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ABSTRACT

London seems to be stuck in a continuous housing crisis and faces a difficult future with fewer housing units being built every year. This tendency can be experienced in all bigger cities around the world, which is a serious problem considered the fact that the building and construction sector is already responsible for nearly 40 percent of energy-related greenhouse emissions. In UK homes, 62 % of the energy is used for space heating, which is one crucial factor that we aim to tackle with our thesis.

Our thesis is an investigation on how to apply a low-tech approach in order to lower the overall energy demand of the building.

To do so, we carried out an integrated design process with iterative approaches including simulations and prototyping, which had an essential impact on the shaping of the final design. Our findings show that there is a high potential of an alternative approach to the high-tech implementation systems, such as an HVAC system, in residential buildings and that a low-tech approach can be adopted in a reuse project in order to lower the overall energy demand of the building.

Contents

Motivation

We believe that sustainable architecture can be used as an active instrument to create impact on social inadequacy and climate change. In the past, it has been sufficient to design for the present, but today we need to design for the future. The phenomenon of exponential development combined with the complexity of the construction process, causes the needs for a paradigm shift and going from linear to circular approaches.

We will look into construction methods and passive strategies and rethink the way we use materials. Our aim is to create affordable housing through a low-tech concept to decrease the amount of resources and total energy demands used in the life span of the building.

Building performance calculations will help us to understand the complexity of the external and internal environments of a building.

Our master thesis is therefore an opportunity to investigate, test and develop some of the new approaches in sustainable architecture to challenge the industry and to rethink status quo.

The competition “Re-Stock London Housing” will set the frame for this work.

Competition brief

"London seems to be stuck in a continuous housing crisis with fewer housing units being built every year. The sale of local authority housing stock under the "right to buy" scheme has diminished the available housing stock even further.

The competition looks to revisit, reimagine, reinvigorate and rethink existing iconic council housing. Either by transformation, or by extension of an existing building, or by echoing their spirit with a new design.

Bold and creative design is needed to tackle the housing crisis, whilst honoring London's situation, heritage, and approach some of the urgent issues cities worldwide are facing today. Such as lack of community cohesion, high energy consumption, reducing carbon footprint, use of resources and food production. The design must be flexible enough to roll out to any location within London and increase the capacity of current housing stock." (BeeBreeders, 2020).

Perspective
Our Master Thesis uses the competition "The RE-Stock London Housing architecture competition" hosted by Bee Breeders as a starting off point.

Primary Perspective
We primarily focus on the issue of high energy consumption of buildings during its operational life stage.

Secondary Perspective
We will investigate and propose a possibility of reusing and transforming an existing structure to reduce the use of resources.

Methods

Our design process is based on the integrated design process (IDP) taught at Architecture & Design at AAU. It is a design process that unfolds various factors in the first process phase, to create a holistic and integrated process when designing a building. The factors are architectural design, functional aspects, energy consumption, indoor environment, technology and construction. The IDP is "combining knowledge from architecture and engineering in order to solve often very complicated problems connected to the design of buildings." (Knudstrup, M., 2006). We embraced the transdisciplinary factor of the IDP by dividing the main responsibility of the technical and the architectural roles between us, but with the premise that we both took part in both developments and agreed on key decisions.

The IDP consists of five phases; problem statement, sketching, analysis, synthesis and presentation (Knudstrup, M., 2006).

Our IDP applied secondary methods such as desk research, exploratory field study and case studies and consists of following phases; a project motivation and problem finding phase, our analysis phase, the iterative sketching and prototyping phase, the synthesis phase and the presentation phase resulting in the report and finally the oral exam. The key outcome in working with this model as opposed to a regular design process, is the early integration of the technical approach, which in this case included immense calculations on heat gain simulations, wind studies, shadow/daylight simulations and indoor climate analyses.

The IDP is partially based on a late development of Design with Climate (Olgyay, V., 1963) which refers to prioritizing climate and comfort before architectural functions. Focusing on the climate balanced house. The process of building a climate balanced house can be divided into four steps: Step one is to specify climate data of the location, regarding temperature, wind, humidity etc. Relevant information on this part can be found with the analysis of the project.

We worked with case studies in order to explore state of the art research and collect inspiration about materials, construction theory and organization of communities. The ground theory and case study in the architectural part are based on Jan Gehl's urban theory about using public space to create livability and healthier cities (Gehl, 2010) and the case study of Ainsworth Estate (p34), which we have chosen because of its significant way to deal with accessibility regarding the creation of communities.

Since the project is located in London city, England, the British regulations for construction are mandatory. These *aproved documents* are freely available online on gov.uk (ministry of housing, 2020). However these regulations do not yet have a methedology to asses overheating. only a limiting solar gain check is needed to pass building code. Therefore Ashrae standard 55-2017, as is provided by the online Thermal Comfort Tool (Tartarini et. al., 2020), is used as a method to determine the thermal comfort in the building. This method does not only focus on the overheating but also on the minimal heating demand.

The technical case study of 2226 (p30), provides knowledge about a low-tech approach that succeeded in creating a constant temperature between 22' and 26' in an office building, without adding technical appliances for heating.

FRAMEWORK

ill. 01: Farringdon road façade, own image.

Prologue

The Climate change has become one of the biggest challenges for our generation and the ones to come. The greenhouse gasses emitted by human activities is the leading force behind the global warming and has increased the average global temperature by 1 degree in 2017 since pre-industrial period. The change in climate will have impacts on ecosystems and organisms, as well as human communities and well-being. Such impacts include increased frequency of heat waves, rising sea-levels, more erratic weather, and disruptions to infrastructure. (IPCC, 2018)

The building and construction sector is responsible for almost 40 per cent of energy-related greenhouse gas emissions and therefore plays a crucial role in influencing the global warming. (GlobalABC, 2019). Within architecture this means we should not only reconsider the way we built, we should also rethink when to built new or when to renovate, as well as focusing on reducing the energy demand for constructing and operating buildings, which can be influenced, among other things, by building design, choose of materials and passive solutions.

One promising development is that of high-tech designed and low-tech build architecture. Focusing on using as much of the internal energy sources of the building and using passive strategies as much as possible. Only using energy consuming tactics where there is no other rational option. This results in buildings with lower energy demands and improved longevity with no need of renovation of active systems after 25 years.

With this project we want to tackle the increasing technical complexity of buildings, especially for residential housing, investigate possibilities of renovating old structures and adapting the low-tech methodology to lowering the overall energy demand.

Design with climate

THE BEGINNING OF ADAPTIVE THERMAL COMFORT

The concept of vernacular architecture has transformed the status quo of sustainable architecture. It involves the use of green architectural principles, such as recycled and energy-efficient materials among others. These buildings often consider climate responsiveness and cultural values through thermal comfort features and, therefore, they incur minimal costs and maintenance (Chandel et al. 2016).

In the 50's the Hungarian architect, city planner and pioneer in bioclimatism Victor Olgyay introduced his design theory of Architecture and climate, which builds upon the concepts from vernacular architecture. The book *Design with climate* (Olgyay, 1963) describes the relationship between buildings and the surrounding climate together with the influence of climate on building principles. Olgyay believed that the architectural expressions should be drawn upon other sciences, as an integrated approach. He suggests applying a biological approach to identify the requirements and aims for comfort, the meteorological science to review the climatic conditions and the science of engineering to investigate the rational solutions. With his bioclimatic design approach, he developed a chart to illustrate the human comfort zone for moderate climates (ill. 02). His further investigations into architecture share the common goal of reaching a comfortable indoor climate as depicted in the graph by clever design. Olgyay shows a different design approach where the architecture and construction are used to create a comfortable indoor climate.

Olgyay's research and bioclimatic chart has set a basis for sustainable architecture and thermal comfort design. A basis that AAU's IDP is also building upon, in particularly in terms of implementing a technical part in the design process. Where Olgyay's approach is to prioritize the technical foundation, the IDP balances it out 50/50 through an iterative transdisciplinary process and considers the technical, socioeconomic, and environmental factors (Knudstrup, M., 2006).

Nowadays, buildings are generaly designed for a set indoor temperature, however studies have shown that humans can live comfortable between 15 and 35 degree Celsius. This indicates that the indoor temperature of buildings could change up and down in relation to the outdoor conditions, giving a potential lower demand for heating and cooling (Hellweg et al., 2019). People instinctively adapt to the indoor climate by interacting with the conditions of their environment, therefore if a change occurs that would generate discomfort people react in ways that would give back comfort (Nicol and Humphfreys, 2002). There several ways in which occupants can interact with their environment, clothing, openable windows, fans and shades are examples of this. This behavior in combination with access to building controls enables occupants to accept a wider range of indoor temperatures (Leaman and Bordass, 1999). The adaptive thermal comfort is based on these principles by giving a range of temperatures that would be found comfortable given the outdoor temperature.

Ashrae standard 55-2017 as is provided by the online Thermal Comfort Tool (Tartarini et. al., 2020) will be used throughout this report to determine the thermal comfort of the occupants in the design.

Low-tech vs high-tech

In the last decades, many countries have highly increased the legal requirements for energetic construction quality to meet the latest energy regulations. Stricter regulations have led to new buildings with less heat loss to the building envelope and an increasing implication of technology. Besides, the development of new building materials has made many new shapes possible.

Under the paradigm of technology will solve all our issues, many new approaches took the path of integrating sophisticated building technology and therefore increased the complexity of the buildings regarding planning, building, and operating.

High-tech buildings are more likely to be associated with complicated and prize intensive construction methods and building technology and extensive functionality. Technology can increase the performance of the building and consequently improve its efficiency. Nevertheless, efficiency can only be reached through more precise planning and executing, and therefore requires many people involved in the building process, which creates the challenge to ensure the right quality in each step.

However, the user's comfort requirements concerning different temperature requirements, summer heat protection, and controllability have not always been sufficiently implemented. Many technical components are challenging to control, consume more energy during production, and increase both the construction costs and the buildings' final energy requirements. Additionally, the more complex processes in service and maintenance require a high level of specialist knowledge for a more extended period, and a shorter life expectancy for building technology is considered likely. (Ritter, 2014)

Moreover, the interaction between occupants and systems is leading to unpredicted outcomes often related to response time and misunderstanding of the system. (Bordass & Leaman, 1997)

By reevaluating and questioning the necessity of the ongoing increasing complexity of the built environment, other methodologies concentrating on Low-Tech principles gained more interest. Low-tech buildings utilize simpler, more robust principles, and, therefore, longer-lasting construction methods and building techniques. Associated with these attributes are assumptions about lower costs and little technical effort regarding production, operation, and maintenance. Low-tech architecture make buildings less dependent on the use of technologies, as these are associated with susceptibility to failure, with maintenance costs that are difficult to calculate in advance and high consumption. Low tech architecture stands for thoughtful design, taking local conditions, material properties, and inter-relations into account. (Ritter, 2014)

Thus it can be summarized that in contrast to high-tech architecture, low-tech has the goal of achieving sustainability and energy efficiency through simple systems, a smarter choice of materials, and natural operating principles. As a side effect, it forgoes complicated user interactions to make the building easier to manage.

Also, the use of low-tech is not necessarily the more primitive approach, because it is not terminating the use of smart solutions, which are made by the newest research and scientific findings. However, to ensure high comfort in a low-tech building, the planning process is often higher, e.g., due to calculating and adjusting the building to the local climate. (Ritter, 2014)

Therefore, the term low-tech can be understood as a planning philosophy that consciously questions the use of high-tech or wants to reduce the proportion of high-tech installations in buildings to the bare minimum.

Natural Ventilation

The forces of buoyancy and differences in air pressure can be used to ventilate buildings naturally, without the aid of mechanical systems. In order to accomplish this, the shape and architecture of the building must be designed to work with the forces of nature.

With the two forces many different solutions can be designed. Though all of these solutions are derived from four key principes; single sided ventilation, cross ventilation, stack ventilation, and atrium ventilation. Depending on the size and location of openings, natural ventilation comes with a risk of uncomfortable airstreams. Therefore a few principles should be kept in mind to design a good indoor climate with natural ventilation (Yang, Derek, & Celments-Croome, 2013):

- Some parts of the body (i.e., ankles, back of the neck) are more susceptible to draft.
- Temperatures should vary within a vertical gradient limit, higher level of warmth being preferable at below knee level rather than at head level.
- For freshness higher air velocitys are required at higher temperatures, an air velocity change of 0.15 m/s being equivalent to a change of about 1C in temperature. Air at a lower temperature and relative humidity of 40–60% (i.e., air with a lower enthalpy is perceived as

fresher than air with a higher enthalpy).

- Above the head, the convection air velocities can be 0.25 m/s or higher depending on the occupancy density and also the amount of artificial lighting.
- Air movement helps to dispel a sense of stuffiness.

The exterior of the building plays an important role in the possibility of ventilation openings in the building. Different shapes generate different presure zones creating several options (ill. 02). Thus the shape of the building must be designed together with the ventilation paths in the interior.

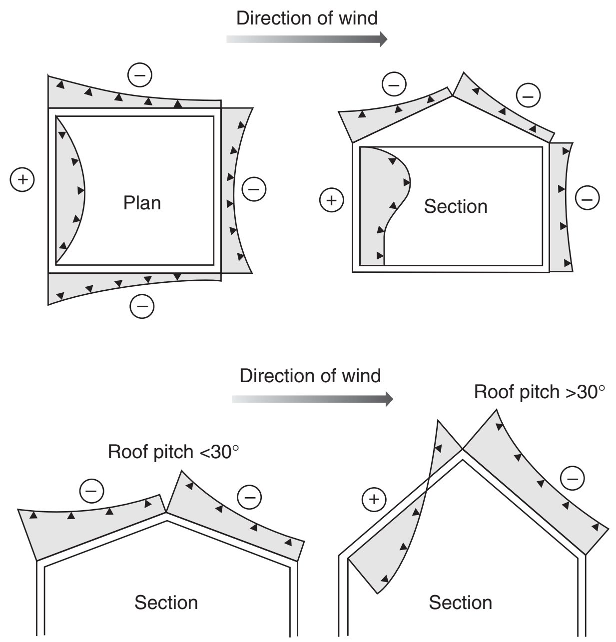
This gives a few design principles for the project. Depending on the temperatures, high air speeds should be avoided at the height of body parts that are more susseptable to drafts. And the windpressure distribution on the building skin should be taken into account when placing the openings for natural ventilation.

Thermal Mass

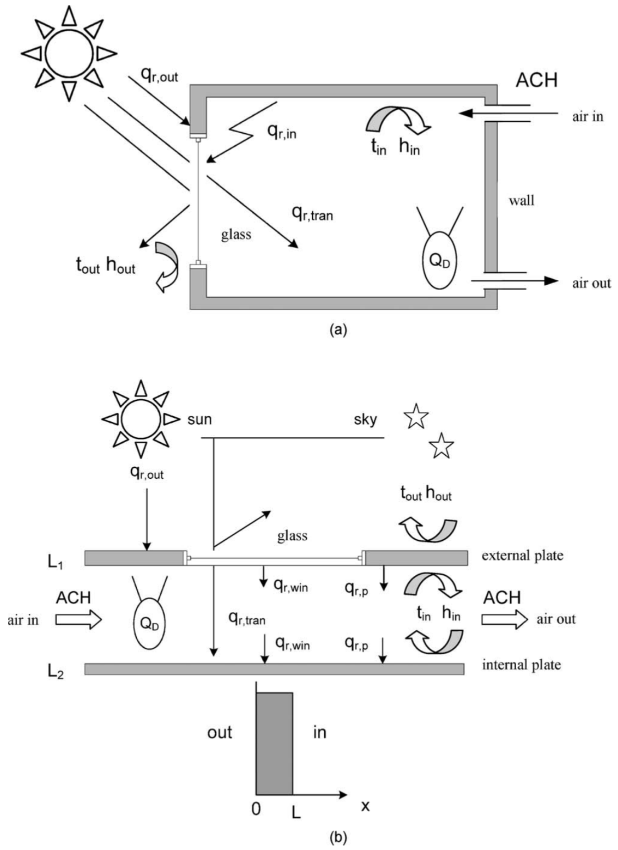
Traditional building methods work from a known architectual building where HVAC systems are implemented afterwards. With these traditional methods we work from information that is unknow in the design stage towards a goal that is known in the design stage of the building. A different aproach is discussed in the paper "New concepts and approach for developing energy efficient buildings" (Zeng et al., 2010). In this thermal mass is descriped as one of the key factors to do the opposite. To work in the design phase of the project to the known endgoal; a known thermal comfort demand.

To do so a series of formulas are suggested. These formulas depict a simplified two-plate room model (ill. 03) that help the designer to optimize the amount of thermal mass, in relation to the locations climate, the architecture and the required indoor thermal comfort. Comparisments with fully calculated roomsimulations show that the simplified model has a margin of error of less than 11% (Zeng et al., 2010). Making this method a viable starting point for the design of a thermal mass based social housing project.

The simulation program Diva4 is an interface for Energy Plus 8 that calculates following the simplified two plate model.



ill. 02: Windpressure distribution on buildings (left) Wind pressure on building (right) Wind pressure on roof, image by Yang et al., 2013.



ill. 03: A more simplified plate model vs a full room model, image by Zeng et al., 2010.

Adaptive reuse

Today's city planners and occupants desire environmentally sustainable and vibrant communities. Resourceful and innovative strategies for the built environment and existing buildings are crucial to achieving future sustainability.

Adaptive reuse has always been connected with the history of ancient monuments and the development of policy to preserve heritage. Nevertheless, in the last decades, the focus on sustainability has brought a shift in this division of adaptive reuse (Wong, 2016). One approach to reducing a buildings' environmental impact is to adapt them rather than demolish or build new. Adaptive reuse is a way to convert a building to a new purpose because its original function is no longer relevant or needed.

The relative costs, related benefits, and constraints of reuse versus demolition and new built have been widely discussed. Increasing the lifespan of a building through reuse can lower the use of materials, transportation, overall energy consumption, and lessen pollution during construction and, thus, significantly impact sustainability (Munarim & Ghisi, 2016; Bullen, 2007). Research has shown that it is potentially cheaper to adapt than to demolish (Shipley et al., 2006).

By contrast, demolishing discards the potential of the already available resources. As such, in addition to cultural value, the existing built environment has a physical and economic value. Given that 70 to 80% of the built environment in 2030 is already built today, reveals that there is significant potential in adaptive reuse (Cramer & Breitling, 2007).

Architectural factors to consider are dimensions, proportions, and relationships between elements, as well as materials and construction techniques, to determine the identity of a building and thus constitute limitations to its transformation. Careful identification of exterior and interior architectural elements is needed in order to define the building's identity and assess the impact of the changes required by the new function. Nevertheless, the choice of the new function must also consider the goals of economic and social enhancement, notably in terms of the effects of the reuse on the urban environment (De Medici et al., 2017).

Community and Neighbourhood

The city is a place where people meet to exchange physical and mental resources - a place of interactions, diversity, activity and unfolding experiences. It is a continuous process were the city's public domains - the streets, parks and squares - are the catalyst for these activities. But as any scenery it is never interesting without the life.

As Gehl describes in *Life Between Houses* even the most beautiful building or interesting city cannot stand alone without its local and regional citizens and tourists. This is more clear than ever after the pandemic of Covid-19 occurred and we see many cities with very few or no people. With empty streets and squares the city seems to have lost its magic. As Gehl also observed in his studies and later on described - people attract people.

"Wherever people stay in houses, in cities, in recreational areas etc., it is a common feature that people, and human activity attracts other people. People orient themselves towards people, they stay and meet with others, place themselves close to others, new activities happens near events that are already underway" (Gehl, 2010)

The role of humans in the city's domains have changed radically throughout the history and the way we 'think' cities has changed as well. The trends of modern planning in the 21. century is a higher focus on livability and healthier cities as well as pedestrians, cyclists and better public transportation. As Gehl describes in 'Cities for people' 2010, living, safe, sustainable and healthy cities have become a general and important desire.

As the city exists of many networks of public domains it also exists of many networks of buildings. In a city one building can never stand-alone - it will always be seen in its context of other buildings and in its surroundings. Even the multifunctional building that contains many urban activities and meetings must relate to its context to unfold its potential to be a part of the city. As a part of reformatting the old car park the construction will undergo a transformation from a monofunctional building towards a building obtaining many new functions and therefore many new types of users.

As Gehl describes human interactions attracts even more people and that also creates a safer and social healthier environment. The possibility to often meet neighbours or co-workers outside of to the daily flow creates a valuable possibility to create and or strenghten social relations in informal settings. By being in and observing our environment we create confidential relationship to our context through the social knowledge we gain in our daily life. And as Gehl describes we must create spaces where it is safe to observe and participate in the scenery (Gehl, 2012).

Costs and energy

THE OBVIOUS AND HIDDEN TRUTH

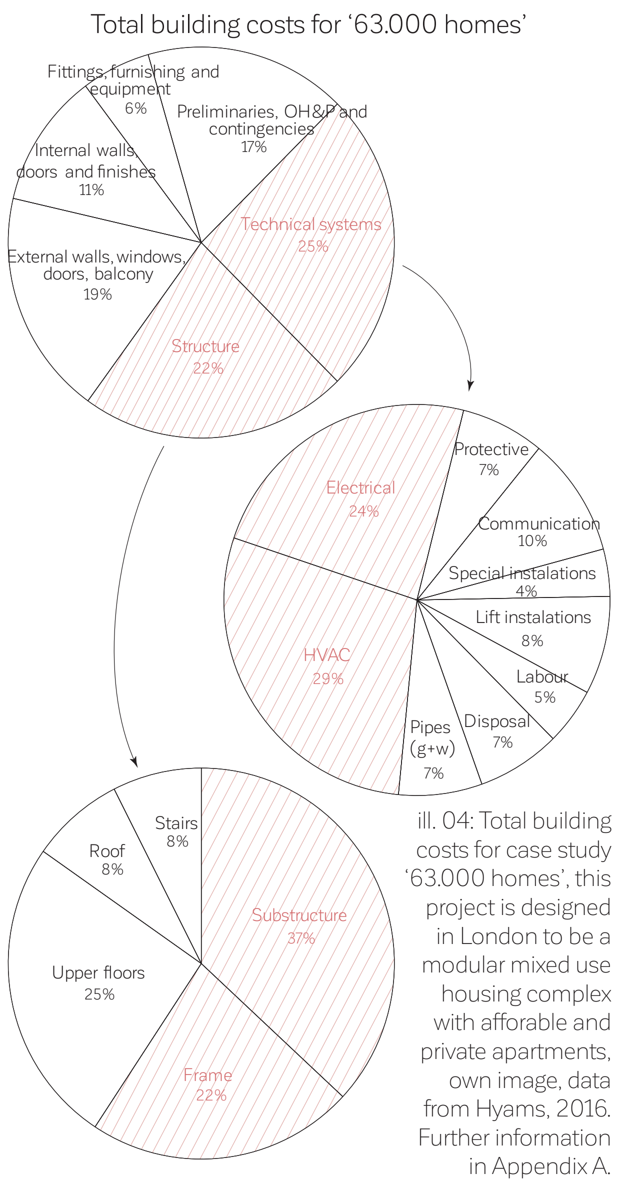
The building industry is getting more and more complex, in an effort to save more and more energy. Walls are packed with insulation and complex ventilation and heating systems are used. At the same time cooling systems are being installed in climates that would not suggest the need for them.

Building costs

A case study of '63.000 homes' (Appendix A) shows that the total cost for technical instalations in affordable housing can be up to 25% of the total building costs (ill. 04), making it the biggest expense for new houses. Of this 25%, 29% is being put into heating and ventilation. another 24% is put into the complicated electrical wiring of the apartments and of these systems.

And that is only the cost of purchase for these systems. They also require the use of specialized subcontractors, which comes with an labourcost increase of 16% per hour (PropertyData, 2020). Further it increases the need for special materials and complicates the detailing and planning of the construction. These are top factors that lead to construction delays (Odeh & Battaineh, 2002).

The second biggest cost lies in the structure of the newbuild building. 22% of the construction costs are used for the structure of which 37% is used for the substructure and foundation (ill. o3).



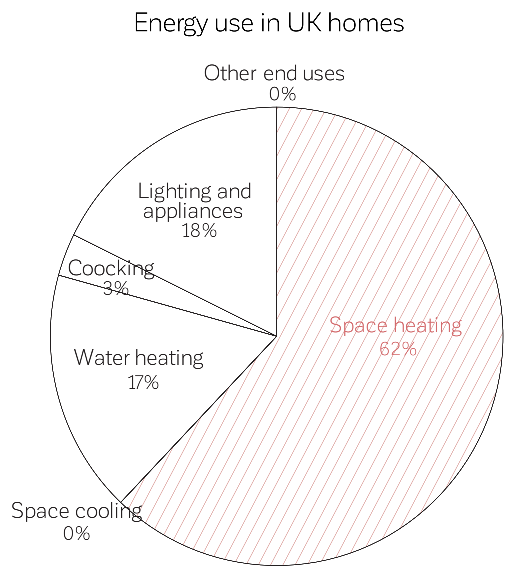
ill. 04: Total building costs for case study '63.000 homes', this project is designed in London to be a modular mixed use housing complex with afforable and private apartments, own image, data from Hyams, 2016. Further information in Appendix A.

Running and Maintenance

After instalation HVAC systems need to be maintained. Generaly the air handling unit and special components need to be inspected by a specialist once a year. With filter changes between 6 months and a year, depending on the buildings location. The total lifespan of typical HVAC systems is 25 to 35 years. After this time the systems need to be retrofitted or replaced with a complete new system. Sometimes components can be replaced when broken but replacement parts are not always available, or are outdated. Again this has te be done by specialist constructors that are 16% more expensive per hour than general constructors.

The running costs of todays buildings are primarily focused on heating. Statistics from Eurostat show that 62% of the energy used in UK homes is used for heating (ill. 05). The primary energy source for heating is gas at 74.5% (Eurostat, 2019).

In order to decrease the maintenance for technical systems and energy use for the building, an effort will have to be made to decrease the amount of technical systems drasticly and reduce the heating energy demand of the building.



ill. 05: Energy use in United Kingdom homes in 2017, own image, data from Eurostat, 2019

England's council housing in a nutshell

Throughout the history of housing in England, Labour voters lived in council houses and Tories owned their own homes. It was not until the "right-to-buy" regulations that were put into place by Margaret Thatcher in 1980 that the average family was able to buy their own home. Fulfilling a longstanding conservative dream of creating a "property-owning democracy" (Wheeler, 2015).

Council housing started in 1918's with the introduction of the Housing Act. This enforced local authorities to provide council housing to the public (Bee Breeders, 2020). Though council housing really started to take off after the second world war with a big shortage of homes due to the destruction during the war (Wheeler, 2015).

During the 1970s homeownership became more and more realistic for the working class. Mortgaged homeownership became a central element in consumer culture. Coincidently the *fiscal crisis of the state* in the mid-1970s forced the government to cut back on investment in maintenance, improvements, and development of council housing (Ginsburg, 2005).

This political environment made way for the *right to buy act* introduced by Magarath Thatcher in the 1980s. This act enabled homeowners to buy the council houses they were renting from the local governments at a greatly reduced market price. Two million apartment tenants made use of this policy to buy the council houses they were renting. This greatly reduced the available stock of council housing. Especially since the cutting on funds from the government prevented the local authorities to use the income from the sales to build new council accommodation (Wheeler, 2015).

The total sales of stock reduced from the 1980s until 2010, after that the government decided to lower the qualifying period to 3 years of residence and increased to a discount between £75,000 to £100,000. Still, with the decline of council housing stock, England did not manage to reach the necessary 250.000 new council homes built by 2014, which the Barker Review of Housing Supply said was required (Wheeler, 2015).

For the 2015 elections, all the major parties had different promises regarding council housing. But all of them were promising an increase in new homes built and further discounts for first time buyers. All of these promises would put further strain on the housing construction industry to build more houses for less.

Londons strategy

With the housing crisis being so severe in London the politicians have stepped into the game. The mayor of London, Sadiq Khan, has made a Strategy Plan for 2018 and onwards to cope with the housing crisis in London.

The lack of housing in London specifically does not come from the lack of houses being build, but is also caused by a surge of jobs availabile in the area. Inbetween 1997 and 2016 the number of jobs grew by 40 percent to 1.6 million. This has been accompanied by a population growth of 1.7 million people, an increase of 25 percent. Meanwhile, most of the housing construction relied on the private sector resulting in just 470.000 homes added to the London housing stock in the same period (Khan, 2018).

The worsening situation of housing stock has resulted in house prices and rents rising rapidly, with more than a quarter of Londoners living in poverty once housing costs are taken into account (DWP, 2017).

This has lead the Mayor to take on five priorities to tackle the current housing issue (Khan, 2018):

- Building homes for Londoners.
- Delivering genuinely affordable homes.
- High-quality homes and inclusive neighborhoods.
- A fairer deal for private renters and leaseholders.
- Tackling homelessness and helping rough sleepers.

From these five priorities, several policies emerge. A few noteworthy policies are:

- Diversifying the homebuilding industry: To increase levels of homebuilding in London, a broader diversity of homes should be built that is affordable to more Londoners. Identifying and bringing forward more land for housing: London's current land-use policies, have failed to bring forward enough sites for building new homes. Therefore more government-owned land will have to be devoted to housing projects, and housing projects should aim to densify. In order to protect the Green Belt.
- Improving the skills, capacity and building methods of the industry: At the moment, there are not enough people with the skills that London's construction industry needs, nor enough people who want to choose it for a career.
- Meeting London's diverse housing needs: Homes must be developed with the needs of all Londoners in mind, this means more homes for families and minorities. Such as elderly and disabled.

When building affordable housing within central London city, the focus should be on homes for families and elderly, keeping accesability of the apartments high for disabled.

ill. 06: Photograph of 2226, image by Hueber, 2013.

ill. 07: Answorth estate road, image by Codrington, 2016.

Going back to basics in 2226

Date completed:	2012
Location:	Lustenau, Austria
Architect:	Baumschlager Eberle
Floors:	6
Floorsize:	410 m2
Typology:	Office

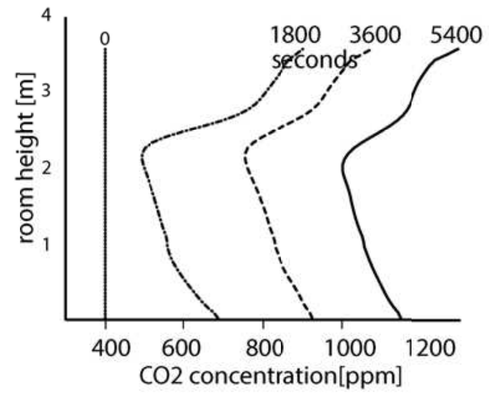
At the foot of the Austrian alps stands the office of Architect Dietmar Eberle. An office building without a central heating system, without a HVAC system and with 72 centimeter thick brick walls.

The system

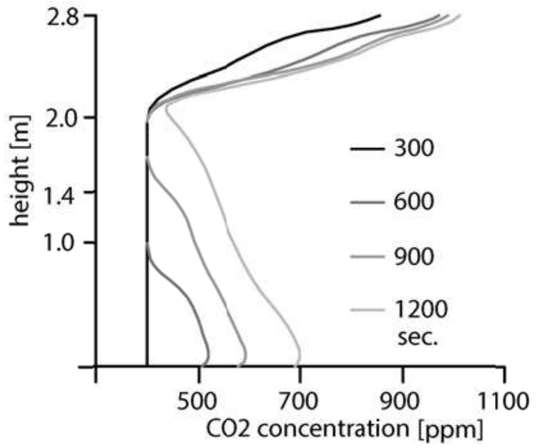
Dietmar Eberle designed the building as a response to the current increase of incorperation, and ever increasing complexity, of HVAC systems into offices and homes alike. 2226 goes back to the basics and solves climate control in a natural way. To prevent the need of an HVAC system or a central heating system the building relies on buffers, internal heat gains, solar gains and natural ventilation.

There are two buffers used to capture and control heat, moisture and CO_2. Buffer one is a homegenous construction with 72cm thick brick walls (ill. 13). The brick in the construction buffers heat and moisture, and with a u value of 0,1W/m²K and 0,5W/m²K for the windows, (Junghans, 2015) very little heat transfers from the indoor climate to the outdoor climate and vice versa. During cold periods the bricks can disapate the captured heat to the indoor enviroment to warm the building. The second buffer is the application of 3,4 meter high ceilings. The extra height allows for longer periods without ventilation since the higher temperature of the expelled air causes the CO_2 to rise, where it will slowly cool down and flow allong the walls to the floor (Junghans, 2015). It will therefore take longer for the room to reach a 1000ppm CO_2 level at breathing heights (ill. 8 and 9).

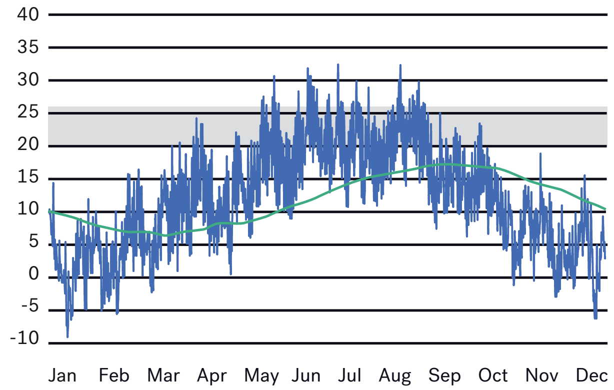
These buffers allow for short and intermitted natural ventilation. A central server uses a series of sensors throughout the building to monitor the levels of H_2O and CO_2. Aditionally a weather station on the roof monitors the outside climate (ill. 14). Using this data the server controls motorised vents throughout the building to naturaly crossventilate the building (Eberle & Aicher, 2016). Short durations of ventilation keep the drop in temperatures low, drops that the buffered heat in the walls can heat up again. The climate control of the building, using buffers and natural ventilation, is ballenced against the heat gains of the office building (ill. 13). These heat gains are caused by the occupants and their behavior, the appliences they need and use, and the sunlight that enters the building.



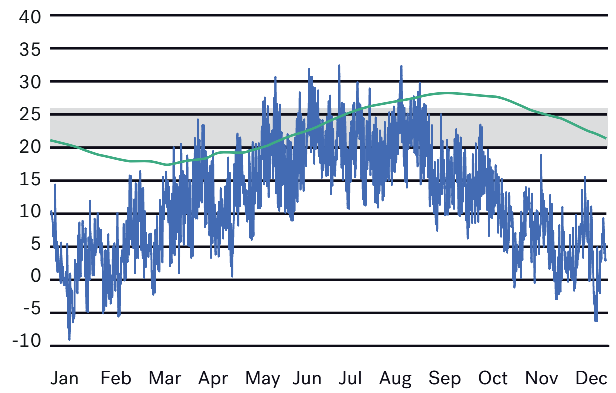
ill. 08: Simulation data for the CO_2 concentration at different height levels in the room in different time steps, image by Junghans, 2015.



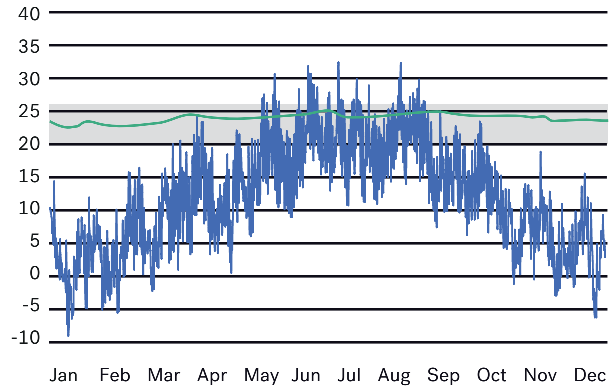
ill. 09: Measured data for the CO_2 concentration at different height levels in the room in different time steps. (The CO_2 sensor does not illustrate data below 400ppm), image by Junghans, 2015.



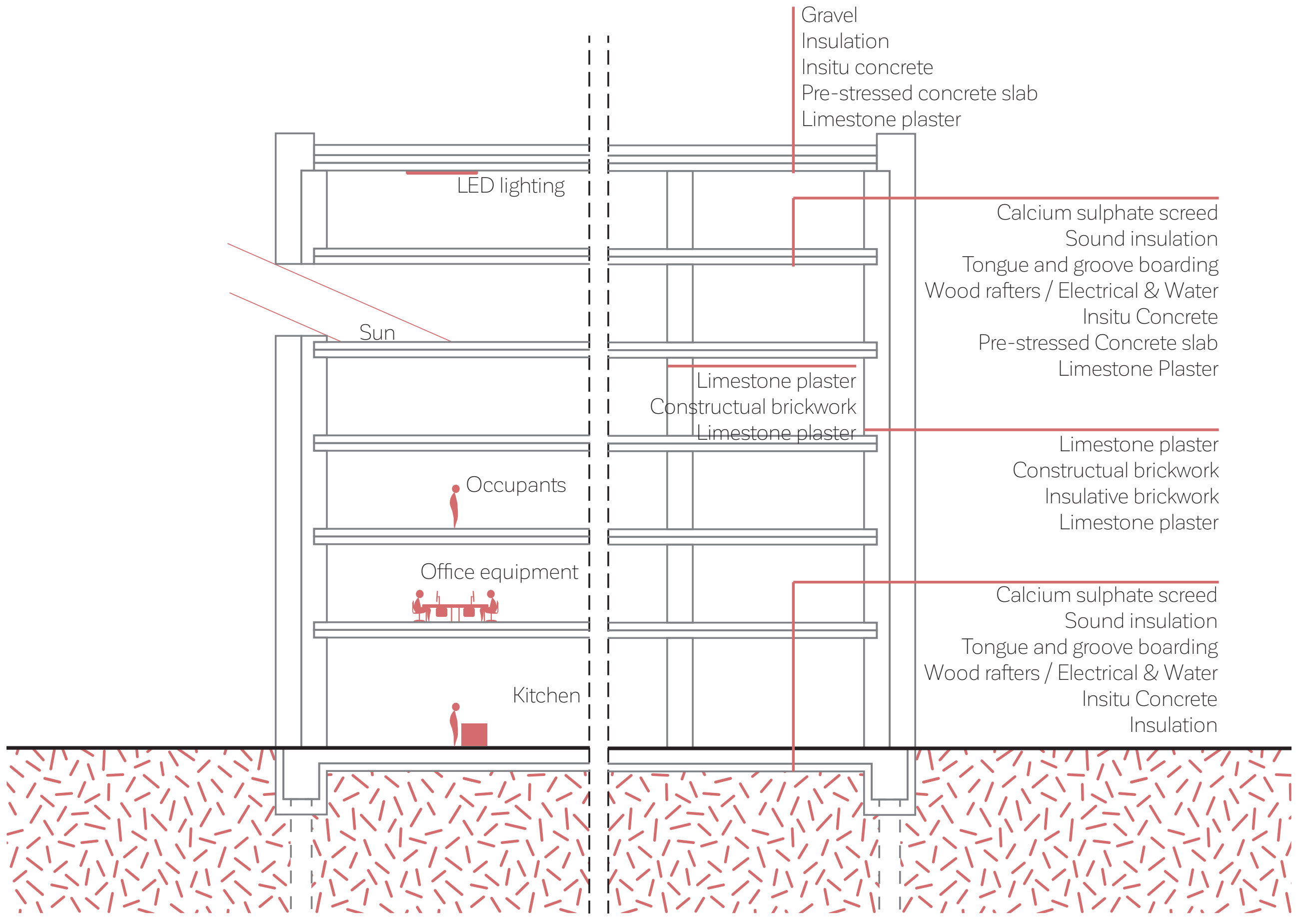
ill. 10: External (blue) and internal (green) temperatures of 2226 empty. image by Eberle, 2016.



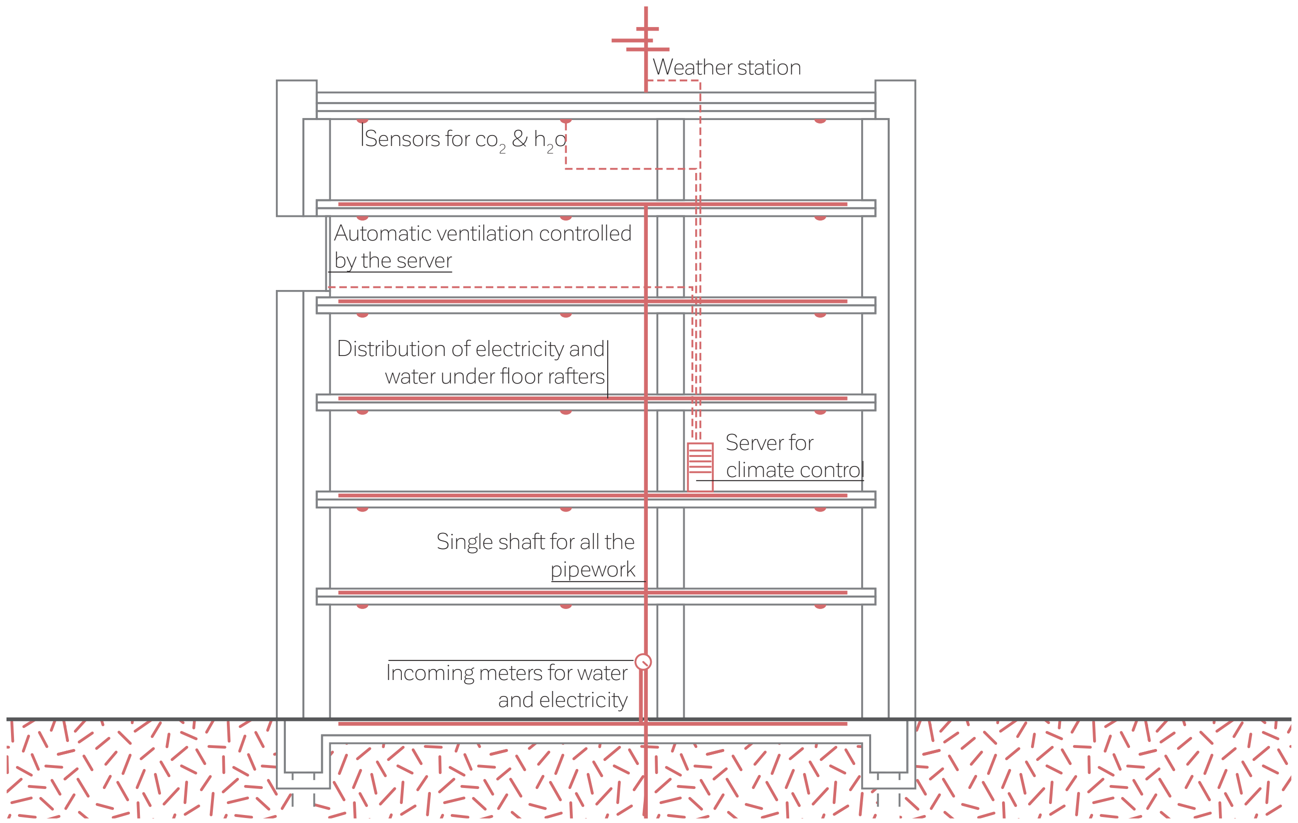
ill. 11: External (blue) and internal (green) temperatures of 2226 without control system, image by Eberle, 2016.



ill. 12: External (blue) and internal (green) temperatures of 2226 with control system, image by Eberle, 2016.



ill. 13: Illustration of gains in 2226 on the left and the construction of 2226 on the right, own image.



ill. 14: Illustration of the technical systems in 2226, own image.

Construction

With the lack of HVAC and other heating systems the amount of specialist subcontractors on the construction site is minimalized. This could help with Londons specific problems in the construction market as stated on page 26.

The selection of materials is chosen for their properties, enviromental impact and cost. this has lead to the use of brick, cement, steel (rebar), glass, limestone, calcium culphate, sandstone, and oak wood. The details are mostly designed using only these materials with insulation materials only used where absolutly neccecery.

Results

As a result of the simple but thought through climate control the building only uses 38 kWh/m^{2}a. In comparison offices with an HVAC system can use up to 136kWh/m^{2}a (Eberle & Aicher, 2016). In terms of mainenance there are no mechanical systems that would have to be revised after 20 or 30 years. Also, all the sensors and vents are constructed using readily available elements that are easy to repair and maintain (Eberle & Aicher 2016).

The internal temperatures swing between 22 and 26 degrees all year round (ill. 12). Even though these temperatures seem to be in a comfortable range, no information is provided regarding the adaptive thermal comfort level of the indoor climate. Though a internal study unrelated to the exterior climate shows that 2226 has and IDA of 1 (high room air quality) according to the European indoor room specifications (EN 13779) (Eberle & Aicher, 2016).

2226 shows how low tech stratagies as thermal capacity, internal heatgains and intermitted natural ventilation can help to reduce the energy usage in the build enviroment. Further it shows that by carefull consideration of building materials the construction details can be simplified greatly with a minimal usage of dedicated insulation materials.

Answorth Estate, 70s architecture

Date completed:	1978
Location:	Camden, London
Architect:	Neave Brown
Area:	6.47 hectare
Units:	522
Typical unit size:	63 m2
Typology:	Social housing

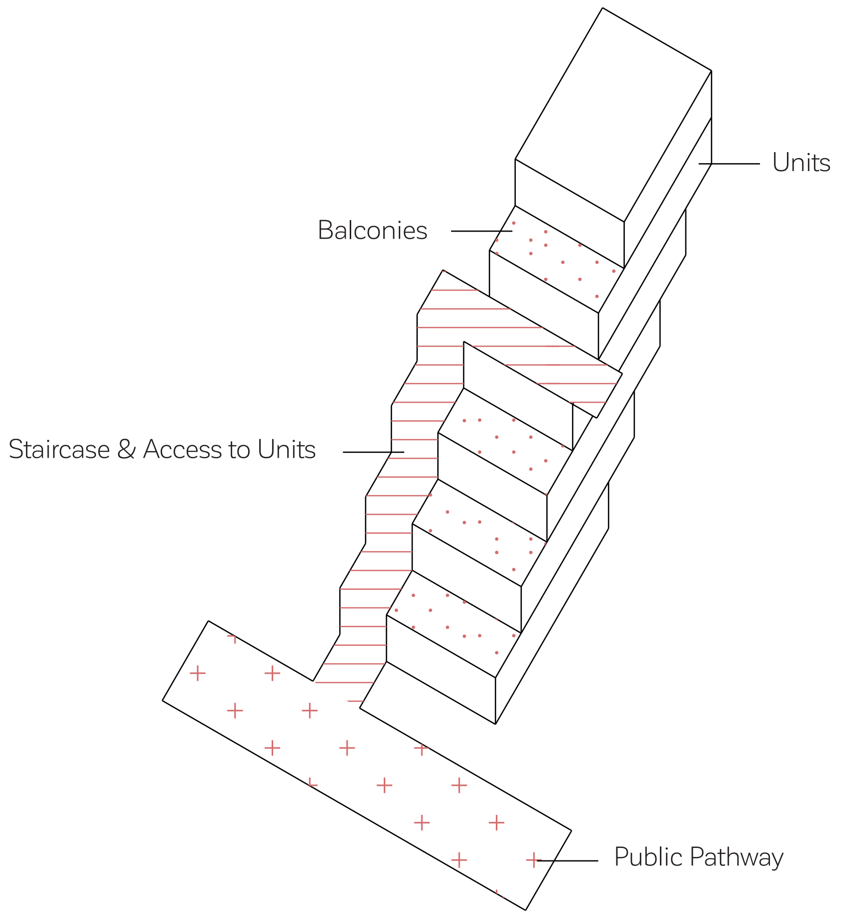
Alexandra Road is an example of the 70s modernist architecture, which embraced the heritage of the terraced house typology and responded to the needs of high density living at that time.

The estate has a continuous frontage along the railroad to the north. The site contains three parallel rows of dwellings, organized along two pedestrian streets and incorporates a 1.16 km2 sized park. The seven-story-high row to the north is designed to block out the noise from the train followed by the other two four-story-high ones. In addition, it offers a cluster of community services, including a community center, school, shops, a youth club, a children center, and parking space below.

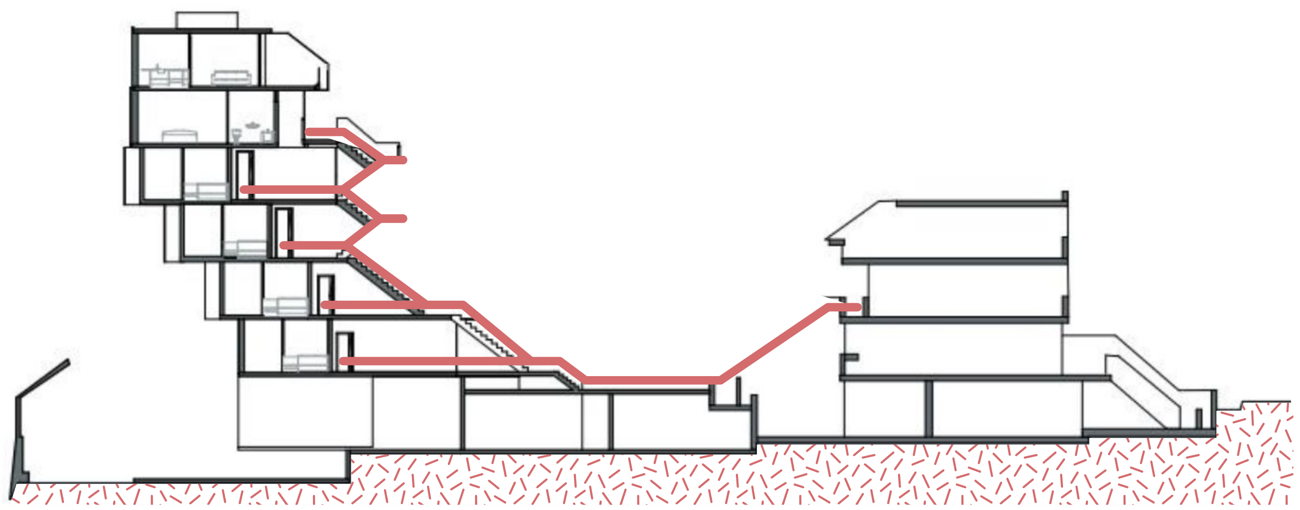
The units in each block are based on a terrace model; some are offered a back garden and all have acces through staircases connected to the shared pathway. The staircases are architecturally defined as the vertical and spatial extension of the pathway, occupying voids between the terraced units. For the concept, it was fundamental that every unit was accessible from that street; strengthening the community. The staircases are highly articulated and have the same public status.

The estate includes three different types of units with one to three bedrooms, all oriented south or south and north. Most are single-floor apartments, except the top ones, which are duplex apartments. The layouts are consistently repeated. Nevertheless, the interior architecture gave space for personal adaptation.

The shared pathway is the core of the design and will taken as inspiration for our project. Accessing every unit from this elevated pathway creates a safe feeling for the residents and visitors. The lack of motorized vehciles on this street futher enhances that feeling.



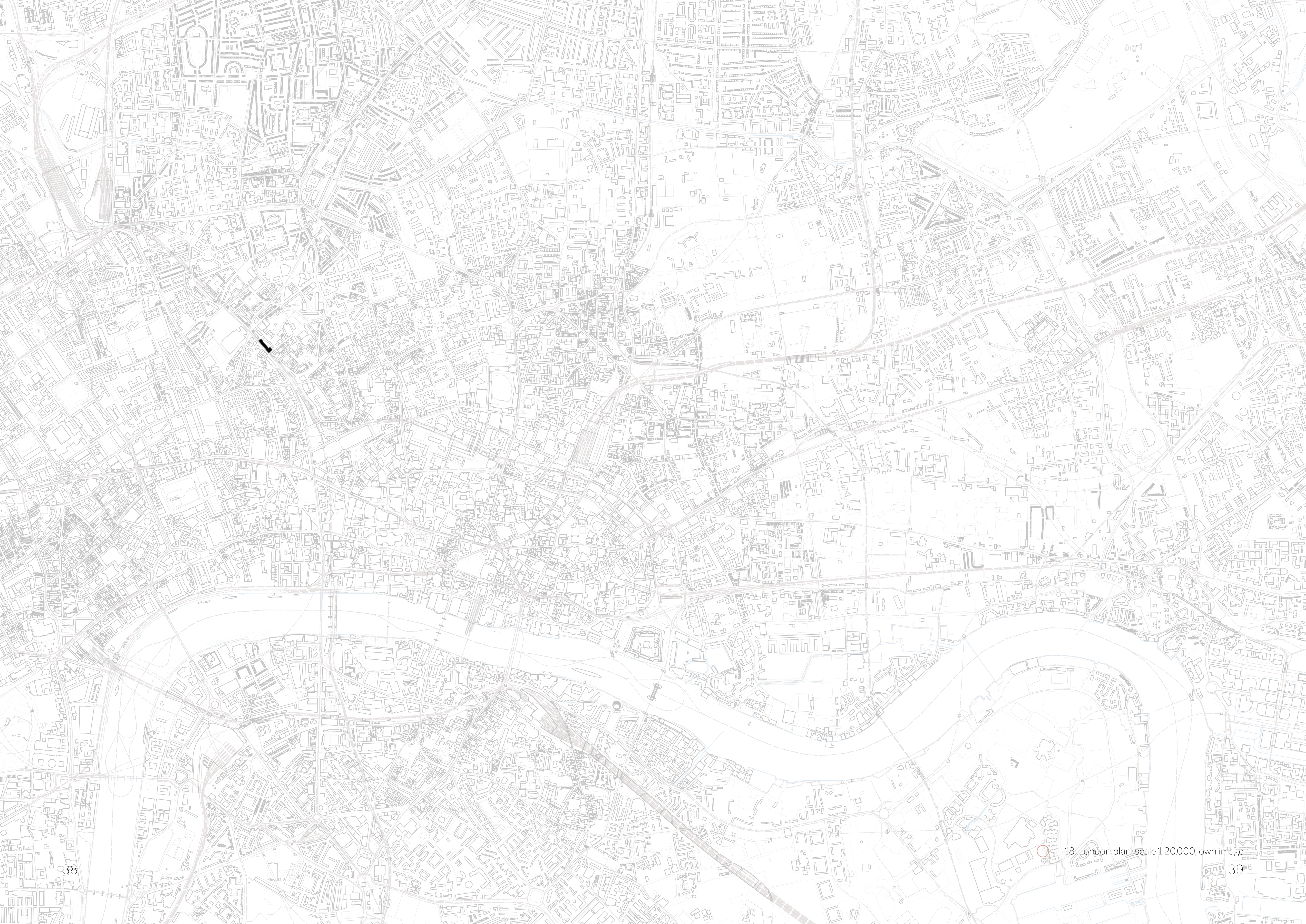
ill. 15: Diagram, Apartment acces from the shared pathway, own image



ill. 16: Section, Accessibility from pathway, own image

ANALYSIS CONTEXT

ill. 17: Farringdon station sign, image by Davis, 2014.



ill. 18: London plan, scale 1:20.000, own image

Location

The green belt around London must be protected from large scale housing construction to conserve flora and fauna around London. To do so the Mayor of London has put densification as one of the main priorities in the housing strategy of 2018.

With the densification, care has to be taken in regards to accessibility. New projects should not be reliant on transport by car but should focus on having local amenities and public transport within walking and cycling distance (Khan, 2018). This makes the choice of location of a significant factor to reduce the carbon footprint of households, helping London to become a zero-carbon city.

Car garages are within these walking distances of amenities and/or public transport. Also with the focus on decreasing the use of cars in the inner city on London, many of them have been decommissioned. This project will focus on a specific decommissioned parking garage on Farringdon Road. But the project has the aim to be applicable to other similar build parking garages.

Islington

The site is located in the most south western part of the borrough Islington, almost on the border with the borrough of Camden. Clerkenwell, the southwesten reagion of Islington, is an older parish from London's medieval years. In recent years the area of Clerkenwell has been subjected to major interventions. The railway was constructed. Rosebery Avenue has been cleared and space was made for the construction of modernist housing estates after the war. And is now well known for loft-living young professionals, nightclubs, restaurants and art galleries. It also houses many creative professions and business offices that focus on architecture and design (Foxtons, 2019).

ill. 19: Excisting parking garage south view, image by Sheppard Robson's, 2015

Climate

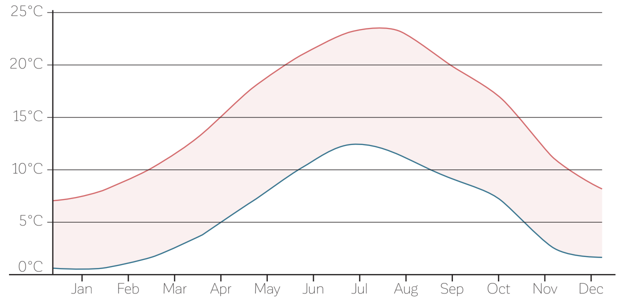
Conventional buildings with HVAC systems have a predicted life span for the systems of 25 years. A low-tech building has the potential to stand for over 100 years. The climate system of a low-tech building is embeded in its architecture therefore it is vital that this system responds correctly to the current and future climate.

The local climate will play a curcial role in indoor comfort simulations for the building. To design with the climate, climate change scenarios will be taken into account to evaluate the buildings preformance in the future. Of course, it is still necessary to be critical about the outcome. The complexity of the climate and its system will call for many uncerntenties. The program used for the transformation is CCWeatherGen, based on the paper *Climate change future proofing of buildings* (Jentsch et.al., 2008).

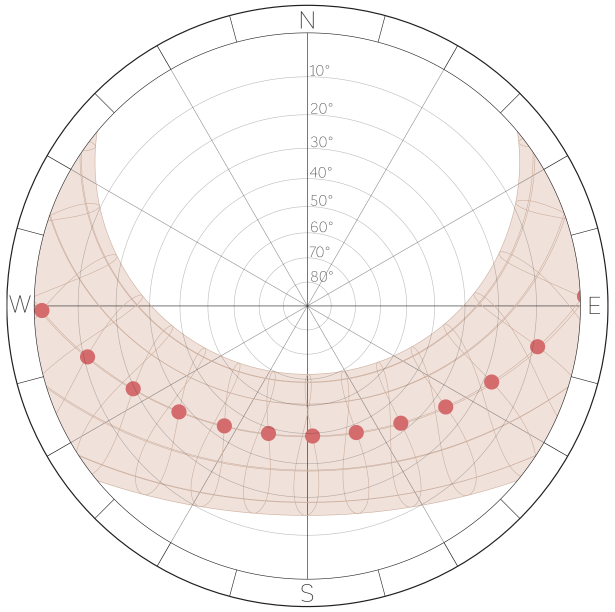
Just like most of western Europe, London has a temperate oceanic climate. Giving relativly warm winters and moderate summers. Though the heat island effect can give an increase of 6.0 to 8.7 degree celcius in high density build areas and an -1.5 to 0.5 degree celcius increase in urban green areas (Holderness, et.al., 2013).

The sun travels through the sky to 62 degrees at summer solstice and dips down to 15 degrees at winter solstice (ill. 22). This low angle might give some issues regarding solar heatgains and solar acces to surrounding buildings in winter. Especially the houses east of the site must be taken into account should we add additional height to the building. The wintermonths give just a few direct sunlight hours per day, but the summermonths make up for this with at least 6 hours of sunlinght in May through to August (Ill. 21).

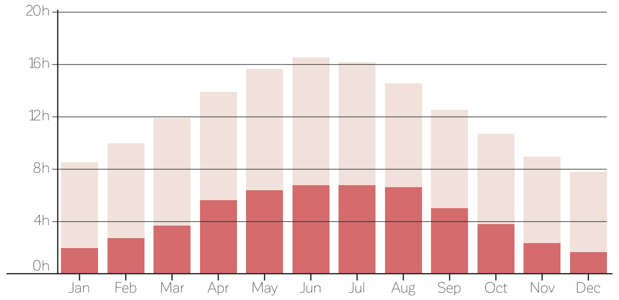
The wind is predominantly from a southwest direction (ill. 25) bringing in plenty of precipitation from the ocean. On average 52mm of rainfall hits London every month (ill. 23). The driest period stretches from Februari untill August with a significantly wetter period the rest of the year. These periods can be seen in the realtive humidity that shifts from 65% to 85% depending on the season (ill. 24).



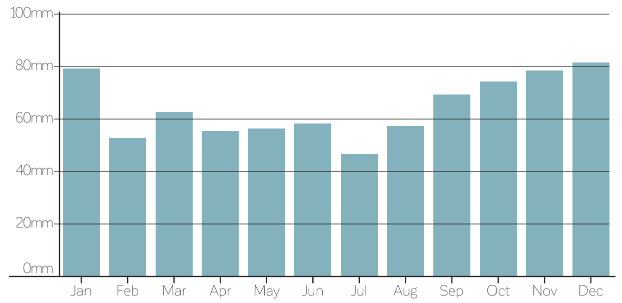
ill. 20: Monthly mean minimum and maximum daily temperature, adapted image from Weather&Climate, 2019.



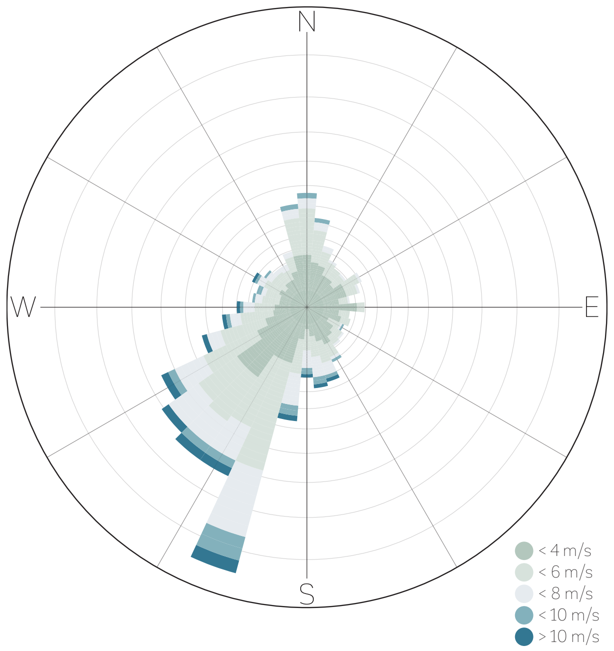
ill. 22: Sunpath for location, own image.



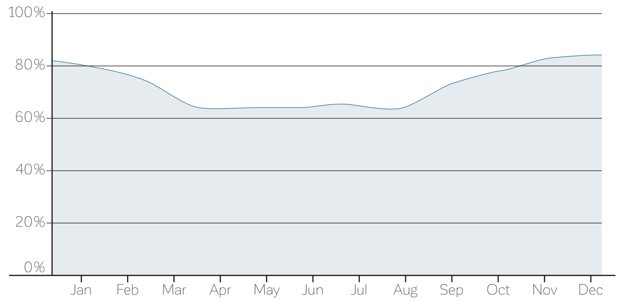
ill. 21: Average daylight and sunshine hours per day for each month, adapted image from Weather Atlas, 2019.



ill. 23: Average percipitation (rain/snow) per month, adapted image from Weather&Climate, 2019.



ill. 25: Windrose, data from London City Airport, Adapted image from Jeanjean, 2017.

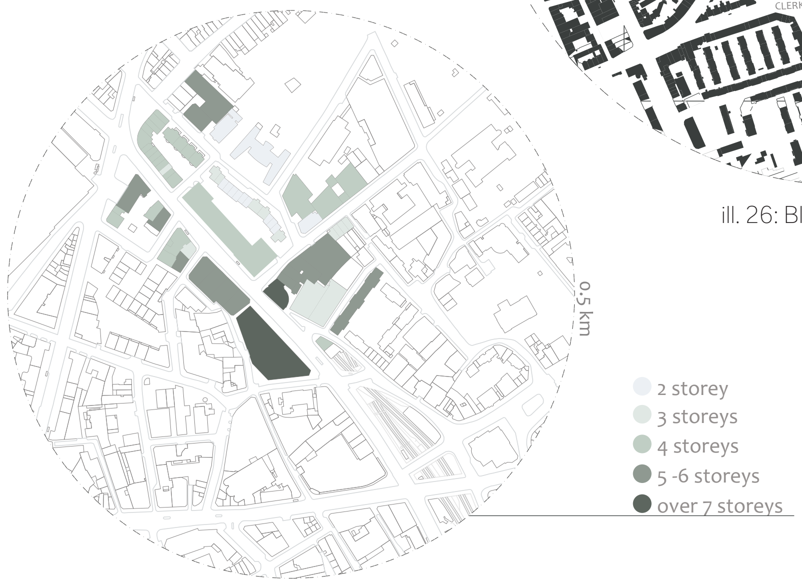


ill. 24: Monthly mean relative humidity, adapted image from Weather&Climate, 2019.

CONTEXT

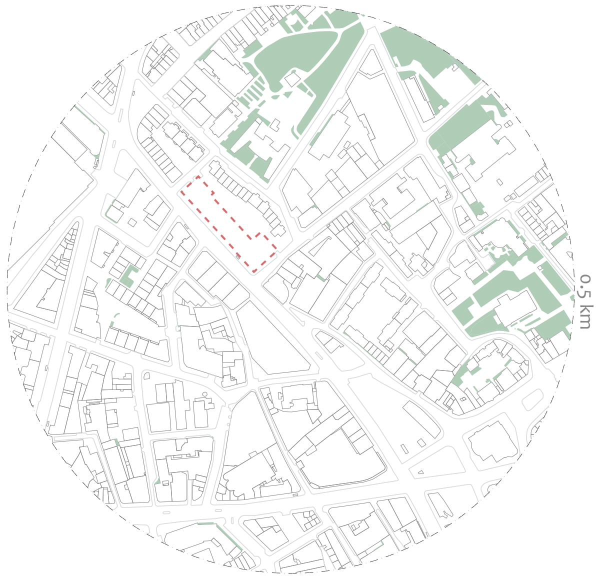
ill. 26: Blackplan of context, scale 1:10.000, own image.

BUILDING HEIGHT



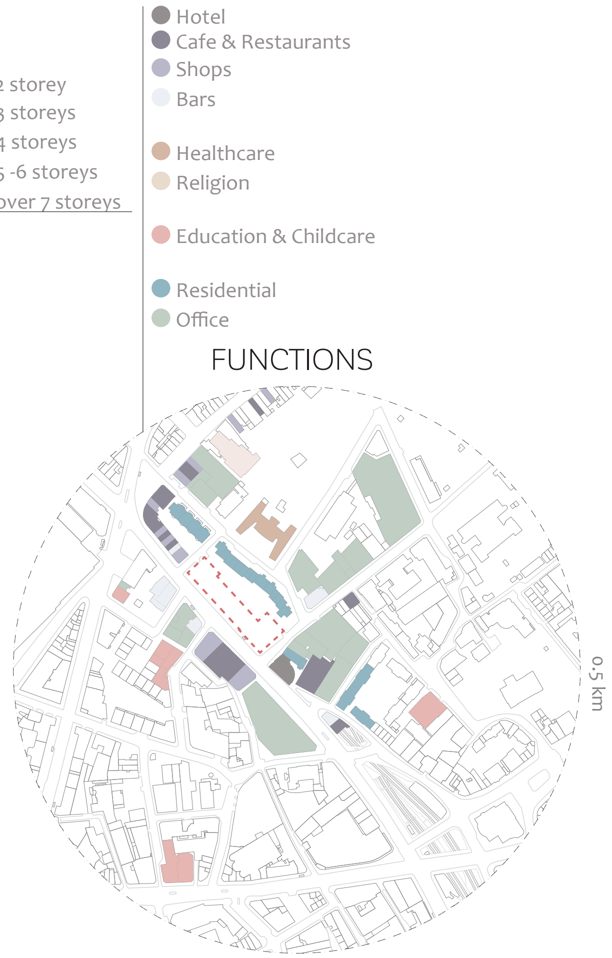
ill. 27: Building height, scale 1:7.500, own image.

GREENERY



ill. 28: Greenery, scale 1:7.500, own image.

FUNCTIONS



ill. 29: Functions, scale 1:7.500, own image.

Inmediate surroundings

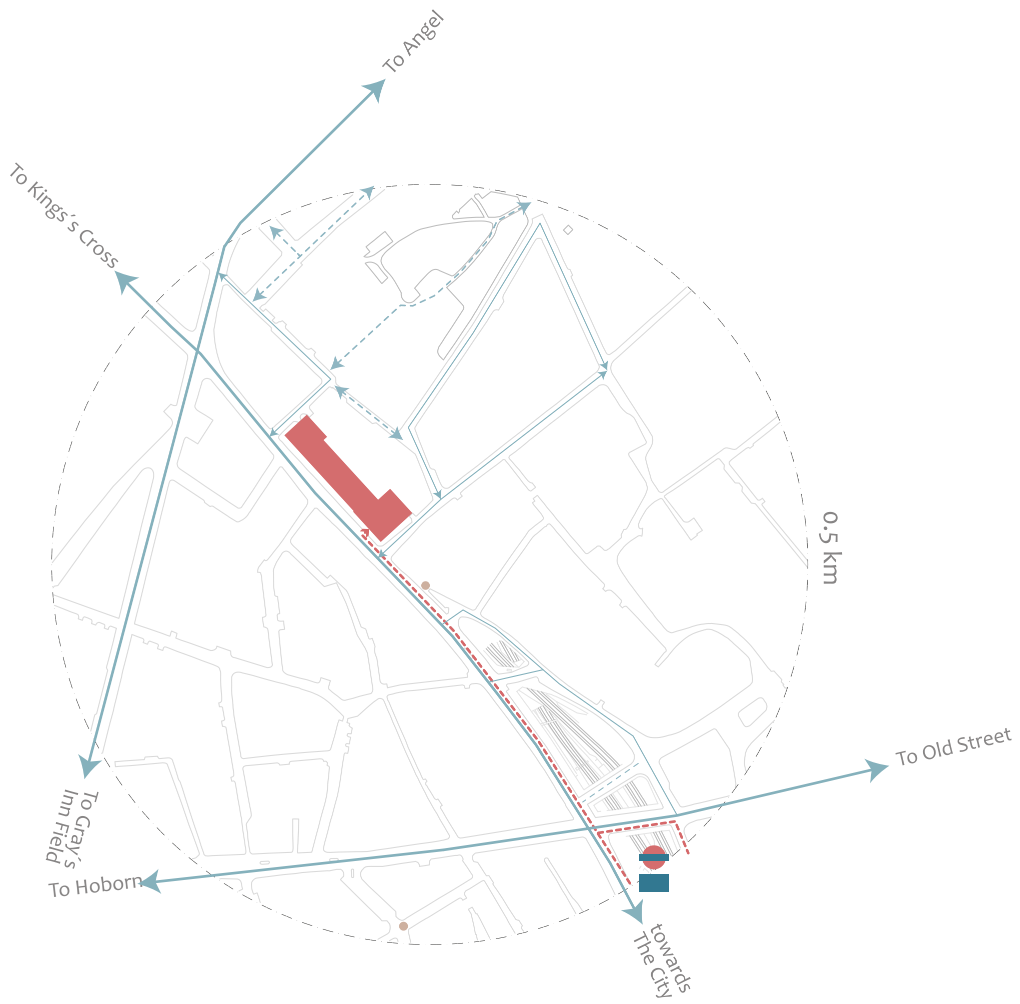
The site is located in a very rich and constrasting context. It is directly located next to a broad and vital road but is is also connected to alleys. The building height ranges from 2 to 3 stories in the north east up to 7 stories in the southwest. The richness is given by the broad diversity of building functions around the site with schools, cafes, shops, bars and offices in close proximity to the site. Further, lush green parks are within walking distance to the location.

Connections & public transport

Within the inner ring of London City, the site has good connections towards mayor points in the centre. Farringdon Road leads north towards Kings Cross and south towards the Thames. Towards the northeast of the building therre is a large park, Spa Field, with plenty of walking paths from Farringdon Road towards Spa Field. These walking paths create a opportunity to cut down from Farringdon Road towards Rosebery Ave, a shoppingstreet with multiple small local shops, The architecture of the proposal could help connectivity from the underground towards the Rosebery Ave with a shortcut through the building.

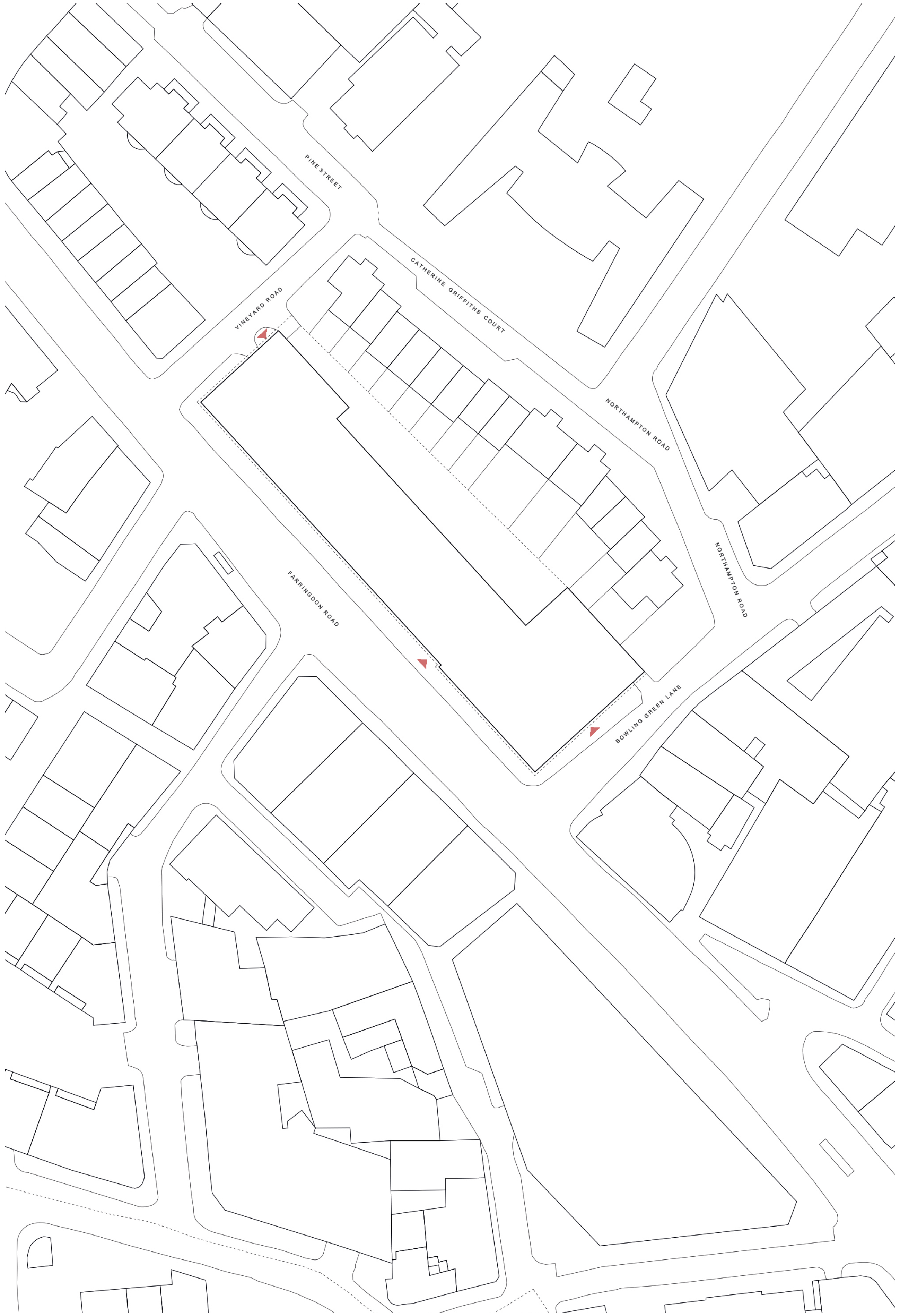
The site has a Public Transport Accessibility Level (PTAL) of 6b. PTAL is a standard method of calculating public transport accessibility in London and 6b is the highest classification, indicative of excellent accessibility. It is approximately 475 metres from Farringdon Road Station, which is served by both National Railways and the London Underground. In front of the building is a bus stop which serves the 63 & N63 bus routes to Crystal Palace, and there are several bus stops and routes within walking distance, including those on Clerkenwell Road to the south, and Rosebery Avenue to the north (Islington Council, 2016).

Due to the excelent accesibillity with public transport, and londons wish to promote bycicles, the choise is made to design for cyclists and not cars.

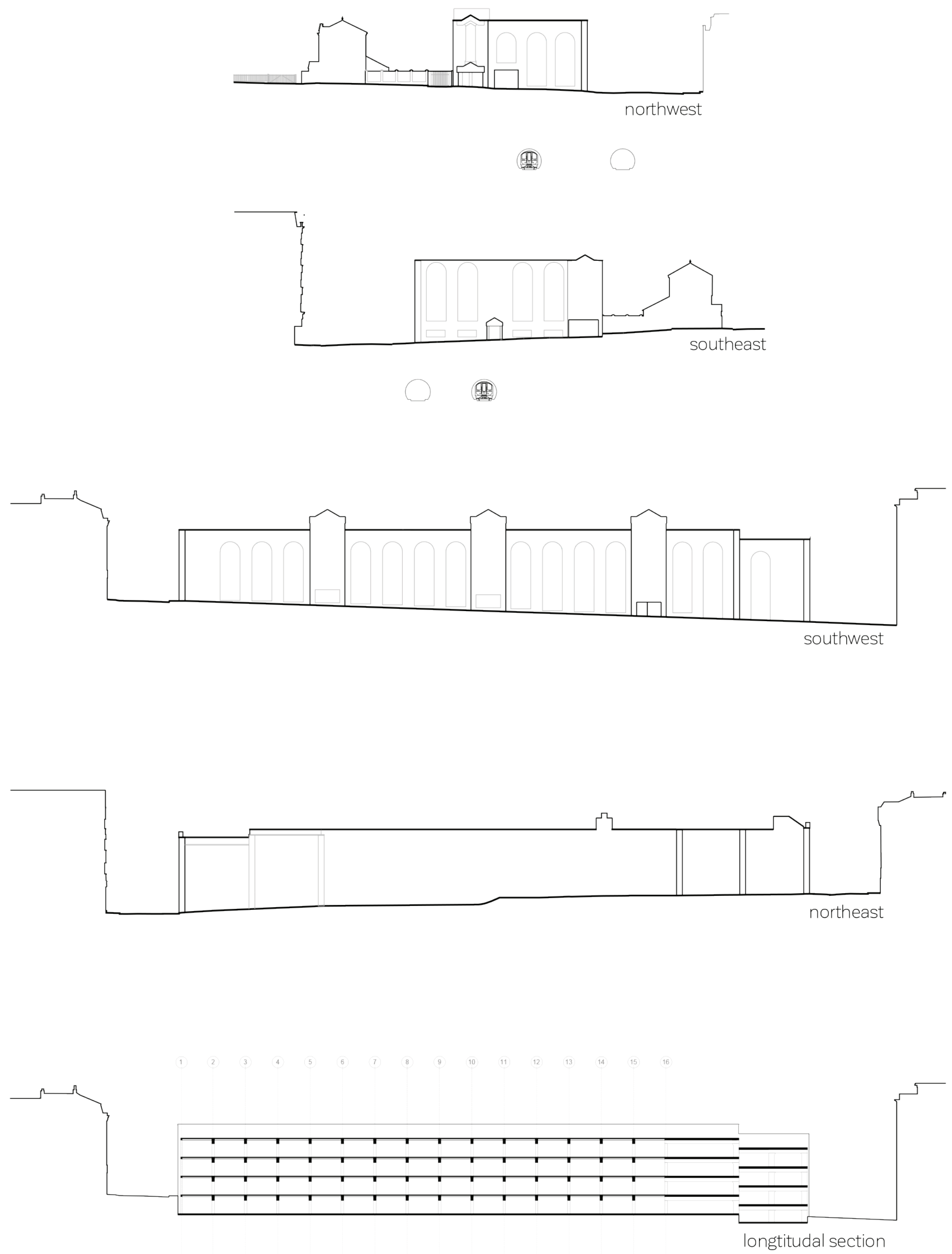


ill. 30: Connectivity, scale 1:5.000, own image.

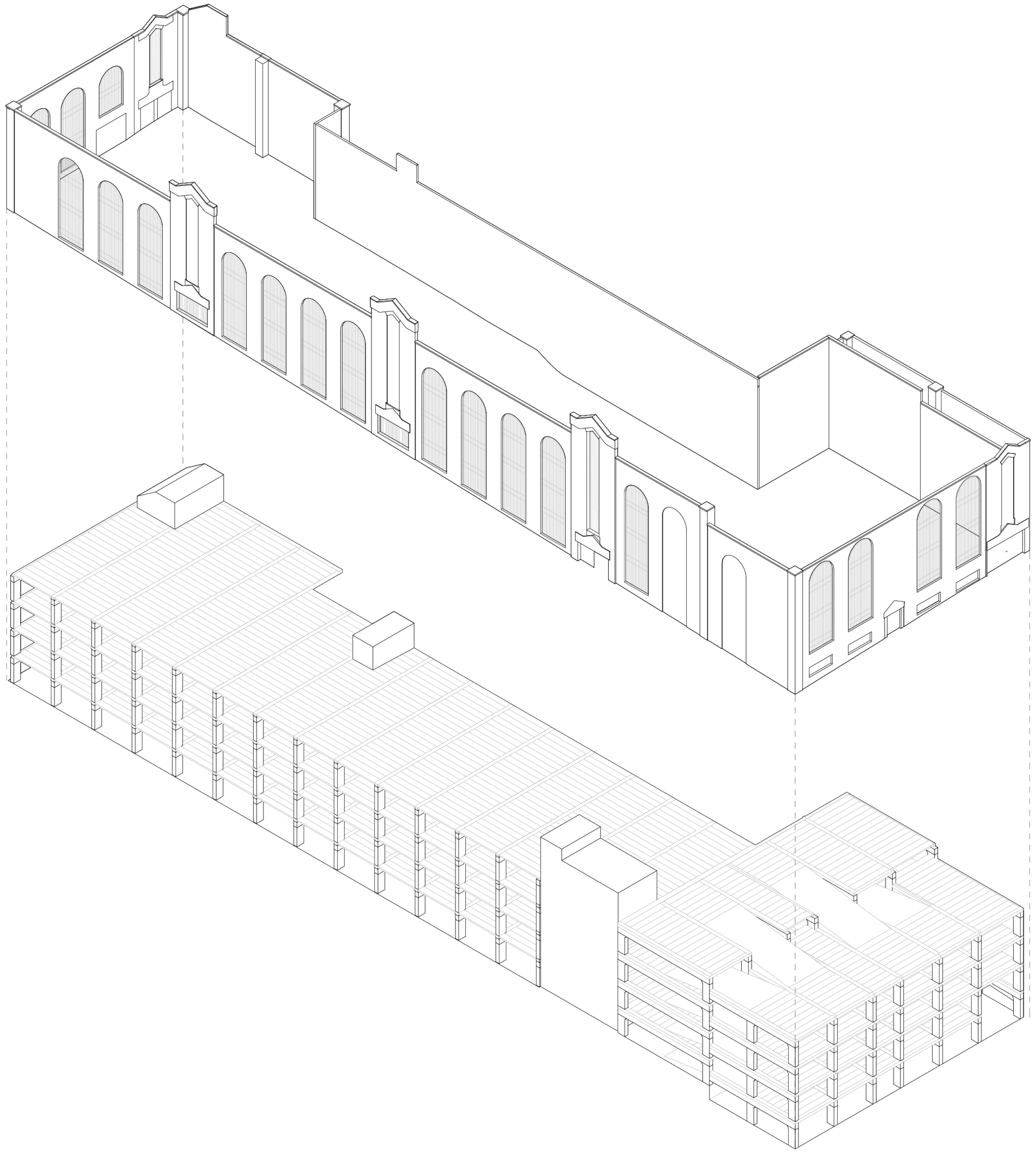
ill. 31: Public transport, scale 1:10.000, own image.



ill. 32: Accesibility current parking garage, scale 1:1.000, own image .



ill. 33: Elevations and section of excisting parking garage, scale 1:1.000, own image.



ill. 34: Construction and skin axonomitry, own image.

Carpark on Farringdon Road

The building we're investigating is a former car park and was built end of the 80s, located on Farringdon road 68-86. The street has a steep gradient towards south. The building's main façade lies towards Farringdon Road and the building can be accessed on three sides: one car and one staircase access each on Bowling Green Lane and Vineyard Road and one primary staircase access on Farringdon Road. Due to the slope, the site levels step down from the south to the north, approximately a third of the ground floor area lays underground. Dimensions of the Building are 96m along Farringdon Road, 28m along Bowling Green Lane, and 20m on Vineyard Walk.

The building can be split into two parts: a main section and a service section. The central northwest part consists of five floor-levels, including the rooftop, two staircases and contains the parking lots. The southeast part is rotated 90 degrees to the main construction and divided into eight split-levels, includes two car ramps and one small staircase.

The existing site conditions:

- Main frontage towards Farringdon Road.
- Steep gradient from the north to the south.
- Elongated site plan.
- Main Entrance to Farringdon Road, Secondary to Bowling Green Lane and Vineyard Walk.
- Building consists two diffrent parts; main part along Farringdon Road for parking, second part to Bowling Green Lane for car ramps.

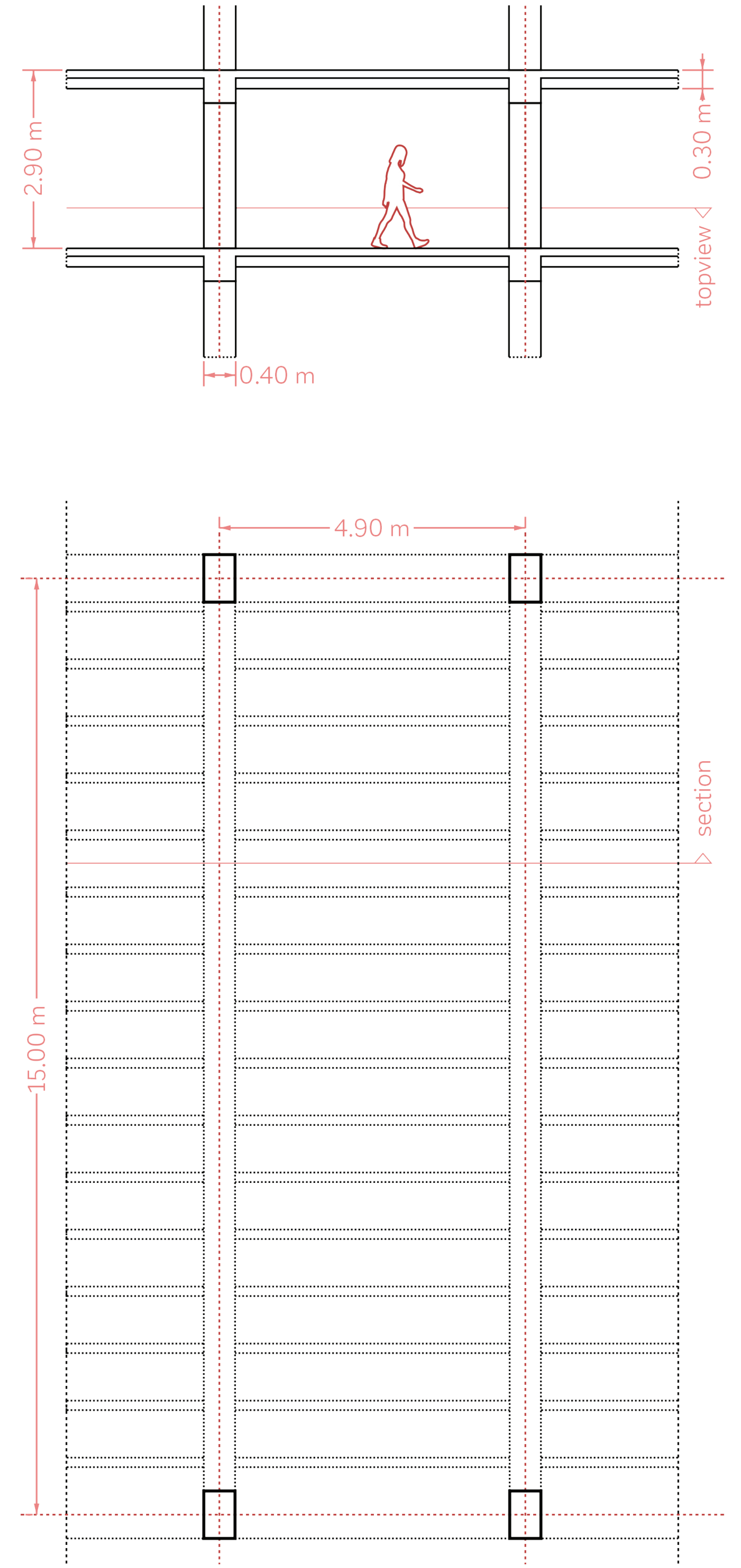
Structure and Fabric

Structural System

The general construction of the building is a post-tensioned one-way concrete floor slab supported by reinforced concrete ribs. The ribs are supported on girders that rest on columns. The ribs are slightly tapered and are uniformly spaced at a distance of 0.50m. The girders have a span of 15m and are paralell placed every 4,90m. The floor, including the ribs, is 290mm thick. The columns rest on the foundation that runs along the northeast and the southwest façade. The metro runs directly inbetween these foundation piles. Making any aditional foundation work troublessome.

Envelope

The existing envelope is wrapping the concrete construction and has no load-bearing functions. It is made from a two-layer brick construction. The facade's main elements are the big open arches and staircase "tower", showing the rhythm of the structure behind. The frontage appearance is very closed and therefore has a lack of connection to the street-level. Overall it can be a comment that the facade lacks architectural quality even though the use of brick is typical for London and part of the heritage of the city.



ill. 35: Critical dimensions in horizontal and vertical section, scale 1:100, own image.

ill. 36: Visualization of the mixed use proposal, image by Sheppard Robson's, 2015

Political situation

The achitectual company Sheppard Robson has made a design proposal for 68-86 farringdon Road. This design will bring 3800m^2 offices, 400m^2 retail/restaurants and a 171 bedroom hotel. This brings a lot of work opportonities to the area and gives tourists quick acces to the London metro system with Farringdon station closeby.

Islington council and community campainers did not approve of the plans however. The campainers were led by the Catherine Griffiths and Clerkenwell Community Tenants and Residents Association (TRA). They argued that social housing and usefull shops would be more bennificial to the area (Morris, 2018).

The council gave three offical reasons for their refusal for the planning permissions. (1) The proposed mix of uses would not maximise business uses on site nor include an element of residential use and would thus be contrary to Finsbury Local Plan Site Allocation BC46. (2) The proposed building is not appropriate in this location by reason of its failure to relate to the surrounding context and adjoining conservation areas and its inappropriate detailed design and choice of materials which result in an incongruous visual appearance. And is therefore contrary to several pollicies regarding the areas achitectual policies. (3) The proposed lack of adequate delivery and servicing arrangements, delineated cycle paths and cycle parking would result in a potential adverse impact on the proposed designated servicing area and street network in terms of their impact on highway safety and the free-flow of vehicle and pedestrian traffic, and not ensure that sustainable forms of travel to work (cycling) are promoted (Islington Council, 2016).

Endurence Land, the developpers of the project, did not agree on this descision however and took it to the Planning Insperctorate on appeal. Which has now overturned the town hall's decision (Morris, 2018). This would add more working opportunities within London without working on the growing housing problem the citizens of London face.

To develop a succesfull social housing project for Farringdon Road 68-86 the design has to take the policies of the area into account. Especially the ones that were mentioned in the three reasons from Islington council.

Councils wishes

Out of the policies the council provides for the area and the arguments they have given against the design proposal of the hotel at Farringdon Road, several wishes can be taken as guidelines. These wishes will play a key role in the design paramaters for the social housing complex.

Policies regarding business use

The site is located within the London Central Activities Zone (CAZ). London Plan Policy 2.10 recognizes the 'mixed' nature of much of the CAZ and seeks to enhance and promote the unique international, national and London wide role of the CAZ through the promotion of a range of mixed uses, including support of the office and retail sectors to ensure sufficient capacity to meet identified demands across business cycles (Islington Council, 2016). As such the boroughs are encouraged to keep developing the unique and dynamic clusters of businesses. The Mayor promotes a sustainable and diverse economy, ensuring an availability of suitable workspaces for different types of enterprizes. For the chosen site location Policy BC8 of Finsbury Local Plan states that floorspace should not be devoted to offices alone but that groundfloorspace should include one of the following:

- Appropiate retail
- non-B1(a) business or business-related floorspace (e.g. light industrial workshops, galleries and exhibition space)
- Office (B1a) or retail (A1) floorspace that is suitable for renting by small enterprises by virtue of its design, size or management.
- Affordable workspace, for the benefit of occupants whose needs are not met by the market.

Policies regarding housing

London Plan Policy 3.11 states that boroughs should seek to maximise affordable housing and ensure an average of at least 17,000 more affordable homes per year over the plan period. Of this provision, 60% should be for social and affordable rent, and 40% for intermediate rent or sale. Islington's Core Strategy Policy CS10 (part G), sets out a required 70% council housing / 30% immediate housing split. Further it is stated that where housing comprises less than 20% of the floorspace, an equivalent contribution has to be sought for the provision of housing. (Islington Council, 2016).

Policies regarding design

Even though the site is not subjected to heritage designations. There are a few policies regarding architectual design for the location. London Plan Policies 7.1, 7.4 and 7.6 state that the design of new buildings should help reinforce or enhance the character, legibility, permeability, and accessibility of the neighbourhood; make a positive contribution to the character of a place, be informed by the surrounding historic environment; and comprise details and materials that complement the local architectural character (Islington Council, 2016).

Further the Design considerations and constraints section of site allocation BC46 states the following: "The design of the building should respond positively to the change in topography and reflect the height of neighbouring buildings. Active ground floor uses should be provided to animate Farringdon Road and Bowling Green Lane. The site is adjacent to the Clerkenwell Green and Rosebery Avenue Conservation Areas. Proposals should respect and enhance this heritage setting. The site falls within protected viewing corridors defined by the London View Management Framework" (Islington Council, 2016). According to the council the site is within an area that is architectually rulled with masonry building that are consistent with regular window patterns. The openings are generally larger on ground floor, getting smaller at the higher floors. Rich detailing is provided by various decoration and relief on the façades.

Policies regarding deliveries

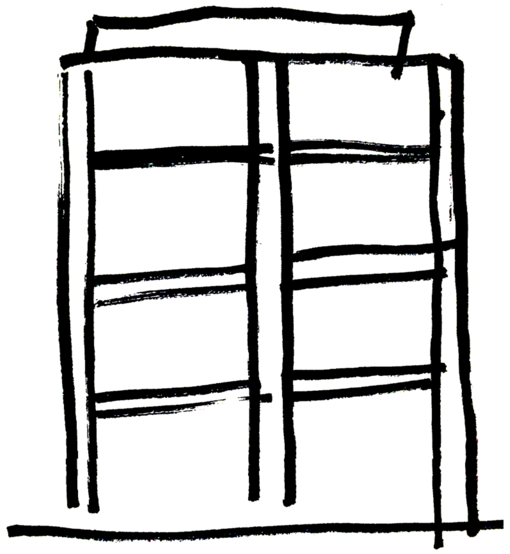
Development Management Policies (2013) Policy DM8.6, part A, states that for commercial developments over 200 square metres, delivery/ servicing vehicles should be accommodated on-site, with adequate space to enable vehicles to enter and exit the site in forward gear. Where servicing/delivery vehicles are proposed on street, Policy DM8.6 Part B, requires details to be submitted to demonstrate that on-site provision is not practical, and show that the on-street arrangements will be safe and will not cause a traffic obstruction/nuisance (Islington Council, 2016).

Also there is a risk of cyclists and delivery vehicles using the servicing yard at the same time, ideally there paths should not cross. Should this not be feasible, then no deliveries may take place during the morning and afternoon peak when most cyclists will be expected to arrive/leave for work; it is recommended that this would be secured via condition in the Delivery and Servicing Management Plan (Islington Council, 2016).

In short the council states that they wish the following:

"Redevelopment of multi-storey car park to provide business uses, retail at ground floor and an element of residential uses. This is a major site fronting Farringdon Road and close to Farringdon station and has significant potential for providing new commercial and residential floorspace. (Islington Council, 2016)"

Architecture of Clerkenwell



Late 19th-century mercantile commercial buildings mostly characterize Clerkenwell and Farringdon Roads architecture. The building's expressions are simple with pragmatical structures with regular bays giving a vertical emphasis. Secondary horizontals outline street frontages and cornices. Detailed decorative features typically supplement vertically proportioned and deep-set windows. Chamfered bays or features are used to articulate depth and corners. Contemporary architecture seems to follow the pragmatic vertical and horizontal expression to compliment the traditional forms and materials. Brick facades are predominant around London.

- Different ground and upper floors banding with large ground floor glazing.
- Contrasting ground floor and upper floor.
- Verticality is the main emphasis with secondary horizontal banding.
- Ornamental features and chamfered corner facade.
- Repetitious facade with vertical or horizontal proportion.
- Brick is predominant.

ill. 37: Farringdon road 59-61, image by Colliers London, 2020.

ill. 38: Clover House office, image by Cre8te, 2020.

ill. 39: Farringdon road 109, image by Realla, 2020.

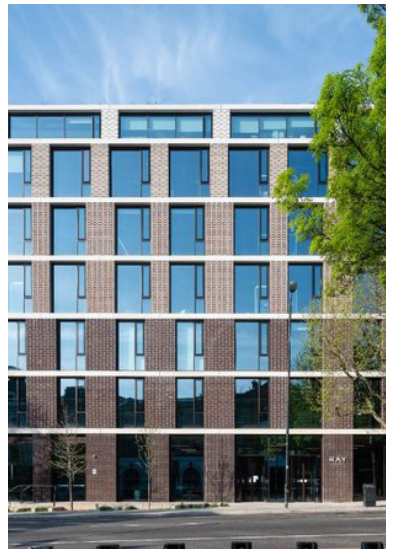
ill. 40: Bowling Green lane 17-23, image by James Boatman, 2020.

ill. 41: Farringdon road 17-23, image by Trehearne, 2020.

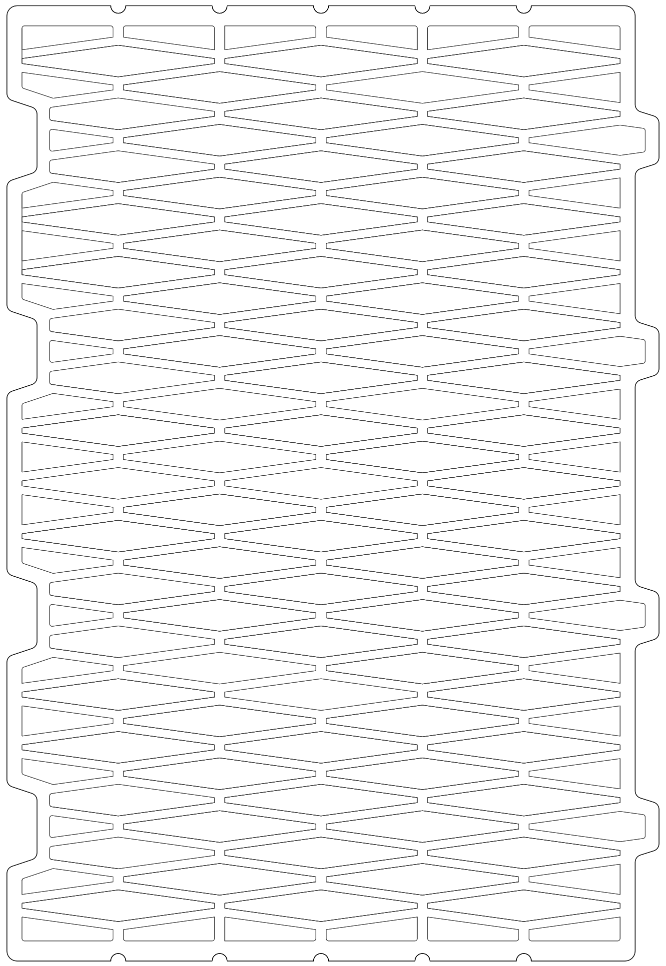
ill. 42: Kitt Offices, image by HubbleHQ, 2020.

ill. 43: Clerkenwell 15, image by DeZeen, 2020.

ill. 44: Farringdon road 75, image by RightMove, 2020.



ill. 45: The Ray Farringdon, image by Soar, 2019.



ill. 46: Generelized representation of the thermal bricks as used in "2226", own image.

Brick aint brick

With the project of 2226 the main material for the outer walls is a perforated thermal clay brick. Due to its geometrical and physical properties, it makes the energy concept of 2226 possible. A quick analysis of the thermal brick will be done to get a deeper understanding of the material and to utilize its full potential for our project.

Bricks have been used in architecture for centuries. Most of the time, as a solid material. Increasing demands on structural thermal insulation led to continuous innovations. In early 1970 (BaustoffWissen, 2013), perforated clay bricks were invented. Micropores with encapsulated air made a thermal conductivity of 0.40 W/mK possible.

These bricks are made from a sand mixture, clay, and specialized additives. The production process includes several necessary steps. First, the clay and sand mass will be cleaned, then special rapid-release additives are added to the raw materials. During the heat treatment of the bricks, the organic material quickly burns out, resulting in small tight pores.

Today, due to further development, the highest quality thermal bricks with better structural behavior and with infills and/or more complex inner geometry can reach a thermal conductivity of 0.07 W/mK.

An example of the main characteristics of thermal bricks that are widely available today are (Lucideon, 2014):

Dimension (l x w x h):	248 x 365 x 249mm
Thermal conductivity (lambda):	0.08 W/mK
Density:	0.6 Kg/dm^3
Typical strength:	10 N/mm^2
Characteristic compressive strength:	3 N/mm^2
Water absorption: of volume?	< 6%
Fireclass:	F1
Sound insulation value :	50-66 dB

- The thermal performance of the material in combination with the high heat capacity of clay makes this material a good match for the energy concept of this project.
- To ensure airtightness, the masonry should be used with a coating or plaster on the inside.

Conclusion Of Analisys

60 percent of the energy use in Englands households is allocated to heating purposes. This number needs to go down and we are therefore focussing on bringing the heating demand to zero kwh. Principles from 2226 and the thermal brick will be investigated architectually to reach this goal.

Brick is predominant within the architecture of London. It will be interesting to investigate the use of the thermal brick as an outer finish layer. The split use of the building from public functions on the ground floor to private functions on the upper floor makes for a good combination with the contrast inbetween the lower and uper floors that is often seen in the archtitecture of london.

To further lower the carbon footprint of the building and its occupants there will be a focus on cyclists instead of cars, the excelent public transport connection enables us to do so.

Problem Statement

Can we transform the old car park on Farringdon Road into a sustainable contamporary living place, with a strong community to address London's housing crises, and can we apply the low-tech methodology from 2226 to decrease its energy demand to make the build environment more sustainable?

User groups

The focus lays on developing a housing complex, that will house families with their ofspring and will house elderly. This is in line with the London Housing strategy where mixed housing is encouraged to ensure more of London's new and existing homes are accessible and appropriate for disabled Londoners, elderly Londoners, and families with children (Khan, 2018).

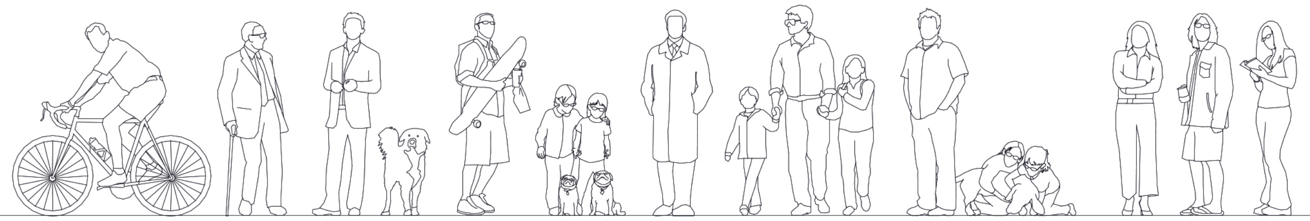
With different occupants come different needs, which the building will have to provide.

The parents use the underground daily to get around Londen since it is more affordable and quicker then a car. They have a need for safe play areas for the children that is easily accessible and can be shared with the other kids from the neighbourhood.

As engaged with their family as the children are, they still want to go out to play and hangout with their friends. They want to connect to their neighbours and other kids within the building, needing lots of free space to run around joyfully.

The elderly care for the vibrancy and connectivity of London. They do not work fulltime anymore but are active in the community. They need a spacious accessible apartment in which they can live for the length of their retirement. The close proximity of young families with children makes them feel youthfull.

On the lower levels the building engages with the street with a youth library and makerspace. The makerspace has rentable premisses for small creative businesses. focussing on affordable living and businesses in the centre of london.



ill. 47: Users, own image

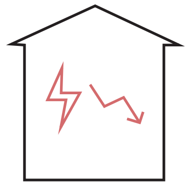
Room program

	Approximated m2 (netto)		Acitvity level	Requirments
Studio apartment x6	55	m2	Low activity	Comfortably house singles, elderly or couples
- living/bedroom	27	m2		
- kitchen	10	m2		
- hallway	6	m2		
- bathroom	6	m2		
- balcony	6	m2		
Two bedroom apartment x 13	73-91	m2	Low activity	Comfortably house a family with one or two children
- living room	20-30	m2		
- kitchen	9-14	m2		
- hallway	4	m2		
- bathroom	6	m2		
- bedroom x2	11-23	m2		
- balcony	8	m2		
Three bedroom apartment x13	119-126	m2	Low activity	Comfortably house a family with one or more children
- living room	26-46	m2		
- kitchen	10-24	m2		
- hallway	17	m2		
- bathroom	5	m2		
- toilet	3	m2		
- bedroom x3	10-24	m2		
- balcony	1-7	m2		
Shared living apartments x2	163	m2	Low activity	Comfortably house two or more families, singles, elderly or couples
- living room x2	21	m2		
- kitchen	35	m2		
- hallway	14	m2		
- bathroom	6	m2		
- bedroom x4	13	m2		
- balcony	8	m2		

	Approximated m2 (netto)		Acitvity level	Requirments
Youth library	270	m2	Low to medium activity	Provide acces to knowledge and the internet for the youngsters in the community
- reception	12	m2		
-wardrobe	12	m2		
- bookshelfs	80	m2		
- computer area	13	m2		
- playfull reading area	120	m2		
- storage	13	m2		
- toilets	16	m2		
- elevator	4	m2		
Makerspace	1330	m2	Medium to high activity	Provide different styles of workspaces for the community and small busness owners
- reception	100	m2		
- hallway	380	m2		
- wood workshop	60	m2		
- spray workshop	50	m2		
- general workshop	420	m2		
- rentshops x19	22-30	m2		
- kitchen	35	m2		
- meetingroom	50	m2		
- storage	120	m2		
- elevator	4	m2		
- technical	16	m2		
Additional	591	m2	Low to High activity	
- bike storage	120	m2		Minimum of 100 bikes
- roof terraces	153	m2		Accesable to all occupants
- covered playground	280	m2		Playground for kids off all ages
- washing rooms x3	12	m2		Washing rooms for occupants
- guest bedroom	26	m2		Small bedroom with bathroom for occupant guests

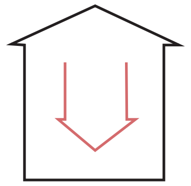
Design Criteria

1 Decrease the energy demand of the building by applying the low-tech strategies of 2226.

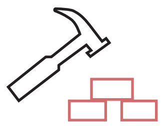


2 Provide comfortable indoor conditions by following the adaptive thermal comfort model.

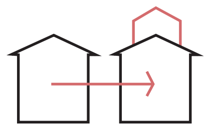
3 Decrease the building's complexity to ensure manageability for the users by using technical appliances just where it is necessary.



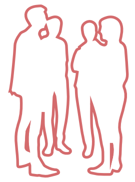
4 Careful selection of materials through properties to enhance longevity and minimize maintenance.



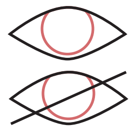
5 The additional structure needs to respect the original structural system and elements to determine the identity of the building



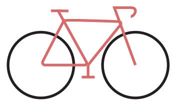
6 Encourage gatherings and strengthen the community by creating social spaces and shared access structures.



7 Support community and neighborhood by establishing a clear hierarchy between private and public functions.

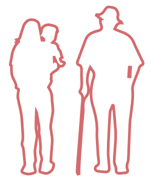


8 Promote bicycles by enabeling access routes for bikes and safe storrage.



9 Besides residential units, provide new commercial floorspace to use the full potential of the central location in London.

10 Regarding Londons Strategy, apartments for families and elderly are needed



FINAL DESIGN PROPOSAL

ill. 48: Biking guy, own image

Concept

Wider context

On Farringdon Road, London - you will find an old, inactive car park house build in the late eighties. It contrasts with the rest of Clerkenwell, which is a contemporary start-up hub consisting of SME's and well known design led companies. The area was originally driven from small startups attracted to the availability of cheap, shared warehouse space.

Our perspective

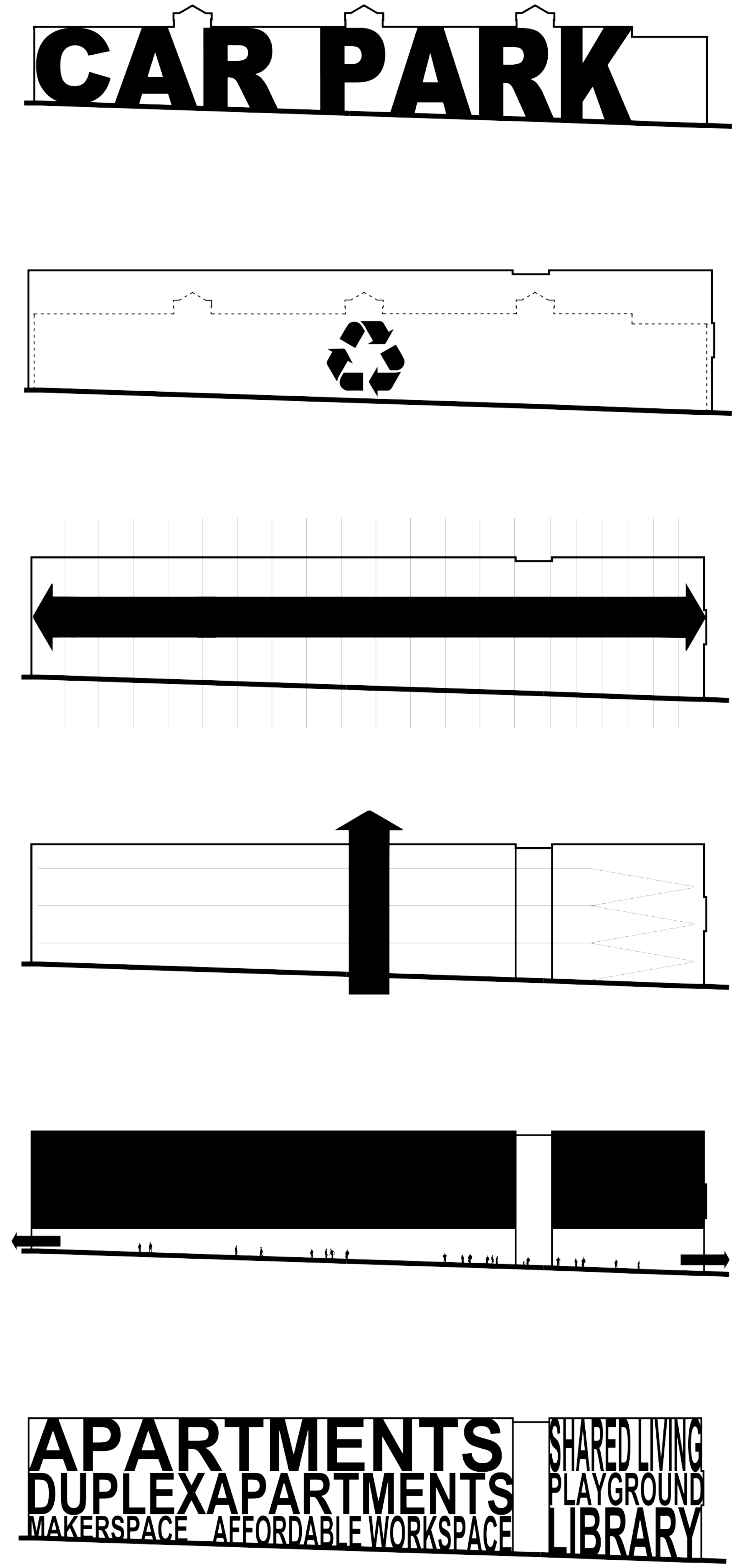
Our main concept arises from the dynamic span in supporting the original startup culture, meeting the crucial need for affordable housing for the average citizens and families in London and actively using the structure of the car park to design for a sustainable future with energy efficient architecture.

Front stage, back stage

Our thought behind the concept is based on the idea of a front stage and a backstage. The front stage refers to the interaction between the building's public functions in the ground floor and first floor and the public urban setting on Farringdon Road. The backstage refers to the back alley where an interaction between the building's residents and the neighborhood creates a semi public space for the local community.

Vertical road

The vertical road arose from the combination of retrofitting the existing ramp and working with a gallery entrance. The vertical road is a physical object that transfigures into a holistic unifying actor.



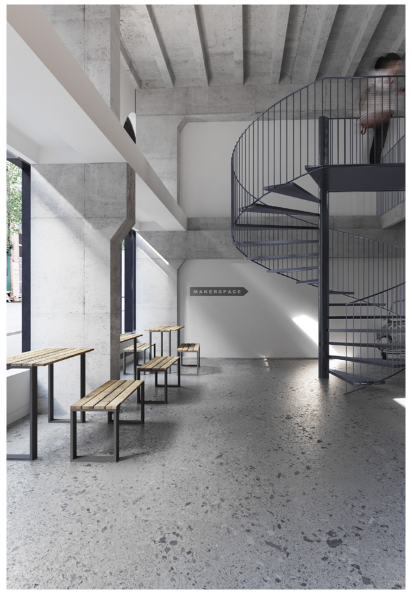
ill. 49: Architectual concept diagrams, own image.

ill. 50: Roofplan, scale 1:350, own image.

View from Topham St

The interaction between the building and its surroundings is grounded in the idea of a frontstage and backstage. All of the public functions accessed through the front stage.

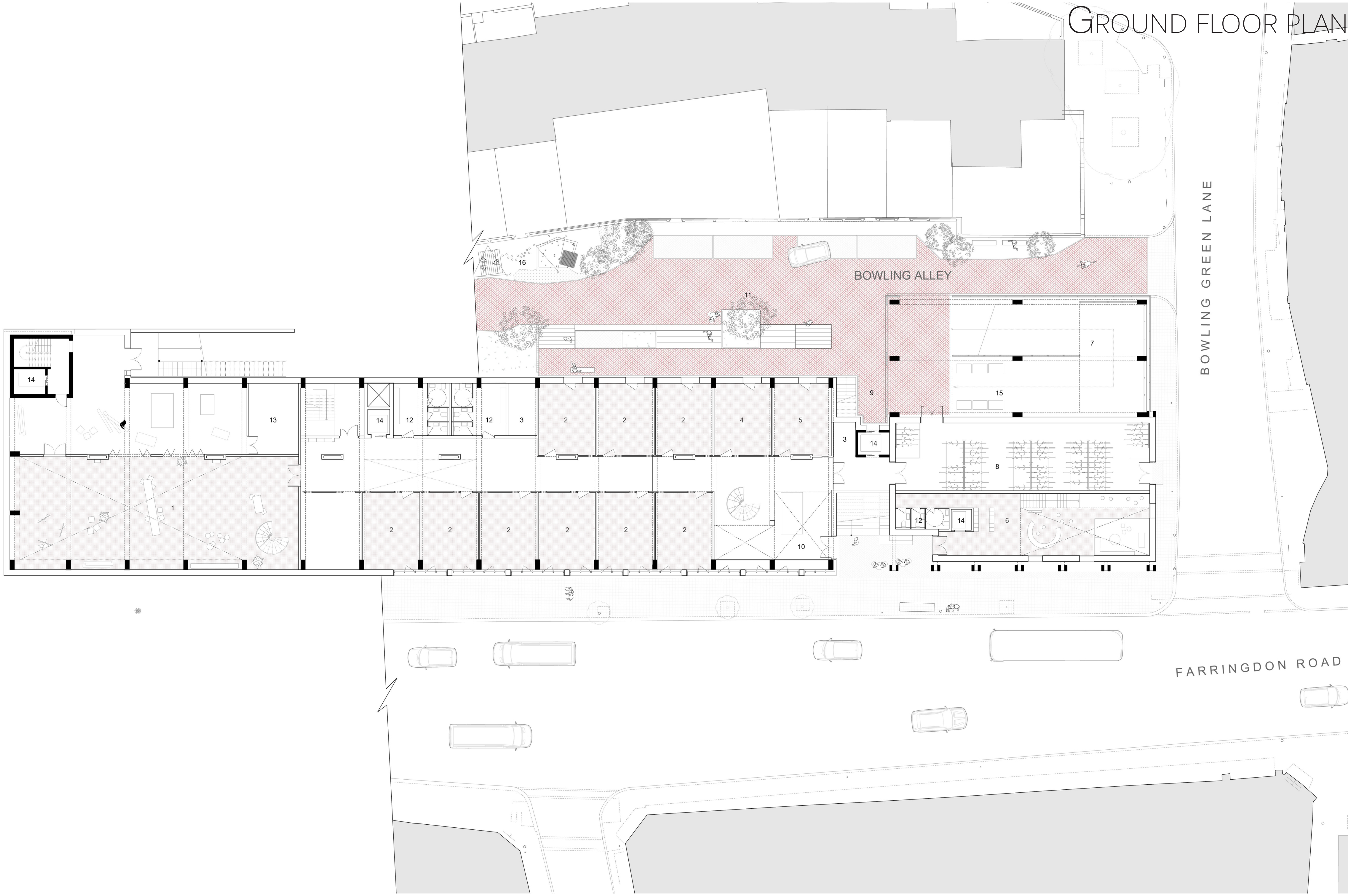
We created an active front stage out to Farringdon road, by choosing an open facade on the street level. The open facade supports views and creates easy access to the public urban scene. The ground floor and first floor provide public access to the youth library, maker space, and affordable workspaces. Due to these public functions inside of the building, London citizens are invited to join the community.



ill. 51: Visualization of the makerspace entrance, own image.

ill. 52: Visualization of the façade from Topham St, own image.

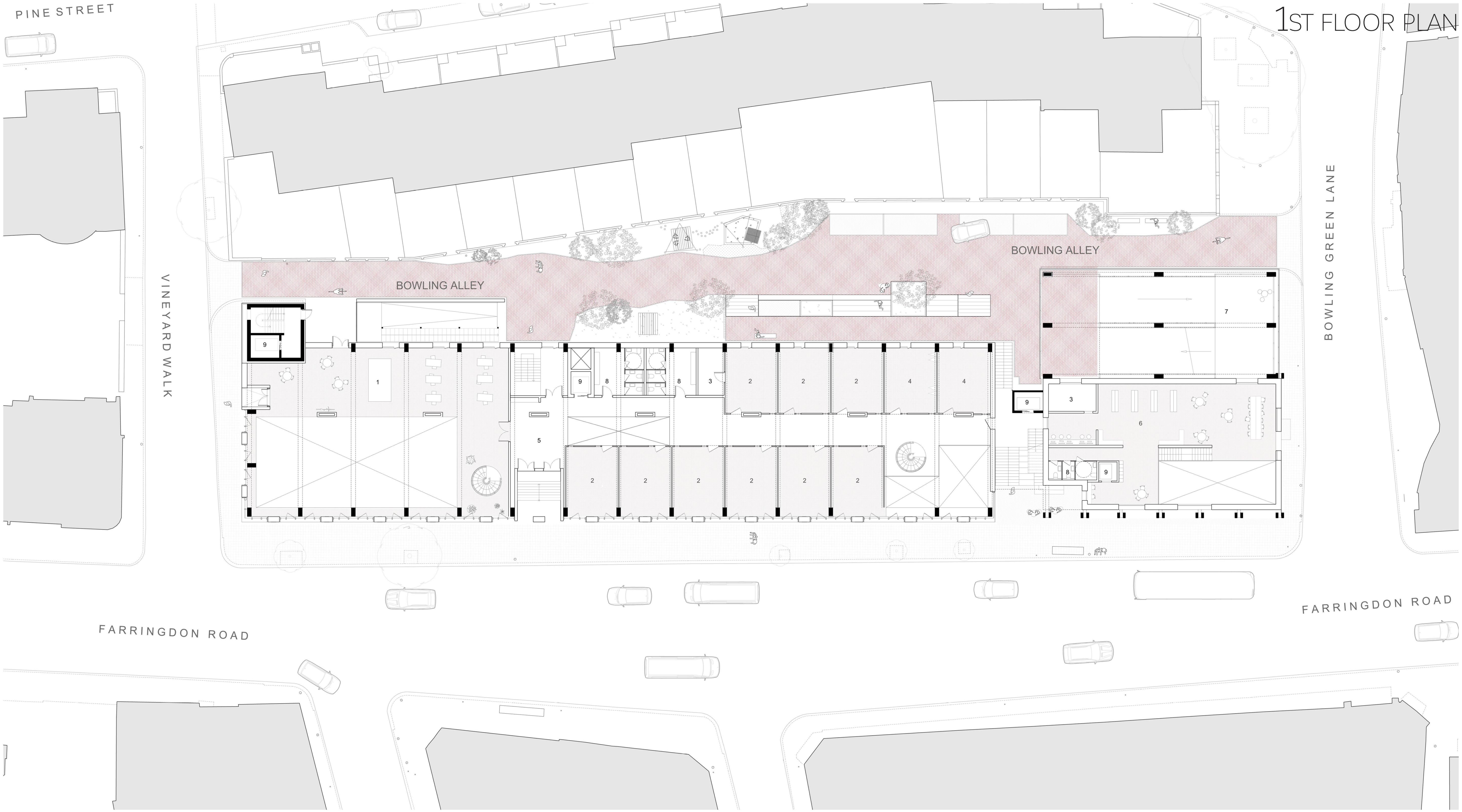
Ground floor plan



1. Makersspace
2. Affordable Workspace
3. Storage
4. Administration
5. Meeting/ Kitchen
6. Library
7. Ramp
8. Bycycle Parking
9. Entrance Residents
10. Entrance Public
11. Back Alley
12. WC
13. Technical Room
14. Elevator
15. Trash
16. Playground

ill. 53: Ground floor, the horizontal community, scale 1:350, own image.

1ST FLOOR PLAN



1. Makersspace
2. Affordable workspace
3. Storage
4. Meeting/ kitchen
5. Secondary entrance
6. Library
7. Ramp
8. Toilet
9. Elevator

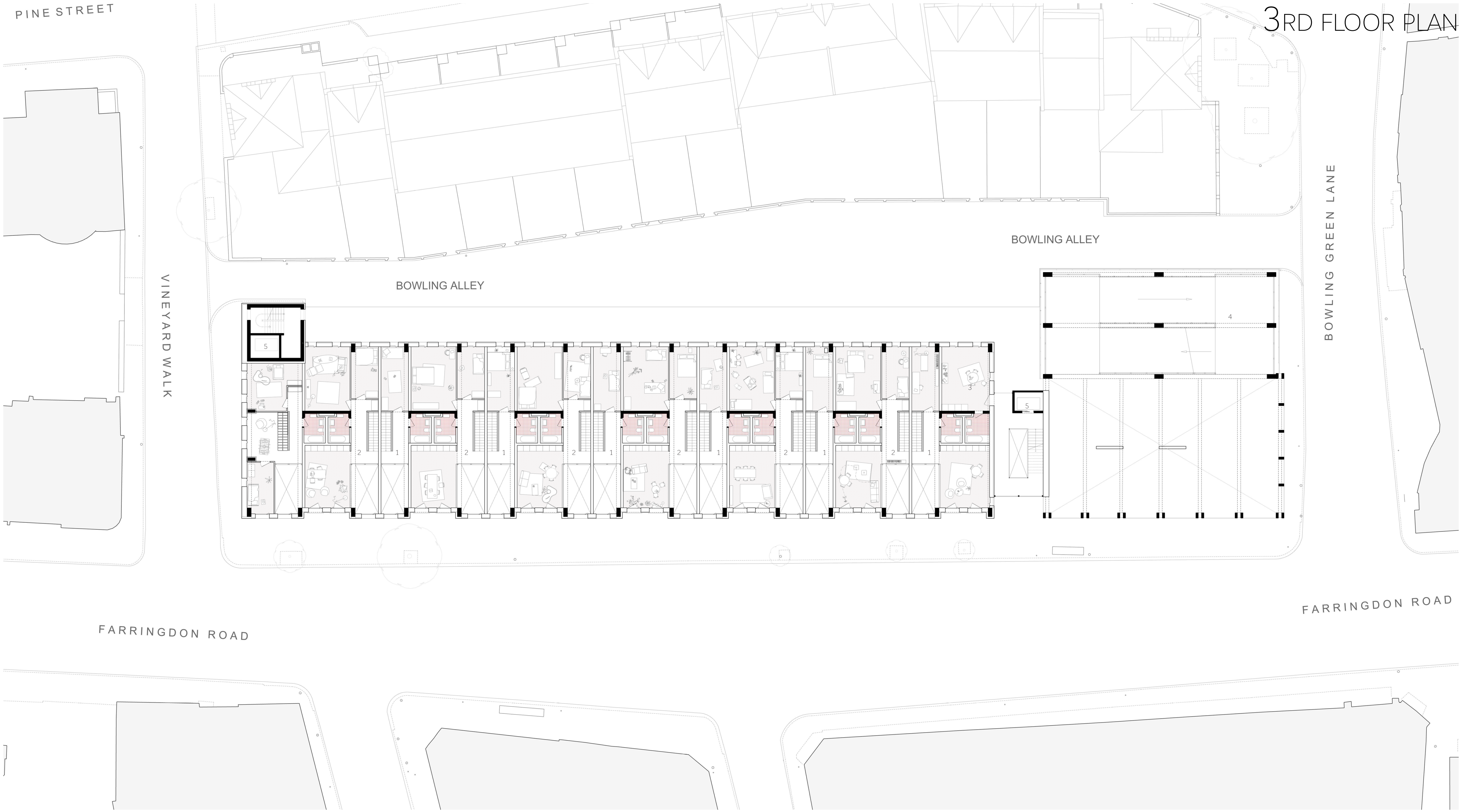
ill. 54: 1st level the horizontal community, scale 1:350, own image.

2ND FLOOR PLAN

1. Duplex apartment A
2. Duplex apartment B
3. Washing room
4. Playground
5. Gallery walk (entrance)
6. Ramp
7. Elevator

ill. 55: 2nd level, the vertical community, scale 1:350, own image.

3RD FLOOR PLAN



1. Duplex apartment A
2. Duplex apartment B
3. Washing room
4. Playground
5. Gallery walk (entrance)
6. Ramp
7. Elevator

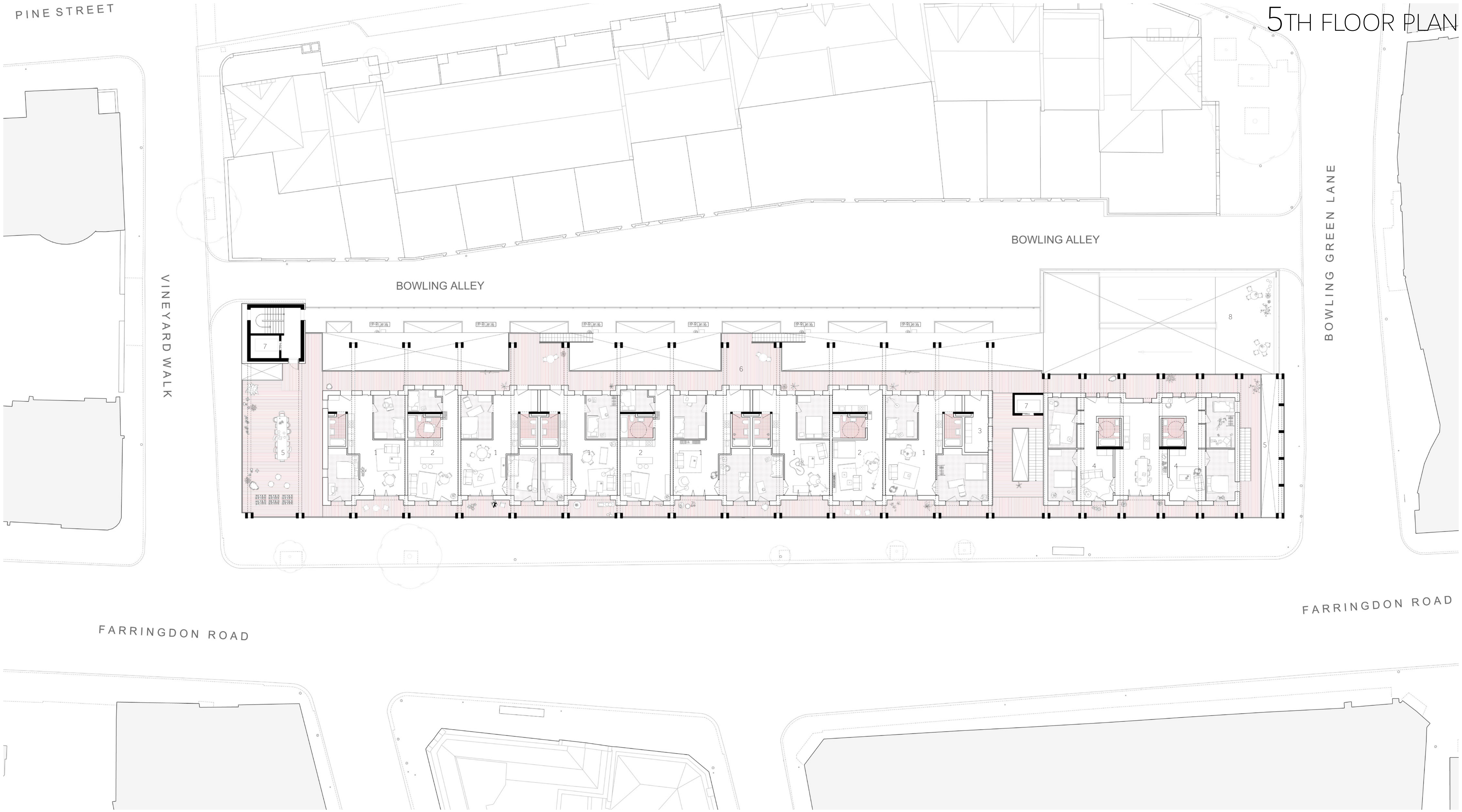
ill. 56: 3rd level, the vertical community, scale 1:350, own image.

4TH FLOOR PLAN

1. Three room apartment
2. Studio apartment
3. Washing room
4. Shared living apartment
5. Shared terrace
6. Wide gallery
7. Elevator
8. Ramp

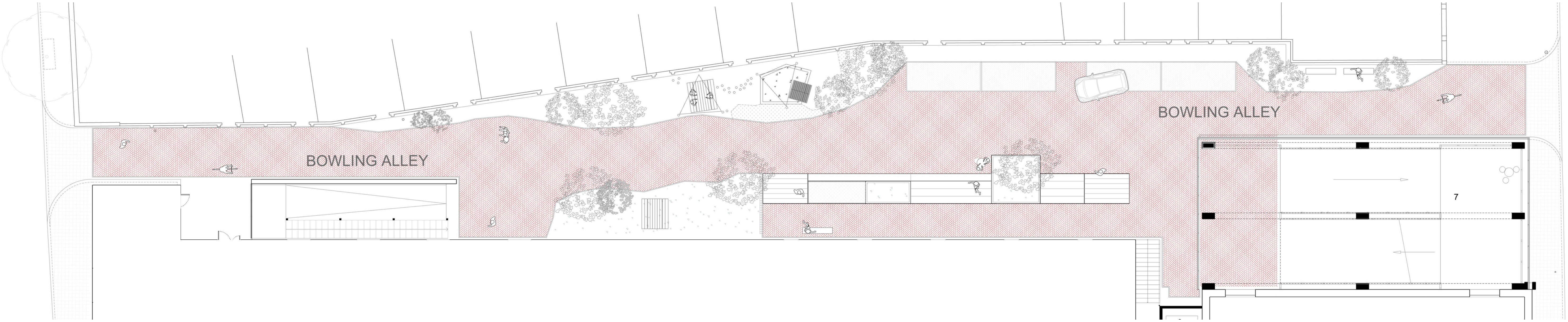
ill. 57: 4th level, the vertical community, scale 1:350, own image.

5TH FLOOR PLAN



1. Three room apartment
2. Studio apartment
3. Washing room
4. Shared living apartment
5. Shared terrace
6. Wide gallery
7. Elevator

ill. 58: 5th level The vertical communty, scale 1:350, own image



ill. 59: Groundfloor the back ally, scale 1:250, own image

Back "stage" alley

The backstage refers to the back alley where an interaction between the building's residents and the neighborhood creates a semi public space for the local community. Originally the back alley only had one entrance from Vineyard Walk, so we decided to open up the alley into an active walking path between the two parallel streets 'Bowling Green Lane' and 'Vineyard Walk', so that the pedestrians can have use of the back alley as well. This supports the urban flow and brings more traffic to the work spaces located on the ground level in the building. To extend the interaction area even further, we created a multi-leveled sitting area outside the co-working spaces. The green spots are consisting of small areas with grass, plants and small trees. We also made a small playground and several sitting options spread out in the back alley.

We support London's ambition to integrate more bikes in the city, and for this purpose have created an inner bike parking garage in connection to the beginning of the ramp. We made it possible to park up to four cars in the back alley. These parking spots are thought of as a chance to share cars. We met the regulations for fire trucks and made it possible for delivery- and moving trucks to park while on and off loading.
The design of the back alley aims to connect and create a local and strong community around the building.

The back alley does not only support the horizontal community, but also the vertical community in which the residents, co-workers and local community can meet.

Vertical communities

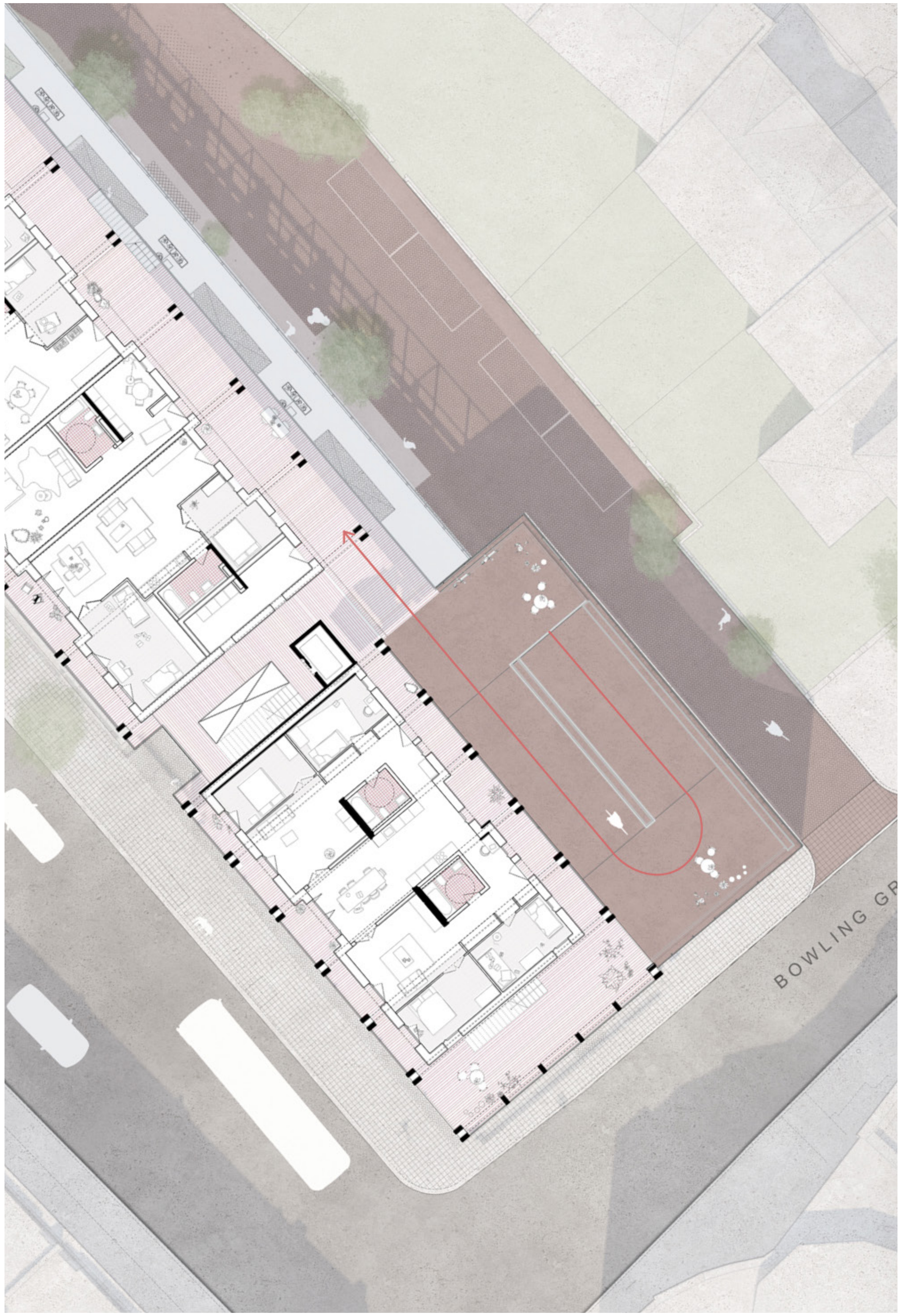
The idea behind the back stage is referring to the back alley, which is a semi public space, where the neighborhood can interact and from which the residents access the building.

Vertical community

The repurposed ramp is an extension of the back alley and mediates the transition of the flow through semi public, semi private and private spaces, and connects the back alley with the wide gallery upstairs. The ramp pulls the street up providing bikeable access to the apartments. It turns into a vertical road which is not just a physical connecting element, but also creates movement and communication. The ramp and the wide gallery becomes mediators between the residents and their activities.

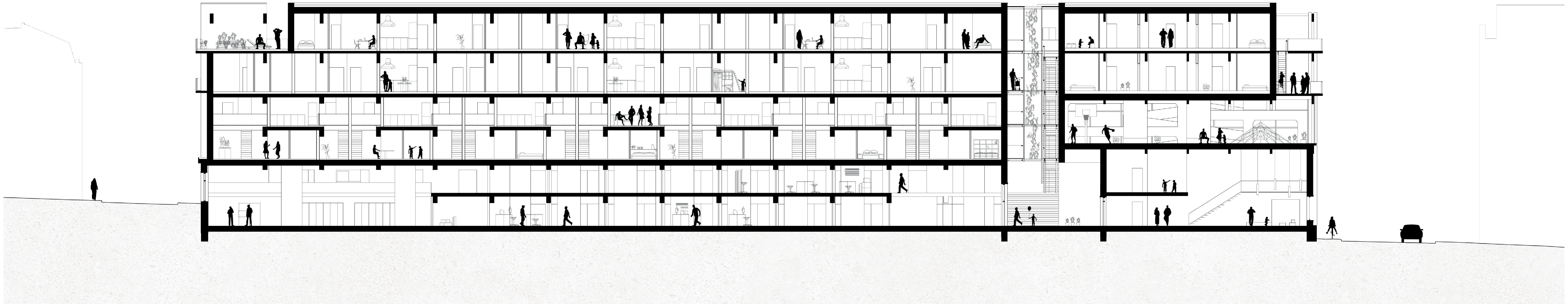
Gallery

The galleries have multifunctional purposes. The gallery on the 2nd floor is entered through the ramp and functions as an access road to the apartments. The galleries on the 4th and 5th floor are entered through the ramp and circles all around the building, providing access to all apartments. The ramp on the 4th floor is wide and open and houses a shared space for the community and also creates small sized private niches together with the balconies. The 5th floor gallery has a similar private niche function.



ill. 60: Closer view of the ramp on fourth floor, scale 1:250, own image

SECTION



ill. 61: Section of the building, scale 1:350, own image

ill. 62: Birdseye visualization, own image.

Materiality

The materials lay at the heart of climate control. Their properties and dimensions define the building that controls its own climate. Brick plays the central role, its high heat storage capacity and high thermal conductivity makes it great for storing and releasing exces heat throughout the day. By making clever use of geometry in the brick, the travel path from inside to outside is greatly increased to make sure as much heat as possible is stored in the wall instead of being released to the outside enviroment.

The exterior wood construction is made using Accoya acylitated wood. This modified woodtype has a 50 year warenty on above ground applications with minimal maintenance. Due to the acylitation process the wood is resistant to insects and is highly stable with no visable shrinkage, distortian or movement (Accoya Technologies, 2020).

Through optimization of one material the need for further insulation materials is minimized. Where higher insulation values over short distances are required, wood is choosen as a constructive or finishing element in combination with a thin layer of high preformance Thermablock Aerogel.

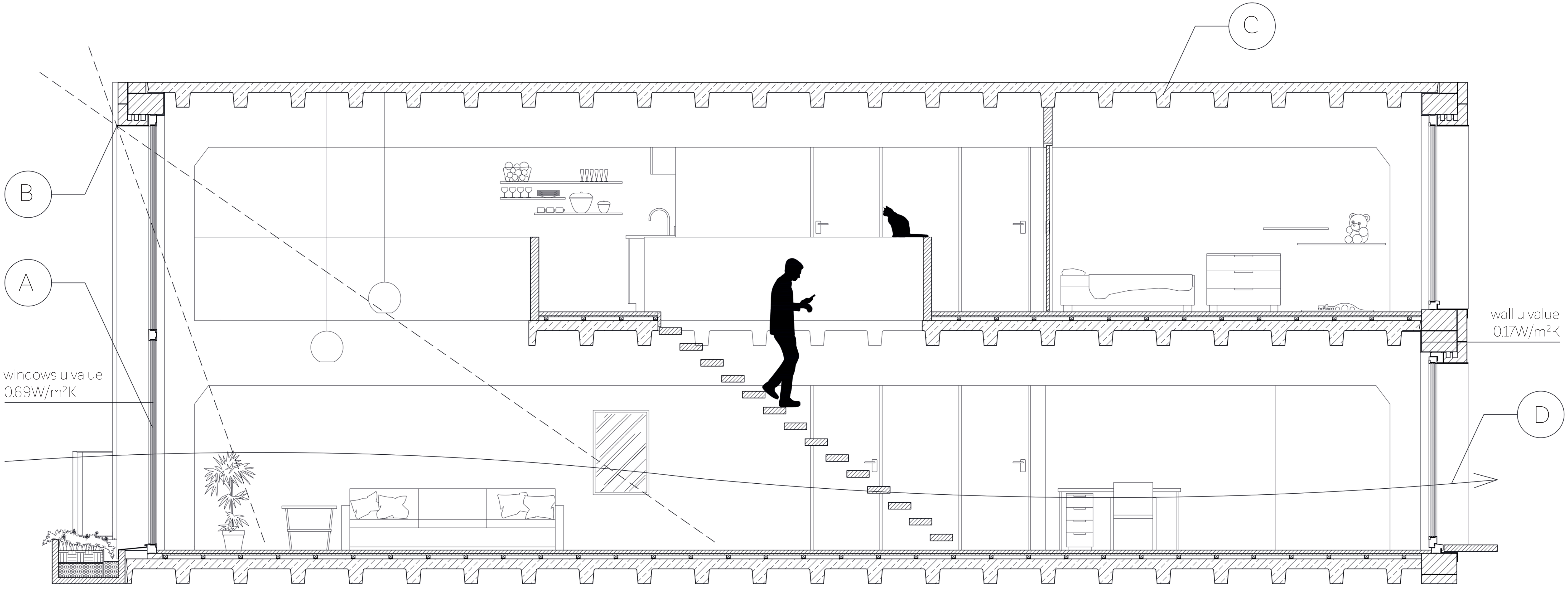
By choosing the materials based on the mechanical properties that are needed, the use of carbon heavy materials can be limited to special aplications.

ill. 63: Materials collage, own image

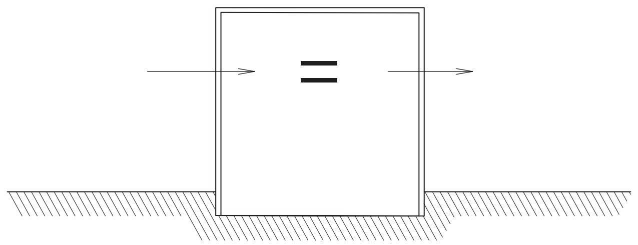
Energy concept

ZERO KWH FOR HEATING AND COOLING

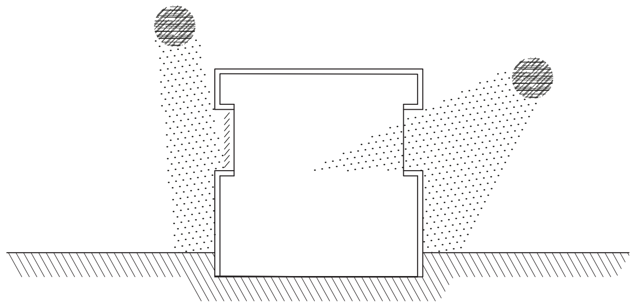
Following the lowtech design philosophy the building is designed without technical heating systems and is purly heated by solar and internal gains. The indoor climate is controlled by a centrealized server, with override capacity by the occupants, controlling the natural ventilation openings. Swings in temperature and gains are balanced out by the heavy construction of the floors and wall, with the walls and windows keeping the energy in with u values of 0,17W/m²K and 0,69W/m²K respectivly (ill. 64).



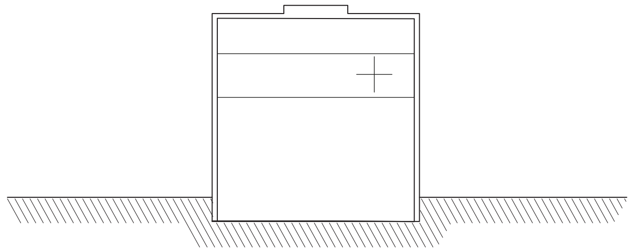
ill. 64: Section of an apartment with the heating stratagies, scale 1:50, own image.



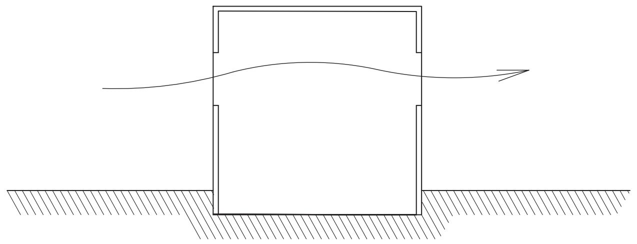
A The fundamental principle of energy balance defines the inner workings of the building. The amount of energy that the building gains is balanced out with the energy losses. Therefor the building can maintain its own temperature without aditional energy sources.



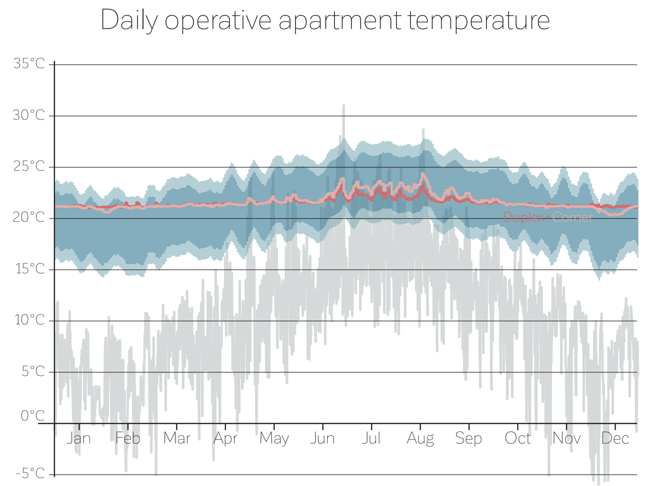
B The window openings are optimized for optimal heat gains in winter and minimizing heat gain in summer. With the NE façade comprized of 20 percent windows and the SW of 30 percent. Additionally a shading system kicks in in summer that shades just enough to keep heat out and still lets enough sunlight through to keep the artificial lights of.



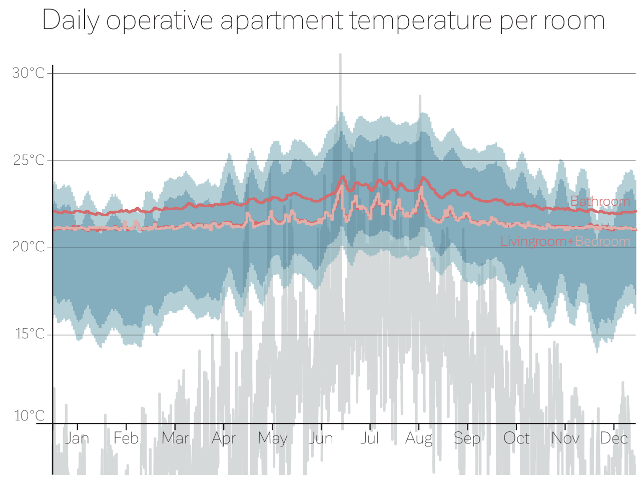
C Supply and demand of heat is unevenly distributed over the use of the building. To counter this the construction and envelope act as a battery to store exces heat for later. The old concrete construction plays a big role together with the monolithic thermal brick build façade.



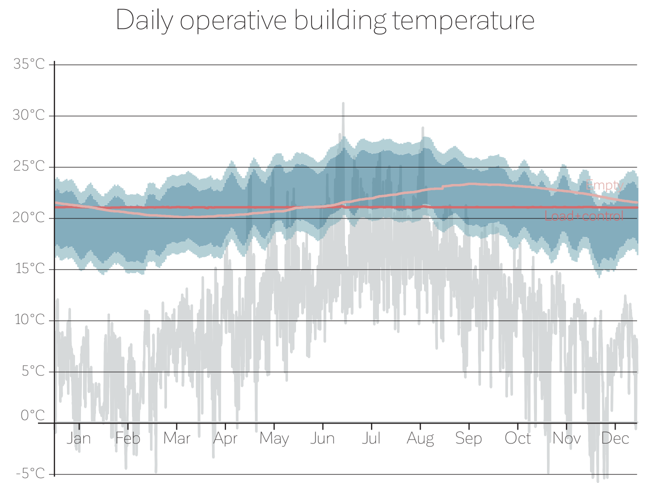
D Any exces heat that is stored in the buildings construction is disapated through natural ventilation. Due to the depth of the apartments additional height is needed for the natural ventilation to work. Therefore the apartments in the original construction are duplex with a douple height ceiling in the living room.



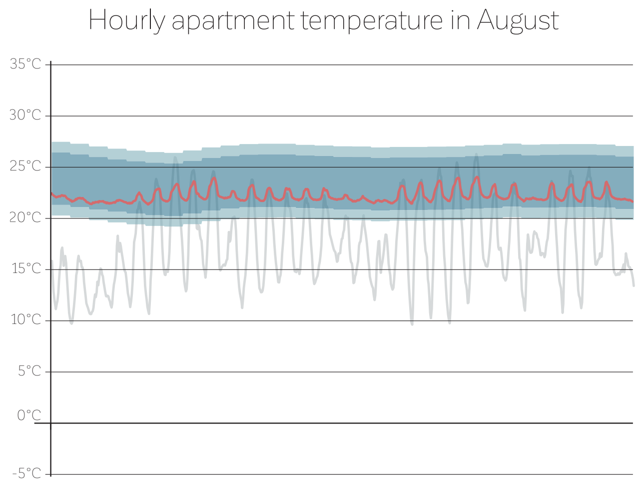
ill. 69: Simulated daily average temperature of the building with proposed construction methods, own image..



ill. 67: Simulated daily average temperature of an occupied apartment, own image.



ill. 68: Simulated daily average temperature of the building floors with proposed construction methods in the year 2080, own image.

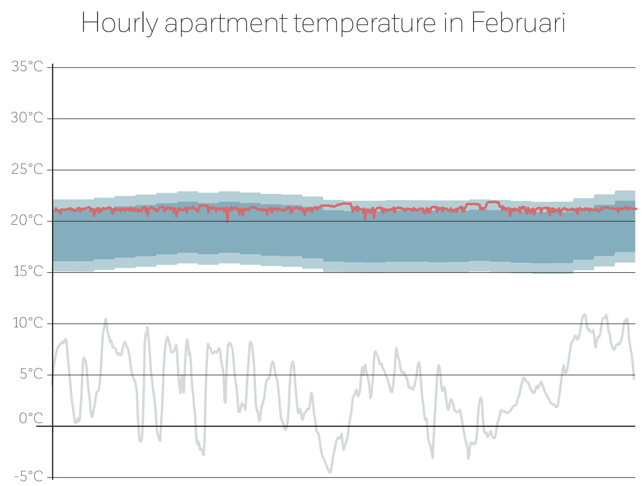


ill. 66: Simulated hourly temperature of an occupied apartment in August, own image.

The building and its climate have been simulated in Diva4. The climate stays within the 90% satisfaction temperature almost all year round. Only in winter it pops into the 80% satisfaction rate, but extra ventilation by the occupant can easely lower this temperature. More indepth information can be found in the process part of the report.

Legenda for all graphs.

- Outdoor temperature
- 80percent satisfaction temperature
- 90percent satisfaciton temperature
- Indoor temperature



ill. 65: Simulated temperature of an apartment in Februari, own image.

Windows

All windows feature a 20 cm wide ventilation panel. These computer controlled panels open and close according to the buildings and occupants needs. By regulating the size of the openings the apartments air can be refreshed up to 7 times an hour, ensuring an excelent indoor air quality. The only mechanical ventilation can be found in the toilets, these are vented by a 125mm shaft with a moisture and heat activated fan in each bathroom.

The widows are reccesed into the walls by 40cm to provide shading in summer, additional shading is placed on the exterior walls in the form of large wire mesh panels, with 50 percent transparency they block enough light to keep the building from overheating, but still allow for a daylight factor of minimal 2 percent in the bedrooms and living room.

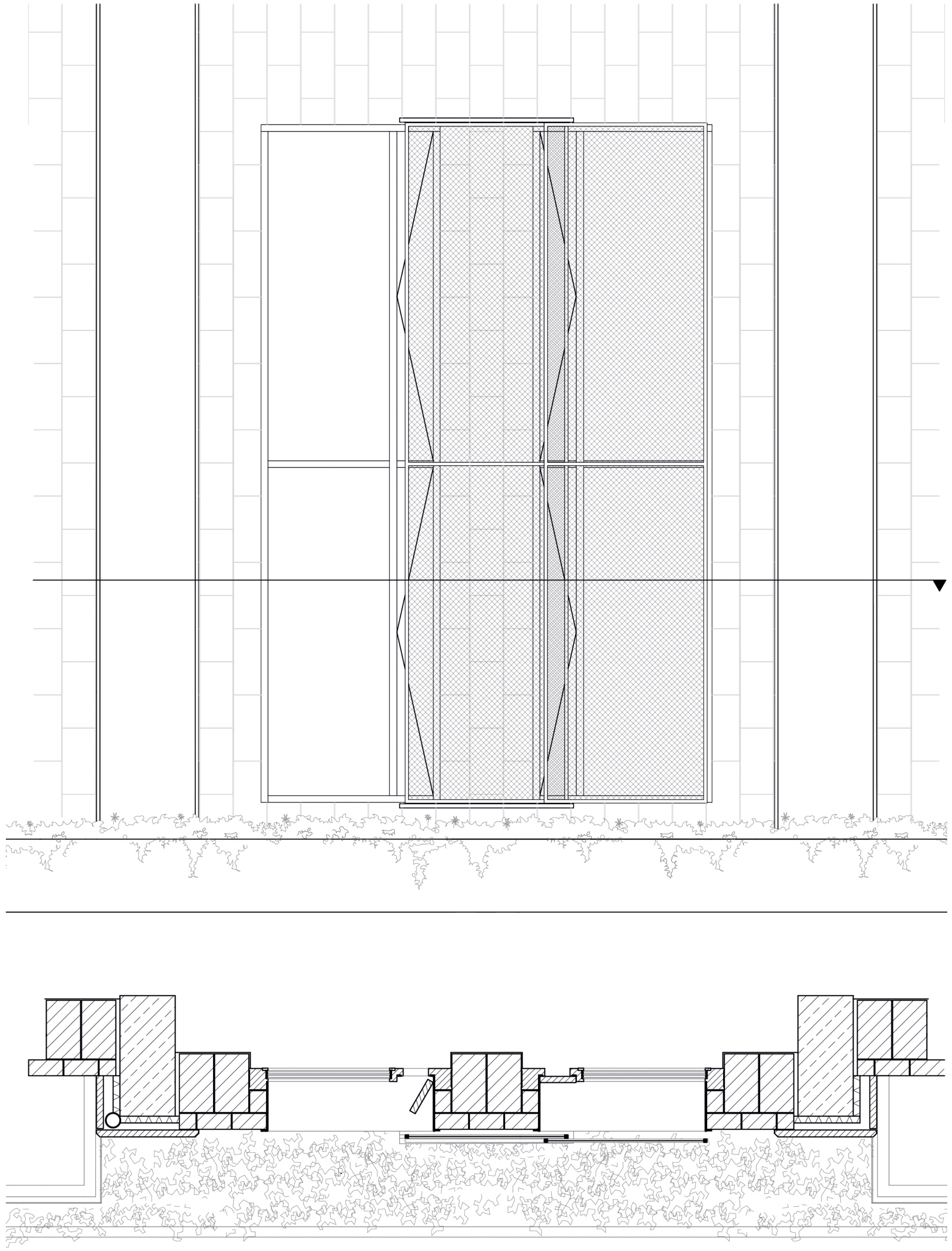
Thermal mass

Three constructial elements provide the basic thermal mass for the apartments, brick, concrete and wood. the proportians of the materials change from floor to floor. the duplex apartments have a higher proportian of concrete, and the new build apartments have a higher proportion of wood in their construction. The different apartments have the following amount of mass in their construction relative to floorspace:

Apartment in excisting structure	
Brick:	450kg/m^2
Concrete:	300kg/m^2
Wood:	23kg/m^2

Apartment in new structure	
Brick:	310kg/m^2
Concrete:	0kg/m^2
Wood:	130kg/m^2

When taking the specific heat capacity into account the duplex apartments can store 75,9MJ by heating up the construction one degree celcius. With the new construction apartments storing up to 32,7MJ per degree celcius increase of the construction



ill. 70: Section and view of window in the southwest façade, scale 1:40, own image.

Construction strategy

1 STRIP - the parking garage is striped of all the non-constructional elements. Leaving the bare concrete structure behind.

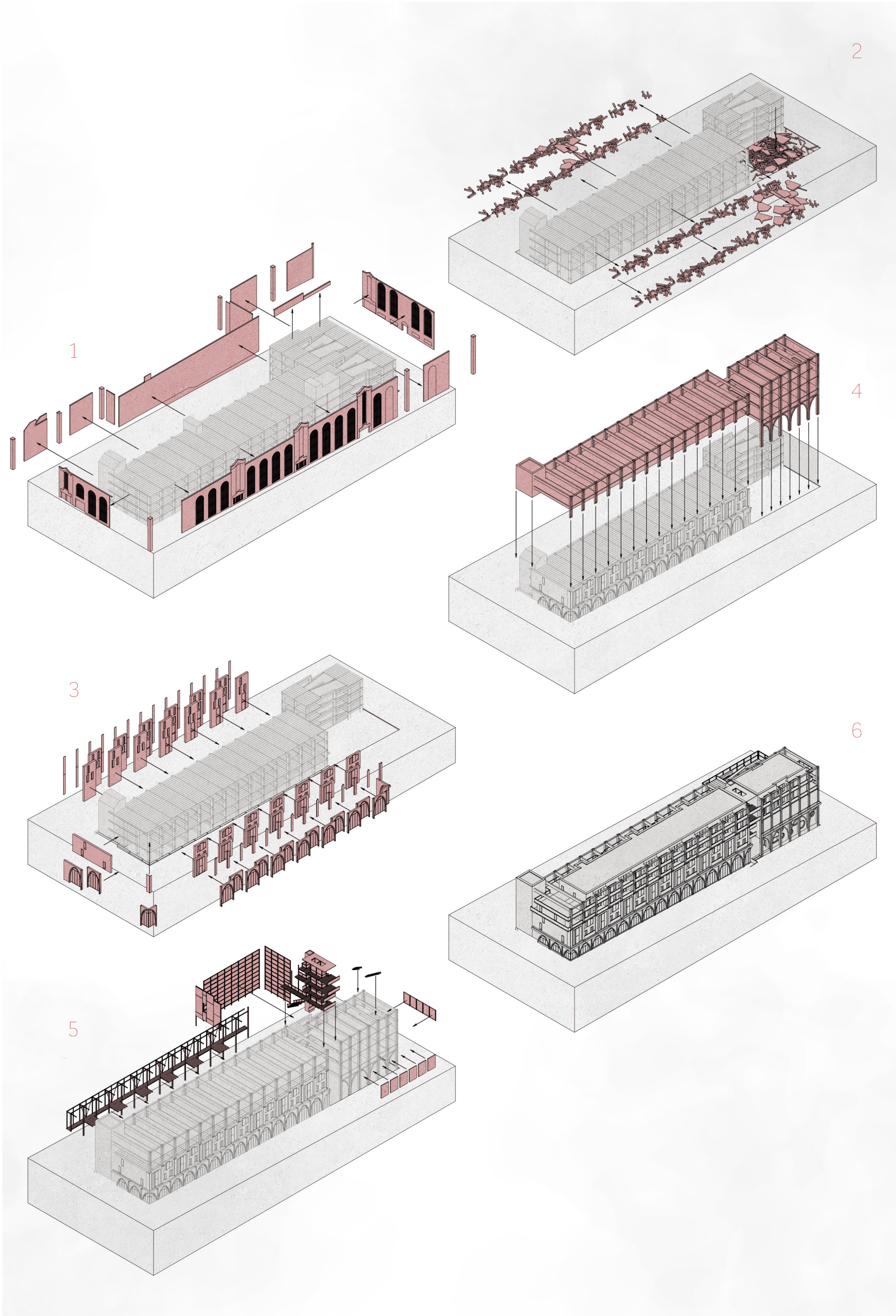
2 ADAPT - the concrete construction is adapted to the design of the apartment complex. Holes are cut into the floor for staircases and nonessential ramps and staircases are demolished.

3 FILL - The first four floors are closed with prefab wall elements that are slotted inbetween the concrete columns. The columns are insulated and a wooden panel is fitted over the columns to finish the wall and cover the edges of the prefab elements.

4 ADD - Additional structure is added on top of the garage to support the additonal two floors. Further the structure besides the ramp is build to house the youth library, playground and aditional apartments.

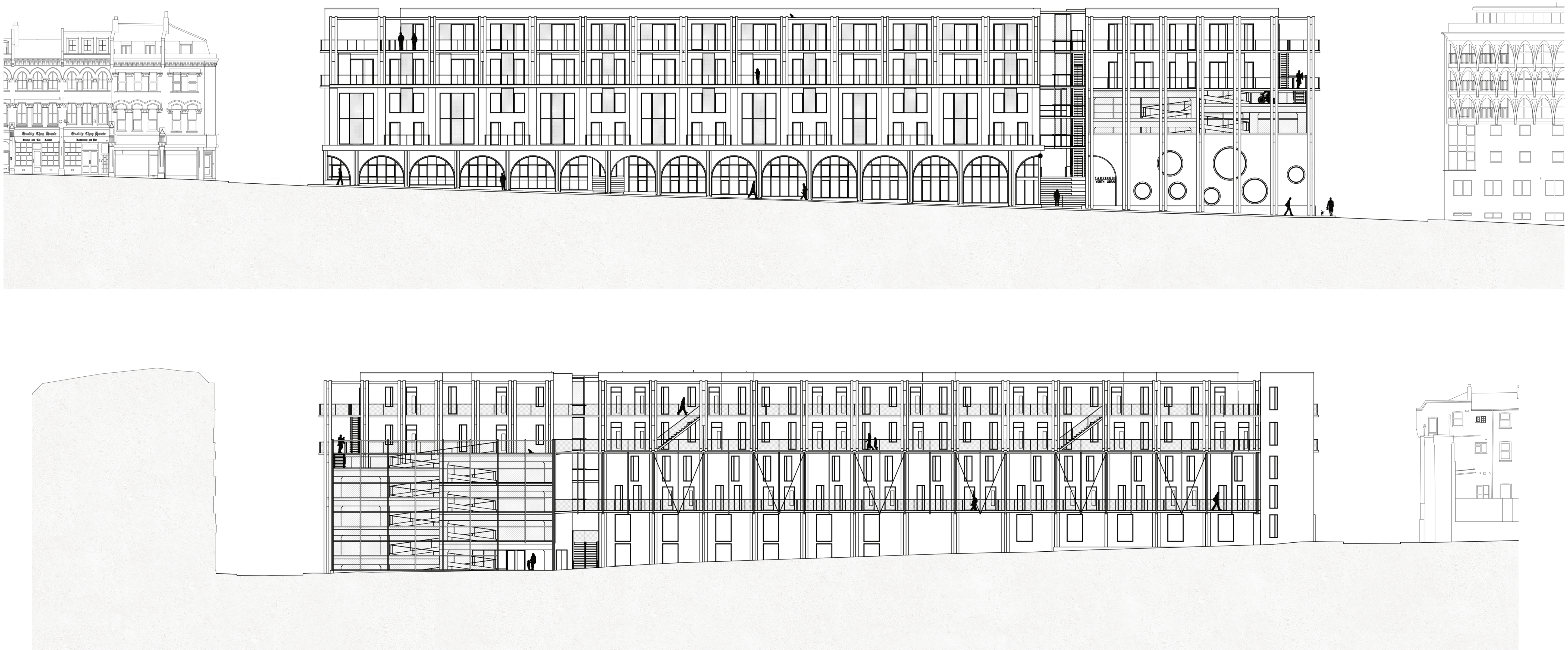
5 METALURGY - Adding all of the steelwork around the new construction to support the outside galleries and staircases.

6 FINNISH - Interior walls are fitted together with the prefab wall elements for the last two floors. Railings are added to all galeries and instalations are fitted.



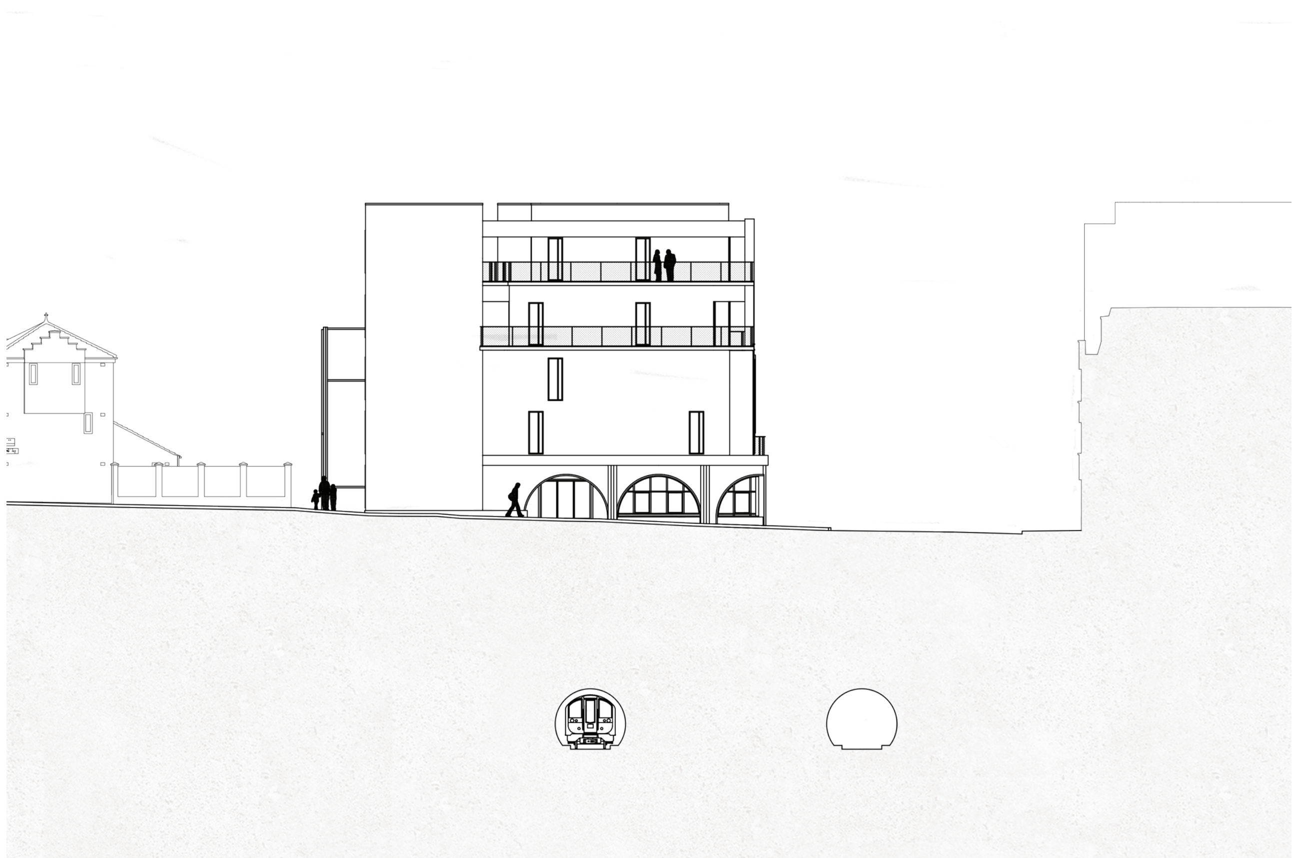
ill. 71: Construction tactics axonomitries, own image.

Elevation southwest



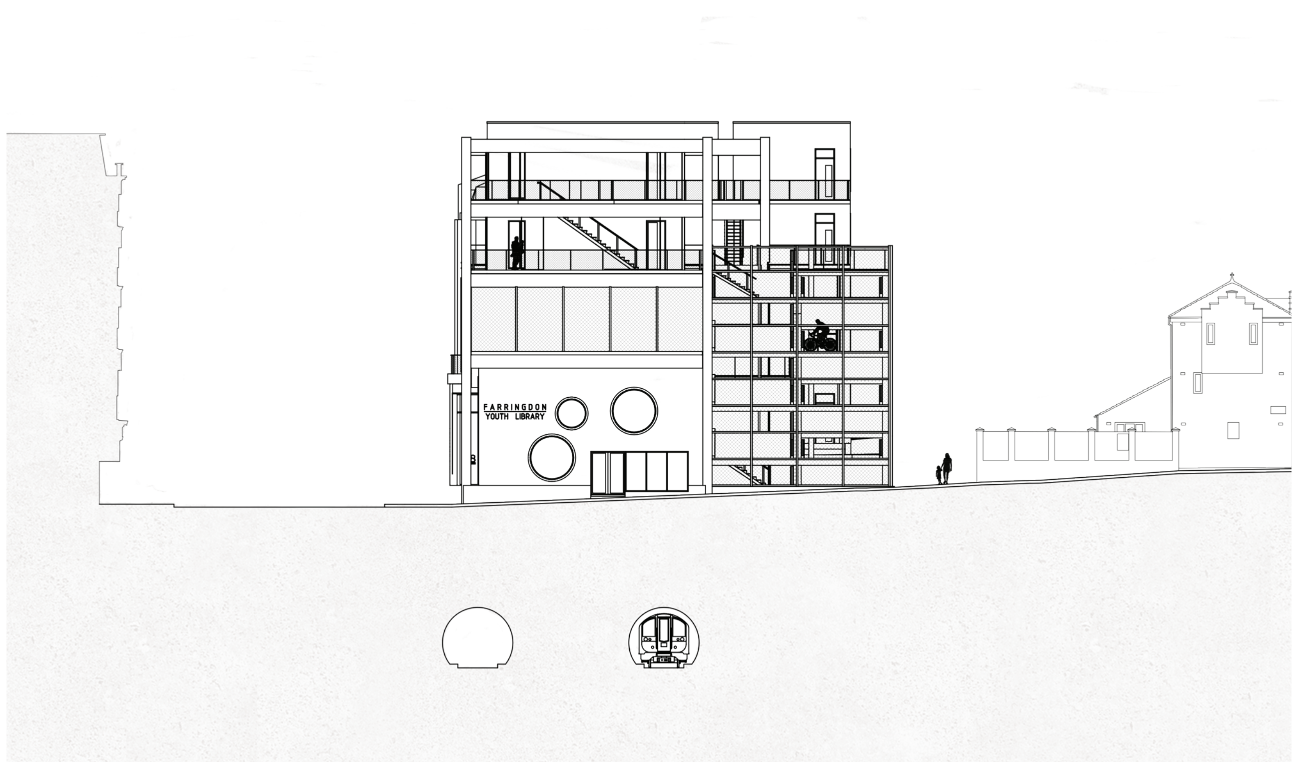
ill. 72: South West and North East elevation, scale 1:400, own image.

Elevation northwest

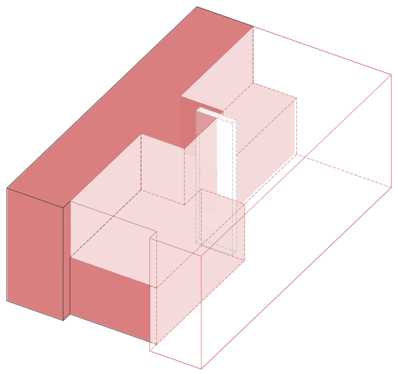


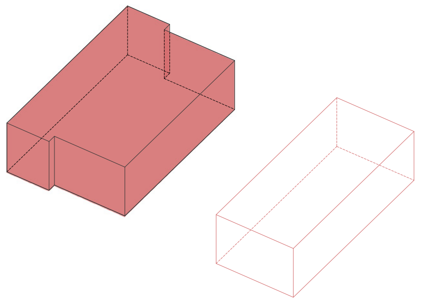
ill. 73: North West elevation from Viveyard walk, scale 1:400, own image

Elevation southeast



ill. 74: South East elevation from Bowling Green lane, scale 1:400, own image.





Apartments

Duplex apartments

The duplex apartments can be entered through the north east side from a gallery. To provide the duplex apartments with natural daylight, we decided to partially open up the ceilings towards the southwest. This leads to an open connection within the two levels and to a more interesting spatial experience. Only through a horizontal shift in the duplex apartments, we succeed in creating two functional and different apartments with an interesting layout and unique expression. The inner wooden walls complement the visible concrete beam and bring warmth into the apartment.

One-level apartments

The one-level apartments are 80m^2, efficient, and include many various functions in a limited space. We stacked through the apartments to maximize the daylight and gain the full potential of natural ventilation. The kitchen is centered in the middle of each apartment, to mediate the space and to activate the "death" square metres in the hallway. From the kitchen, there is an open space with a dining area and living room which is connected to the two bed rooms by double doors. The bedrooms are placed in each direction, one facing the gallery and the other facing the balcony. The main spatial experience consists of the flexible organisation, where you can either open up the apartment by opening both double doors or closing them and have privacy in each end of the apartment. The inner wood walls serve as a warm element and the walls between the apartments are made from thermal brick, which increases the thermal mass and decreases sound travel between the apartments.

Studio apartments

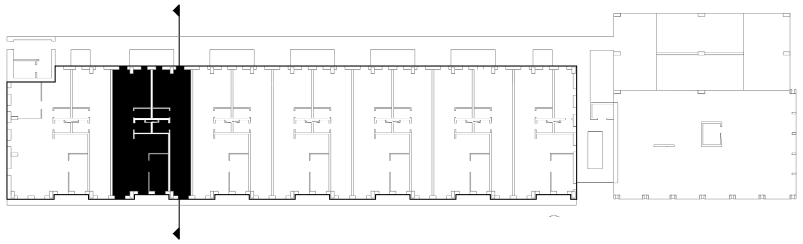
The studio apartments are entered through the gallery. They are stacked through, which provide good daylight conditions. They are divided through the service room with a big kitchen facing the gallery and a southern private space.

Construction and sound

The walls between the apartments are made from thermal brick, which increases the thermal mass and reduces sound between the apartments. Sound insulation is further increased with a floating floor that is installed on all floors and in all apartments.

ill. 75: Interior visualization, own image.

03



Duplex A
130 m2
2-3 bedrooms, big balcony, visible concrete beams, open ceiling towards southwest, gallery access

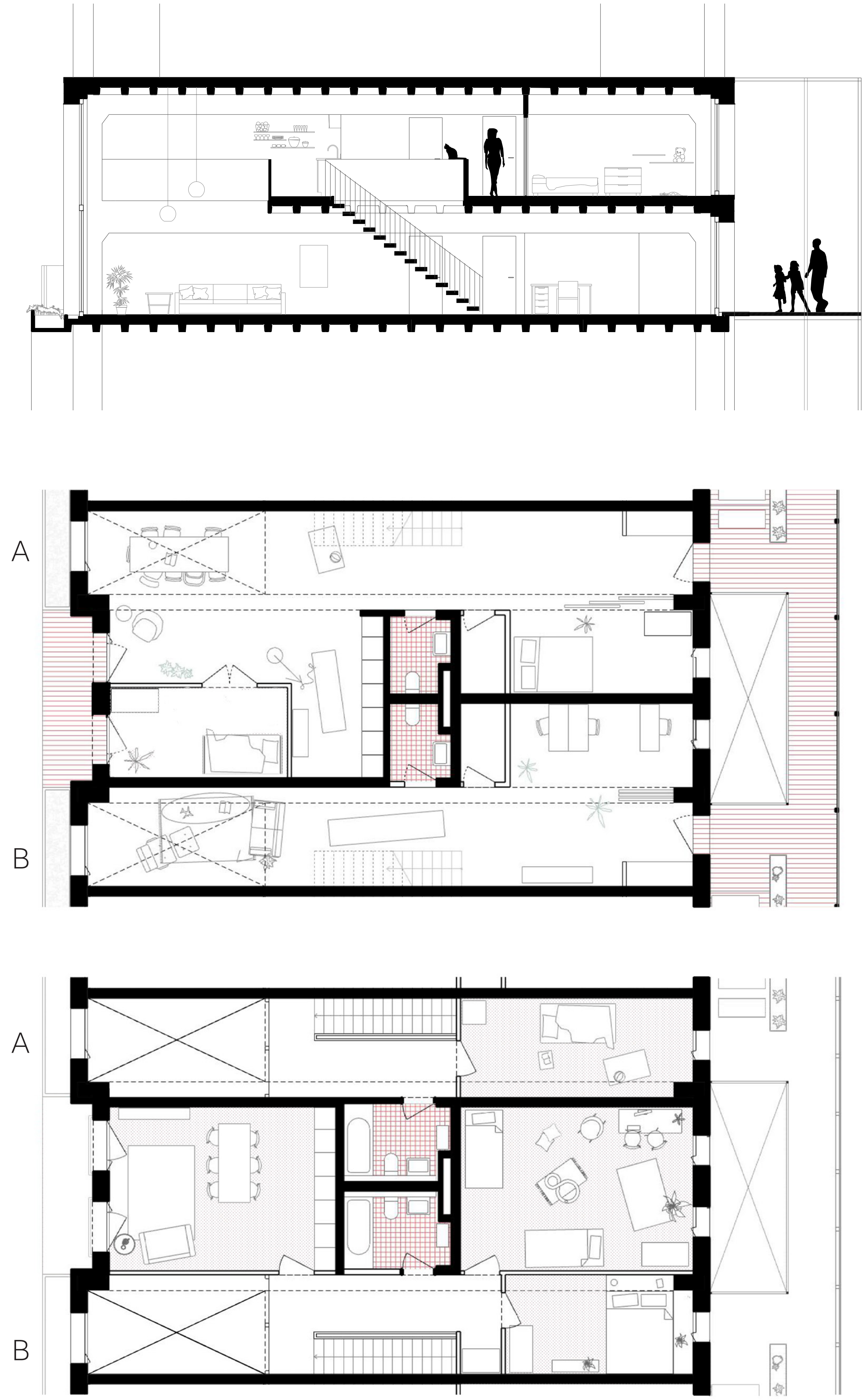
For; families

The apartment is family minded with a spacious organisation, but still flexible to the changing dynamics of a families needs and behavior. Due to the duplex function, the families can adapt their way of living as time goes by and the kids are growing.

Duplex B
150 m2
2-3 bedrooms, french balcony, visible concrete beams, open ceiling towards southwest, gallery access

For; families, home based business owners

To support the possibility of starting your own business, we made it possible to utilize the down area for home based business combined with family living upstairs.



ill. 76: Plans and section of the duplex apartments, scale 1:150, own image.

05

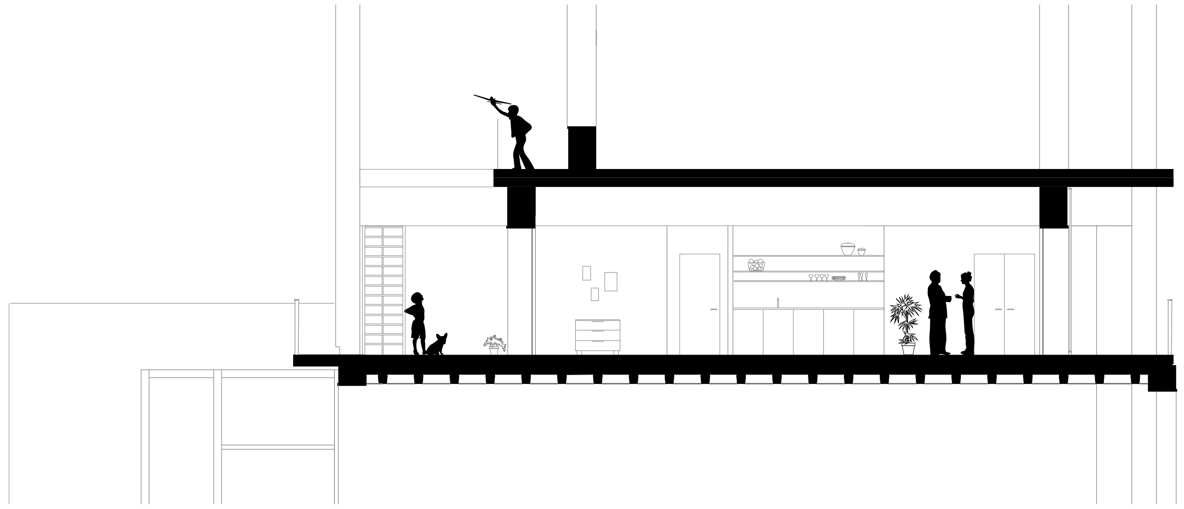
3-room apartments
68 - 80 m2
Big balcony works as living room extension.

For; singles, couples without kids, elderly people.

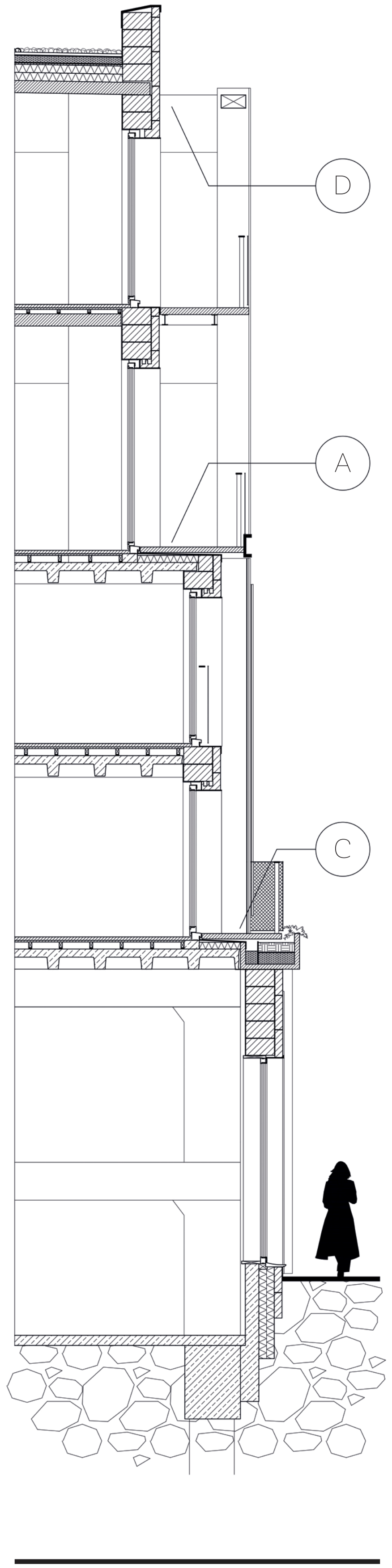
The main spatial experience consists of a flexible organization. It either opens up the apartment by opening both double doors or closing them and having privacy at each end of the apartment.

Studio apartments
50 m2
Open ground plan, living kitchen towards the gallery.

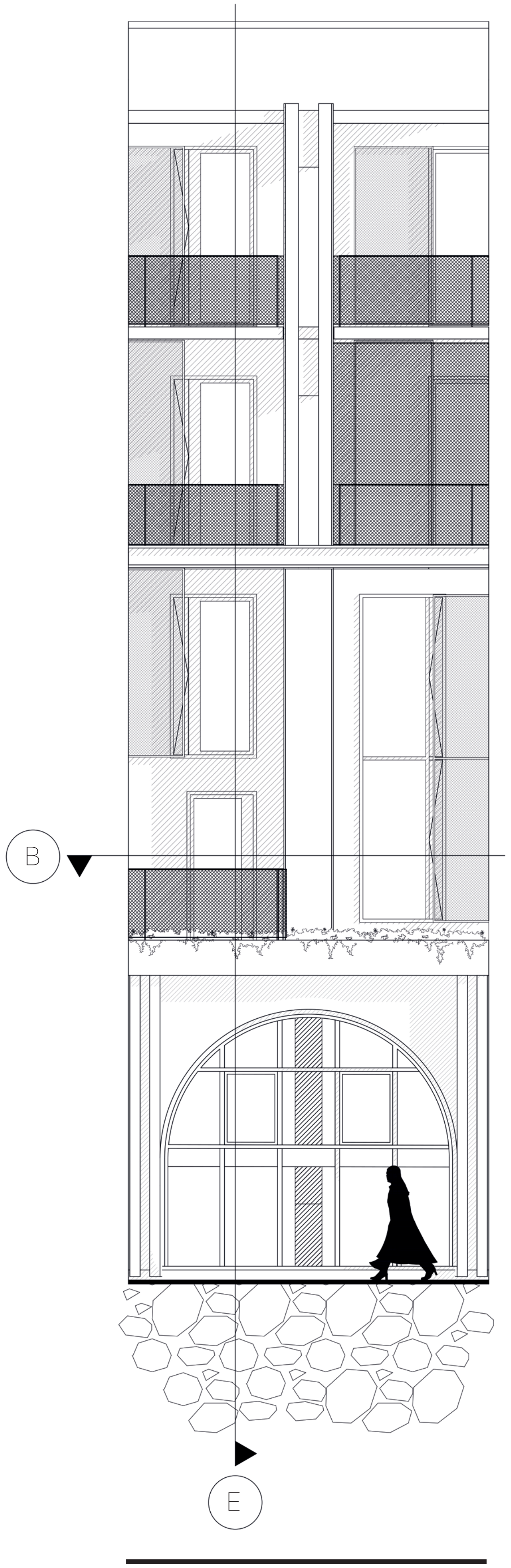
For; singles, couples, small families, elderly people.



ill. 77: Plans and section of the new construction apartments, scale 1:150, own image.



ill. 78: Section E 1:100, scale 1:100, own image



ill. 79: Façade, scale 1:100, own image

Details

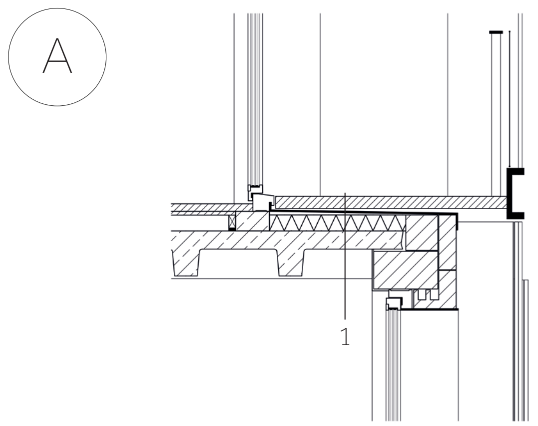
To follow the vertical context of London architecture that we identified during the field research, we choose to work with a vertical and strict rhythm in the facade. We chose the shape of the round arches on the ground level to contrast the strictness of the facade, but still keep it within the geometric silhouettes. We aimed to implement the shading elements to give a playful rhythm that complements the strict facade. The details with with the respective u values are depicted in ill. 80 to ill. 83. The calculation of the u value can be found in Appendix B.

1 — $0{,}14 w/m^2k$
accoya clt floor 80mm
metal sheeting 10mm
thermalblock airogel 98mm
concrete 100mm

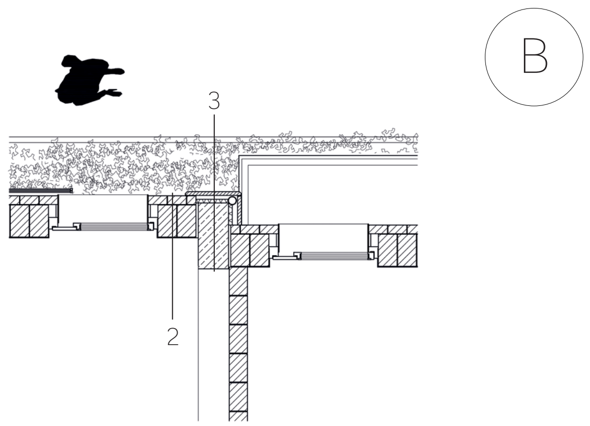
2 — $0{,}17 w/m^2k$
glazed thermal brick 125mm
thermal brick 425mm
plaster 10mm

3 — $0{,}16 w/m^2k$
accoya clt panel 50mm
thermalblock airogel 49mm
concrete 880mm

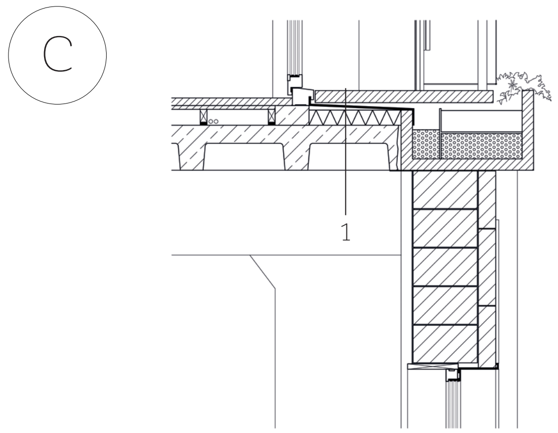
4 — $0{,}11 w/m^2k$
sedum and substrate 60mm
leca balls 100mm
roofing felt 18mm
plywood 18mm
insulation 240mm
vapor barrier 1mm
clt construction 180mm



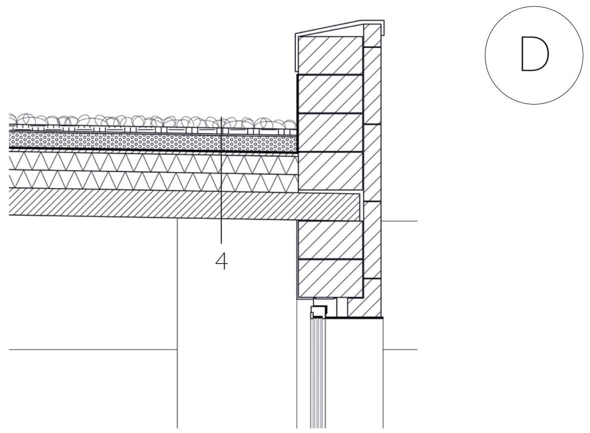
ill. 80: Detail A, scale 1:50, own image.



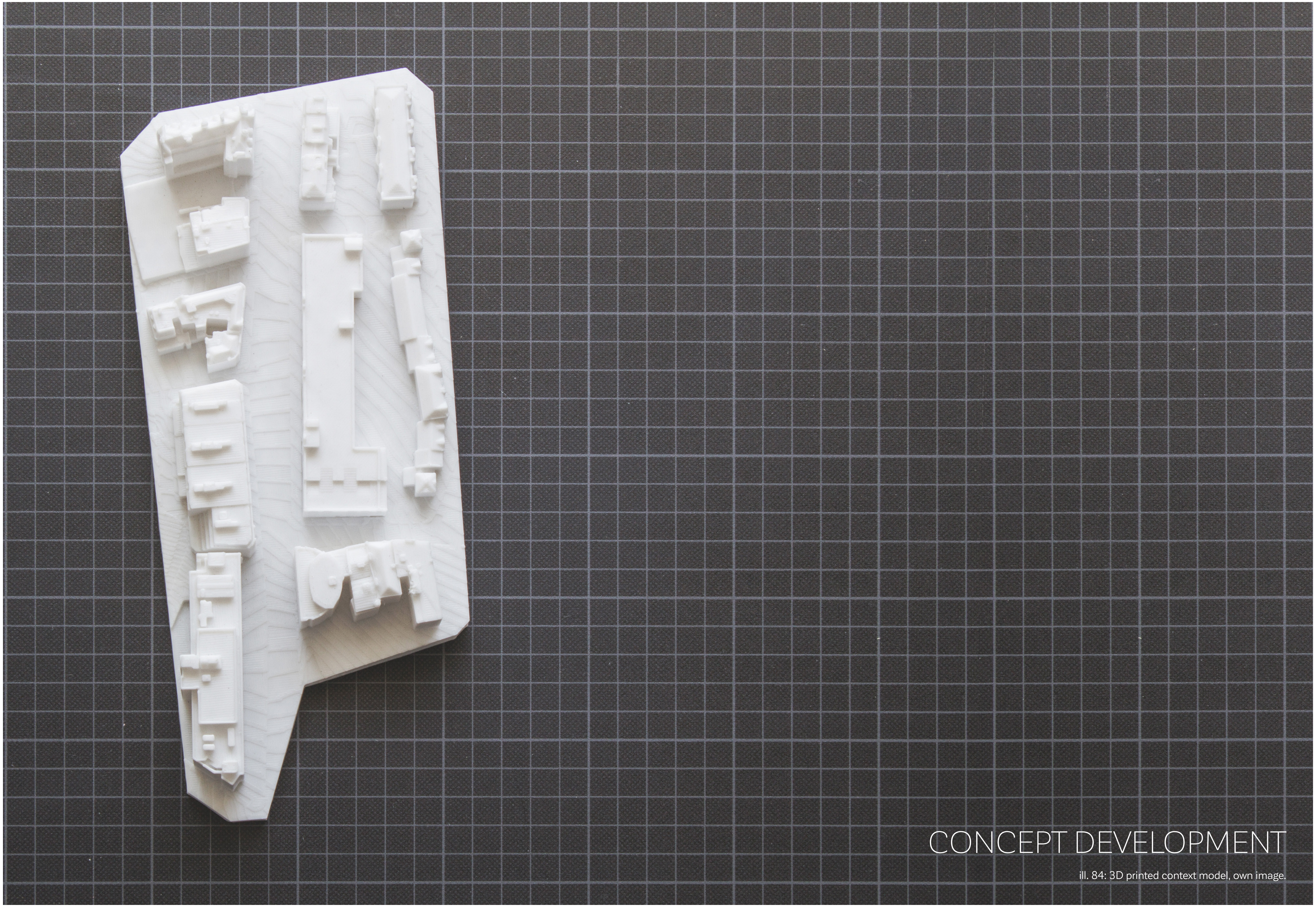
ill. 81: Detail B, scale 1:100, own image.



ill. 82: Detail C, scale 1:50, own image.



ill. 83: Detail D, scale 1:50, own image.

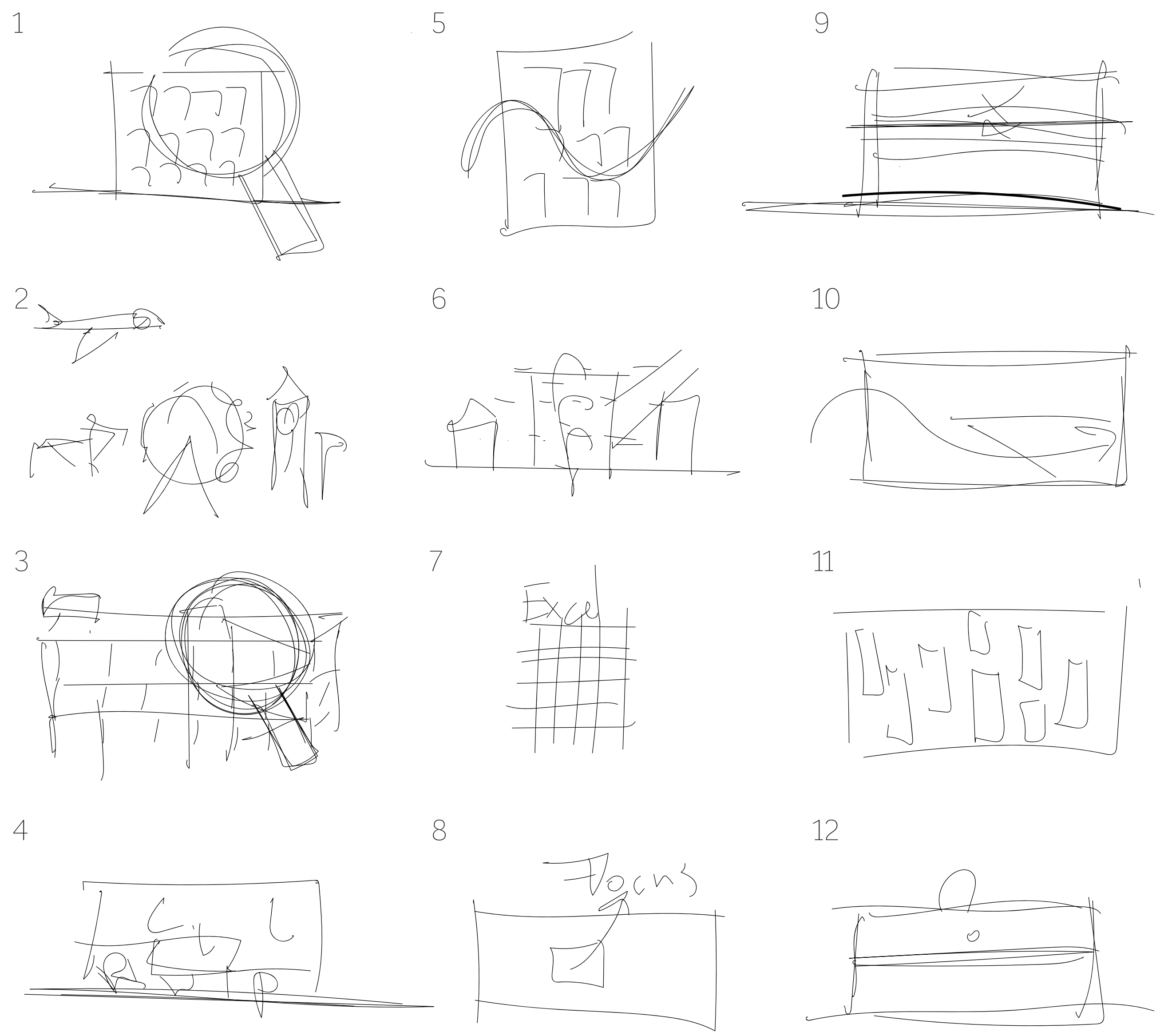


CONCEPT DEVELOPMENT

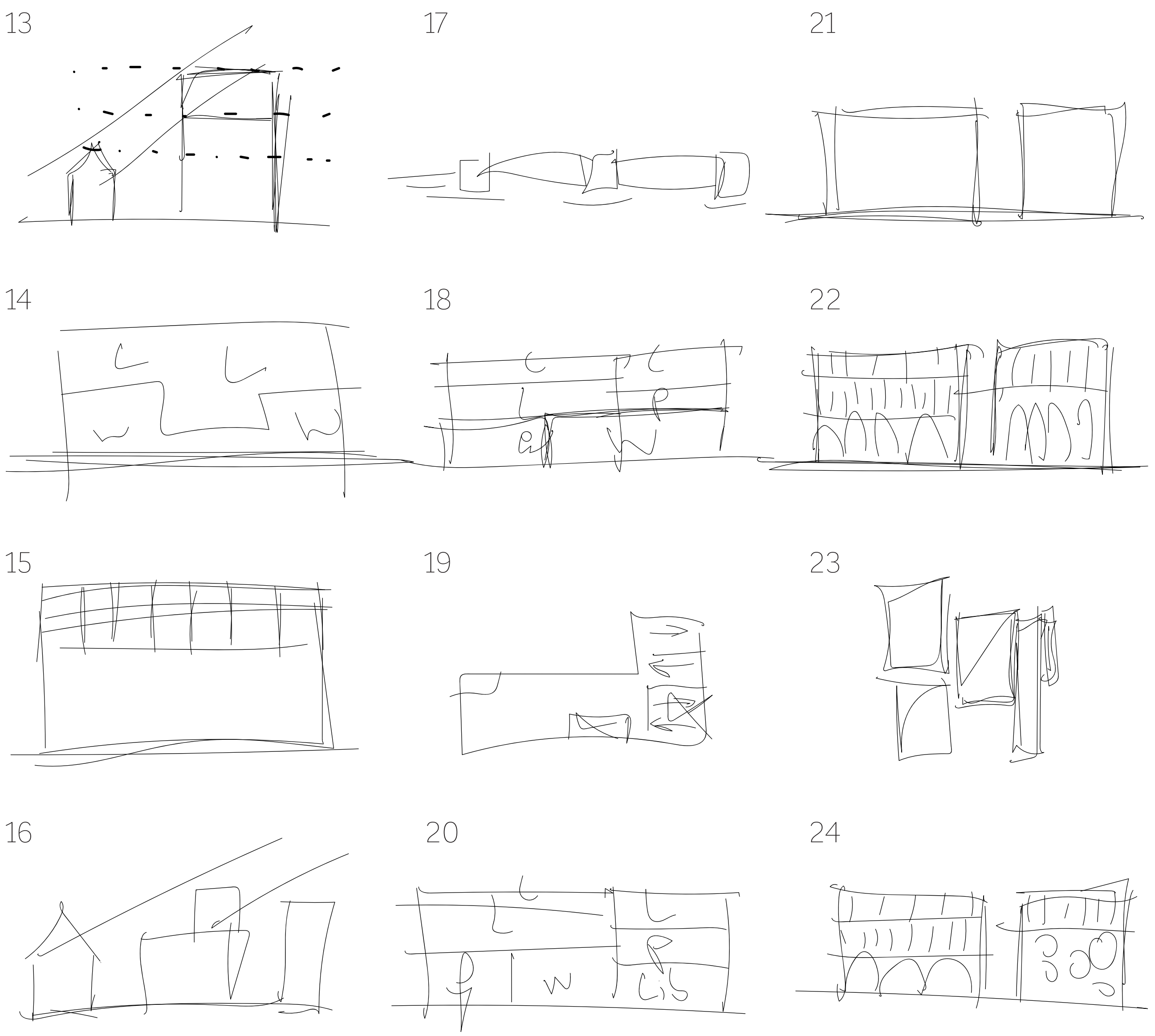
ill. 84: 3D printed context model, own image.

Building development

Our process will reflect upon the development of our initial ideas and how they changed through the dynamics and processes of prototyping, computation, and discussions. We started out by selecting and entering a competition that would function as a starting point for our master thesis. Since the competition focuses on affordable re-imagined housing in London, we decided to take a field study trip to experience London's neighborhoods, typologies, facades, and urban settings with our own eyes. Once we got back, we started the design process with a divergent sketching phase that turned into the prototyping of physical wood models and printed models in the scale of 1:200 and 1:500, which led us to explore and comprehend the physical mass and proportions. When the physical prototypes were not sufficient, due to the limitations of details in the building and the lack of possibilities to upscale and fully understand the volume and spatial experience, we started to create 3D visualizations and apply computation and simulations. During this intense circular learning process, we used the different prototyping tools to make deep dives into our design. In what follows, the key processes are represented and illustrated through photos and graphical data.



ill. 85: Development process part one, own image.



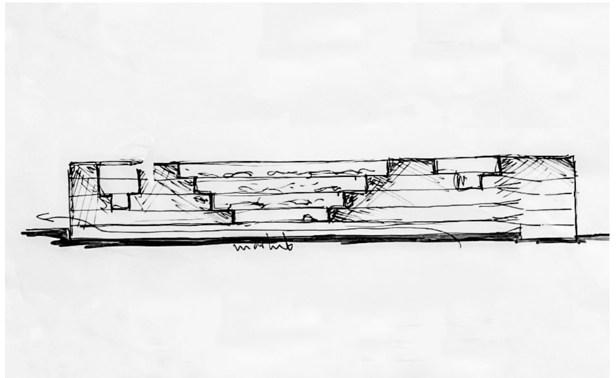
ill. 86: Development process part two, own image.

Illustrations 85 and 86 show a crude version of the actual process that took place over a period of 3 months with these following steps:

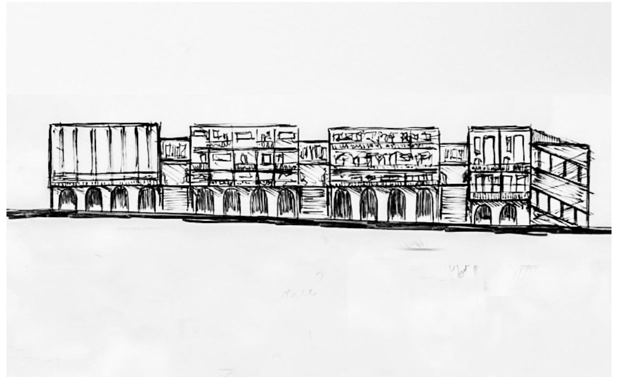
1. Analysis of 2226
2. Field trip to London city
3. Analysis of Farringond road parking house
4. Choice of functions
5. Energy simulations of 2226
6. Form studies digital and physical
7. Shadow studies to decide the place of functions
8. Window gain and losses studies
9. Focus on apartment design
10. Replacing 2 floors with one for extra ceiling height.
11. Keeping floors and going with duplex for ease of construction
12. Window design based on apartments and calculations
13. Shadow studies to determine the total height
14. Rethink of functions
15. Design of top structure
16. Adapting to shadow studies
17. Design of wall construction
18. Removing parking from the building
19. Removing the second ramp structure
20. Rethink of community functions
21. The split of the building
22. Facade design
23. Detailing
24. Change of arches

Initial concept sketches

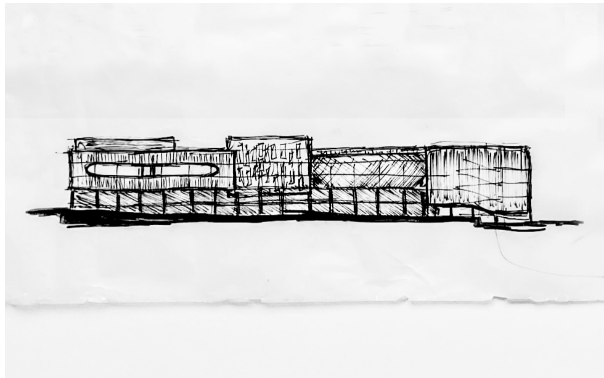
Initial sketches were used to get the design process started. The sketches helped to translate the gained knowledge from the theories and analysis into design practice. Initial ideas about the distribution of functions were explored as well as expressions and the processing of the current structure. The process led to core ideas and concepts that spark further discussions and created the shared starting point.



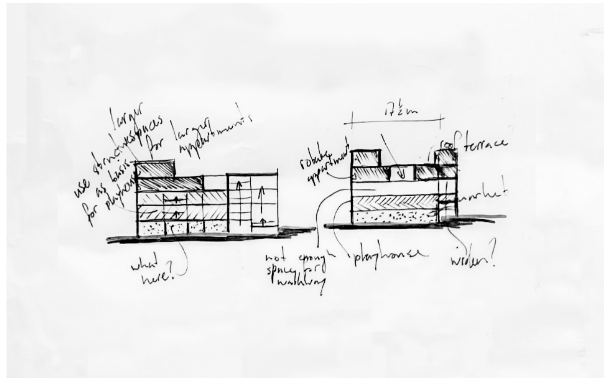
ill. 89: Concept sketch, own image.



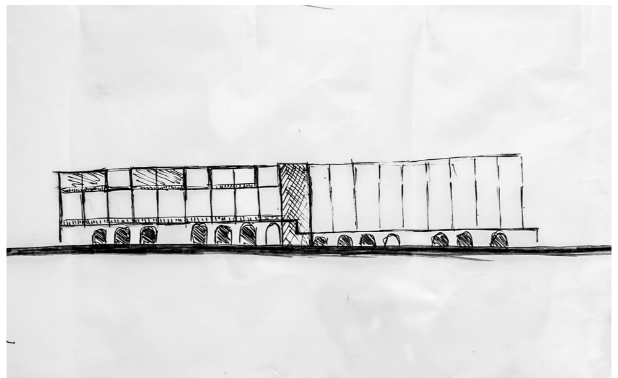
ill. 88: Concept sketch, own image.



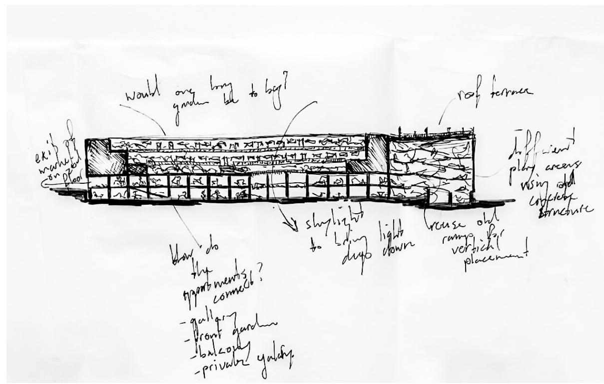
ill. 87: Expression design sketch, own image.



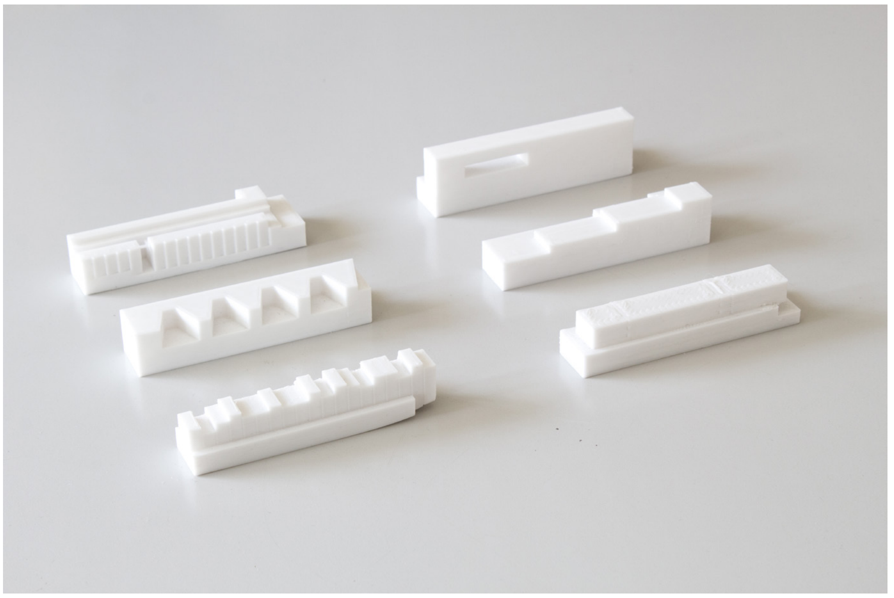
ill. 90: Functions section design sketch, own image.



ill. 91: Facade design sketch, own image.



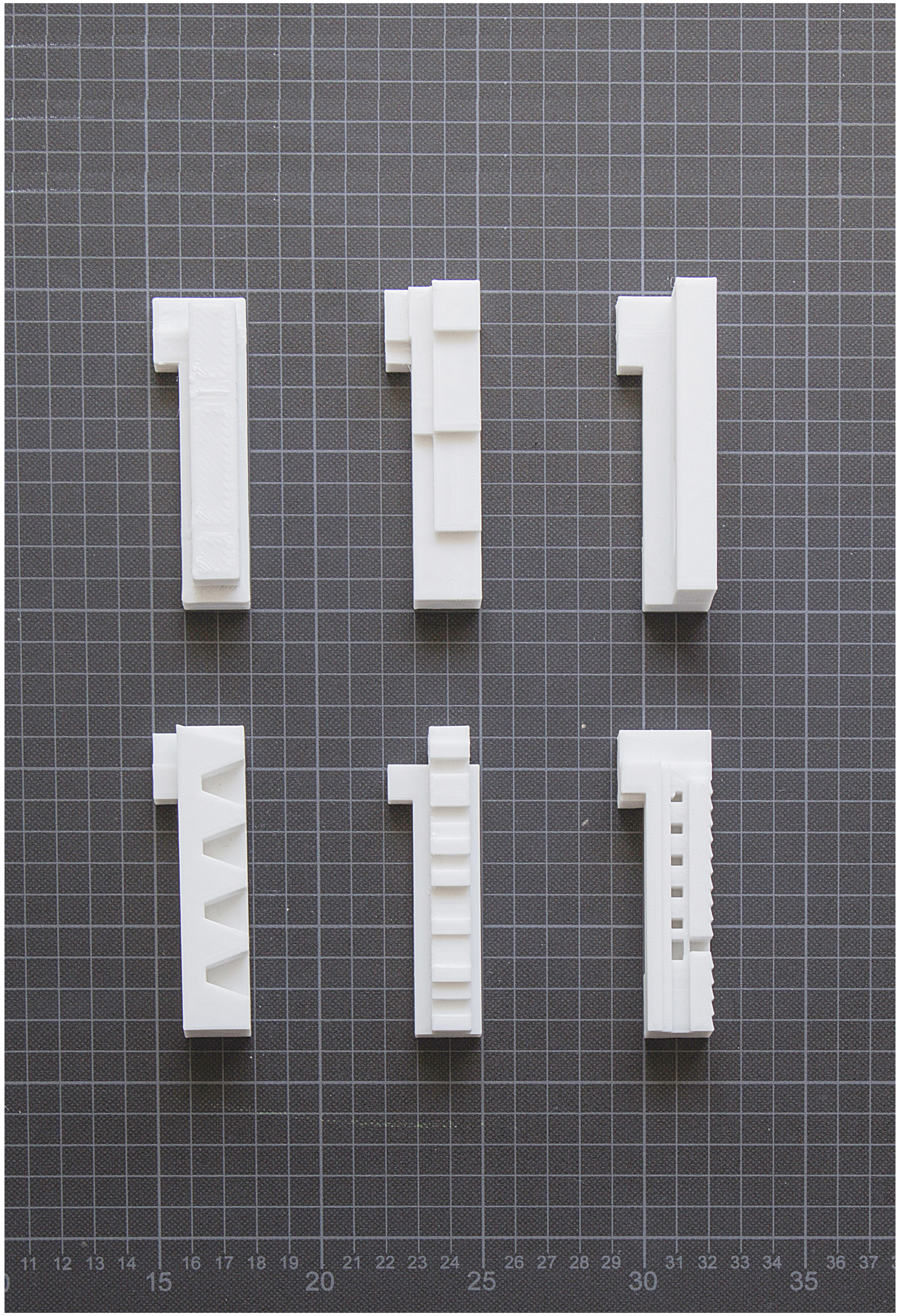
ill. 92: Functions section design sketch, own image.



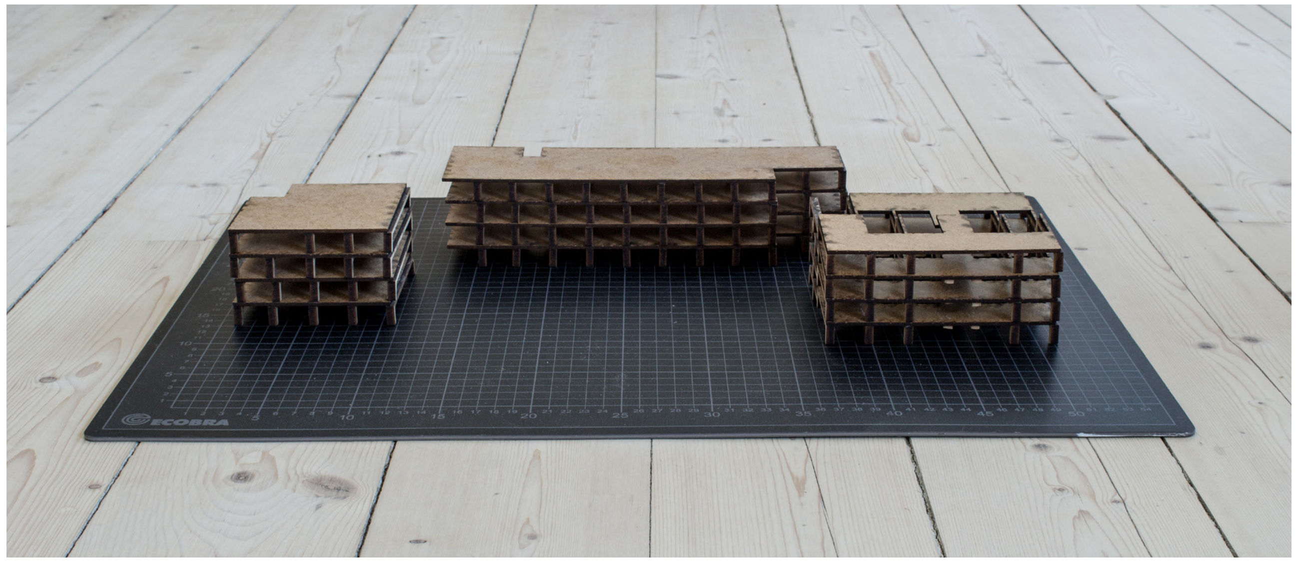
ill. 96: 3D printed models printed in 1:500, Intitial exploration of volumes, own image.

Volume studies

The start of the process had a strong emphasis on physical models, both 3D printed and handbuilt. Originally the plan was a design development through a large 1:200 scale wooden context model but was unfortunately abrupt due to the closing of the workshop. We continued with the 1:500 model on a home-based 3d printer, and even though the outcome is on a smaller scale, it still contributes to a deeper understanding of the proportions and volume regarding the context. Working with the prototypes helped to test initial ideas about the expressions of the new structure. The main outcome of this process was the acknowledgment of how much mass we can add on and the extra levels are placed in order to respond to the lower surrounding buildings.



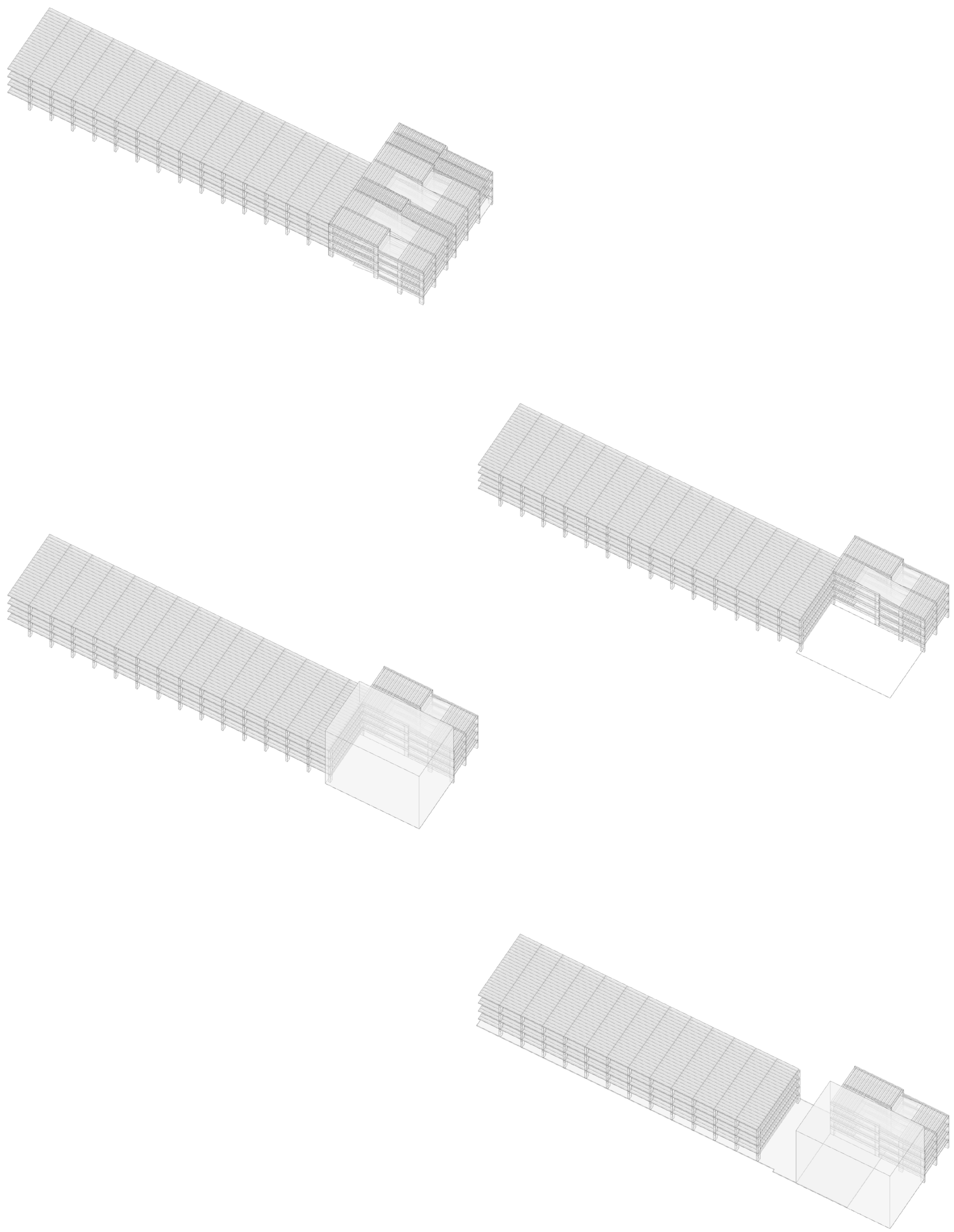
ill. 97: 3D printed models pinted in 1:500, Intitial exploration of volumes, own image.



ill. 98: 3D model of the original parking house structure, own image.

Structural development

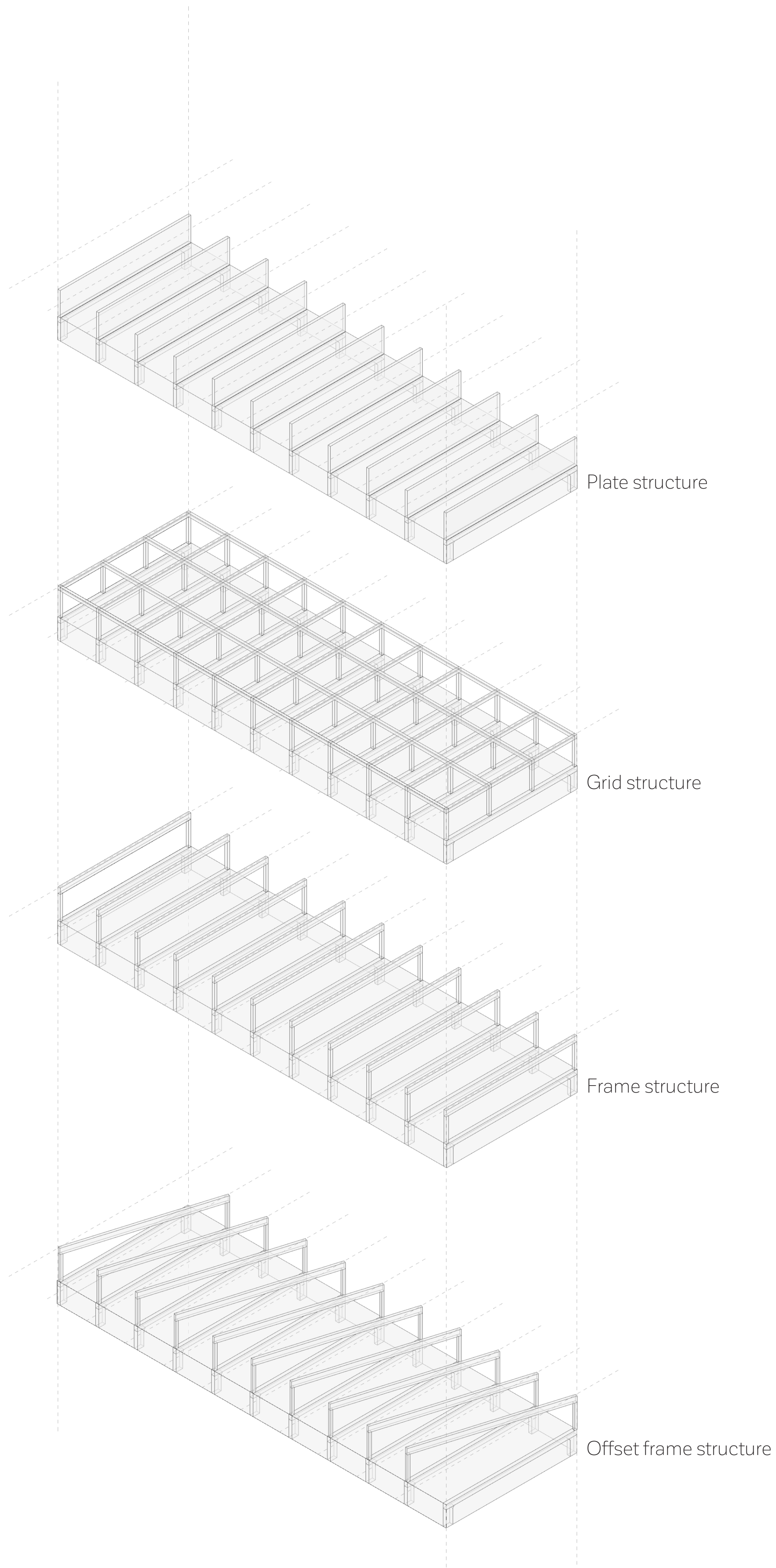
The development of the structure is split into two phases. Phase one, based on a physical model of the structure to make an analysis of the existing structure of the building. The model helped to investigate the structure and thus identify which parts of the building we wanted to implement in the final design. We decided not to keep both ramps, but only the one in the northeast. The idea behind keeping the ramp was a combination of making a reference to the heritage of the building and give the building a playful unique character and give an opportunity to play with the accessibility of the building. That way, the corner part could be redeveloped to give the building a new arrival appearance towards the city. To compensate for the dense and long mass towards Farringdon Road, we made a small gap between the corner building and the existing structure.



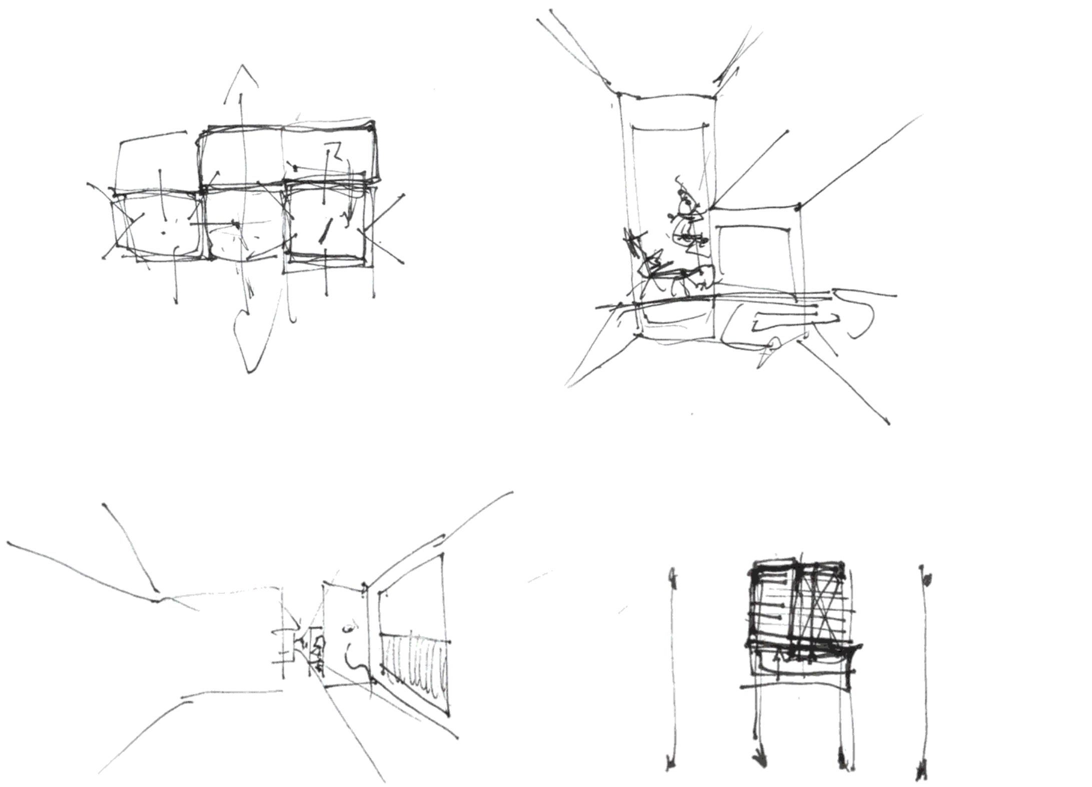
ill. 99: Process steps of retainment of parking house structure, own image.

Phase two was primarily about investigating different structural systems, such as slab, columns, and frames, to build on top and therefore to densify. The investigation contained a series of different structural systems and was carried out through 3D models, to evaluate spatial and adaptable potential. This process led to the conclusion that we should continue the existing structure, but translate the structure into a more modern building method, such as implementing wood as a warm and sustainable material in contrast to concrete.

This modern method was a frame structure with solid Accoya wood beams and clt flooring plates. transferring the forces down the original concrete columns meant that no additional foundation work was needed, something that was difficult given the metro line location. The sizes for the beams and wooden columns were calculated with rules given by Polytechnisch Zakboek (Leijendeckers, 2010).



ill. 100: Top structure investigations, own image.



ill. 101: initial sketches duplex spatial experiance, own image.

Layout

During the focused phase of the apartment development, we sketched to iterate and discuss how to solve the complexity of the architectural design. The sketching was supported by schematic 2D plans and 3D visualizations. Due to the fixed concrete structure in the car park and the decision to keep some of the existing structure, we had to be creative in regard to the organization of the apartments and the spatial experience. We worked with the following constraints:

Low tech

The technical structure became essential for the architecture

No heating installation, how do we design without it, and at the same time meet the comfort criteria?

Installation shaft; The installation shaft must be fixed in the middle between two concrete beams and placed after every second beam. Since we already knew that we would add a new structure on the top, the shafts needed to meet those criteria.

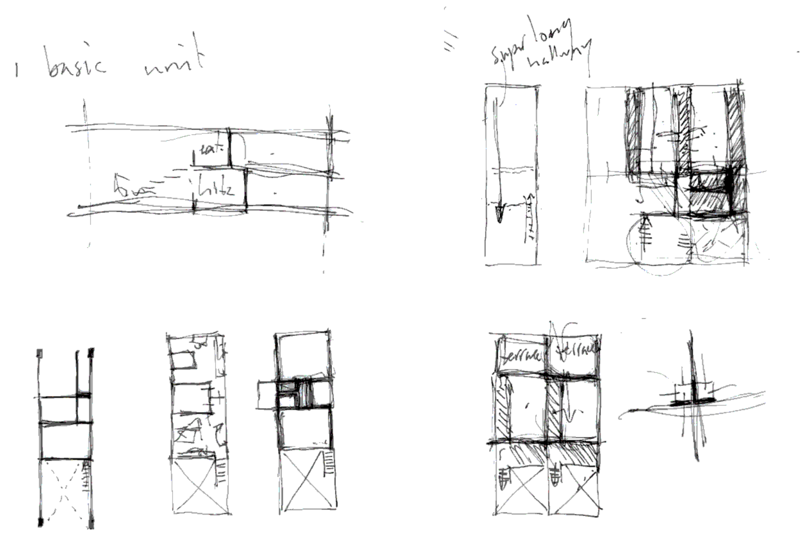
Venting; To utilize proper venting conditions, the apartments must be stacked through.

Spatial experience

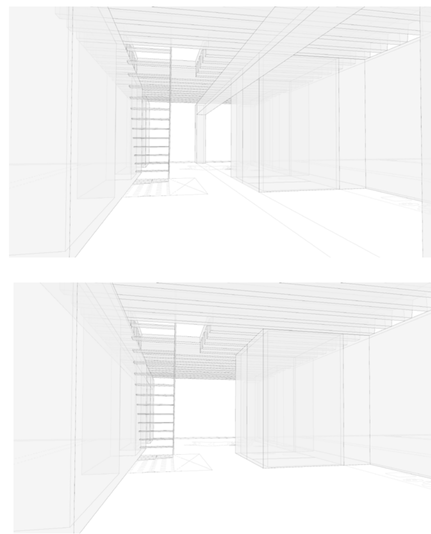
Concrete beams; How to reveal the existing building by using the concrete beams in the apartments?

Daylight; How to design apartments with sufficient daylight conditions, when the existing building provides a structure that is 15m wide and 2,5m tall?

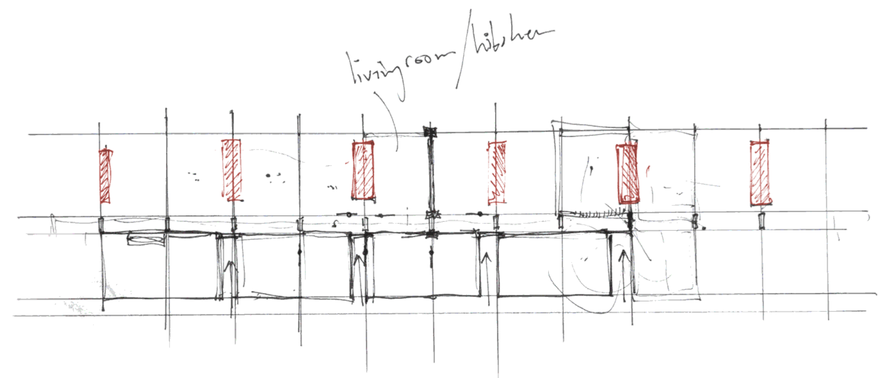
Inner Walls; What materials, room walls, wall between apartments, connection to the structure relating to sound?



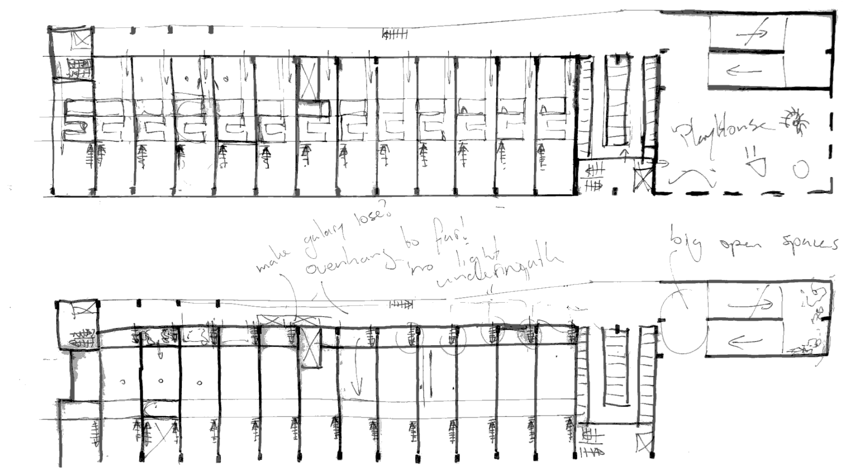
ill. 105: initial apartment sketches duplex, own image.



ill. 104: Visualisation of ISpatial Integration of the exsiting structure, own image.



ill. 102: Regular placement of shafts, own image.



ill. 103: Room distribution in Apartments private semi-private, own image.

ENERGY BALANCE

To get a better understanding of the energy flow through the building an excel sheet was made to investigate the effect of different parameters on the heat gains, heat losses, and the temperature inside an apartment. To do so the calculations that are described in A method for calculating the energy consumption in buildings by means of a desk calculator (Nielsen, 1979) were followed.

The basics of the excel sheet gave the possibility to calculate an estimate of optimized window opening size, with the goal of minimizing heat loss. To do so the monthly gains and losses were calculated and summed up, resulting in a total gain or loss per month for each percentage of window size. (tbl. 01). This research gave a starting point of an optimal 10 to 20% of glazing on the northeast wall and a minimum of 30% glazing on the southwest wall. Given that we would use triple glazing with an u value of 0,72W/m²K and construct a wall with an u value of 0,21W/m²K.

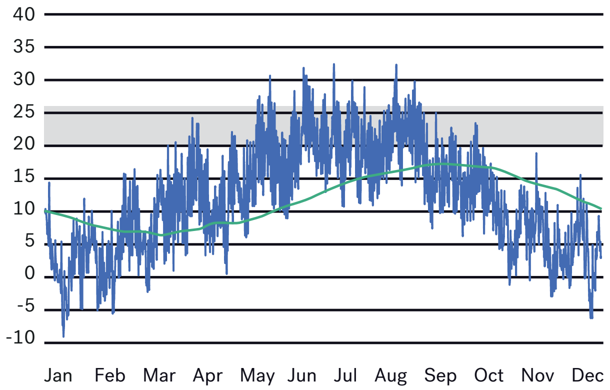
Transmisson totals SW (kWh)		Window size										
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
		0.0 m2	5.6 m2	11.2 m2	16.8 m2	22.3 m2	27.9 m2	33.5 m2	39.1 m2	44.7 m2	50.3 m2	55.9 m2
Month	Jan	-70	-44	-18	8	34	60	86	112	138	164	190
	Feb	-55	31	117	202	288	374	460	546	632	718	804
	March	-52	121	294	467	640	813	986	1159	1332	1505	1678
	April	-42	248	539	830	1120	1411	1702	1993	2283	2574	2865
	May	-31	361	752	1143	1534	1925	2316	2707	3099	3490	3881
	June	-21	372	765	1158	1551	1944	2337	2730	3123	3516	3909
	July	-9	411	831	1250	1670	2089	2509	2929	3348	3768	4187
	Aug	-9	346	700	1054	1409	1763	2117	2472	2826	3180	3535
	Sept	-17	231	478	726	973	1221	1468	1716	1963	2211	2459
	Okt	-35	96	226	357	487	618	749	879	1010	1140	1271
	Nov	-46	11	68	125	182	239	296	353	410	467	524
	Dec	-61	-44	-27	-11	6	23	40	57	74	90	107
	Sum of loss:	-448	-88	-45	-11	0	0	0	0	0	0	0

Transmisson totals NE (kWh)		Window size										
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
		0.0 m2	5.6 m2	11.2 m2	16.8 m2	22.3 m2	27.9 m2	33.5 m2	39.1 m2	44.7 m2	50.3 m2	55.9 m2
Month	Jan	-70	-73	-75	-78	-81	-84	-86	-89	-92	-95	-97
	Feb	-55	-23	8	40	72	104	136	168	199	231	263
	March	-52	25	103	181	259	337	415	493	570	648	726
	April	-42	99	241	382	523	665	806	947	1089	1230	1372
	May	-31	166	362	559	755	951	1148	1344	1540	1737	1933
	June	-21	178	378	578	777	977	1176	1376	1575	1775	1975
	July	-9	208	424	640	856	1073	1289	1505	1722	1938	2154
	Aug	-9	174	356	538	721	903	1085	1267	1450	1632	1814
	Sept	-17	108	233	358	483	607	732	857	982	1107	1232
	Okt	-35	25	85	145	204	264	324	384	444	503	563
	Nov	-46	-28	-9	10	29	48	67	85	104	123	142
	Dec	-61	-67	-72	-78	-83	-89	-94	-99	-105	-110	-116
	Sum of loss:	-448	-190	-156	-156	-164	-172	-180	-188	-197	-205	-213

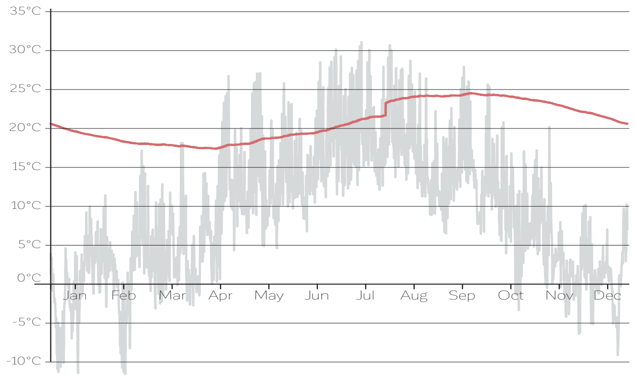
tbl. 01: Transmission values for walls and windows as calculated through excell, more values can be found in Appendix C

Original 2226 temperatures

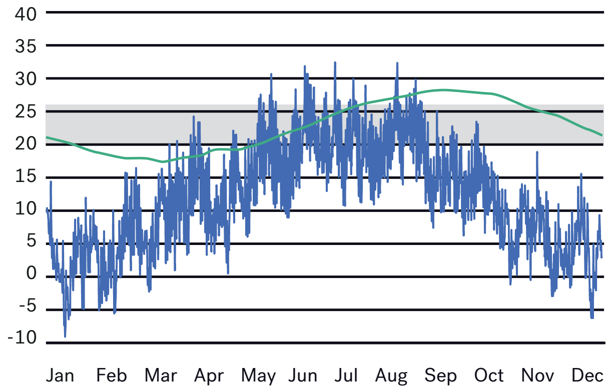
Our simulations



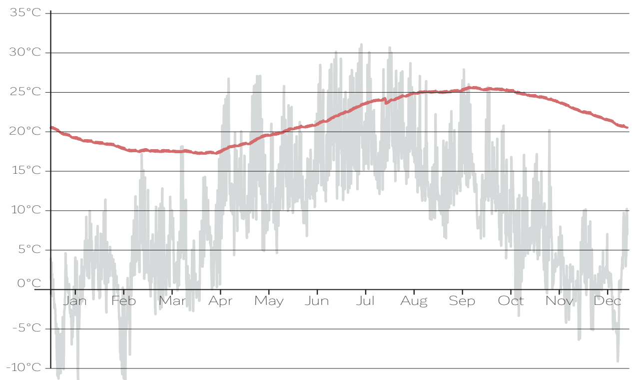
ill. 106: External and internal temperatures of 2226 empty. image by Eberle, 2016.



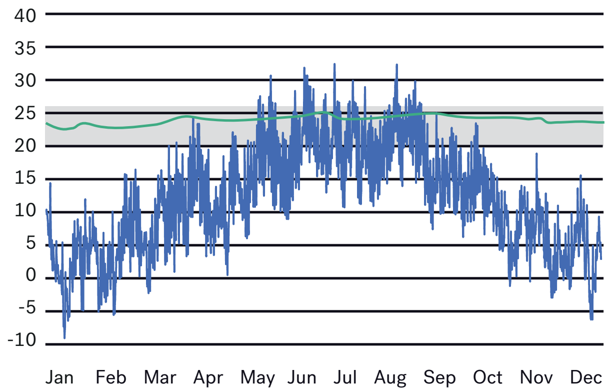
ill. 109: Simulation results of an empty 2226 building, own image.



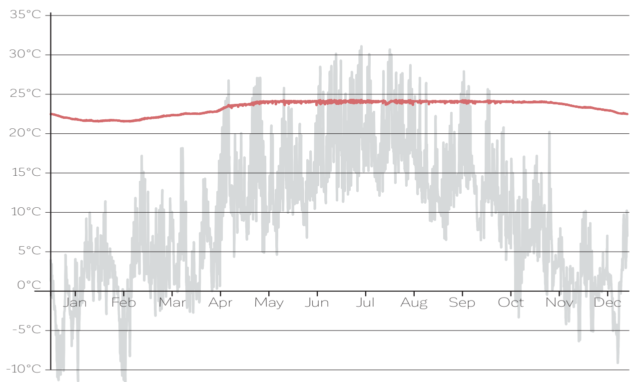
ill. 107: External and internal temperatures of 2226 without control system, image by Eberle, 2016.



ill. 110: Simulation results of 2226 without control system, own image.



ill. 108: External and internal temperatures of 2226 with control system, image by Eberle, 2016.



ill. 111: Simulation results of 2226 with control system, own image.

2226 Simulations

Rhino6, Grasshopper, and Diva 4 have been used to design parametrically with the simulations. The indoor climate of 2226 was simulated first for several reasons.

It would be the first time using the program, simulation a known condition would be the best way to learn the program's interface. Simulating a known condition would also ensure that the results of the simulation could be validated against the known conditions. Subsequentially playing with the parameters of 2226 gave an opportunity to learn more in-depth about which parameters would affect certain elements of the indoor climate. for example how the mass of the internal walls affects the indoor climate differently than the mass of the external walls.

The simulation used the weather file for Salzburg (EnergyPlus, 2019). A cube with the dimensions of 2226 was modeled on a flat plane with no surrounding trees or buildings modeled. Custom walls were modeled within Diva4 to depict the walls of 2226, with an u value of 0,1W/m^2K. Basic triple glazing, as provided by Diva4, was used for the windows. Further information regarding the thermal skin composition can be found in Appendix C.

The three different scenarios were simulated with different internal heat gains. Scenario one was simulated with no occupancy, equipment, or venting (ill. 109). Scenario two was simulated with occupancy, equipment but with no ventilation (ill. 110). Scenario three was simulated with occupancy, equipment, and ventilation control (ill. 111). the occupancy and equipment followed schemes set by EN 16798-1 (Danske Standard, 2018). The ventilation controlled followed a custom made scheme with a set point at 20 degrees celsius.

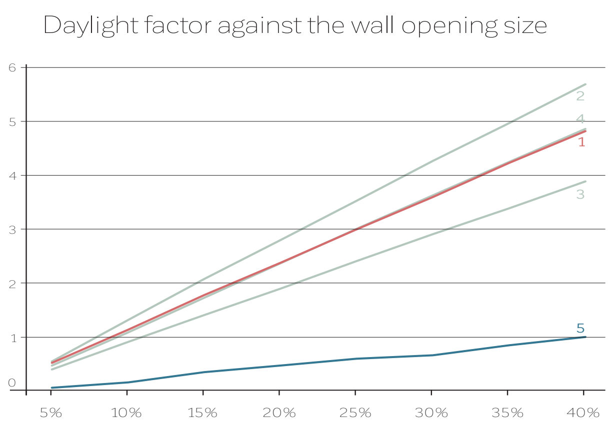
One of the limitations of Diva4 can clearly be seen when one compares ill. 106 to ill. 109, it is not possible to set a starting temperature within the simulation, nor is it possible to simulate for more than one year. The sudden rise in temperature in Juli is caused by the simulation starting at that date to minimize the defect in the final temperature. Though still, the final result is not correct when compared to the official temperatures. This issue is not as apparent anymore in ill. 110 and completely not apparent anymore in ill. 111 since the indoor temperatures are closer to what could be considered "normal" internal temperatures.

Daylight

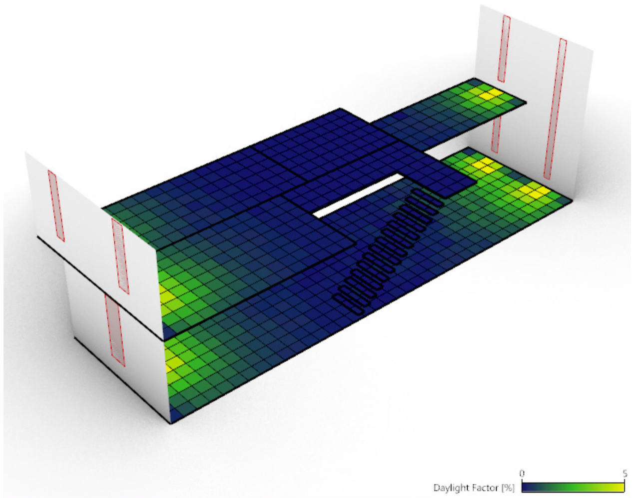
Daylight simulations were conducted to determine the amount of glazing that could be shaded to prevent overheating while still providing adequate lighting indoors. With the goal to be able to control the indoor climate without loosing in interior light quality. Thereby Increasing the quality of the living environment and ensuring the wellbeing of the inhabitants.

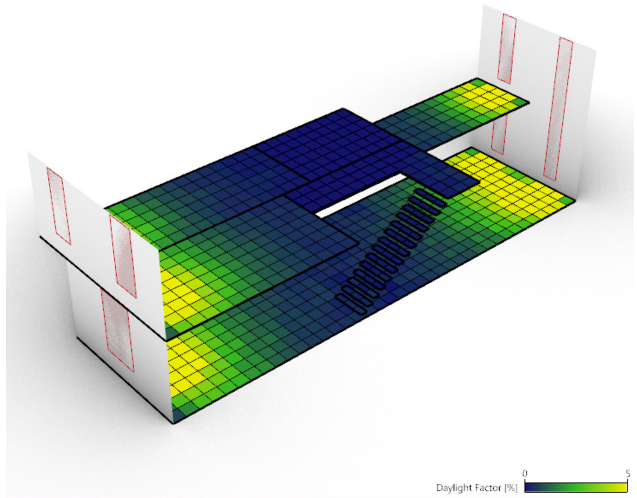
One of the duplex apartments has been selected to conduct the study since these apartments have the highest depth with lower ceiling height and are therefore the most difficult to light adequately. The simulation software Diva4 has been used to perform the simulations to keep an integrated process.

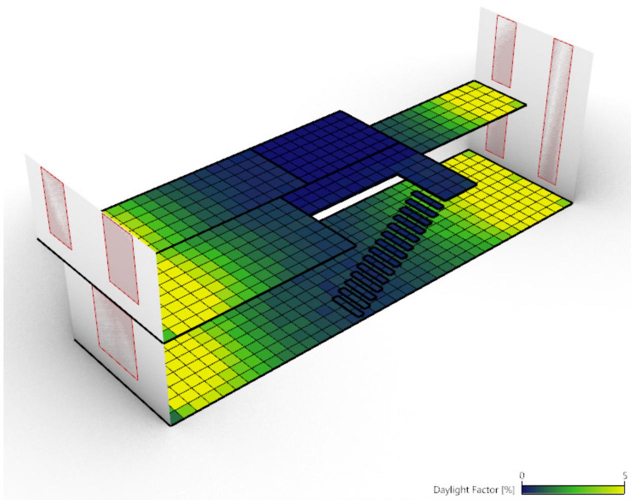
Illustrations 113 to 116 show four different simulations from 10% opening size to 40% opening size. The average daylight factor for the simulations can be seen in ill. 112. These simulations show that a minimum of 15 to 20 percent of opening size is needed to light the rooms in the building sufficiently.

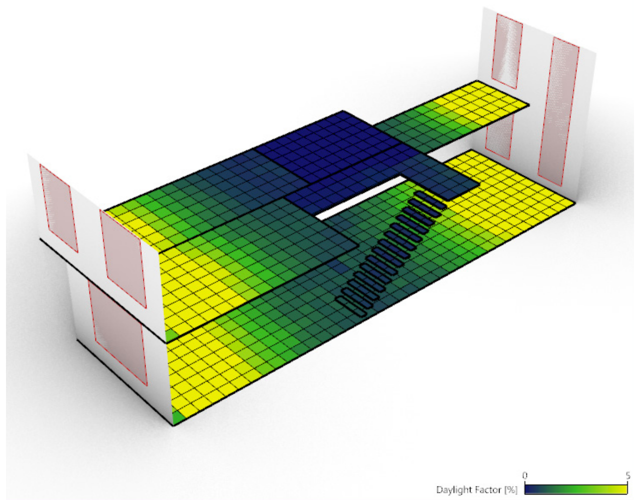


ill. 112: Daylight factor per opening size, own image.


ill. 113: Daylight factor with 10% sized windows, own image.


ill. 114: Daylight factor with 20% sized windows, own image.


ill. 115: Daylight factor with 30% sized windows, own image.


ill. 116: Daylight factor with 40% sized windows, own image.

Energy and simulations

After the simulations of 2226 and a preliminary study on the apartments and building volume, two different simulation files were set up. File one (ill. 117) was a smaller section of the building, consisting of one apartment, but later expanded to one apartment on each of the floors in the building. File two (ill. 118) depicted a simulation of the complete building without internal segregation of the apartments. This segregation of the simulation files gave less complicated simulations to work with, resulting in quicker simulation times, but still gave a more in-depth look into the temperatures in one apartment. The simulation for the single apartment was validated through Bsim by simulating a similar block with no internal loads and ventilation. These results can be found in Appendix C

Windows

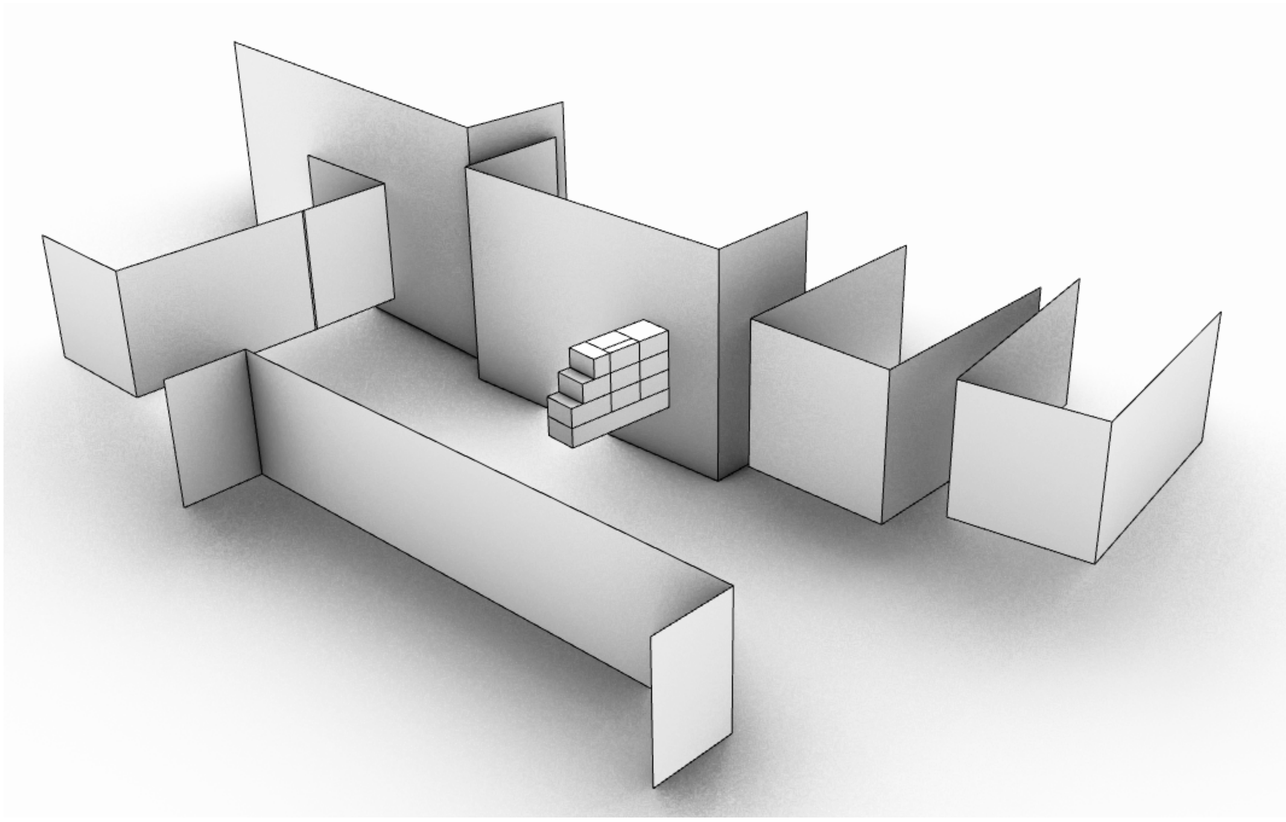
Both of the simulation files are setup fully parametric for quick simulation of different building setups. The window size is determined by a percentage, this percentage can be set for either façade independently. The window depth is modeled by a shading box around the window, its depth can be set on each façade independently.

Further shading was set within the window properties of Diva4. These settings ware set after the daylight calculations with a transmittance of 0,5. this gave a good indoor daylight factor whilst still shielding the internal temperatures from the solar gains. The setpoint for the shading was found through multiple simulations to be best at 100w/m^2.

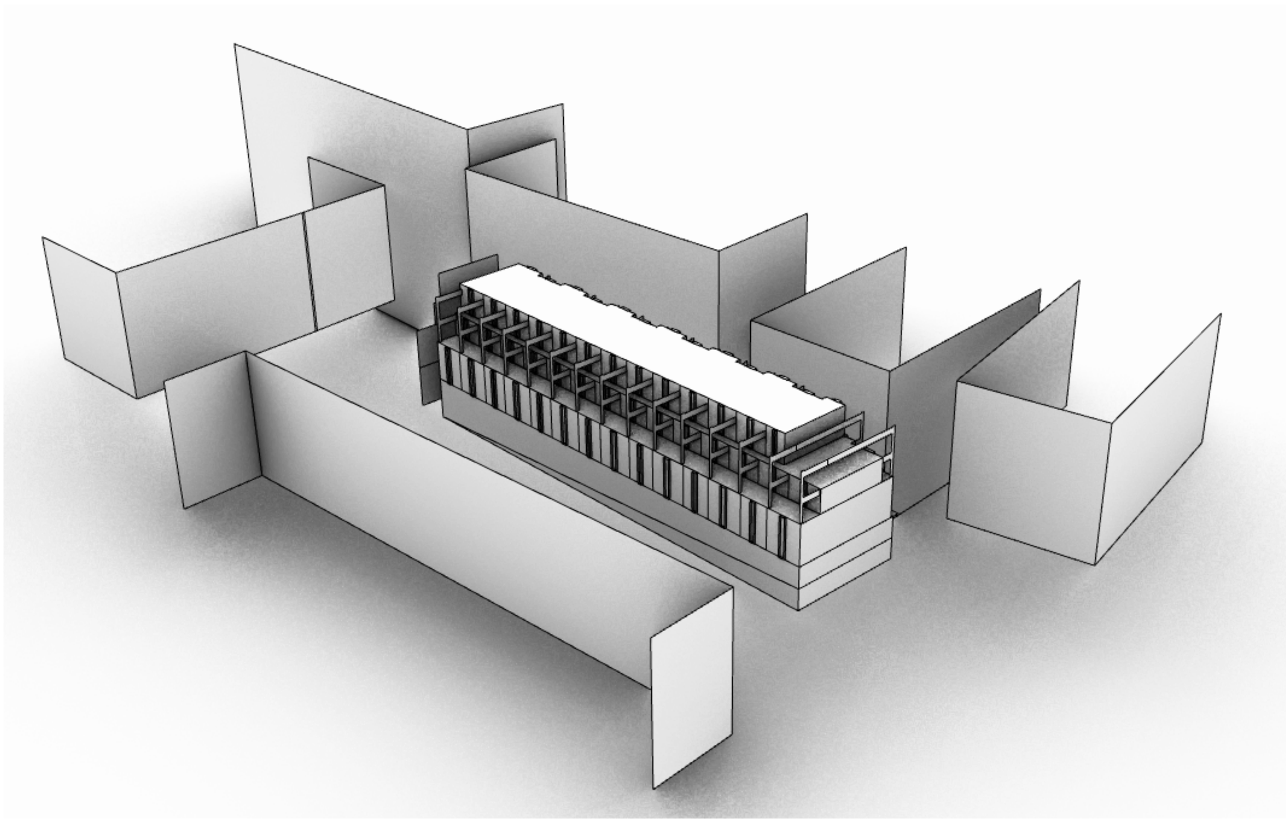
Walls

The wall composition was built fully in Diva4, numbers for these can be found in Appendix E and F. the goal was to see what wall composition was needed to reach a comfortable indoor climate. The composition of 2226 with 72cm thick walls was deemed to thick for usage in Central London where m^2 prices are high. The difference in climate from Austria and London enabled the use of a thinner wall composition while still retaining the use of the thermal bricks. Ill. 119 and 120 show how the external temperatures in Salzburg fluctuate more between the seasons than they do in London, enabling a higher u value with thinner walls.

Within the singular apartment simulations, all walls that do not face the external environment were set to adiabatic, meaning that the simulation assumes the temperature on the other side of the wall to be the same as the temperature on the inner face of the wall, eliminating any heat traveling completely through the wall.



ill. 117: Final simulation geometry for the apartment simulations, own image.



ill. 118: Final simulation geometry for full building simulation, own image.

Gains and losses

For the simulations, interior gain values from EN 16798 (Danske Standard, 2018) were used. This has led to one drawback, the gains are only given as an average for the entire apartment, therefore different internal gain values for different rooms have not been used. It can be expected that the actual temperatures for the living room and or kitchen would be higher and the temperatures for the bedrooms to be lower.

Ventilation

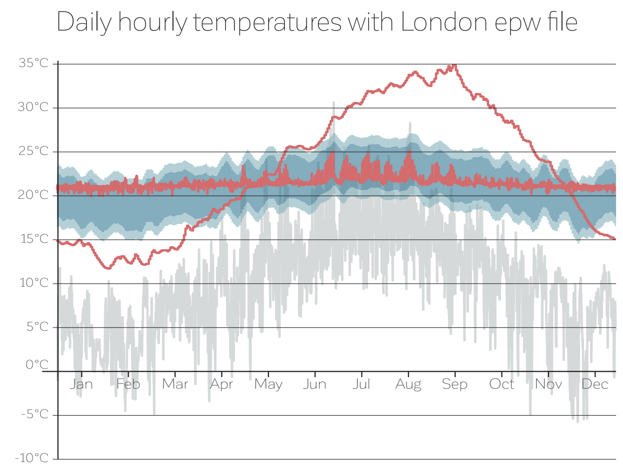
Mimicking the ventilation controls from 2226 proved more challenging. At first natural ventilation control in Diva4 was used. This is controlled by a set yearly setpoint, maximum outdoor temperature, minimum outdoor temperature, and the openable window size. There is a lack of control that changes throughout the simulation depending on the indoor and outdoor temperature. This led to an indoor climate that was acceptable temperature-wise but with an hourly air change, due to the incorporation of wind, in excess of 20ACH on most days throughout summer. This was deemed unrealistic so another solution was needed.

The openable window size was reduced to a 20cm slot on the side of the window. Together a custom scheme was made to mimic night venting in summer and enabling venting all day in winter (ill. 121). This gave quite high temperatures in summer though, since on colder days venting was still only limited to the nights in summer. Therefore The natural ventilation was enabled again, though this time purely run by buoyancy. This gave the final result for the indoor climate. The hourly air change was reduced to a maximum of 2,6 in summer for the current climate (ill. 122) and 3,2 for the scenario of 2080 (ill.123).

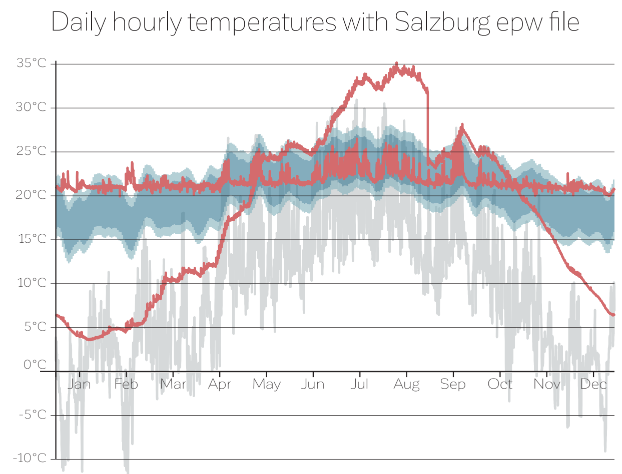
Ashrae 55 gives a maximum of 1,2m/s airspeed for raising the indoor comfort temperature (Tartarini et. al., 2020). Taking the total volume of the apartment, 330m^3, with the total size of openable ventilation windows, 1,75m^2, gives a total airstream of 1,05m^3/s through the windows, assumed that half of the windows take in air and half take out at 1,2m/s. This a maximum acceptable hourly air change of 11,5. Adding meshing in front of the windows to hold of insects would likely reduce the effective area of the opening by 60%. giving a maximum hourly air change of 6,8.

Backup system

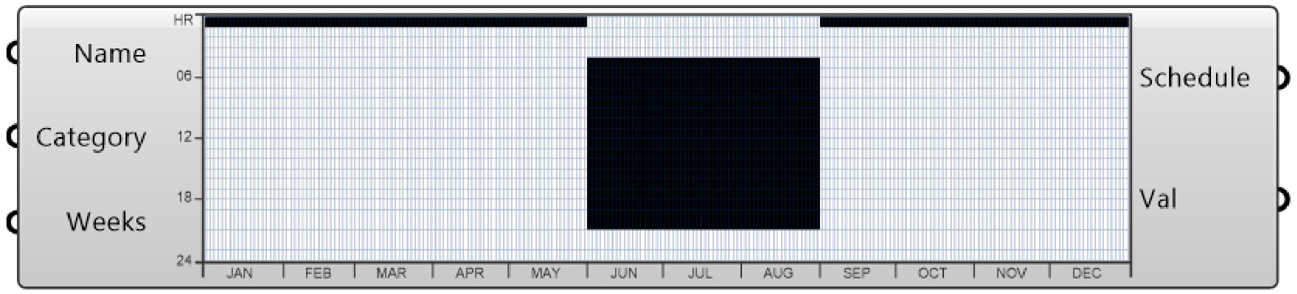
Throughout the process a backup system was discussed multiple times, in case the goal of 0 kWh for heating could not be reached. Thus the option of adding a floor heating system on the floating floor has been preserved throughout the design process. Switching from chipboard subflooring to a chipboard subfloor with groves for floor heating allows for a quick and effortless backup system, run on district heating, that can always be installed during the build process.



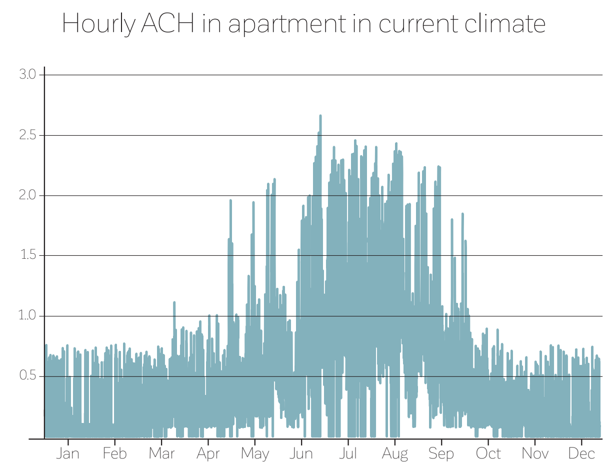
ill. 119: Simulation of apartment with London weather file, own image.



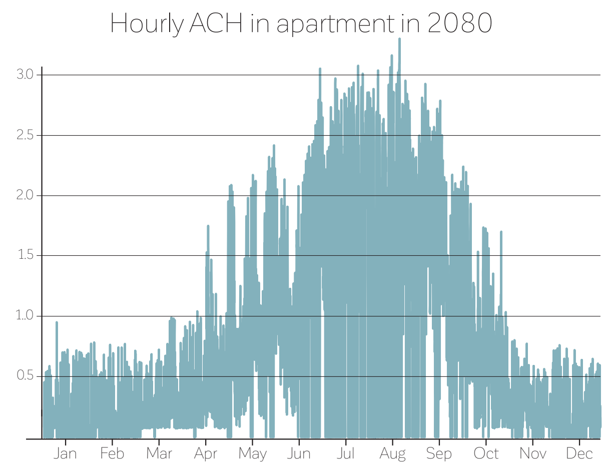
ill. 120: Simulation of apartment with Salzburg weather file, own image.



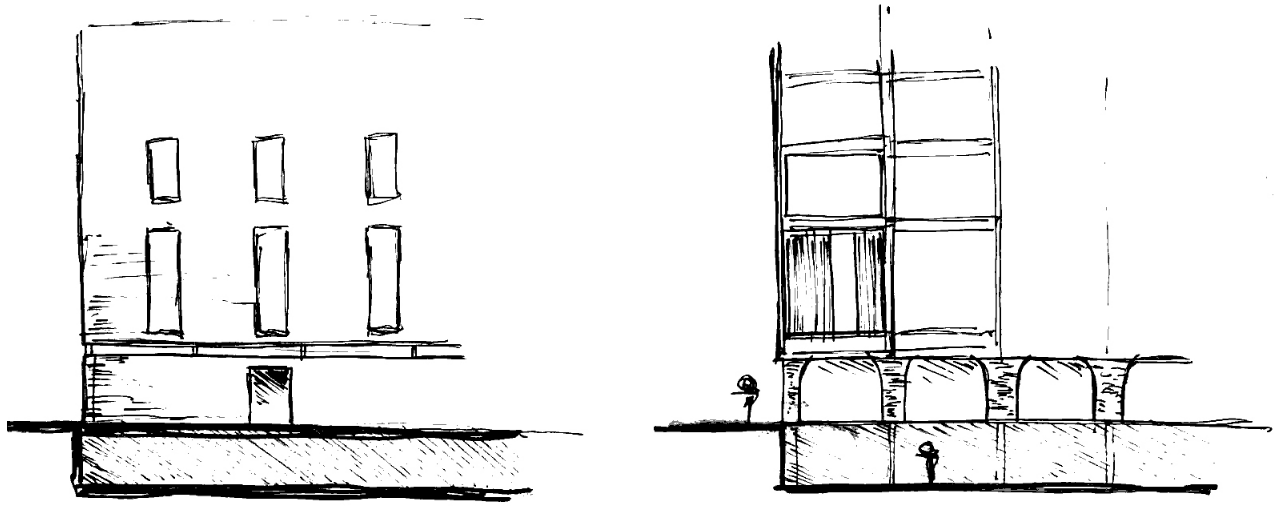
ill. 121: customized night venting shceme, own image.



ill. 122: Air changes per hour, own image.



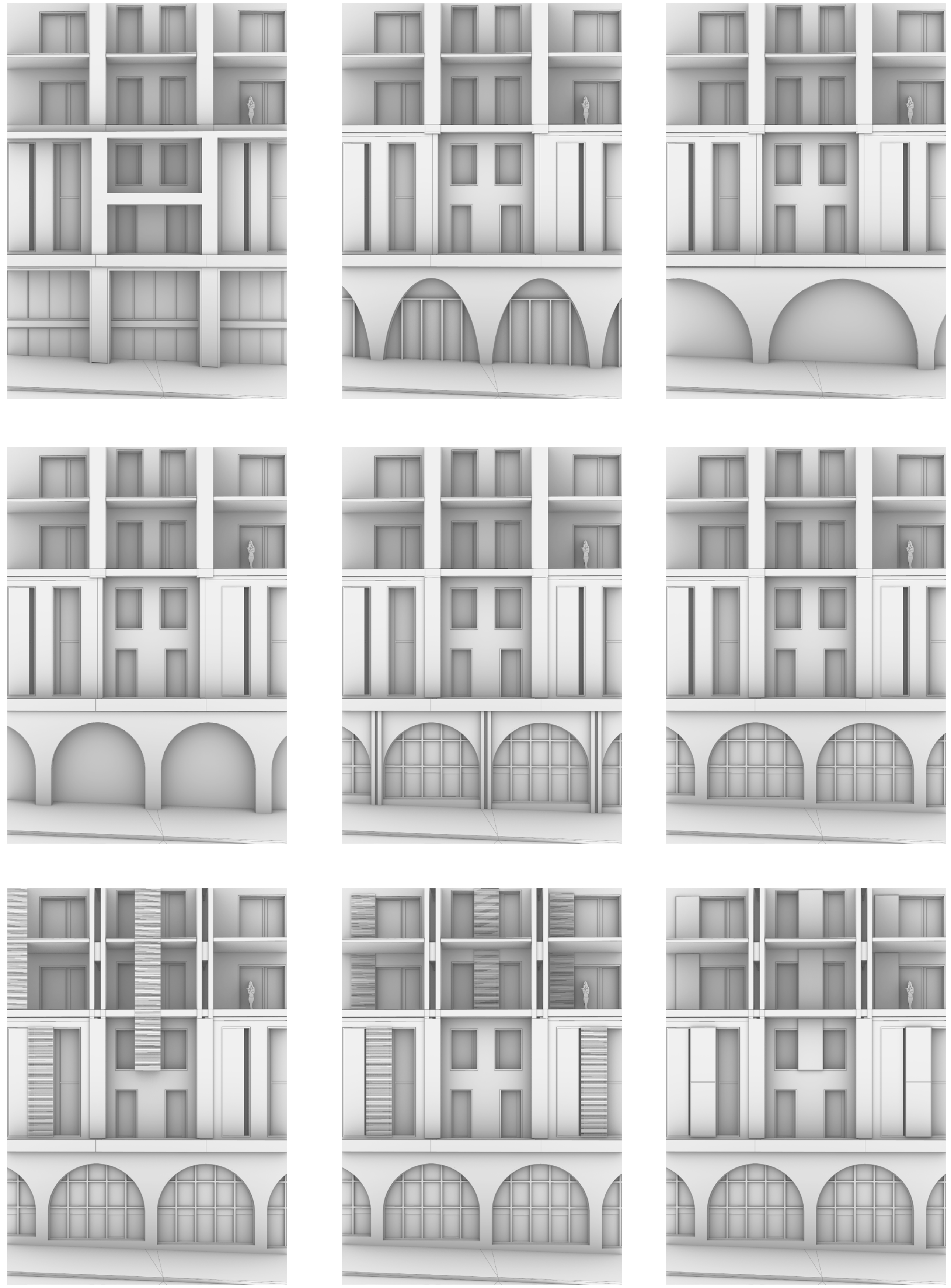
ill. 123: Air changes per hour for 2080 scenario, own image.



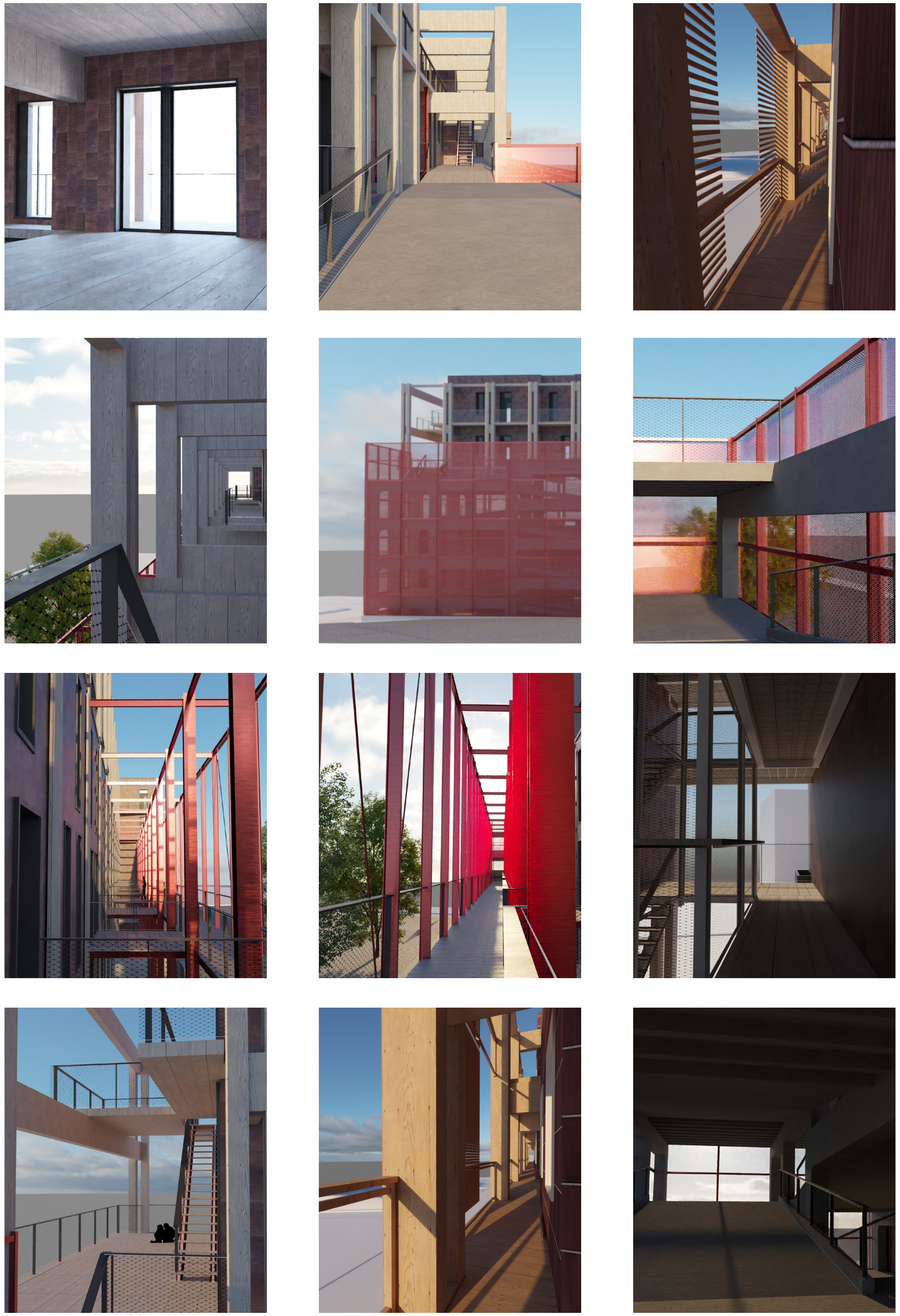
ill. 124: Expression design sketches, own image.

Expression

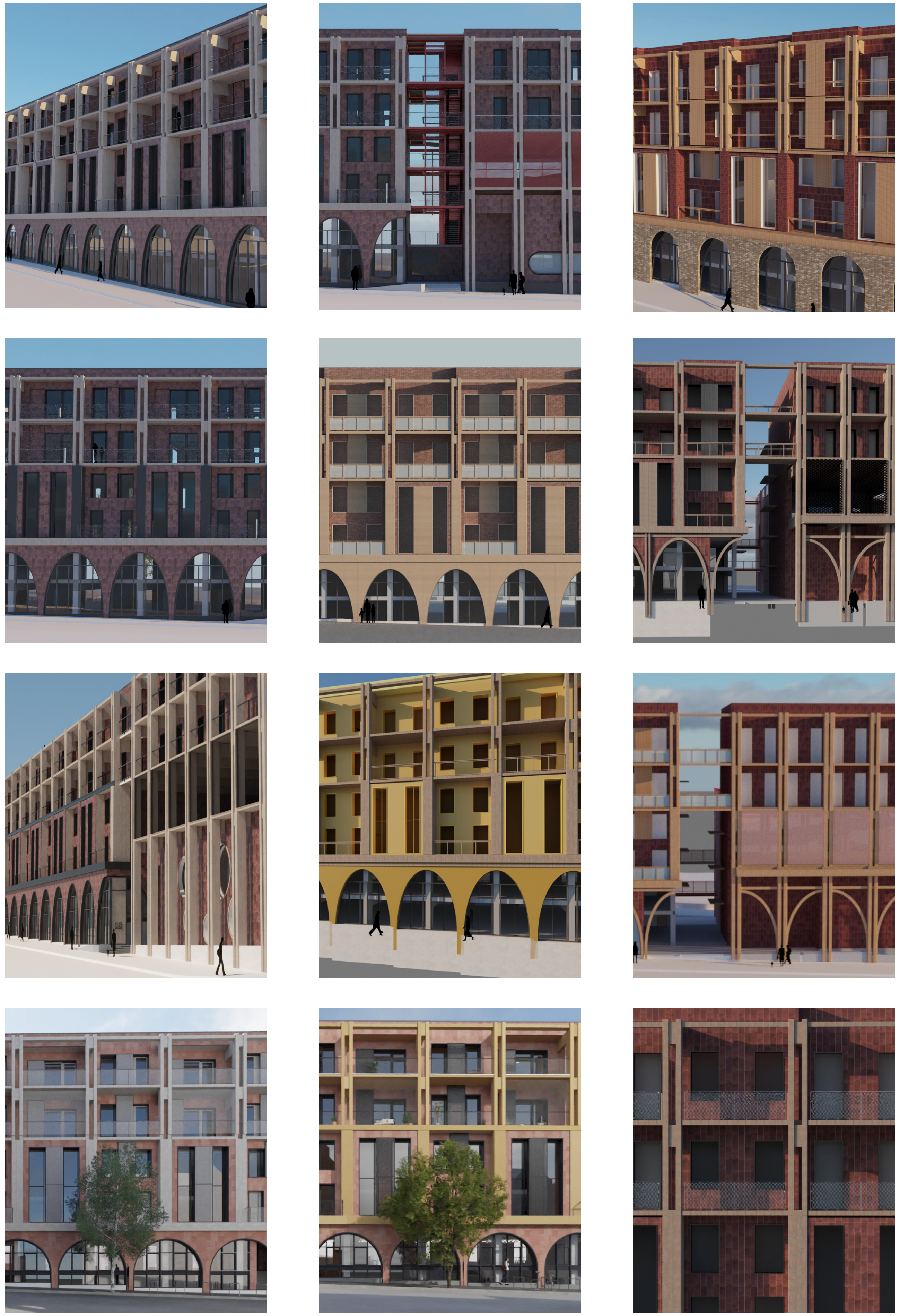
This stage of the process had a closer look at the architectural and local context, resulting in a clearer understanding of the critical factors such as vertical vs. horizontal lines, form, and dominant materials. The facade treatment was studied in tandem with the development of the floor plans and structural addon. This analysis and contextual research led to a series of studies, as seen in the pictures. Further investigations on different ensemble methods of the used brick were explored to give the possibility of reinterpreting the characteristic brick facades into a new format, complementing the existing architecture, and giving a new expression. The composition of the different elements was tested, to find the right hierarchy between the various elements (Structure, Openings, Shading elements) and helping to organize the expression of the facade. Different patterns, materials, and colors were explored through virtual models and visualizations.



ill. 125: Expression design models, own image.



ill. 126: Expression design models, own image.



ill. 127: Expression design models, own image.

Conclusion

The amount of systems installed into domestic buildings has been rising over the years. Currently taking 25% of the building budget, and with those systems taking 62% of the energy demand in order to heat and ventilate the buildings.

By taking a step back from systems and start thinking about the materials, and their properties and functions at the start of the project, the thermal performance can be optimized quickly through simulation software. The main elements that influence the results are the windows and their placement, the envelope construction, the thermal mass of the indoor construction, and the natural ventilation of the indoor climate.

By having sufficient knowledge of these elements it is possible to design homes and or apartments that do not rely on an abundance of technological systems to control the indoor climate.

But the climate where the building is placed, and the culture of the inhabitants have a significant impact on the climatic performance that the building needs to deliver. The solutions that are applied in this proposal for apartments in central London do not inherently apply for a similar building in central Europe.

This could be an effective way of lowering the construction, running, and maintenance costs of housing projects. By simplifying the construction process with fewer and simpler materials, requiring a lower diversity of professions on the job site as well as shortening the assembly period required onsite.

The running costs are lower due to the lack of need for heating energy. At the same time, there is a decreased need for the maintenance of technical systems. Filters do not have to be changed, ducts do not have to be inspected and all mechanical systems are clearly visible to the occupants.

The calculations show that there is a high potential for this method to rethink the way we build our highly technical build environment and could be a solution to lower the used resources and environmental impact of our buildings.

ReThinking of the current building climatization is possible, this thesis has shown that optimization of the building though software before adding technology to the design can drastically lower the energy requirements for heating and or cooling of the built environment.

Reflection

The results of this project are showing that the concept of 2226 has the potential to be adapted to other building uses then offices. And is an interesting way to lower the energy demand of buildings. We are aware that the calculations are static and do not necessarily depict every situation you might encounter in residential buildings, but the results still showcase a good average.

Process

The design process was grounded in the technical simulations, which leads to the digital design to have a big impact on the design process. That can be a challenge when the programs are very data sensitive and have certain limitations. A lack of thorough understanding of the software slowed down the design process. Working with the low-tech methodology gave less time to experiment, due to verification of every design decision, and inherently higher complexity of the design process directly from the start. Since the simulations add a step into the process that we went through, each problem that we had to solve in Diva4 gave delays in the process.

In hindsight, deciding to construct new apartments on top of the original parking house added quite a large workload. Leaving out the top two floors of new construction might have been more sensible, even though that doesn't work in the context of central London, and the mayors wish to densify. Leaving out the new construction would have given more opportunities to go more in-depth into other problems in the construction.

Simulations

The program Diva4 presented certain limitations during the development;

- Unable to control starting temperature.
- Unable to simulate for longer periods than 365 days.
- Inability to set up a computer-controlled natural ventilation system that reacts to the ongoing outdoor temperatures, for example setting the setpoint temperature to the adaptive thermal comfort one.

However, the simulations in Diva4 are run by EnergyPlus. these files are accessible for the end-user, thus some of these problems might be possible to solve with custom code.

Otherwise a better integration with, for example, Bsim. could be a solution to calculate the elements that Diva4 is unable to compute. Though this lack of integration was, and still is, our main reason for choosing Diva4 over Bsim. For more in-depth simulations it would be interesting to investigate the possibilities of adding dynamic parameters to the inhabitants. simulation programs have many caveats where a small error due to inexperience can lead to simulation errors. For example, in Diva4, shared walls need to be of the same geometry and cannot be of the same shaped overlapping geometry. The software would not give an error, but the results will be different.

Details

With a heavy focus on the walls, there are some aspects of the details that could need further investigation. For example, the roof construction is currently a quite generic green roof construction, but it is also quite complicated with nine different layers and eight different materials. Whereas the walls only have three layers with three different materials.

During the development the use of thermal bricks as an external layer was questioned, an assumption was made that glazing would make the bricks resilient enough for outdoor applications. Contact with Wienerberger taught us that the bricks are not suitable for exterior wall usage because of their porous character. Glazing would not solve this problem, because a higher backing temperature than 1000 degrees celsius would compromise the bricks structure. However, they did give another possibility, using a mineral-based sealing slurry the texture of the brick wall could be retained while still protecting the elements. An example can be seen in Stacked House Berlin by Michelle Howard.

Further

To further optimize the material used in the building the solar gains should be simulated more precisely. Currently, Diva4 and Bsim take the solar gains and distribute them evenly across the room, unlike reality where the solar gains are more focused on certain elements of the construction. Simulating with geometric simulation programs, for example, IDA-ICE would make this possible, and open up more design possibilities where the architecture could react more to the solar gains.

Theoretically, the building should be more sustainable using no energy from the grid to cool or heat the indoor climate, however, LCA calculations should be made to verify. Also, the lack of HVAC, foundation work, and the limited framework should lower the cost of construction. However, the low-tech methodology does add a significant strain to the design process. LCC calculations should shed more light on the potential cost benefits of designing in this manner.

With the heavy reuse of a concrete structure, the process of concrete carbonization becomes interesting. It is not investigated how this process could help with the sustainability aspect of the project, or how that process might affect the architecture of the apartments.

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APPENDIX

ill. 128: image by Davis, 2014.

Appendix A - A case study of 63,000 homes

The following pages depict the excel file used for analysing the costs of construction for 63.000 affordable high quality social homes. The date collected by Hyams (2016) has been used to make this analysis.

Hyams, A. (2016). Cost model: Affordable housing. https://www.building.co.uk/main-navigation/cost-model-affordable-housing/5082032.article

Numbers as taken from Hyams (2016)

Shell Works					
Substructure	**£**	**3,664,360.00**	**£**	**203.00**	**12%**
Frame	**£**	**2,208,960.00**	**£**	**123.00**	**7%**
Upper floors	**£**	**2,522,850.00**	**£**	**140.00**	**8%**
Roof	**£**	**776,445.00**	**£**	**43.00**	**2%**
Stairs	**£**	**416,500.00**	**£**	**23.00**	**1%**
External walls, windows, doors, balcony	**£**	**8,236,140.00**	**£**	**457.00**	**26%**
Internal walls and partitions	**£**	**408,300.00**	**£**	**23.00**	**1%**
Internal doors	**£**	**195,600.00**	**£**	**11.00**	**1%**
Internal finishes	**£**	**504,756.00**	**£**	**28.00**	**2%**
Fittings, furnishing and equipment	**£**	**-**	**£**	**-**	**0%**
Systems	**£**	**6,111,153.00**	**£**	**339.00**	**20%**
Disposal			£	28.00	8%
Water			£	15.00	4%
HVAC			£	93.00	27%
Electrical			£	54.00	16%
Gas			£	2.00	1%
Protective			£	20.00	6%
Communication			£	37.00	11%
Special instalations			£	24.00	7%
Lift instalations			£	50.00	15%
Labour			£	16.00	5%
Preliminaries and contigencies	**£**	**6,104,108.00**	**£**	**339.00**	**20%**
Total shell works	**£**	**31,149,172.00**	**£**	**1,729.00**	**100%**

Communal Areas					
Stairs	**£**	**245,000.00**	**£**	**14.00**	18%
Internal walls and partitions	**£**	**-**	**£**	**-**	0%
Internal doors	**£**	**24,500.00**	**£**	**1.00**	2%
Wall finishes	**£**	**526,670.00**	**£**	**29.00**	38%
Floor finishes	**£**	**110,557.00**	**£**	**6.00**	8%
Ceiling finishes	**£**	**102,120.00**	**£**	**6.00**	7%
Fittings, furnishing and equipment	**£**	**108,950.00**	**£**	**6.00**	8%
Systems	**£**	**-**	**£**	**-**	**0%**
Disposal					
Water					
HVAC					
Electrical					
Protective					
Communication					
Labour					
Preliminaries and contigencies	**£**	**265,815.00**	**£**	**15.00**	**19%**
Total communal areas	**£**	**1,383,612.00**	**£**	**77.00**	**100%**

Private apartments					
Stairs	**£**	**65,000.00**	**£**	**4.00**	1%
Internal walls and partitions	**£**	**479,915.00**	**£**	**27.00**	5%
Internal doors	**£**	**433,550.00**	**£**	**24.00**	4%
Wall finishes	**£**	**433,728.00**	**£**	**24.00**	4%
Floor finishes	**£**	**650,430.00**	**£**	**36.00**	6%
Ceiling finishes	**£**	**307,320.00**	**£**	**17.00**	3%
Fittins, furnishing and equipment	**£**	**2,007,204.00**	**£**	**111.00**	20%
Systems	**£**	**3,875,805.00**	**£**	**215.00**	**38%**
Disposal			£	11.00	5%
Water			£	19.00	9%
HVAC			£	64.00	30%
Electrical			£	75.00	35%
Protective			£	17.00	8%
Communication			£	19.00	9%
Labour			£	10.00	5%
Preliminaries and contigencies	**£**	**536,992.00**	**£**	**30.00**	**19%**
Total private apartments	**£**	**8,789,944.00**	**£**	**488.00**	**100%**

Affordable apartments					
Internal walls and partitions	**£**	**157,355.00**	**£**	**9.00**	6%
Internal doors	**£**	**13,600.00**	**£**	**8.00**	5%
Wall finishes	**£**	**138.10**	**£**	**8.00**	5%
Floor finishes	**£**	**174.86**	**£**	**10.00**	6%
Ceiling finishes	**£**	**102,090.00**	**£**	**6.00**	4%
Fittins, furnishing and equipment	**£**	**450,098.00**	**£**	**25.00**	16%
Systems	**£**	**1,099,647.00**	**£**	**61.00**	**39%**
Disposal			£	4.00	7%
Water			£	7.00	11%
HVAC			£	19.00	31%
Electrical			£	17.00	28%
Protective			£	6.00	10%
Communication			£	5.00	8%
Labour			£	3.00	5%
Preliminaries and contigencies	**£**	**536,992.00**	**£**	**30.00**	**19%**
Total affordable apartments	**£**	**2,795,134.00**	**£**	**155.00**	**100%**

Cummunal areas			Private apartments			Affordable apartments			Total		
									£ 203.00	8%	**Substructure**
									£ 123.00	5%	**Frame**
									£ 140.00	6%	**Upper floors**
									£ 43.00	2%	**Roof**
£ 245,000.00	**£ 14.00**	18%	**£ 65,000.00**	**£ 4.00**	1%	**£ -**	**£ -**	0%	£ 41.00	2%	**Stairs**
									£ 457.00	19%	**External walls, windows, doors, balcony**
£ -	**£ -**	0%	**£ 479,915.00**	**£ 27.00**	5%	**£ 157,355.00**	**£ 9.00**	6%	£ 59.00	2%	**Internal walls and partitions**
£ 24,500.00	**£ 1.00**	2%	**£ 433,550.00**	**£ 24.00**	4%	**£ 13,600.00**	**£ 8.00**	5%	£ 44.00	2%	**Internal doors**
£ 739,347.00	**£ 41.00**	53%	£ 1,391,478.00	£ 77.00	13%	£ 102,402.95	£ 24.00	15%	£ 170.00	7%	**Internal finishes**
£ 108,950.00	**£ 6.00**	8%	**£ 2,007,204.00**	**£ 111.00**	20%	**£ 450,098.00**	**£ 25.00**	16%	£ 142.00	6%	**Fittings, furnishing and equipment**
£ -	**£ -**	**0%**	**£ 3,875,805.00**	**£ 215.00**	**38%**	**£ 1,099,647.00**	**£ 61.00**	**39%**	£ 615.00	25%	**Systems**
	£ -	0%		£ 11.00	5%		£ 4.00	7%	£ 43.00	7%	Disposal
	£ -	0%		£ 19.00	9%		£ 7.00	11%	£ 41.00	7%	Water
	£ -	0%		£ 64.00	30%		£ 19.00	31%	£ 176.00	29%	HVAC
	£ -	0%		£ 75.00	35%		£ 17.00	28%	£ 146.00	24%	Electrical
	£ -	0%		£ -	0%		£ -	0%	£ 2.00	0%	Gas
	£ -	0%		£ 17.00	8%		£ 6.00	10%	£ 43.00	7%	Protective
	£ -	0%		£ 19.00	9%		£ 5.00	8%	£ 61.00	10%	Communication
	£ -	0%		£ -	0%		£ -	0%	£ 24.00	4%	Special instalations
	£ -	0%		£ -	0%		£ -	0%	£ 50.00	8%	Lift instalations
	£ -	0%		£ 10.00	5%		£ 3.00	5%	£ 29.00	5%	Labour
£ 265,815.00	**£ 15.00**	**19%**	**£ 536,992.00**	**£ 30.00**	**19%**	**£ 536,992.00**	**£ 30.00**	**19%**	£ 414.00	17%	**Preliminaries and contigencies**
£ 1,383,612.00	**£ 77.00**	**100%**	**£ 8,789,944.00**	**£ 488.00**	**100%**	**£ 2,795,134.00**	**£ 155.00**	**100%**	**£ 2,449.00**		

Total building costs	
£ 550.00	**Structure**
£ 457.00	**External walls, windows, doors, balcony**
£ 273.00	**Internal walls, doors and finishes**
£ 142.00	**Fittings, furnishing and equipment**
£ 414.00	**Preliminaries, OH&P and contingencies**
£ 43.00	Disposal
£ 43.00	Pipes (g+w)
£ 176.00	HVAC
£ 146.00	Electrical
£ 43.00	Protective
£ 61.00	Communication
£ 24.00	Special instalations
£ 50.00	Lift instalations
£ 29.00	Labour

Structure subtabs		
£ 203.00	8%	**Substructure**
£ 123.00	5%	**Frame**
£ 140.00	6%	**Upper floors**
£ 43.00	2%	**Roof**
£ 41.00	2%	**Stairs**

Appendix B - U value calculations

The following pages depict the excel file used to calculate the u values of several wall and roof structures in the building.

ROOF	Thickness (mm)	λ	Rc	
Rsi	-	-	0.13	
Accoya CLT	180	0.120	1.50	
Insulation	240	0.040	6.00	
Plywood	18	0.120	0.15	
Leca balls	100	0.100	1.00	
Rse	-	-	0.04	+
totaal			8.82	
		U=	0.113	W/m²K

FAÇADE	Thickness (mm)	λ	Rc	
Rsi	-	-	0.13	
Thermal Brick T0.8	125	0.390	0.32	
Thermal Brick U0.8	425	0.080	5.31	
Plaster	10	0.710	0.01	
Rse	-	-	0.04	+
totaal			5.82	
		U=	0.172	W/m²K

COLUMNS	Thickness (mm)	λ	Rc	
Rsi	-	-	0.13	
Accoya CLT Panel	50	0.120	0.42	
Thermablock Airogel	49	0.015	3.27	
Concrete	440	0.170	2.59	
Rse	-	-	0.04	+
totaal			6.44	
		U=	0.155	W/m²K

GALLERY	Thickness (mm)	λ	Rc	
Rsi	-	-	0.13	
Thermablock Airogel	98	0.015	6.53	
Concrete	100	0.170	0.59	
Rse	-	-	0.04	+
totaal			7.29	
		U=	0.137	W/m²K

Appendix C - Excel file of energy balance

The following pages depict the excel file used for analysing the energy flow within a simplified apartment model. The calculations followed are described in *A method for calculating the energy consumption in buildings by means of a desk calculator* (Nielsen, 1979). The insolation levels for different months are taken from *Release 3 NASA Surface Meteorology and Solar Energy Data Set for Renewable Energy Industry Use* (Whitlock, 2000). With the total insulation level taken from a Rhino/Grasshopper simulation. The theoretical indoor temperature is a rough estimate, calculated by reversing the formulas. Inputting all the calculated heatgains and losses that are based on the set temperature.

Whitlock, C. E. (2000). Release 3 NASA Surface Meteorology and Solar Energy Data Set for Renewable Energy Industry Use. the 26th Annual Conference of the Solar Energy Society of Canada Inc. and Solar. http://www.leidi.ee/wb/media/INSOLATION LEVELS EU.pdf

Nielsen, A. (1979). A method for calculating the energy consumption in buildings by means of a desk calculator. Second International CIB Symposiumm on Energy Conservation in the Built Enviroment.

Appartment type	**01 Mid**	
Parameters		
SW Window:	30	%
NE Window:	15	%
Shading Coef:	0.65	tripple
Exterior wall:	55.86	m²
Wall u value:	0.2	W/m²K
Window u value:	0.75	W/m²K
Indoor air temp:	21	°C
AEH	0.01	/h
Fresh air shift:	4	m³/h
Internal heat gains:	0	kWh/day

Month	Days	T_{out}	Avg Insolation London	Insolation SW	Insolation NE	**$Q_{t,walls}$**	**$Q_{t,window}$**	**Q_V**	**$Q_{S,SW}$**	**$Q_{S,NE}$**	**Q_E**	**Q_{Sum}**	**Theoretical T_{in}**
Jan	31	5 °C	0.67 kWh/m²/Day	17 kWh/m²	9 kWh/m²	-103 kWh	-112 kWh	-15 kWh	90 kWh	23 kWh	0 kWh	-117 kWh	13 °C
Feb	28	7 °C	1.26 kWh/m²/Day	31 kWh/m²	16 kWh/m²	-81 kWh	-89 kWh	-12 kWh	169 kWh	44 kWh	0 kWh	31 kWh	23 °C
March	31	9 °C	2.22 kWh/m²/Day	55 kWh/m²	28 kWh/m²	-77 kWh	-84 kWh	-11 kWh	298 kWh	77 kWh	0 kWh	203 kWh	35 °C
April	30	11 °C	3.48 kWh/m²/Day	86 kWh/m²	45 kWh/m²	-62 kWh	-68 kWh	-9 kWh	467 kWh	121 kWh	0 kWh	449 kWh	53 °C
May	31	14 °C	4.54 kWh/m²/Day	112 kWh/m²	58 kWh/m²	-45 kWh	-49 kWh	-6 kWh	609 kWh	158 kWh	0 kWh	667 kWh	67 °C
June	30	16 °C	4.51 kWh/m²/Day	111 kWh/m²	58 kWh/m²	-31 kWh	-34 kWh	-4 kWh	605 kWh	157 kWh	0 kWh	693 kWh	71 °C
July	31	19 °C	4.74 kWh/m²/Day	117 kWh/m²	61 kWh/m²	-13 kWh	-14 kWh	-2 kWh	636 kWh	165 kWh	0 kWh	772 kWh	75 °C
Aug	31	19 °C	4.01 kWh/m²/Day	99 kWh/m²	51 kWh/m²	-13 kWh	-14 kWh	-2 kWh	538 kWh	140 kWh	0 kWh	649 kWh	66 °C
Sept	30	17 °C	2.86 kWh/m²/Day	70 kWh/m²	37 kWh/m²	-25 kWh	-27 kWh	-4 kWh	384 kWh	100 kWh	0 kWh	428 kWh	52 °C
Okt	31	13 °C	1.65 kWh/m²/Day	41 kWh/m²	21 kWh/m²	-52 kWh	-56 kWh	-7 kWh	221 kWh	58 kWh	0 kWh	164 kWh	32 °C
Nov	30	10 °C	0.89 kWh/m²/Day	22 kWh/m²	11 kWh/m²	-69 kWh	-75 kWh	-10 kWh	119 kWh	31 kWh	0 kWh	-3 kWh	21 °C
Dec	31	7 °C	0.52 kWh/m²/Day	13 kWh/m²	7 kWh/m²	-90 kWh	-98 kWh	-13 kWh	70 kWh	18 kWh	0 kWh	-113 kWh	13 °C
			31.35 Total:	772.09 kWh/m²	401.69 kWh/m²	**-661 kWh**	**-720 kWh**	**-94 kWh**	**4205 kWh**	**1094 kWh**	**0 kWh**		

01 Mid	55.86
02 Top	134.26
03 Corner	225.46

Glass type

Parameters		
SW Window:	40	%
NE Window:	30	%
Shading Coef:	0.65	
Exterior wall:	55.86	m²
Wall u value:	0.21	W/m²K
Window u value:	0.72	W/m²K
Indoor air temp:	21	°C
Maximum value	500	kWh

Month	Days	T_{out}	Average Insolation London	Insolation SW	Insolation NE
Jan	31	5 °C	0.67 kWh/m²/Day	17 kWh/m²	9 kWh/m²
Feb	28	7 °C	1.26 kWh/m²/Day	31 kWh/m²	16 kWh/m²
March	31	9 °C	2.22 kWh/m²/Day	55 kWh/m²	28 kWh/m²
April	30	11 °C	3.48 kWh/m²/Day	86 kWh/m²	45 kWh/m²
May	31	14 °C	4.54 kWh/m²/Day	112 kWh/m²	58 kWh/m²
June	30	16 °C	4.51 kWh/m²/Day	111 kWh/m²	58 kWh/m²
July	31	19 °C	4.74 kWh/m²/Day	117 kWh/m²	61 kWh/m²
Aug	31	19 °C	4.01 kWh/m²/Day	99 kWh/m²	51 kWh/m²
Sept	30	17 °C	2.86 kWh/m²/Day	70 kWh/m²	37 kWh/m²
Okt	31	13 °C	1.65 kWh/m²/Day	41 kWh/m²	21 kWh/m²
Nov	30	10 °C	0.89 kWh/m²/Day	22 kWh/m²	11 kWh/m²
Dec	31	7 °C	0.52 kWh/m²/Day	13 kWh/m²	7 kWh/m²
		31.35	Total:	772.09 kWh/m²	401.69 kWh/m²

	U value	Shading coef
01 Tripple High	0.65	0.56
01 Tripple Mid	0.69	0.56
01 Tripple Low	0.75	0.56
02 Tripple High	0.72	0.65
02 Tripple Mid	0.75	0.65
02 Tripple Low	0.81	0.65
03 Double Mid	1.3	0.7

SW window	11.2	m²
NE window	8.4	m²

02 Tripple High

Transmisson loss SW (Month)	Window size 0% 0.0	10% 5.6	20% 11.2	30% 16.8	40% 22.3	50% 27.9	60% 33.5	70% 39.1	80% 44.7	90% 50.3	100% 55.9
Jan	70	104	138	172	205	239	273	307	341	375	409
Feb	55	82	109	136	162	189	216	243	270	296	323
March	52	78	103	129	154	180	205	230	256	281	307
April	42	63	83	104	124	145	165	186	206	227	247
May	31	45	60	75	90	105	120	134	149	164	179
June	21	31	42	52	62	72	83	93	103	113	124
July	9	13	17	21	26	30	34	38	43	47	51
Aug	9	13	17	21	26	30	34	38	43	47	51
Sept	17	25	33	42	50	58	66	74	83	91	99
Okt	35	52	69	86	103	120	137	154	171	188	204
Nov	46	69	92	114	137	159	182	204	227	250	272
Dec	61	91	120	150	180	209	239	269	298	328	358

Transmisson gain SW (Month)	Window size 0% 0.0	10% 5.6	20% 11.2	30% 16.8	40% 22.3	50% 27.9	60% 33.5	70% 39.1	80% 44.7	90% 50.3	100% 55.9
Jan	0	60	120	180	240	300	359	419	479	539	599
Feb	0	113	225	338	451	563	676	789	901	1014	1127
March	0	199	397	596	794	993	1191	1390	1588	1787	1985
April	0	311	622	934	1245	1556	1867	2178	2490	2801	3112
May	0	406	812	1218	1624	2030	2436	2842	3248	3654	4060
June	0	403	807	1210	1613	2016	2420	2823	3226	3630	4033
July	0	424	848	1272	1695	2119	2543	2967	3391	3815	4239
Aug	0	359	717	1076	1434	1793	2151	2510	2869	3227	3586
Sept	0	256	511	767	1023	1279	1534	1790	2046	2302	2557
Okt	0	148	295	443	590	738	885	1033	1180	1328	1475
Nov	0	80	159	239	318	398	478	557	637	716	796
Dec	0	46	93	139	186	232	279	325	372	418	465

Transmisson totals SW (kWh) (Month)	Window size 0% 0.0	10% 5.6	20% 11.2	30% 16.8	40% 22.3	50% 27.9	60% 33.5	70% 39.1	80% 44.7	90% 50.3	100% 55.9
Jan	-70	-44	-18	8	34	60	86	112	138	164	190
Feb	-55	31	117	202	288	374	460	546	632	718	804
March	-52	121	294	467	640	813	986	1159	1332	1505	1678
April	-42	248	539	830	1120	1411	1702	1993	2283	2574	2865
May	-31	361	752	1143	1534	1925	2316	2707	3099	3490	3881
June	-21	372	765	1158	1551	1944	2337	2730	3123	3516	3909
July	-9	411	831	1250	1670	2089	2509	2929	3348	3768	4187
Aug	-9	346	700	1054	1409	1763	2117	2472	2826	3180	3535
Sept	-17	231	478	726	973	1221	1468	1716	1963	2211	2459
Okt	-35	96	226	357	487	618	749	879	1010	1140	1271
Nov	-46	11	68	125	182	239	296	353	410	467	524
Dec	-61	-44	-27	-11	6	23	40	57	74	90	107
Sum of Losses:	-448	-88	-45	-11	0	0	0	0	0	0	0

Transmisson loss NE (Month)	Window size 0% 0.0	10% 5.6	20% 11.2	30% 16.8	40% 22.3	50% 27.9	60% 33.5	70% 39.1	80% 44.7	90% 50.3	100% 55.9
Jan	70	104	138	172	205	239	273	307	341	375	409
Feb	55	82	109	136	162	189	216	243	270	296	323
March	52	78	103	129	154	180	205	230	256	281	307
April	42	63	83	104	124	145	165	186	206	227	247
May	31	45	60	75	90	105	120	134	149	164	179
June	21	31	42	52	62	72	83	93	103	113	124
July	9	13	17	21	26	30	34	38	43	47	51
Aug	9	13	17	21	26	30	34	38	43	47	51
Sept	17	25	33	42	50	58	66	74	83	91	99
Okt	35	52	69	86	103	120	137	154	171	188	204
Nov	46	69	92	114	137	159	182	204	227	250	272
Dec	61	91	120	150	180	209	239	269	298	328	358

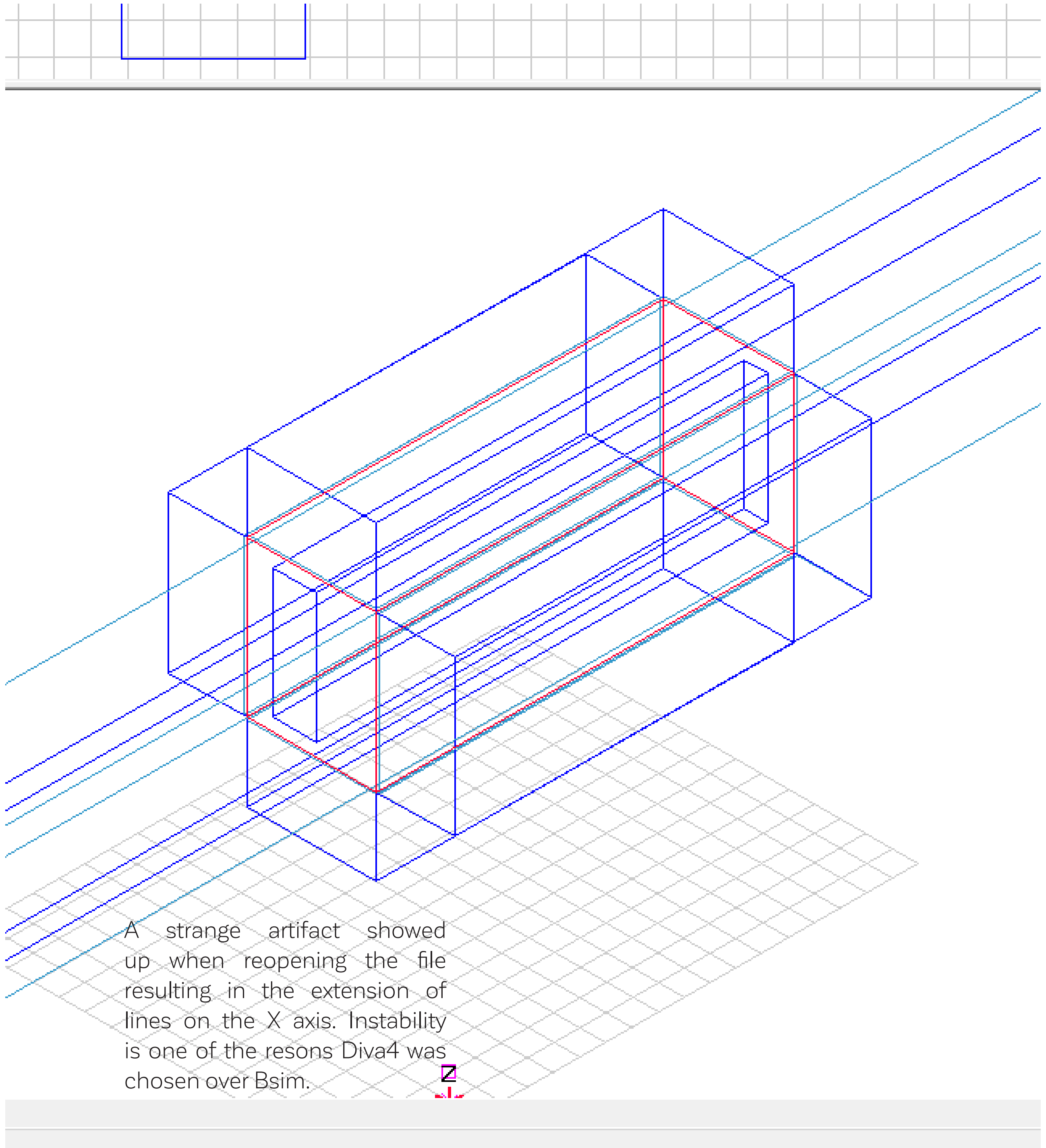
Transmisson gain NE (Month)	Window size 0% 0.0	10% 5.6	20% 11.2	30% 16.8	40% 22.3	50% 27.9	60% 33.5	70% 39.1	80% 44.7	90% 50.3	100% 55.9
Jan	0	31	62	94	125	156	187	218	249	281	312
Feb	0	59	117	176	234	293	352	410	469	528	586
March	0	103	207	310	413	516	620	723	826	930	1033
April	0	162	324	486	648	810	971	1133	1295	1457	1619
May	0	211	422	634	845	1056	1267	1479	1690	1901	2112
June	0	210	420	629	839	1049	1259	1469	1679	1888	2098
July	0	221	441	662	882	1103	1323	1544	1764	1985	2205
Aug	0	187	373	560	746	933	1119	1306	1492	1679	1866
Sept	0	133	266	399	532	665	798	931	1064	1198	1331
Okt	0	77	154	230	307	384	461	537	614	691	768
Nov	0	41	83	124	166	207	248	290	331	373	414
Dec	0	24	48	73	97	121	145	169	194	218	242

Transmisson totals NE (kWh) (Month)	Window size 0% 0.0	10% 5.6	20% 11.2	30% 16.8	40% 22.3	50% 27.9	60% 33.5	70% 39.1	80% 44.7	90% 50.3	100% 55.9
Jan	-70	-73	-75	-78	-81	-84	-86	-89	-92	-95	-97
Feb	-55	-23	8	40	72	104	136	168	199	231	263
March	-52	25	103	181	259	337	415	493	570	648	726
April	-42	99	241	382	523	665	806	947	1089	1230	1372
May	-31	166	362	559	755	951	1148	1344	1540	1737	1933
June	-21	178	378	578	777	977	1176	1376	1575	1775	1975
July	-9	208	424	640	856	1073	1289	1505	1722	1938	2154
Aug	-9	174	356	538	721	903	1085	1267	1450	1632	1814
Sept	-17	108	233	358	483	607	732	857	982	1107	1232
Okt	-35	25	85	145	204	264	324	384	444	503	563
Nov	-46	-28	-9	10	29	48	67	85	104	123	142
Dec	-61	-67	-72	-78	-83	-89	-94	-99	-105	-110	-116
Sum of Losses:	-448	-190	-156	-156	-164	-172	-180	-188	-197	-205	-213

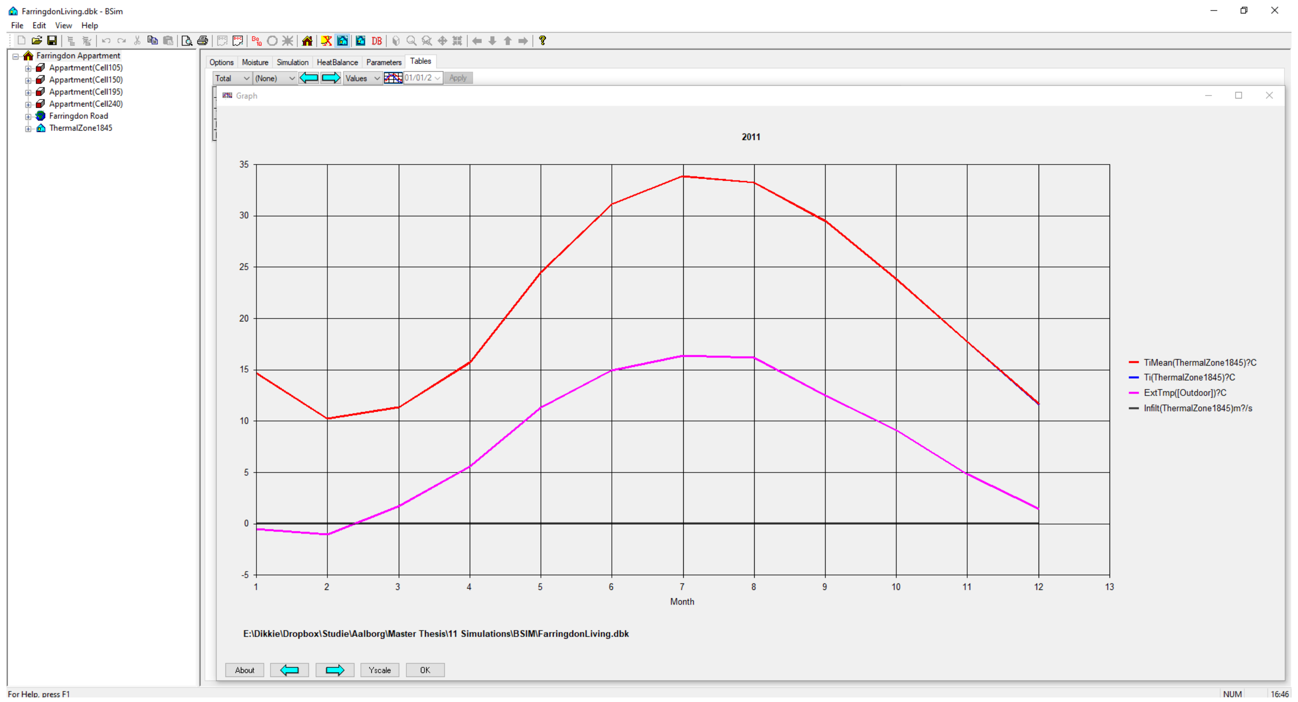
Appendix D - Bsim simulation

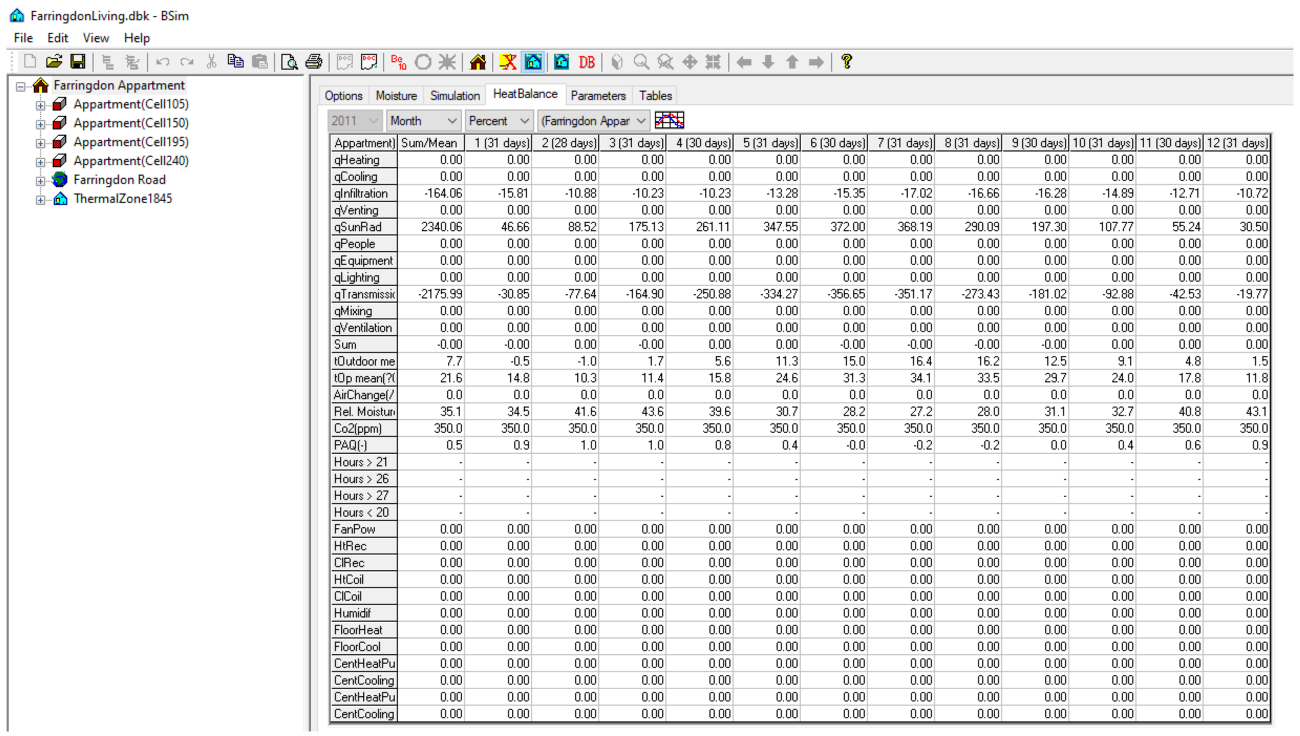
The following pages depict the Bsim simulation and results. The simulation was of a non used apartment complex, with no internal heat gains or ventilation set up. This was compared to a similar simulation of the apartment in Diva4 with no internal heat gains or ventilation.

The form of the curve as seen in Bsim matches the results from Diva4, though the temperatures are different due to the inability of Bsim to use the epw weather file used by Diva4.



A strange artifact showed up when reopening the file resulting in the extension of lines on the X axis. Instability is one of the resons Diva4 was chosen over Bsim.

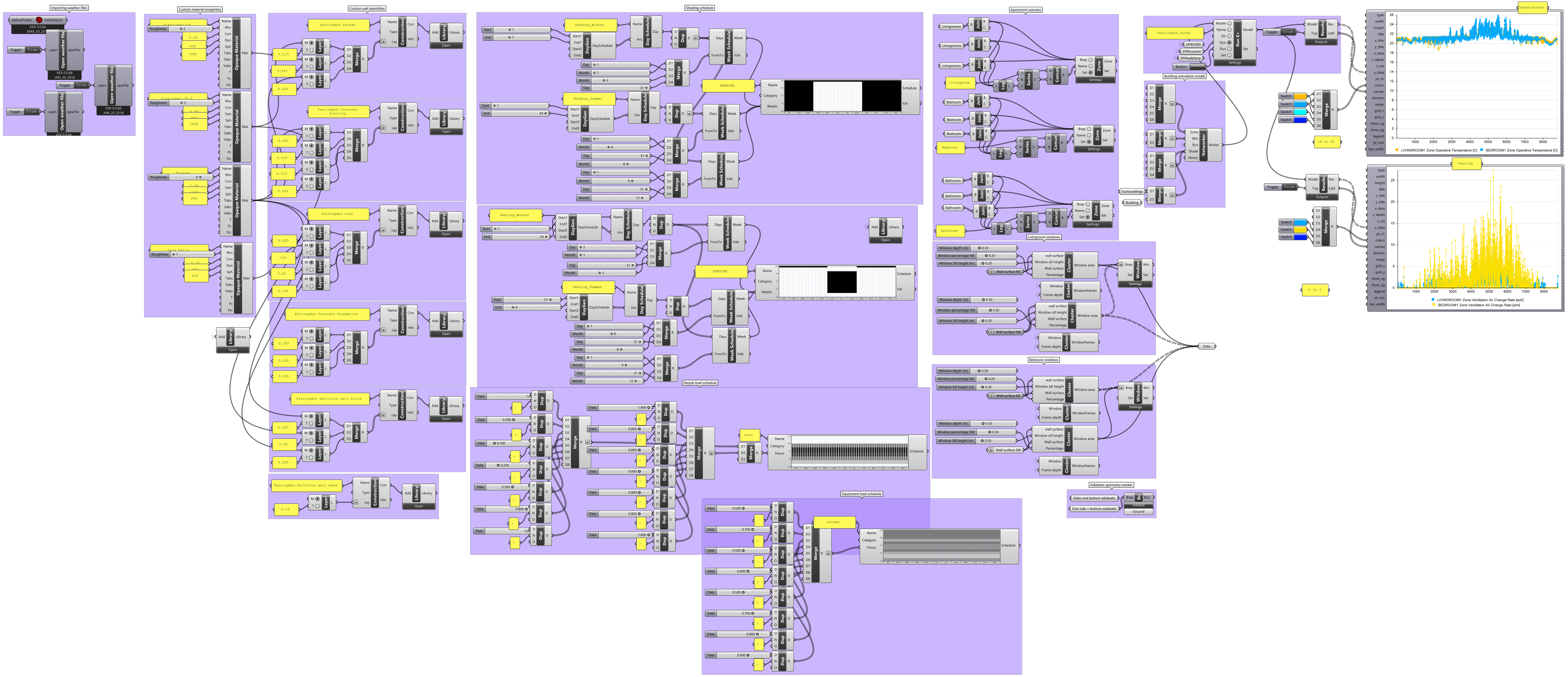




Appartment	Sum/Mean	1 (31 days)	2 (28 days)	3 (31 days)	4 (30 days)	5 (31 days)	6 (30 days)	7 (31 days)	8 (31 days)	9 (30 days)	10 (31 days)	11 (30 days)	12 (31 days)
qHeating	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
qCooling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
qInfiltration	-164.06	-15.81	-10.88	-10.23	-10.23	-13.28	-15.35	-17.02	-16.66	-16.28	-14.89	-12.71	-10.72
qVenting	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
qSunRad	2340.06	46.66	88.52	175.13	261.11	347.55	372.00	368.19	290.09	197.30	107.77	55.24	30.50
qPeople	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
qEquipment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
qLighting	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
qTransmissi	-2175.99	-30.85	-77.64	-164.90	-250.88	-334.27	-356.65	-351.17	-273.43	-181.02	-92.88	-42.53	-19.77
qMixing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
qVentilation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	-0.00	-0.00	0.00	-0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00
tOutdoor me	7.7	-0.5	-1.0	1.7	5.6	11.3	15.0	16.4	16.2	12.5	9.1	4.8	1.5
tOp mean(?(	21.6	14.8	10.3	11.4	15.8	24.6	31.3	34.1	33.5	29.7	24.0	17.8	11.8
AirChange(/	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rel. Moistur	35.1	34.5	41.6	43.6	39.6	30.7	28.2	27.2	28.0	31.1	32.7	40.8	43.1
Co2(ppm)	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0
PAQ(-)	0.5	0.9	1.0	1.0	0.8	0.4	-0.0	-0.2	-0.2	0.0	0.4	0.6	0.9
Hours > 21	-	-	-	-	-	-	-	-	-	-	-	-	-
Hours > 26	-	-	-	-	-	-	-	-	-	-	-	-	-
Hours > 27	-	-	-	-	-	-	-	-	-	-	-	-	-
Hours < 20	-	-	-	-	-	-	-	-	-	-	-	-	-
FanPow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HtRec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ClRec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HtCoil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ClCoil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Humidif	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FloorHeat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FloorCool	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CentHeatPu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CentCooling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CentHeatPu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CentCooling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix E - Apartment simulation definition

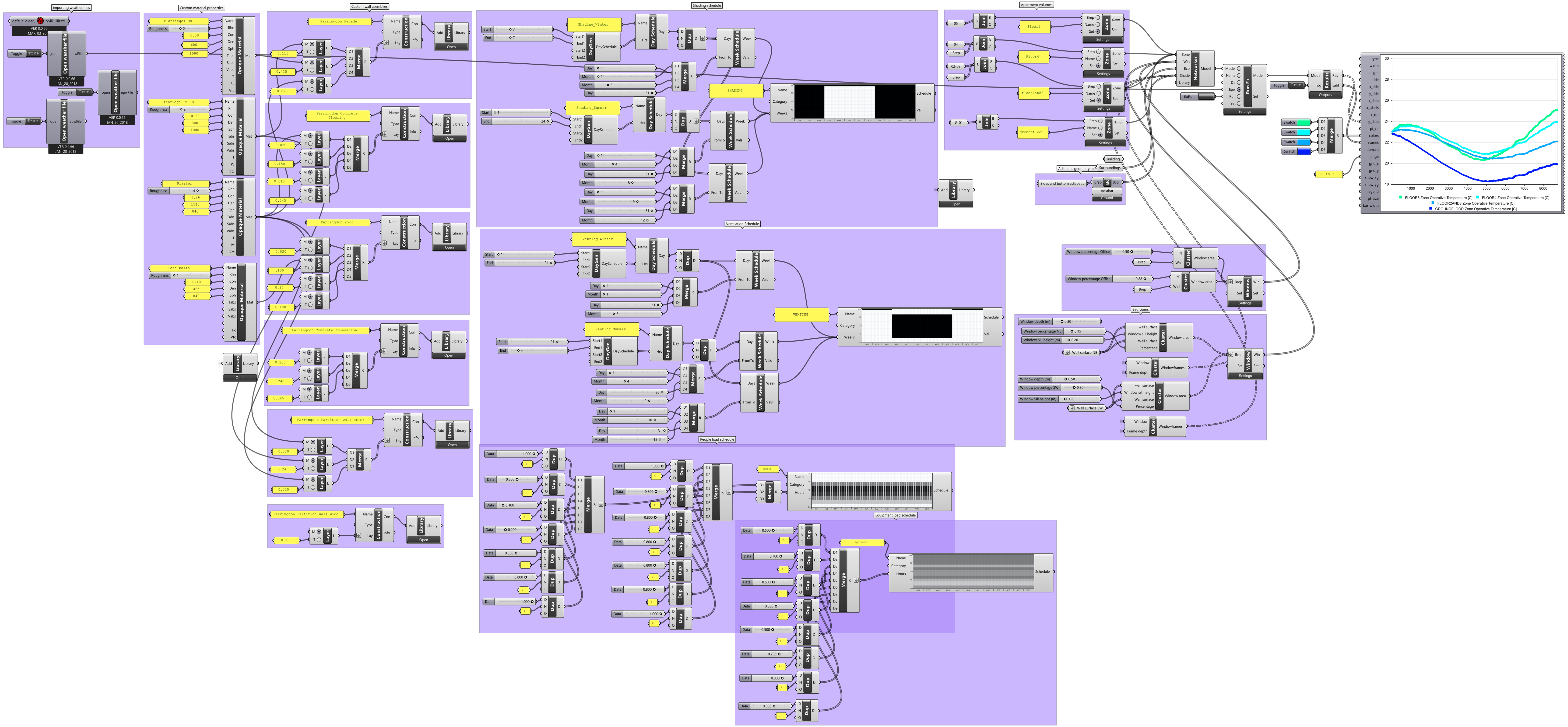
The following pages depict the full grasshoper definition used to simulate the apartments in Diva4



Importing weather files
Custom material properties
Custom wall assemblies
Shading schedule
Apartment volumes
Building simulation model
Livingroom windows
Bedroom windows
People load schedule
Equipment load schedule
Adiabatic geometry marker
Farringdon Facade
Farringdon Concrete flooring
Farringdon roof
Farringdon Concrete Foundation
Farringdon Partition wall brick
Farringdon Partition wall wood
Shading_Winter
Shading_Summer
SHADING
Venting_Winter
Venting_Summer
VENTING
Farringdon_windy
Temperatures
Venting
LIVINGROOM1 Zone Operative Temperature [C]
BEDROOM1 Zone Operative Temperature [C]
LIVINGROOM1 Zone Ventilation Air Change Rate [ach]
BEDROOM1 Zone Ventilation Air Change Rate [ach]

Appendix F - Building simulation definition

The following pages depict the full grasshoper definition used to simulate the building in Diva4


importing weather files
Custom material properties
Custom wall asemblies
Shading schedule
Apartment volumes
Ventilation Schedule
People load schedule
Equipment load schedule
Bedrooms
Farringdon Facade
Farringdon Concrete flooring
Farringdon roof
Farringdon Concrete foundation
Farringdon Partition wall brick
Farringdon Partition wall wood
Shading_Winter
Shading_Summer
Venting_Winter
Venting_Summer
SHADING
VENTING
FLOOR5 Zone Operative Temperature [C]
FLOOR4 Zone Operative Temperature [C]
FLOOR2AND3 Zone Operative Temperature [C]
GROUNDFLOOR Zone Operative Temperature [C]