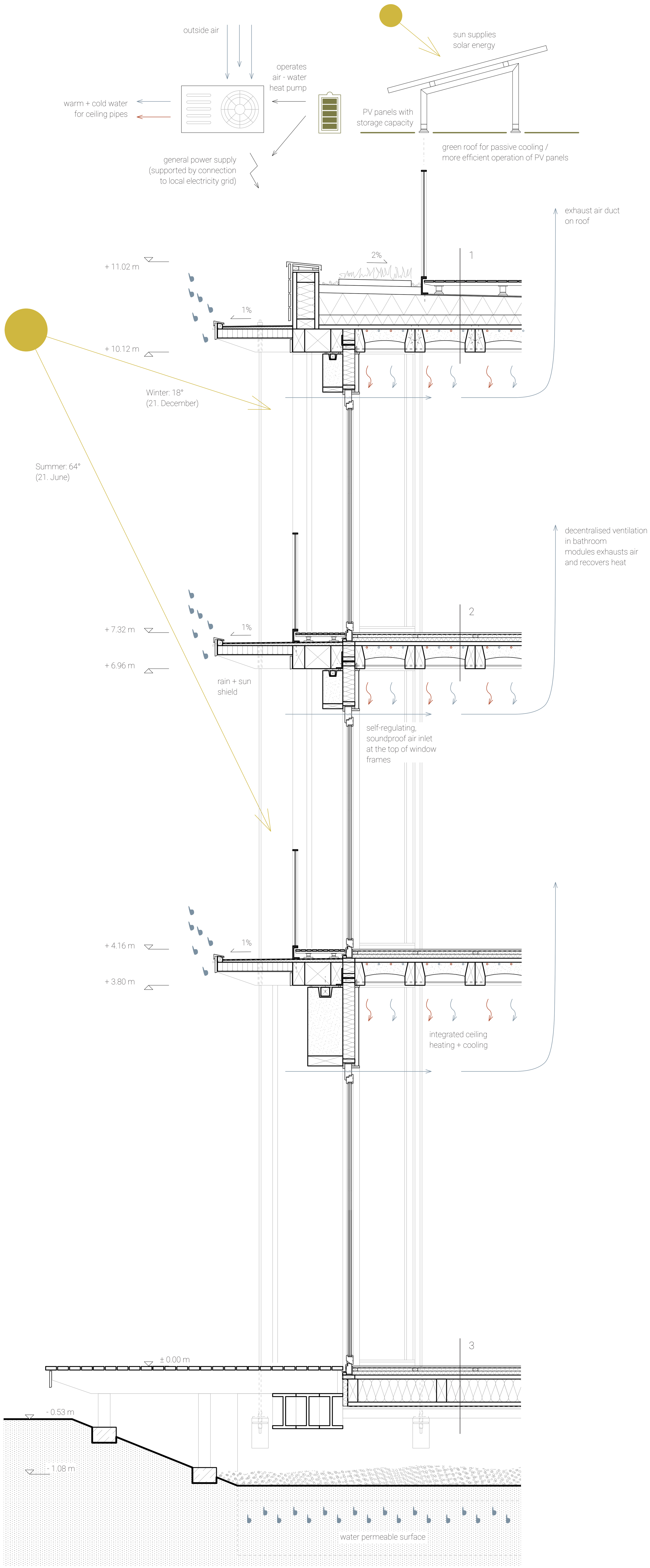

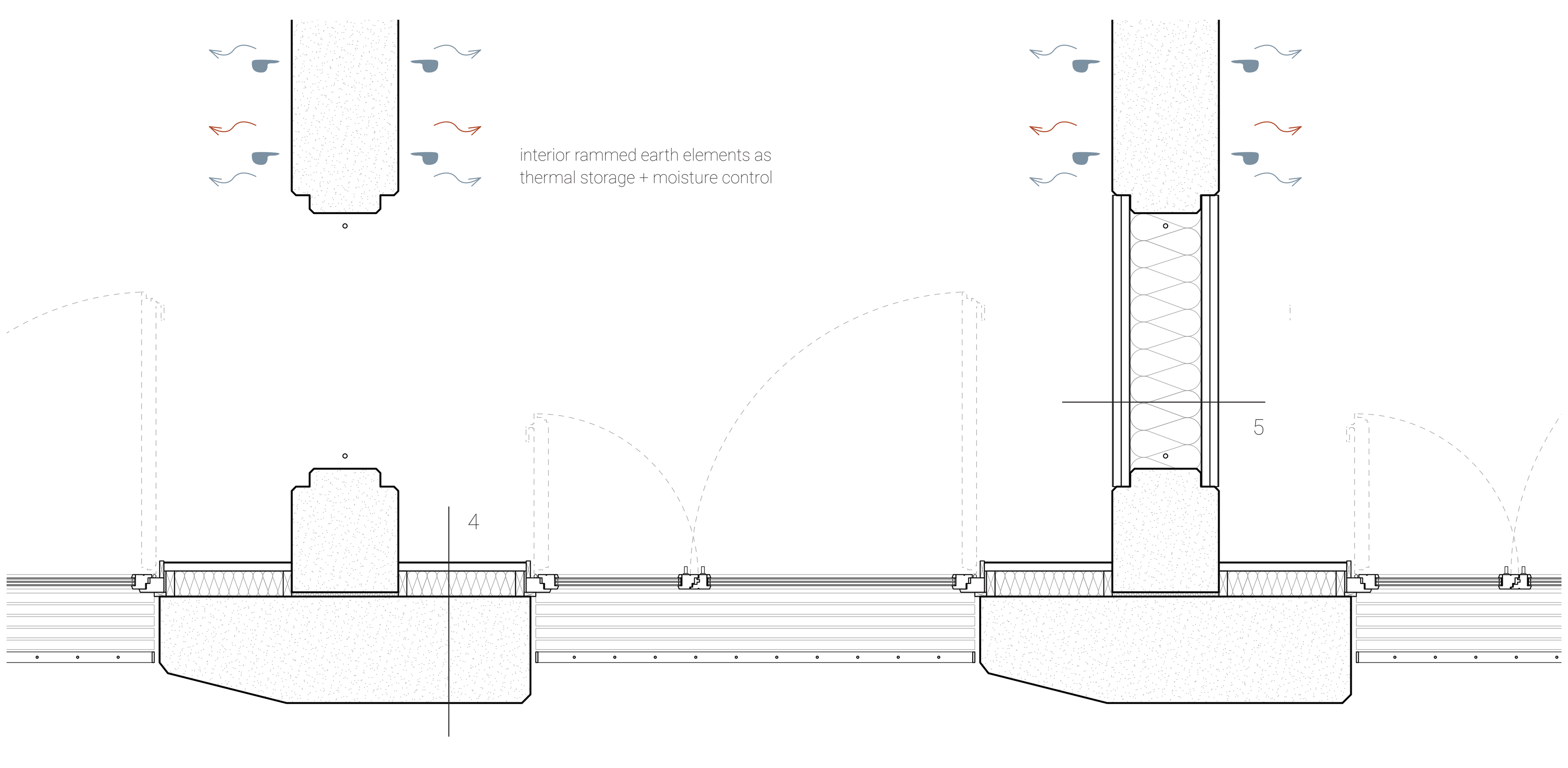

Facade Section 1:25

1 Green retention roof with PV modules / terrace

PV modules with 15° inclination / terrace	
Vegetation	
Extensive plant substrate	60 mm
Absorbent and capillary fleece	
Water retention	80 mm
Separation, protection and storage fleece	
Roofing membrane, mechanically mounted	
Wood fibre insulation	100 mm
Tapered wood fibre insulation	50 - 200 mm
3-layer panel	40 mm
Prefabricated rammed earth floor element	230 mm
Integrated heating pipes	

2 Typical floor

Adaptable flooring	20 mm
Separation layer	
Sand filling	30 mm
Wood fibre insulation	40 mm
3-layer panel	40 mm
Prefabricated rammed earth floor element	230 mm
Integrated heating pipes	

3 Ground floor

Adaptable flooring	20 mm
Separation layer	
Sand filling	30 mm
Wood fibre insulation	40 mm
3-layer panel	40 mm
Wood fibre blow-in insulation	230 mm
3-layer panel	40 mm
Moisture barrier	

4 Exterior wall

Rammed earth wall	500 mm
Straw insulation	120 mm
Straw drywall board	38 mm
Fine clay plaster	4 mm

5 Interior wall

Straw drywall board	76 mm
Straw insulation	340 mm
Straw drywall board	76 mm
Fine clay plaster	4 mm