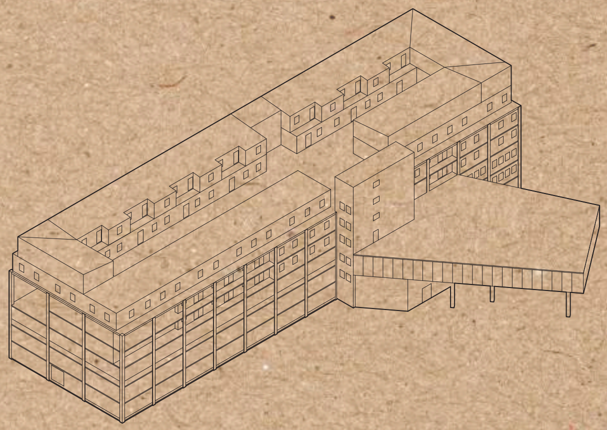
NEVER ENDING STORIES

TRANSFORMATION OF A PAPER STORAGE IN FORSÅKER



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CHALMERS
UNIVERSITY OF TECHNOLOGY

Never ending stories
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Master's Thesis 2023
Chalmers University of Technology
Department of Architecture & Civil Engineering
Direction: Building design for sustainability

ABSTRACT

The purpose of this thesis is to illustrate how building transformations using circular design principles can lower emissions and minimize resource extraction while also enabling more rich, functional and enjoyable environments.

With a rapidly growing global population the pressure on nature and natural resources can be expected to further increase. The Swedish building sector already accounts for 40% of national greenhouse gas emissions and waste generation and 45% of our resource extraction. To avoid the worst-case climate scenarios, it is necessary to make a shift in the current linear system and explore new ways to design, build and live.

This thesis will address these problems by showcasing how a transformation of an industrial building in Forsåker can help lower the environmental impact, revitalize a neglected neighbourhood and add new layers to the story and identity of the place. The project focus on designing out waste and extending the buildings life span by creating more adaptable spaces, utilizing reused and regenerative materials and designing new additions for future reuse. Furthermore, the program of this project strives to intensify the use of the building and promote more sustainable lifestyles within a circular economy, such as offering functions that support sharing goods, services and space.

The carbon and resource savings made in this project are highlighted through a life cycle analysis. The result shows that the structure and climate shell of the existing building contains 10 960 tons materials and 1 390 tons embodied carbon, which is almost 3 times the embodied carbon and more than 30 times of the material mass compared to the new additions.

KEYWORDS:
Circularity – Transformation – Reuse

AUTHORS

We both share an interest in circularity and reuse and are curious to explore the opportunities for circular design that exist today in our local context. We see this as a valuable opportunity to gain knowledge and experience on how we can contribute to a sustainable building industry in our future careers as architects.

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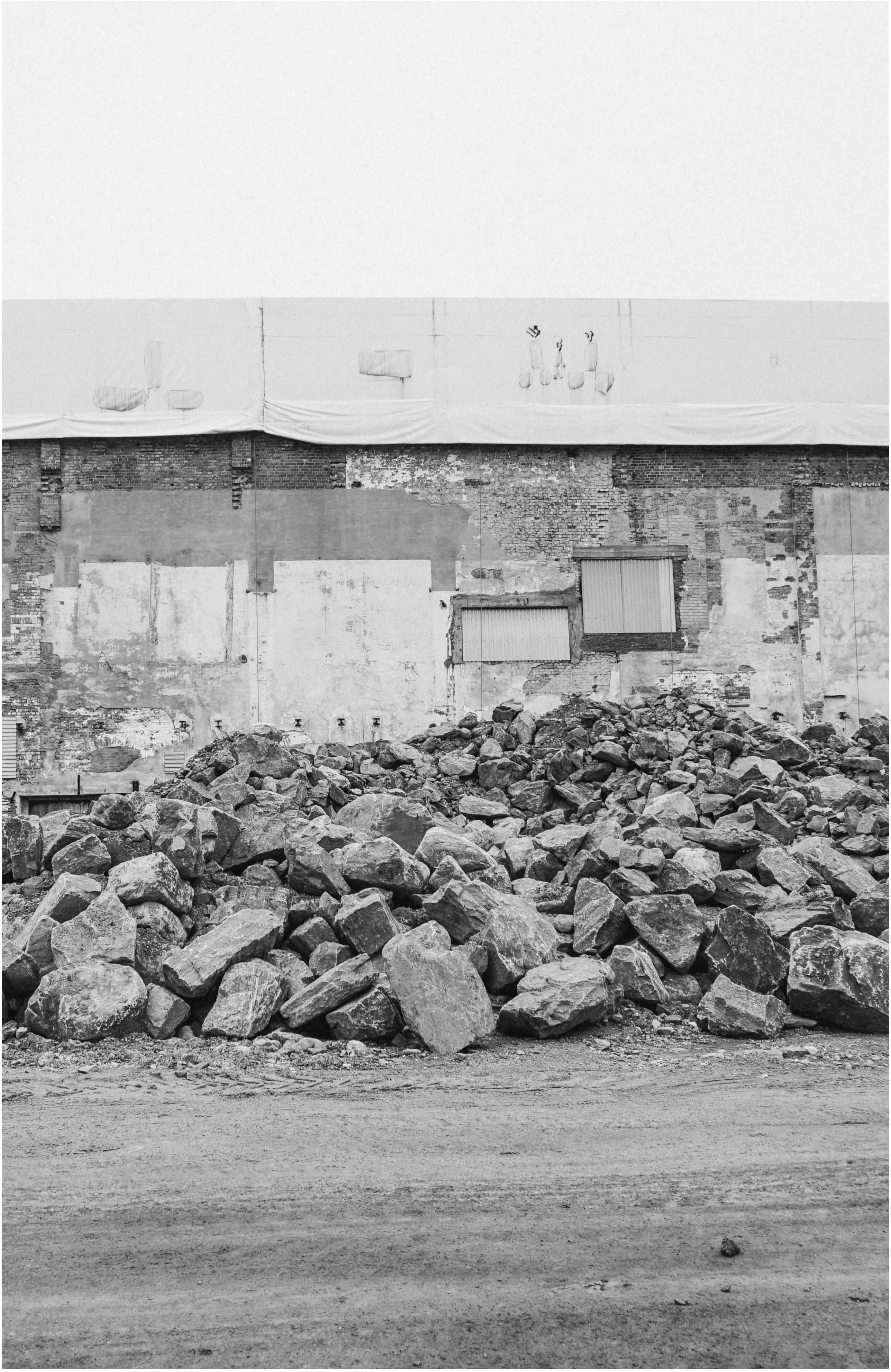
I. PROLOGUE

PROBLEM STATEMENT

The linear economy we are currently operating within relies heavily on large quantities of cheap resources and energy and has started to reach its physical limits. Not even a great improvement of production efficiency and reduced consumption could solve this issue, as the framework for the linear model is to have infinite growth within a finite world. (Ellen McArthur Foundation, 2015) A viable alternative is shifting towards a circular economy that is restorative and regenerative by design and decouples economic growth from resource extraction.

The building industry is one of the major contributors to climate impact and resource consumption. In Sweden it accounts for 45% of the resource extraction, 40% of greenhouse gas emissions (Haeggman et al., 2021) and about 40% of the waste generation. (Naturvårdsverket, 2020) Shifting the industry towards circular ways of building and designing could therefore have a major impact and is a crucial key to fulfilling climate goals.

As the operational carbon from buildings have seen a great reduction in recent years, the importance of embodied carbon – including emissions from manufacturing, transportation, construction and end of life – grows as it becomes a larger proportion of total emissions. These emissions are expected to be responsible for 50% of the carbon footprint in new construction between now and 2050. (World Green Building Council, 2019) If we are to stay within our planetary boundaries it is therefore essential that we start making better use of the buildings we already have and treat them as resources rather than waste. Estimations show that between 20-25% of life cycle emissions in the current EU building stock are embedded in our building materials. Retrofitting existing buildings using circular thinking can therefore play a major role by improving energy efficiency, avoid or delay demand for new constructions and minimize embedded resources and emissions. (European Environment Agency [EEA], 2022)



Demolition waste from site (2023).

AIM & OBJECTIVES

The aim of this thesis is to illustrate how a building transformation in Forsåker using circular design principles can lower emissions and minimize resource extraction while also enabling more rich, functional and enjoyable environments. By illustrating an alternative to the linear way of building and demolishing, this thesis aims to be a critical comment in the debate of sustainability. While this thesis project takes place in the context of Forsåker, the strategies and principles shown can be applied to many other projects all over Sweden.

The project aims to showcase how a transformation of an industrial building in Forsåker can help lower the environmental impact, revitalize a neglected neighbourhood and add new layers to the story and identity of the place. The project focus on designing out waste and extending the buildings life span by creating more adaptable spaces, utilizing reused and regenerative materials and designing new additions for future reuse.

Furthermore, the program of this project strives to intensify the use of the building and promote more sustainable lifestyles within a circular economy, such as offering functions that support sharing goods, services and space.

Research questions:

How can a neglected industrial building in Forsåker be transformed into a long-lasting valuable space and help support the transition towards a circular economy?

- What qualities can be gained by transforming the building instead of demolishing?

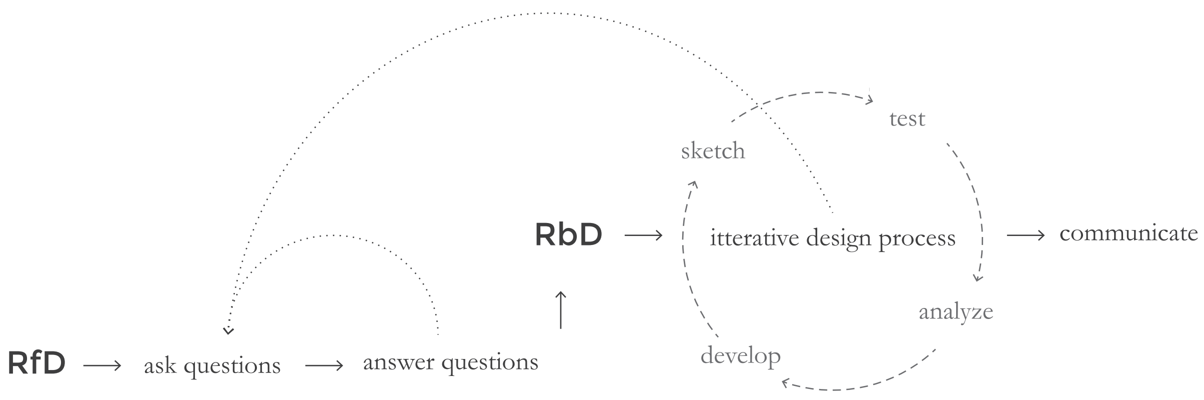
- What are the challenges for doing such a project and how can these be overcome?

DELIMITATIONS

- As this project is based in the local context of Forsåker the research and design will depart from a Swedish and European perspective.

- The design project focuses on the transformation of building 110 and the connecting exterior and interior spaces, not aiming to make a proposal for the entire site. When showing the context for the rest of the site, the current detail plans are used.

- LCA calculations focus primarily on the production stage (A1-A3) and end of life (C3, C4) but also take operational energy use (B6) into account. The benefits and loads beyond the system boundaries including reuse, recovery, recycling and exported energy potential (D) are addressed more generally through the design interventions and strategies. As the primary focus of the thesis is on the resources and emissions caused by built-in materials, the project is not elaborating as much on operational emissions or optimization of energy use.



Process diagram.

METHOD

This thesis was initiated with a *research for design* phase were literature studies, reference projects, site visits, museum archives and interviews were used to determine the scope, focus and strategies for the thesis. The continuation of the project was then an iterative process were both *research for design* and *research by design* were carried out simultaneously. Different design interventions and transformation strategies were tested and evaluated, assessing the impact both on climate, aesthetic qualities and feasibility. Life cycle analysis were made using the tool CAALA. Design work was made primarily using digital tools and models, but also making material samples and detail models. Parallel with the design work more theoretical research and reference studies were carried out as new questions and ideas arose.

II. THEORY

FROM LINEAR TO CIRCULAR

Historically, humans have had a long tradition of reusing materials due to resource scarcity. This changed with the industrial revolution in the 19th century which made large-scale extraction and processing of raw materials possible. Human experience and craftsmanship were replaced by machines and automation and consequently, the society lost the connection to the value of materials and the incentives for reuse faded. This led to a change from circular to linear waste streams, from a use and reuse mentality to a use and disposal mentality. (Lloyd Thomas, 2007) It is now clear that this linear economy has started to reach its physical limits. With major global challenges like climate change, increasing global populations and resource scarcity lining up it is vital that we make a change to our current system. (Ellen MacArthur, 2015)

A key goal for the EU and other policymakers is now to transition towards a more circular economy, which includes the building industry. In a circular building industry waste and pollution are eliminated. Buildings, elements and materials are kept in use for as long as possible and once they reach their end-of-life they are simply fed back into the loop at the highest value possible, being reused or recycled. Keeping material resources circulating for as long as possible has a double benefit as it minimizes both the pressure on natural resources and the emissions of greenhouse gases. (EEA, 2022)

Circular buildings are defined as "buildings that are designed, planned, built, operated, maintained and deconstructed in a manner consistent with circular economy principles". However, it will not be enough to only apply circular economy principles to new buildings, we also need to introduce circularity to the existing building stock. (Pomponi & Moncaster, 2017) If the natural maintenance and retrofit moments of existing buildings will be done using circular building components, the existing building stock will gradually become more circular. (van Stijn & Gruis, 2019)

Fig. 1, Preconditions for a circular building industry.
Adapted from Göteborg stad (2020).

PRECONDITIONS

To shift from the current linear flows to a circular building industry, changes are needed in organisation, business models and workflows. Göteborgs stad (2020) have listed ten preconditions that needs to be fulfilled to achieve a circular building sector. This thesis focuses mainly on number 3 – design for circularity, since this is where architects can have the biggest influence.

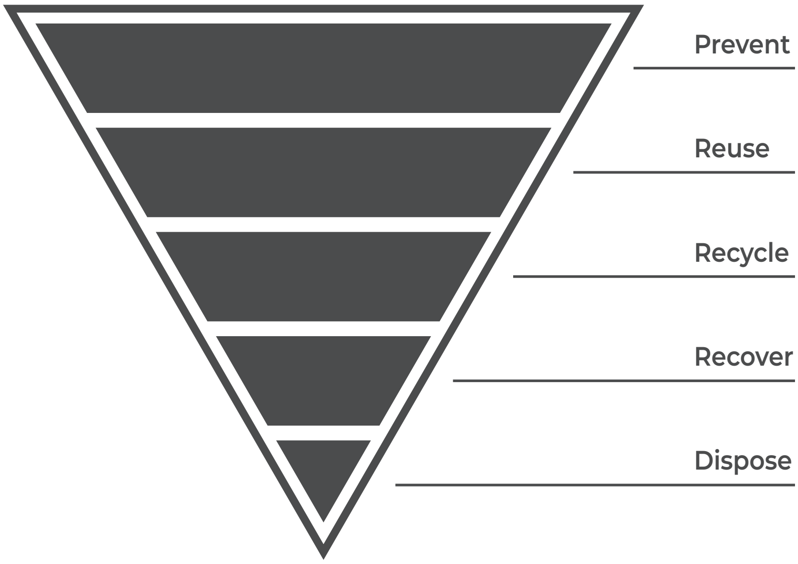


Fig. 2, Waste Hierarchy model.
Adapted from European Commission (2008).

THE WASTE HIERARCHY

The EU have formulated a five-step waste hierarchy aiming to support the transition towards a circular economy which outlines an order of priority for resource management. (European Commission, 2008)

The hierarchy is used as a guideline in this thesis project, where the main focus lies on prevention and reuse, since this is where the biggest savings can be made. In new building projects prevention is mainly about designing buildings with a long lifespan and prepare them for future reuse. By doing so the amount of waste generated in the future is minimized.

Prevention also includes extending the lifespan of already existing buildings by for example renovating or retrofitting them. Reuse is about using building elements or materials again for the same purpose without changing its original state and form. Recycle is where a material or element is transformed into something with a new purpose or form. Recovery; when the material is used to generate substances or energy, and disposal; after which the resource cannot be used again, is the least preferred options and will not be covered by this thesis. (European Commission, 2008)

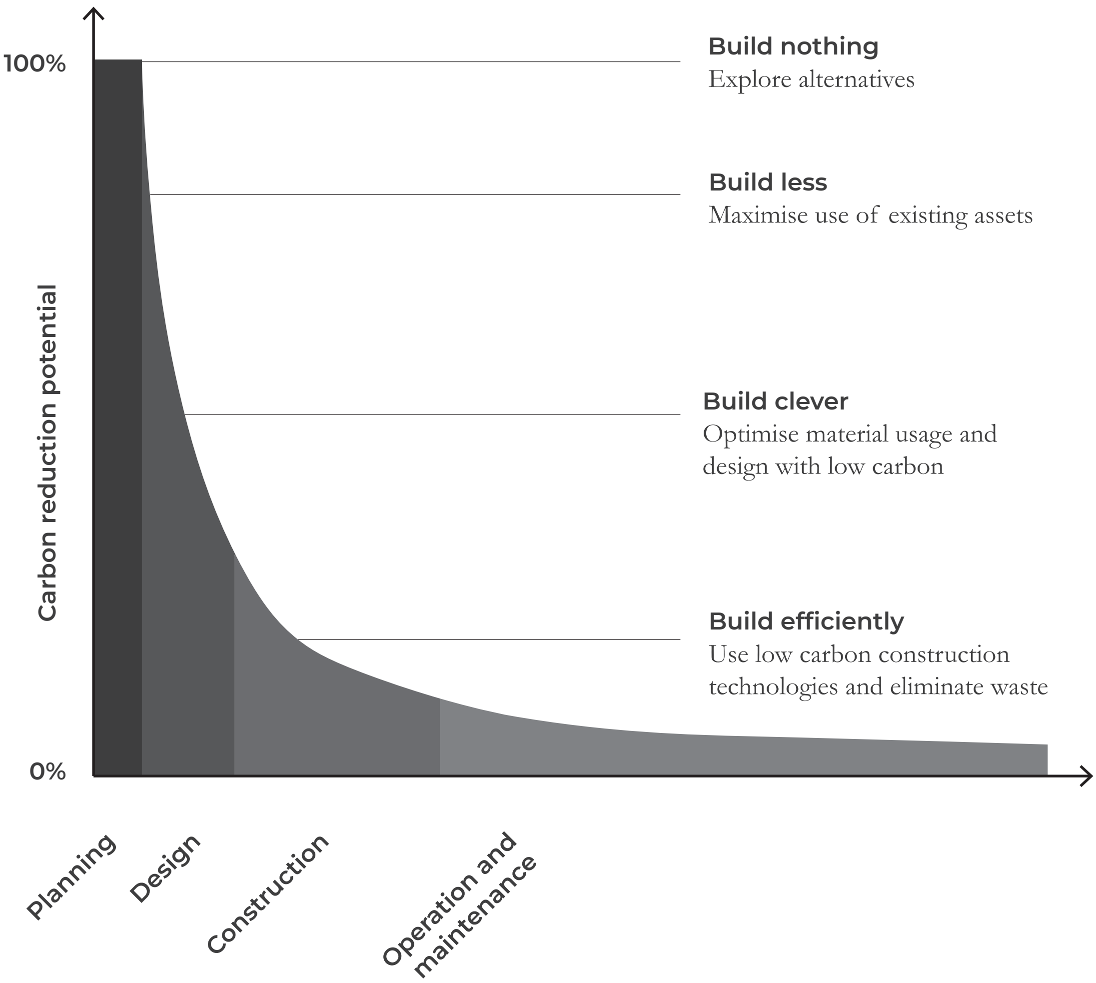


Fig. 3, Opportunities to reduce embodied carbon in a building. Adapted from HM Treasury (2013).

DESIGN PROCESS

In general, the greatest environmental savings can be gained at the early stages of a project, during the planning and design phases. It becomes more demanding and expensive to make design changes aiming to reduce embodied carbon as a project progresses.

To build less or even nothing at all, and instead explore alternative ways of fulfilling the desired functions, are the most efficient actions since it avoids new resource extraction and emissions. This could be done by for example intensifying the utilization or extend the lifespan of existing buildings through renovations and retrofitting. Thereafter, to build clever and optimize material usage and design for low carbon footprints should be prioritized. This includes building with a high degree of reused and recycled building products.

Once a project is designed and planned for, the room for carbon reduction is rather small. However, by choosing efficient construction techniques with a minimum waste generation, smaller environmental savings can be made. (World Green Building Council, 2019)

CIRCULAR GAINS

Applying the principles of a circular economy into the built environment comes with multiple positive effects, both of environmental, social, economic and cultural character.

Environmental value

As mentioned previously, turning the building industry more circular would have a major positive impact on the environment. A circular building industry would significantly reduce greenhouse gas emissions, waste generation, energy consumption, use of virgin materials and biodiversity loss. (Bates et al. 2021) As a matter of fact, a study made by Sweco states that cities can save up to 75% of their total energy usage and reduce their carbon emissions with 97% compared with today by implementing circular systems. (Borneke et al, n.d)

Social value

Establishing a circular economy and building industry will require both technical and social innovations and the implementation of new business models, such as replacing products with services, moving from sales to leasing and introducing more peer-to-peer sharing services. These new circular solutions have the potential to create increased inclusion, new community spaces, reduce socio-economic pressure and increase wellbeing and trust among people. (Casapu & Dippon, 2021)

A circular economy is also expected to create many new job opportunities as the shift away from resource-intensive businesses results in more labour-intensive activities. While some sectors might diminish, new will be created. (EEA, 2016) Studies show that reuse creates over 200 times as many jobs as landfills and incinerations, recycling 70 times as many and remanufacturing almost 30 times as many. (Ribeiro-Broomhead & Tangri, 2021)

Economic value

Apart from creating new jobs and business opportunities, a circular building industry also saves costs from waste disposal, land acquisition and material purchases. Using fewer virgin materials also reduce exposure to price volatility and creates more resilience and supply security. (Bates et al, 2021)

Designing buildings with circular principles also maximises value over time by optimizing the use of resources throughout the whole life cycle. As an example, a building element that is easy to dismantle is also easy to assemble, resulting in a significant lower production cost. It also enables for effortless maintenance and repair, which makes it easier and cheaper to use and operate. Furthermore, products that are designed for disassembly can be used and reused without any loss of quality or value for a long time. (GXN, 2018)

Cultural & historical value

Transformation and reuse of existing buildings and materials allows for the preservation of historical and cultural value. Pallasmaa (2012) states that the understanding of our place in history is a key factor for our sense of belonging and participation. Architecture and buildings play a crucial role as they embody the history, memory and identity of a place and helps create an understanding for the passing of time and cultural changes.

A building does not need to be ancient in order to possess qualities of cultural or historical heritage. Neither is the heritage limited to the physical boundaries of the building itself, it often extends to the surrounding area and the impact it has had on the social and economic development of the place. (Foster, 2020) Industrial sites for example, like the one covered in this project, often plays a very important role in the local life and identity of a place. Both the buildings and their former use are an integrated part of people's history and collective memory.

Fig. 4, Photography from the paper sorting hall.
Mölndal Stadsmuseum. (1931).

CHALLENGES FOR BUILDING CIRCULAR

It is technically possible to build circular in Gothenburg today. However, there are several challenges that needs to be addressed to implement it at large scale, many of them being interdependent. Svenska Miljöinstitutet IVL (2021) made a survey asking 10 organisations in the Gothenburg region what is seen as the biggest obstacles keeping them from increasing their reuse of building products. The participating organizations represented different groups of actors in the construction sector, both public and private property owners as well as consultants, such as architects and technical consulting companies.

According to the survey, the biggest challenge for increased reuse was existing habits and attitudes within the organisations. Lack of knowledge and competence was also seen as a major obstacle. A key strategy to tackle both of these is to increase communication and information about reuse and circularity, for example through further education and by spreading experience and good examples. This also includes increasing the cooperation between different actors withing the building sector. Another important aspect is to develop more simple and systematic processes with methods and tools that are easy to use.
(IVL, 2021)

The challenge to solve storage and logistics in a reuse project was another big challenge frequently mentioned in the survey. Preferably building elements are reused locally on site, but often they must be transported and stored somewhere else before they can be reused. Added transportations and storage needs are sometimes used as an argument against reuse, claiming that it counteracts the intended climate savings. However, another study from IVL (2022) concluded that it almost always pays off to reuse building products, even when reuse on site is not possible. The study made calculations for some common building products, including bricks, timber, windows and doors, which concluded that the studied products could be stored between 23 to 93 years before the climate impact from the storage exceeded the savings from reusing them. The study also stated that the products could be transported with a truck between 1800 to 50 000 km before it was environmentally more efficient to produce new ones. For a timber product with the lowest savings that is equivalent to a trip from Gothenburg to Milan while it for an aluminium window corresponds to a trip from Stockholm to Athens, 15 times!

Circular building projects often comes with a higher risk for the involved stakeholders, which means that more money is at stake. (Danckwardt-Lillieström et al., 2019) By doing more analysis and establish standardized ways to compare costs and environmental gains it will be easier for the clients to make informed decisions and feel more comfortable to introduce risk into the project. (Poulsgaard, K. Personal communication. 2023) Also, the development of a common quality assurance system and guarantees for reused products can make reuse projects easier to execute. (Danckwardt-Lillieström et al., 2019)

Circular projects also requires that we make changes to our planning and building methods. A circular building project calls for a more integrated planning and construction process that is flexible enough to handle the uncertainties that comes with reuse. (Danckwardt-Lillieström et al., 2019) There might also be a need for increased time and resources during pre-studies, project planning and construction in order to make necessary inventories and planning. (Göteborg Stad, 2020) Furthermore, it is important to have good information management since it must be possible to document the buildings lifetime, what it is made of, when changes are made and how elements can be demounted and replaced. This information has to be stored in a way so that the information is easy to find for everyone involved. Digital twins with information lists of materials and products have the potential to become such database. (Danckwardt-Lillieström et al., 2019)

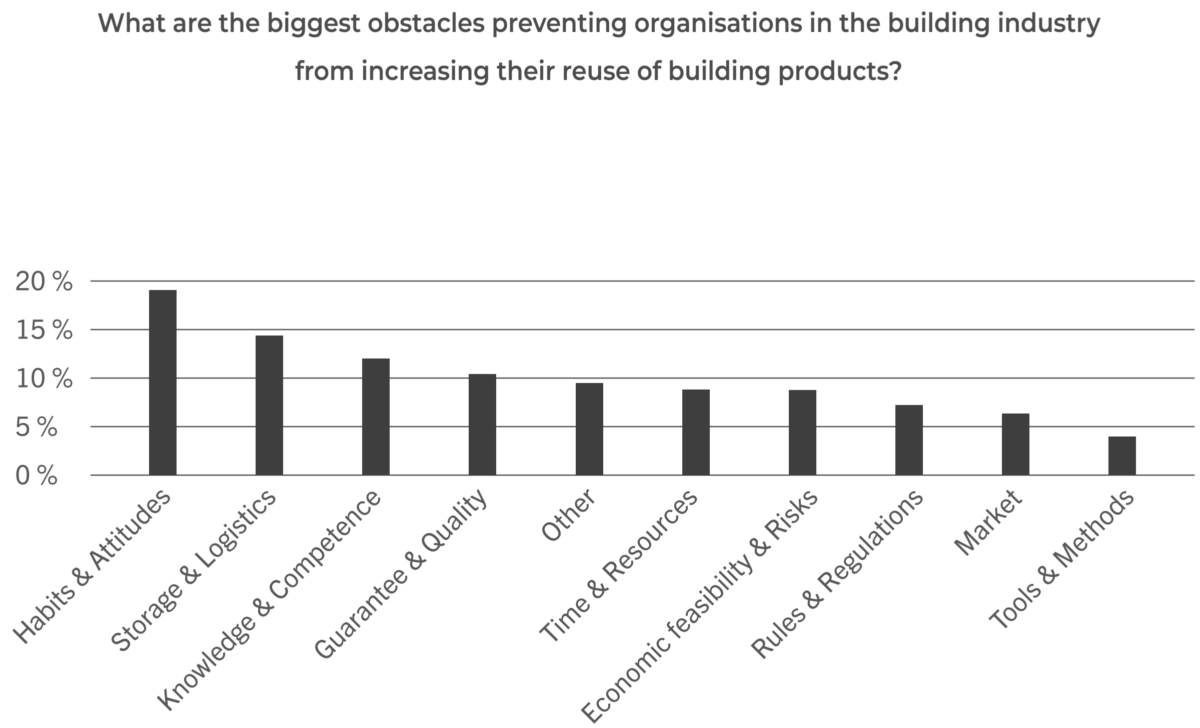


Fig. 5, Diagram adapted from Svenska Miljöinstitutet IVL (2021).

III. CONTEXT

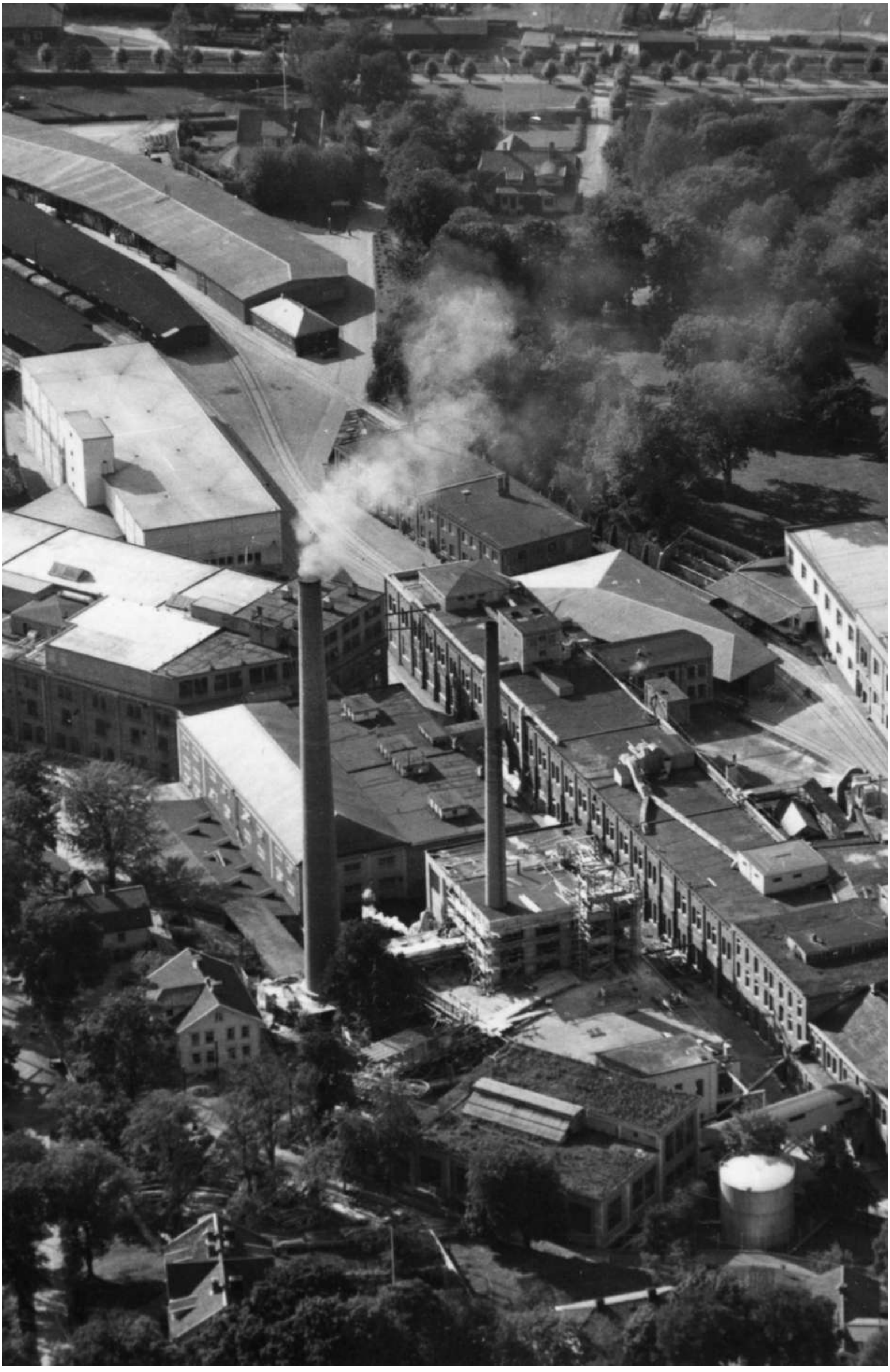


Fig. 6, The factory in 1949.
Mölndal Stadsmuseum (1949).

Map of site location.

BACKSTORY

THE STORY OF FORSÅKER

Forsåker is situated within Mölndal municipality, only a few kilometers south of Gothenburg. The rapid that runs through the area attracted settlers here already in the late 1500s and since then the water has given life and power to many generations.

The site has been a centre for paper manufacturing for over 350 years but for the last decade the buildings have stood empty. As Mölndal and Gothenburg are expanding, the time has come to give new life to the site and begin the chapters of a new story.

THE PAPER INDUSTRY

The village of Forsåker was founded in the late 1500s by the settling of four farms. During the 17th and 18th century the site grew as pre-industrial factories and mills expanded along the rapids to make use of the power from the water. As Gothenburg began to develop in 17th century, the demand increased for many of the goods produced in Forsåker, such as flour and wool fabric. Over time, both the amount and variety of goods increased and expanded to also include paper, linseed oil and sugar.

The first paper mill was founded in 1653 the by bookbinder Thomas Kuhn who was tired of the high paper prices in Gothenburg and wanted to utilize the waterpower to make paper more affordable. In the 18th century two more paper mills were established and later gathered into the same production company of Korndals pappersbruk.

During the 19th century the area saw a rapid industrialization and economic development as new technological progress were made. In 1850 the mill was incorporated with Rosendahls fabriker who also produced textiles and sugar. The paper mill grew, and manufacturing transformed from hand craft to more industrialized production. In 1870 almost 50% of all paper in Sweden was produced in Forsåker. The neighbourhood developed into a lively society and lots of people moved into the modern houses along the steep riverbank. Many of whom are still intact today!

In 1895 there was a large ownership change as Marcus Wallenberg bought many of the properties and formed the paper manufacturing company Papyrus AB. The production was established to primarily focus on high quality white paper which had seen a rising demand in society. However, the wide product range also included hundreds of other products such as wax paper, leather imitation paper and the coloured and patterned "kromo- och fantasipapper" which even won a gold medal during the Paris World Exhibition in 1900. As production expanded the mill was gradually developed with new machinery, buildings and employees. Apart from building housing for their employees the company also established a hot water bathing house, laundries, sport hall, post office and grocery store among other things.

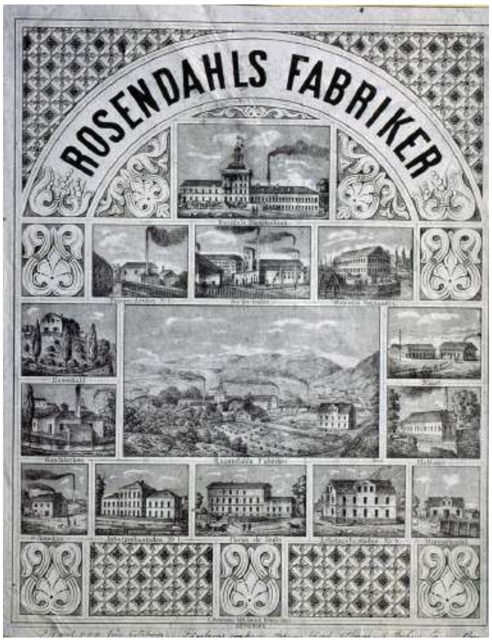
In the later part of the 20th century production progressively became more rationalized with fewer but more efficient machines. The staff reduced from 1200 in 1945 to 400 in the beginning of 2000. The production also transitioned from a wide range of products towards specialising in only a few. After several ownership and name changes in the 90s and 80s the mill was finally bought by Klippan AB in 2004 who ran the company only for four years before they became bankrupt, and production closed for good.

Since then, the buildings have mostly been standing empty with little or no maintenance but been a popular space for local graffiti artists. In 2009 Mölndal municipality bought the land of Forsåker with the plans to give new life to the site. A building consortium consisting of the municipality owned company Mölndala AB and five other housing companies was formed to carry out the planning and development. In 2017 the first detail plan was published but due to many complex challenges it had to be withdrawn and reworked. The new detail plan was accepted in 2022 and is now awaiting final legalization.

(Lindholm Restaurering, 2015)

late 1500s
The village of Forsåker is founded by the settling of four farms.

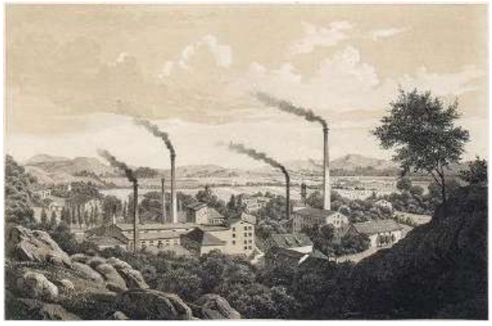
1653
The first paper mill is founded by book binder Thomas Kuhn.



Poster from Rosendahls fabrik (n.d)

1700

1736, 1763
Two more paper mills are established and later gathered into the same production company of Korndals pappersbruk.


Lithography of factory area from 19th century.

1800

1850
Korndals pappersbruk is bought David Otto Francke and incorporated with Rosendahls Fabriker who also produces textiles and sugar.

1895
The paper factories are bought by Marcus Wallenberg who founds Papyrus AB.

1900
Papyrus wins a gold medal for their paper during the Paris Worlds Exhibition.

1900

Sample book of paper products. (1945)

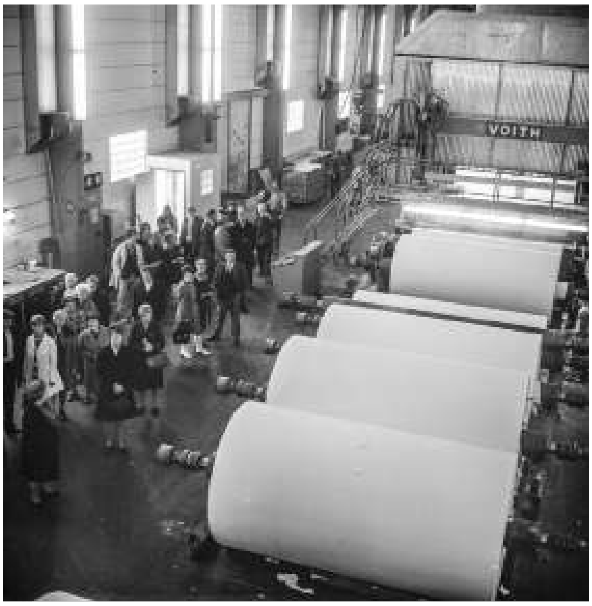

Factory workers (1898)

2000

2008
The factory goes bankrupt and production is closed for good.

2009
Mölndal municipality buys the land and two years later assigns Mölndala AB with the task of developing the area.

Fig. 7, Timeline of factory history.
Mölndal Stadsmuseum.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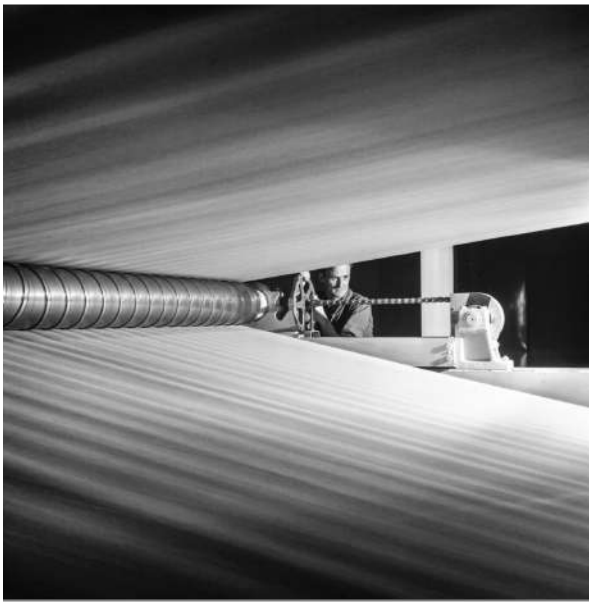


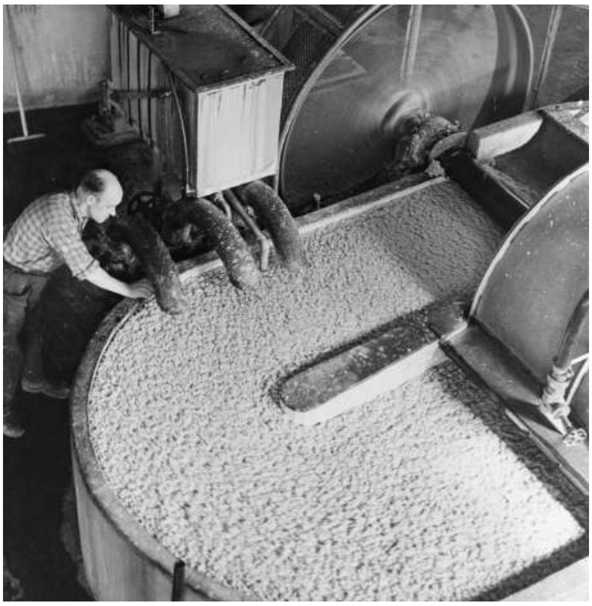


Fig. 8, Photographs from the paper factory.
Mölndal Stadsmuseum (1929-1964).

BUILDING DEVELOPMENT

As mentioned previously, the activity in Forsåker has been going on for hundred of years but most of the current buildings dates back to late 1800s and early 1900s. The site has since then been developed and added to many times, which can be summarized into four main expansion phases.

Start - before 1895

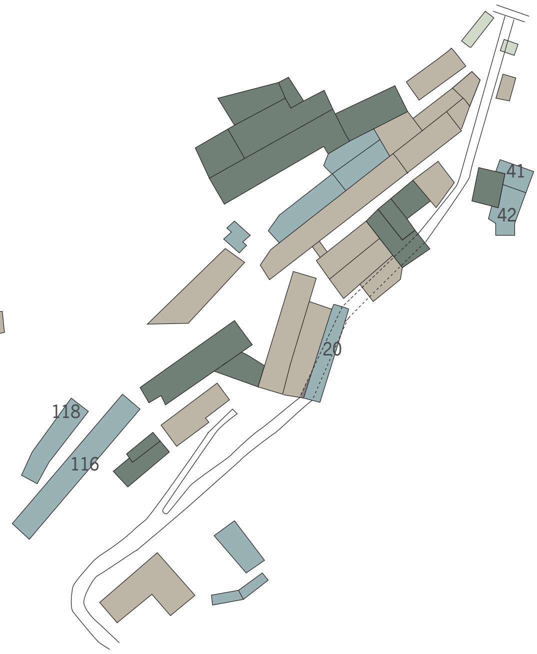
The area was sparsely built and had plenty of green areas in-between buildings. The building typology consisted of a mix of factory buildings as well as smaller wooden villas and multi-family buildings along the stream for workers and their families.

Remaining buildings: Papermill 3 (213), rests from papermill 1 (4)

First expansion - ca 1895-1930

As a result of increased production, many transformations and new constructions took place during these years. Several of the old factory buildings were demolished to make way for new ones and the site became more densified with new buildings interspersed with the old. The new buildings were stylistically connected to the area's older brick buildings.

Remaining buildings: 2, 4, 10, 17, 18, 19, 23, 26, 203 and 217.



Second expansion – ca 1930 - 1960

Several of the older buildings were replaced by new industrial buildings in a larger scale. The new development was characterized by functionalistic ideals and ideas which are echoed in the architecture and design of the houses. Old factory buildings, residential buildings and smaller support buildings were replaced by new larger production, warehouse and office premises.

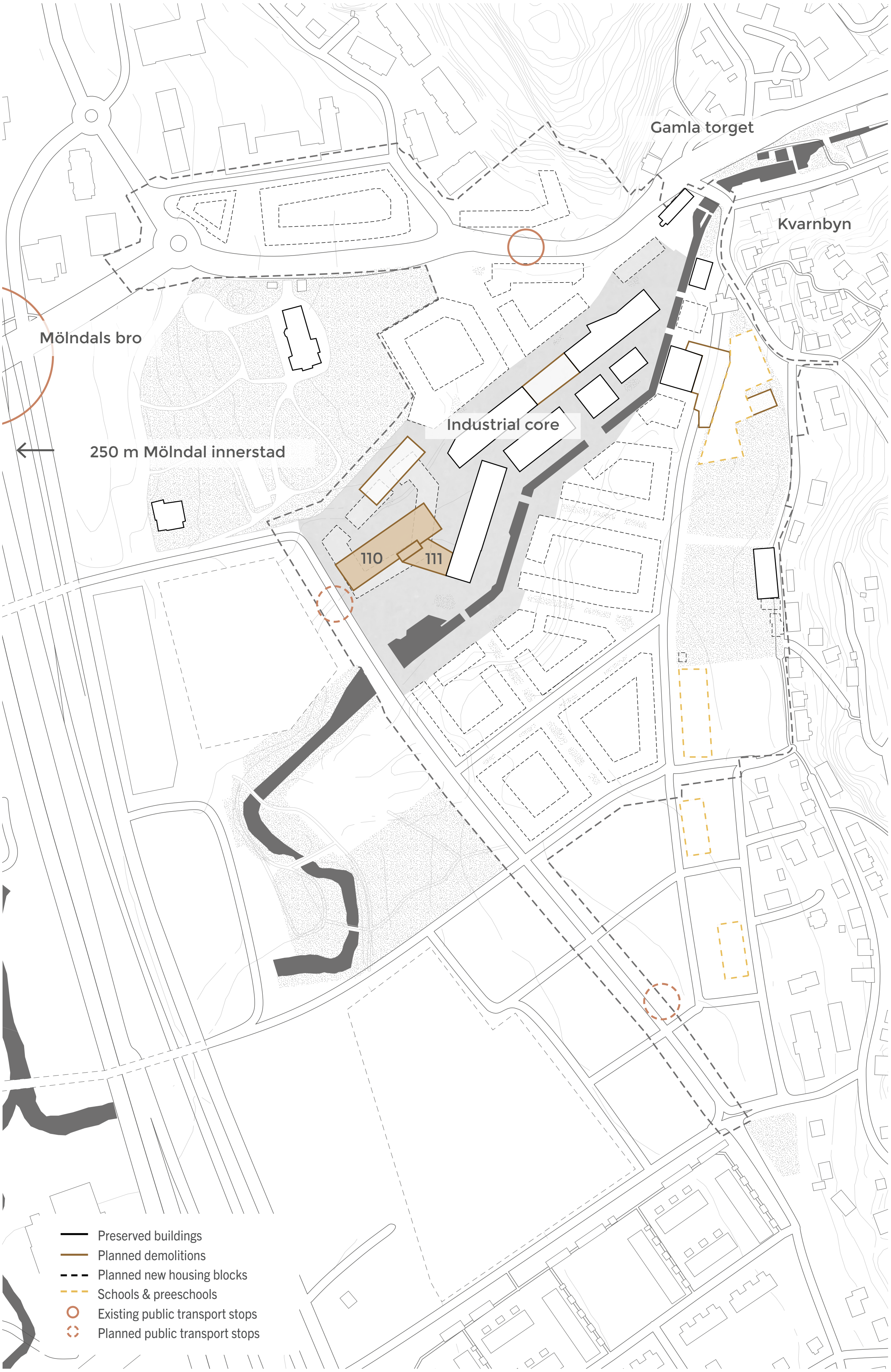
Remaining buildings: 6, 14, 16, 110 and 111.

Third expansion - ca 1960-2005

This era was characterized primarily by specialization and streamlining. The building development consisted mainly of renovations and additions but also some demolitions of older buildings that had lost their use. The aesthetic ideals that prevailed during previous expansion phases were no longer relevant and the focus was now entirely on the needs of production.

Remaining buildings: 20, 40, 41, 116, 118, 125.

(Lindholm Restaurering, 2014)



Site plan adapted from detail plan proposal (2017 & 2022). 1:4000

A NEW CHAPTER

FORSÅKER TODAY

The central location along highway E6 with close access to Mölndal city centre makes Forsåker a very attractive site for new development. In the north, the site borders to another historical area, Kvarnbyn, that shares a lot of Forsåkers industrial history and has several boutiques, local art and craft studios, museum and restaurants. Forsåker and Kvarnbyn forms some of the most well-preserved cultural heritage areas in Mölndal, but both are being partly separated from central Mölndal by the highway and railroad.

The municipality of Mölndal currently has about 70 000 inhabitants (2022) which are expected to grow with 10% within the following decade, further amplifying the already existing housing shortage. (Mölndal stad, 2023) The attractive location with close proximity to Gothenburg, but slightly lower prices, is not only attracting inhabitants, but also business. As a matter of fact, more people commute in than out during the week. (Mölndal stad, 2022)

The municipality aims to transform Forsåker into a lively and varied mixed-use neighbourhood and a new point of destination. Another important part of this project is the reopening of the stream and local hydro power plant to once again give energy to Forsåker. The new plans includes both housing, office and a focus towards the three main themes scene space, food space and creative space.

The site is closed off to the public since a few years back. Some construction work has already started with the demolition of several buildings and preparations for the stream. In order to increase the economic feasibility of the project the latest detail plan includes even more demolitions, including the main focus for this thesis - building 110-111 - but also building 23 and parts of 10.

VISIONS FOR THE FUTURE

Housing

3000 new apartments, including a minimum of 25 % rentals.

Work desks

3000-5000 new workspaces to be placed mainly in the industrial core and the plots along E6.

Scene space

New dance, production and studio spaces where people of all ages can connect through dance and creativity.

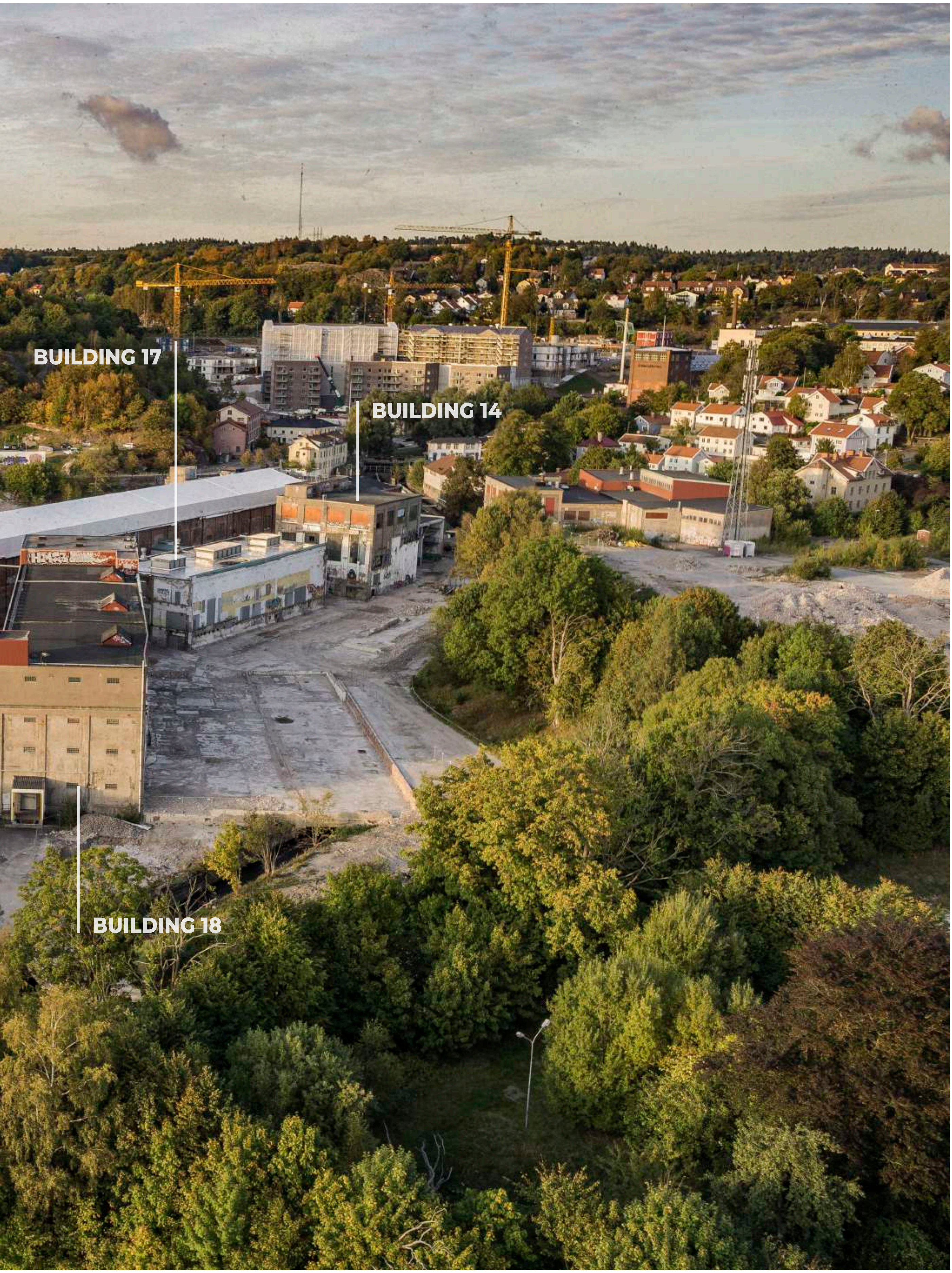
Food space

Restaurant life with mixed kitchens and taste experience promoting food art and craft.

Creative space

Spaces for smaller businesses, art, craft and education that gathers new ideas and innovation.

Fig. 9, Drone photo from south-east.
Nyréns Arkitekter (2016).

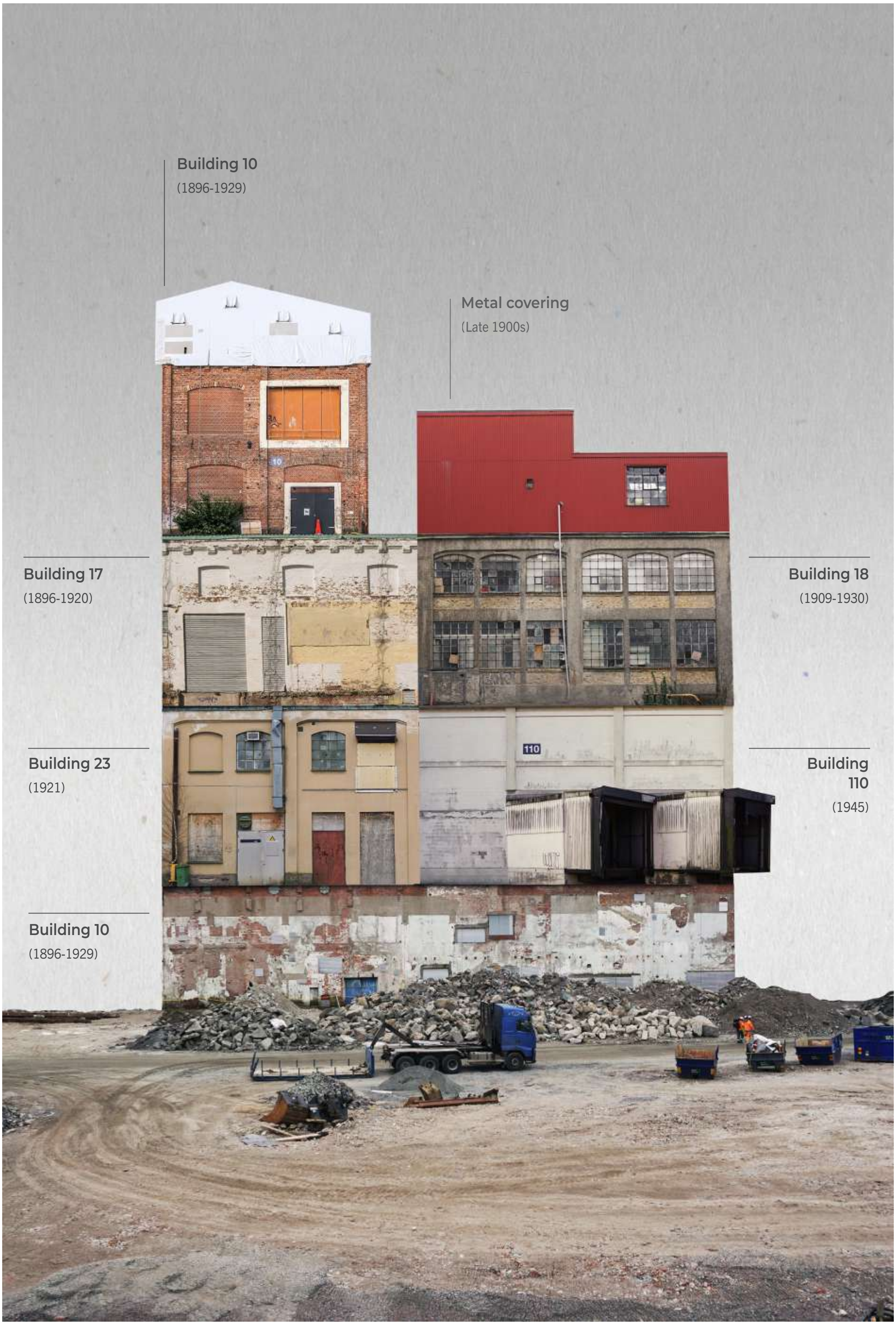

BUILDING 17
BUILDING 14
BUILDING 18

LAYERS OF TIME

As a result from the many years of industrial activity and development, Forsåker has had a very mixed building stock with varying styles and expressions. The last years demolitions have however created a lot more homogenous building stock dominated by buildings from between 1895-1920. This seems a bit contradictory to the municipality's own ambitions of haven a rich and diverse building environment where layers of time and historical development can easily be read.

With the demolition of 110-11 almost all buildings from mid 1900 and later will have vanished, thus removing an important layer of the sites history and heritage. The Enviromental impact report (SWECO, 2022) states that "there will be a significant impact for the individual building, for the understanding of the industrial environment and the possibility to read the history and buildings context". What is also unfortunate is the loss of a building that is stated to be one of the most well-preserved buildings on site with great potential for further development. Replacing it with a new conventional housing block waste a fully functional structure together with tons of material and embodied carbon.

This thesis will try to show an alternative story to what could have happened instead.



Collage showing a selection of existing buildings on site. (2022-2023)

Fig. 10, Building 110.
Föreningsarkivet i Västra Götaland (1948).

BUILDING 110

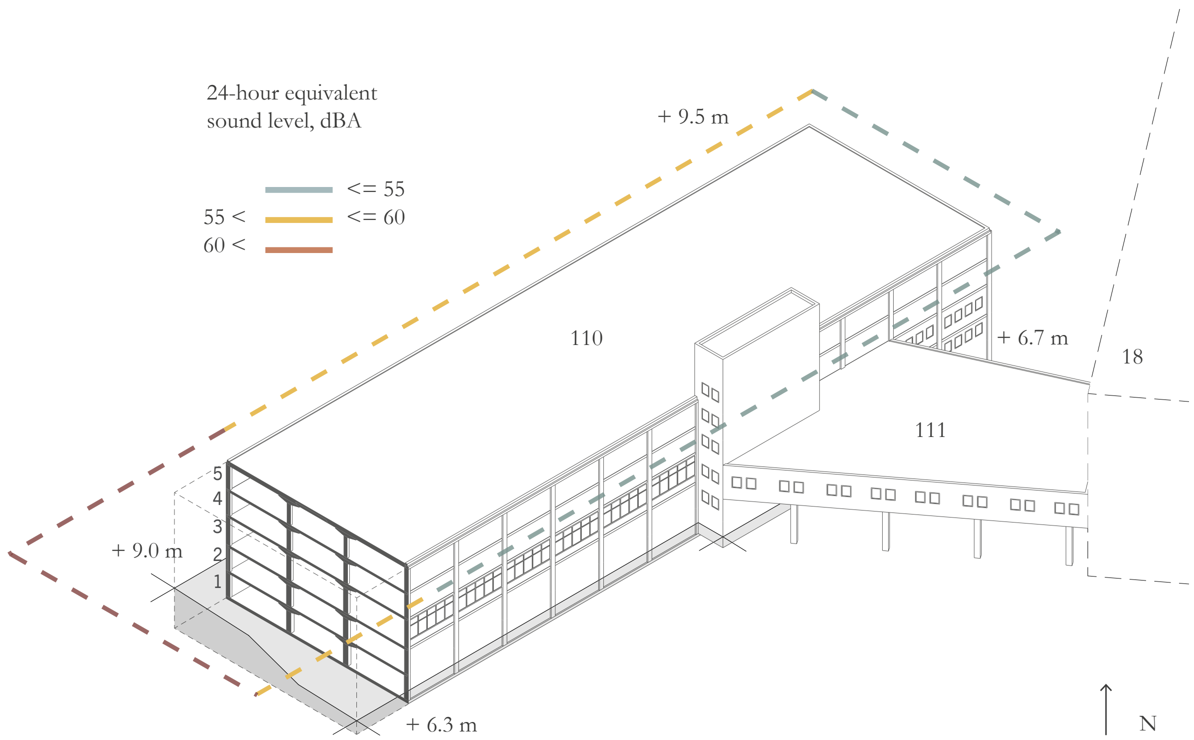
Use

Building 110 was made in 1945 as a paper storage building during the factory's second expansion phase and is one of the most well preserved buildings on the site. Finished paper was delivered to the storage from building 18 via the bridge connection and then picked up by trains ans trucks from the dock along the north facade. The building also contained offices and changing rooms. In a later addition from 1964, a protected bunker where also added to the basement.

Design

The building has a very functionalistic expression typical for its time where the structure is clearly readable. Because of the height difference in the terrain, two of the five floors partly underground. The floors are connected through a seven-story tower containing staircase, two elevator and ventilation shaft. Due to the buildings use the interior is mostly open floor plan. The amount of windows is very limited and consists of both small simple windows and larger window bands in sections. The structure consists of reinforced concrete slabs and columns. Exterior walls are made of concrete, lightweight concrete blocks and white plaster, however parts of the facade have later been covered with corrugated metal sheeting. (Lindholm Restaurering, 2014)

Fig. 11, Building 110 and 111.
Mölndal Stadsmuseum (1946-1970).



SWOT

Strength

- Well preserved buildings, strong structure in good condition.
- Open plan with a slab-column structure that allows for flexible room layouts.
- Good sun conditions and location on site.
- Interesting facade and volume with a lot of character.
- Rich history and cultural heritage.

Opportunity

- Structure allows for 2 new floors to be added on top.
- New openings for windows and/or light shafts could easily be made.
- Neighbouring demolition buildings could be used as material banks.
- Potential for a great outdoor space between building 110, 18 and the stream.
- Location will likely generate large flows on both sides of building, potential for new commercial activities.

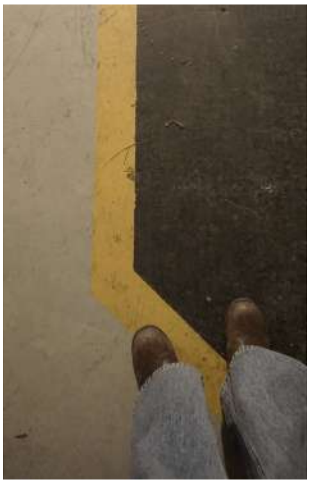
Weakness

- Low floor height (2,59 - 2,97 m)
- Few existing windows and openings.
- Poor connection between floors and street level (adapted to truck/train height).
- Lots of dark spaces, floor 1 and 2 are partly below ground level.
- Poorly insulated climate shell.

Threat

- Challenging to fit new functions into the dark and cramped spaces.
- Noise from highway create limitations for building design and functions. (wsp, 2017)
- Adapting the building to current standards and needs might take a lot of money and resources.

Top: North-east facade of building 110 with the characteristic loading docks.
Bottom: Interiors of building 111 that bridges between 110 and 18.

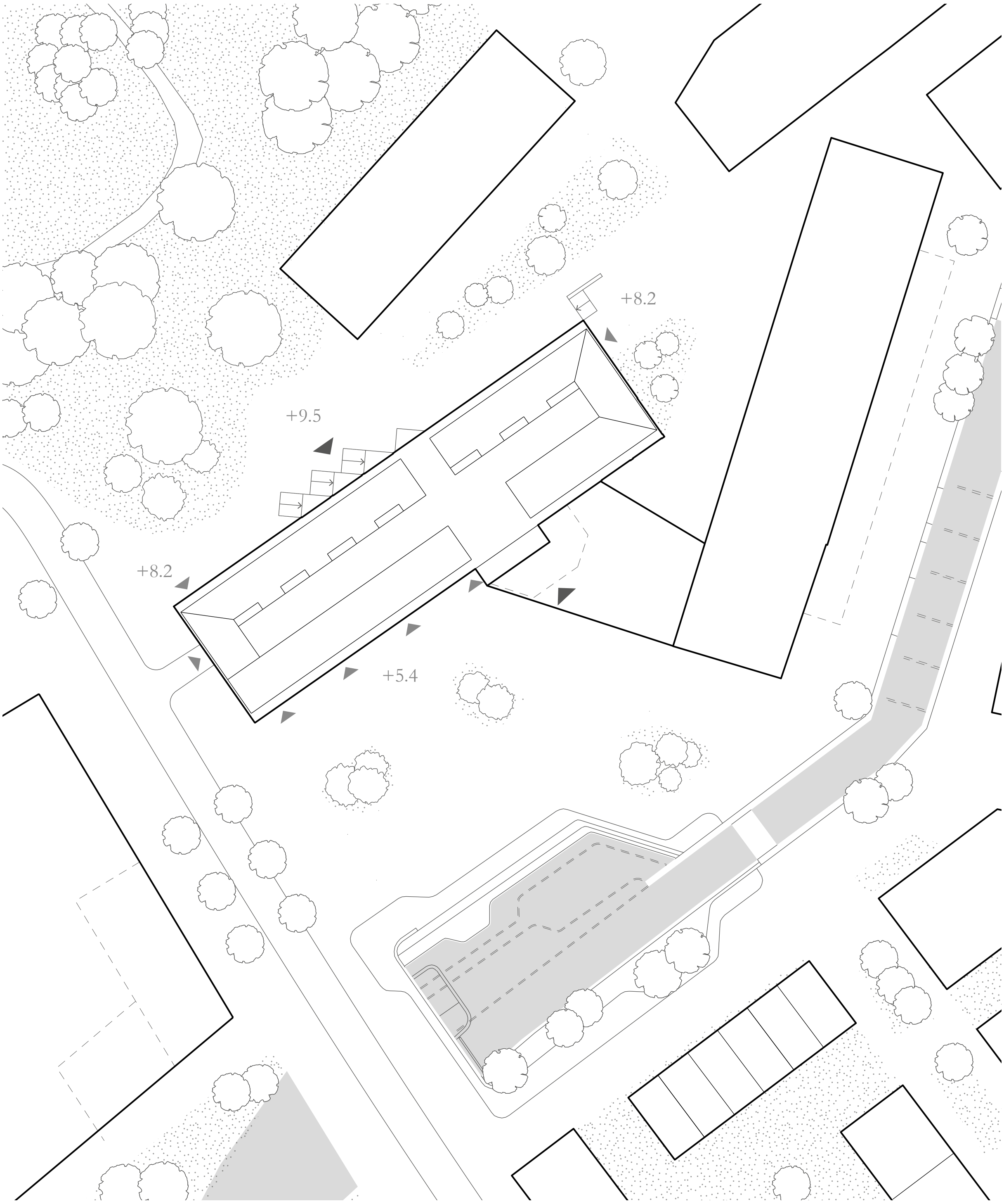


Top: Interiors from floor 3 showing the characteristic column structure and window bands.
Left: Concrete staircase connecting all floors through the 7 floor tower.
Right: Details of asphalt covered floor and concrete ceiling.
Right bottom: Rail-hung doors and signs showing clear traces from the industrial use.

Top: North facade with building 18 in background.
Centre: South facade where large parts have been covered in metal sheeting.
Bottom: North facade.

IV. DESIGN PROJECT

The new site
Design development
Circular design concepts
Material reuse and upcycling
Enviromental savings
Program & Concept
Design proposal & drawings



Siteplan 1:1000

THE NEW SITE

The north-east side of the building is given a new main entrance where the original loading docks were placed and a bike entrance for commuters arriving from the west. Cars and deliveries can access the building from the west short end while the east side gets a more generous entrance to the new circularity hub.

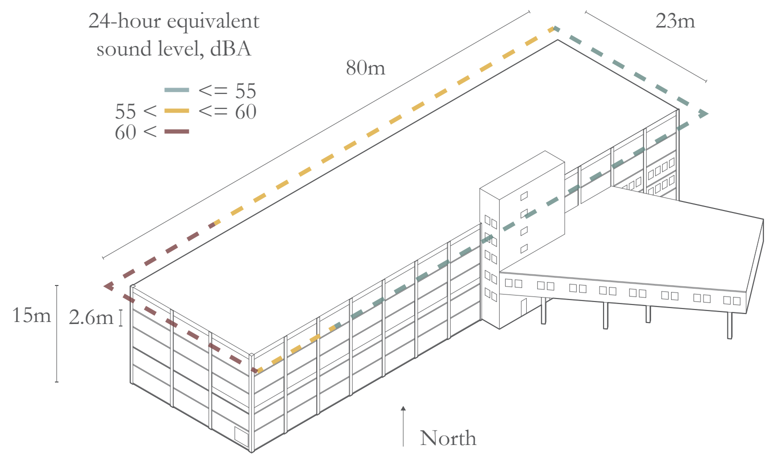
The south-east facade also gets a new main entrance connected to the existing tower. The bottom floor of the facade is opened up towards the outdoor plaza where plenty of sun and access to the stream creates a new waterhole for all the residents of Forsåker.

Fig. 12, Original design of building 110.
Föreningsarkivet i Sydvästra Götaland (1945).

Transformation of building 110

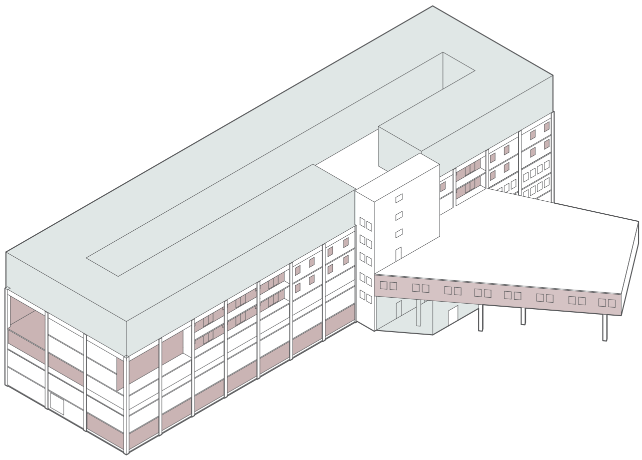
Analysis & inventory

Mapping of preconditions including materials, daylight, noise and building structure.



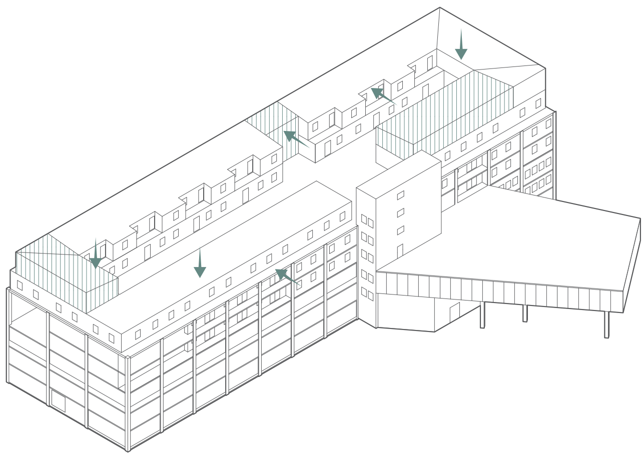
Building adaptations

Adapting the building to align with the new program, adding new openings and rooftop extension.



Design refinement

Adjust the design according to materials, sunlight and existing context.



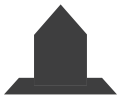
DESIGN DEVELOPMENT

The design process was initiated with a thorough analysis and inventory of the building which outlined preconditions that came to affect the design significantly. For example, high noise levels from the close-by highway had a direct impact on the apartment sizes and placement. The exterior courtyard on top of the building derived from the need to give rooftop apartments a silent façade and also bring in more daylight to the existing building.

The aim for the design was to create an enjoyable and functional building while still being respectful towards the existing by making the original structure and design clearly readable.

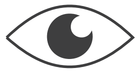
CIRCULAR DESIGN CONCEPTS

The final design strives to incorporate circularity in all scales and throughout the entire life cycle of the building. The design concepts are inspired by the theoretical work of GXN, Danckwardt-Lillieström, Brand, AIA et al. The overall aim for the design is to extend the buildings life span for as long as possible while making sure that the retrofit has a minimal environmental impact.



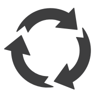
Repurpose of existing structure

Giving new purpose to the existing structure is the action that comes with the largest environmental benefits as it saves tons of resources and emissions. Making a new addition on top utilizes the load bearing ability to the fullest and also saves land from new development.



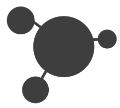
Beauty & Quality design

A building must catch the heart of those who use it, else it will most likely not be maintained properly and few will fight for its adaption and reuse.



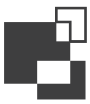
Design for reuse

Facilitate for reuse of materials and elements by using a design framework that is based on the dimensions of standard components but also allows for uncertainty and variation.



Low impact materials

Use materials with low environmental impact, primarily reused materials and secondly renewable materials or materials with a high degree of recycled content. All materials should be healthy, high quality and long-lasting so that they can be reused in the future.



Intensify use of spaces

Promote sharing more spaces between different users by designing spaces that can handle a wide variety of different activities. Also ensure that these spaces can be adapted and changed according to future needs.

Design for disassembly

Facilitate for easy maintenance and future reuse by using reversible connections that can endure repeated assembly and disassembly and are easily accessible. Design components in layers so that elements with short lifespans can be maintained or replaced without damaging the whole building.

MATERIAL REUSE AND UPCYCLING

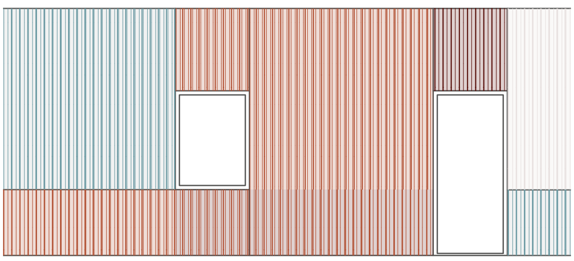
Based on own observations and the material inventory made by White Architects (2023), several materials suitable for reuse and upcycling were identified. The European Union's Waste Hierarchy were used as a guideline, prioritizing prevention and reuse in the first place, followed by recycling and upcycling. Corrugated metal sheets, old windows and damaged bricks are materials that were found directly on site and has been given new purpose in the project to create identity and celebrate heritage while also showcasing reuse more visibly. Some of the added elements also reuses materials from outside the site, for example interior panels and insulation boards based on paper waste and construction boards from composite packaging.

CORRUGATED METAL SHEETS

There is a great amount of corrugated metal sheets in several different colours available on the site. Currently they are serving as facade cladding, but due to renovations and demolitions they will be removed. Most of the metal sheeting is in very good condition and therefore suitable to be reused as cladding for the new rooftop extension. The façade is designed as a collage to allow for an uncertain supply and irregular sizes, which also preserves a piece of history from demolished buildings on the site.

Embodied Carbon: 2.59 kg CO_2-eq / kg
(BM, Boverket 2022)

Embodied carbon for the entire new facade: 25 tons CO2-eq



Facade design allowing for irregular sizes of corrugated metal sheets

Red
Origin: Building 18

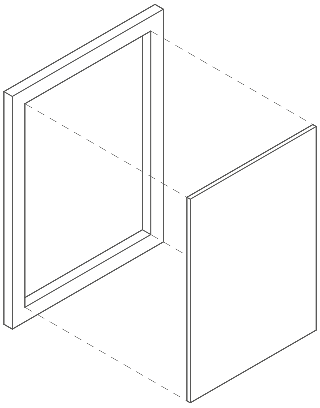
Sage & Offwhite
Origin: Building 110

Blue & eggshell
Origin: Storage building along E6

WINDOWS

The existing windows in building 110 are kept in use where they are, and smaller refurbishments are done if needed. The added windows are partly reused, the frames are new, and the glass are from old windows. These windows in façade are of standard dimensions (900 x 1200) to facilitate when sourcing for old windows. As stated in the figure below, "only" reusing the glass still saves 52% compared to producing new windows.

Glass is also reused in interior partition walls, where they are simply put into new wooden frames. Here the collage is completely random, to allow for differently sized glasses to be reused.



Upcycling of old windows for exterior use

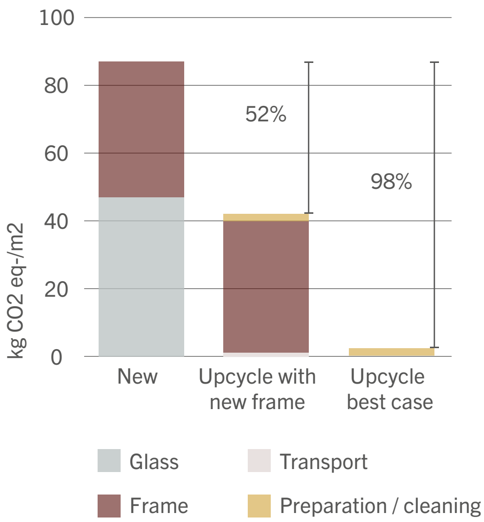
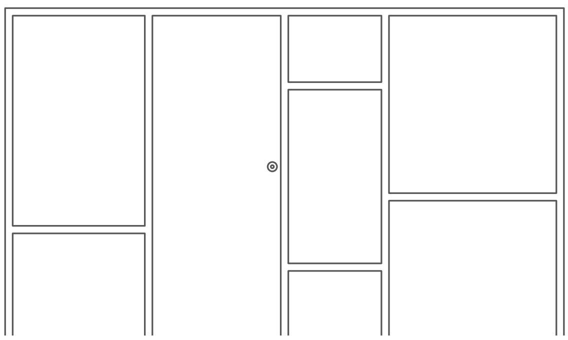


Fig. 13, Potential CO_2-savings from upcycling old windows. Adapted from Lendager & Lysgaard Vind (2018) .

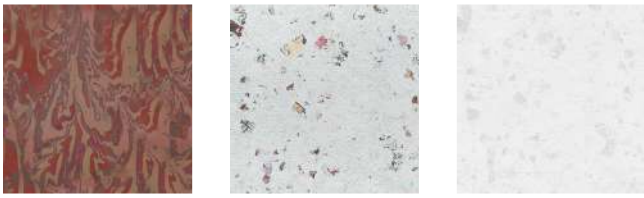
Fig. 14, Prototype of glass interior wall from repurposed windows Vandkunsten Architects (2017).



Concept for interior window collages

Fig. 15, Selection of papers produced by Papyrus in Forsåker.
Mölndal Stadsmuseum (1895-1945).

Fig. 16, Claddings made of recycled paper.
Paper factor (2023).



Own designed paper cladding

PAPER

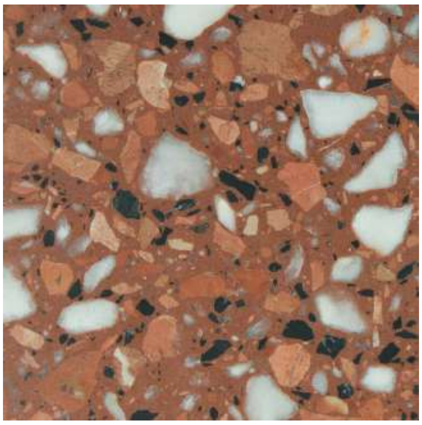
As previously mentioned, the site has been a centre for paper manufacturing for over 350 years. Papyrus Mölndal AB have produced a wide range of paper products, many being of a unique character. In order to refer back to this, paper is used as an interior cladding material.

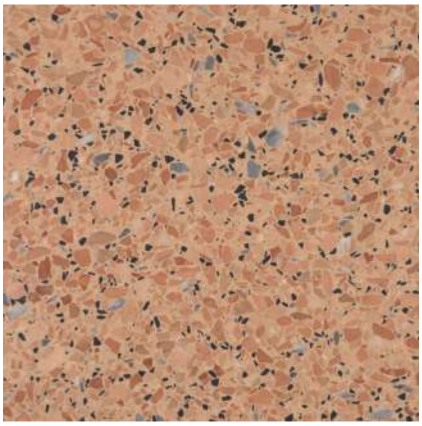
This idea is inspired by the work of Paper factor, who produces interior panels that can be used for walls, ceilings or furniture. The panels are made of recycled paper and natural pigments, attached to plywood boards. The panels are currently being tested for high humidity and exterior use and have a pending certification for fire resistance class 1/A.

In a similar way, paper panels designed with inspiration from the old Papyrus paper collections, are used on selected places in the interior, to celebrate heritage and refer back to history.

TERRAZZO

On the site, there is a lot of brick available that has been damaged by frost and cannot be used for its original purpose anymore. Instead of wasting them they are crushed and used as aggregates in terrazzo tiles. In this way a discarded material is upcycled and turned into a valuable resource, serving as unique worktops and floor tiles in the project. Herrljunga Terrazzo is a local supplier just an hour outside of Gothenburg that specializes in creating circular terrazzo from building waste material, such as old tiles, stones, glass, ceramics and bricks.





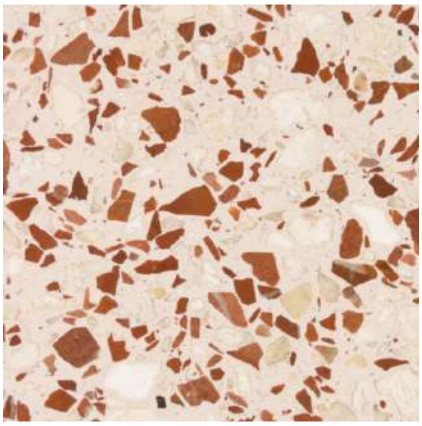
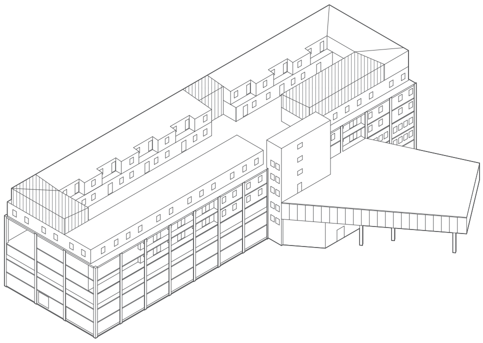
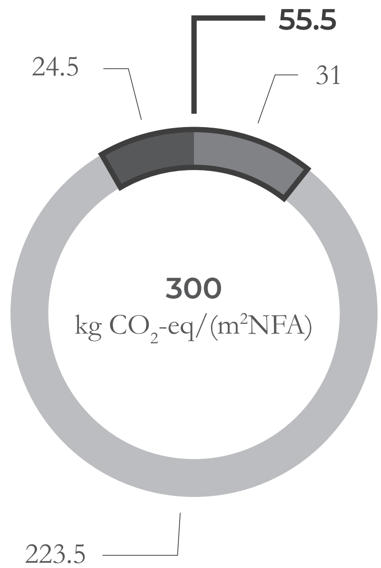


Fig. 17, Terrazzo made of old tiles, glass,bricks, ceramics. Herrljunga Terrazzo (n.d)





IV. Entire transformation

Embodied CO_2: 55.5 kg CO_2-eq/(m²NFA)*
Total embodied CO_2: 532 ton CO_2-eq
Total mass: 326 ton

Primary energy demand:
Excluding user energy: 18 kWh/(m²AN*a)
Including user energy : 65 kWh/(m²AN*a)
a= 50 years

A1-A3 Production
B6 Energy demand in use phase
C3+C4 End-of-life

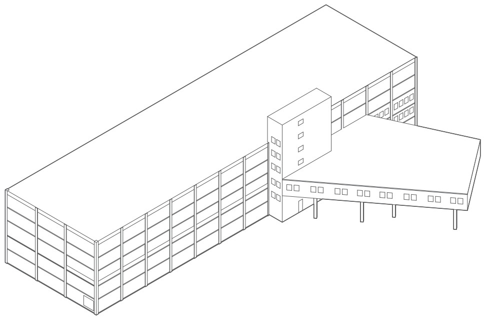
ENVIRONMENTAL SAVINGS

In order to quantify the savings from this project, four life cycle analyses were performed using the tool CAALA, which is a plug-in for SketchUp and Rhino that performs environmental analysis on the basis of 3D models. The calculations have been made for the climate shell and loadbearing structure, excluding all interior features and technical systems. More details about how the analysis was performed is presented in the appendix.

The life cycle analysis shows that the existing building contains 1390 ton embodied CO2 and 10 960 ton of material, which, if demolished would have all been wasted. However, in order to make the building inhabitable, the climate shell needs to be upgraded. Analysis II. states that with a rather small environmental impact, the building gets a significant improvement of U-value, from 2.3 to 0.2 W/ (m²*K) which would lower the energy demand remarkably. In analysis II-IV there are also new windows added, which in the calculation are defined as new aluminium-frame windows. However, these windows will be partly reused, with new frames but reused glass, which is estimated to reduce the related emissions with 52%. (Lendager & Lysgaard Vind, 2018).

The rooftop extension utilizes the load bearing ability of the existing structure and avoids the emissions from a new foundation, which is one of the most CO2 intensive building parts. The new built structure is built from a high degree of reused and renewable wood-based materials, which is visible in the low embodied carbon.

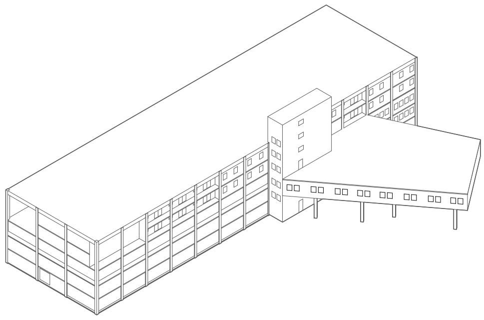
In total, the building transformation requires 534 ton of CO2-eq and 326 ton of material to be added, which is about 1/3 of the carbon and 1/30 of the materials already embodied in the existing building.



I. Existing building

Embodied CO_2: 170 kg CO_2-eq/(m^2NFA)*
Total embodied CO2: 1 390 ton CO_2-eq
Total mass: 10 960 ton

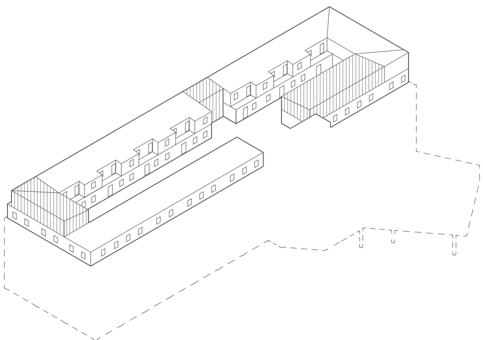
Almost 3 x as much carbon as the entire transformation!



II. Additional layers

Embodied CO2: 39 kg CO_2-eq/(m^2NFA)*
Total embodied CO_2: 319 ton CO_2-eq
Total mass: 139 ton

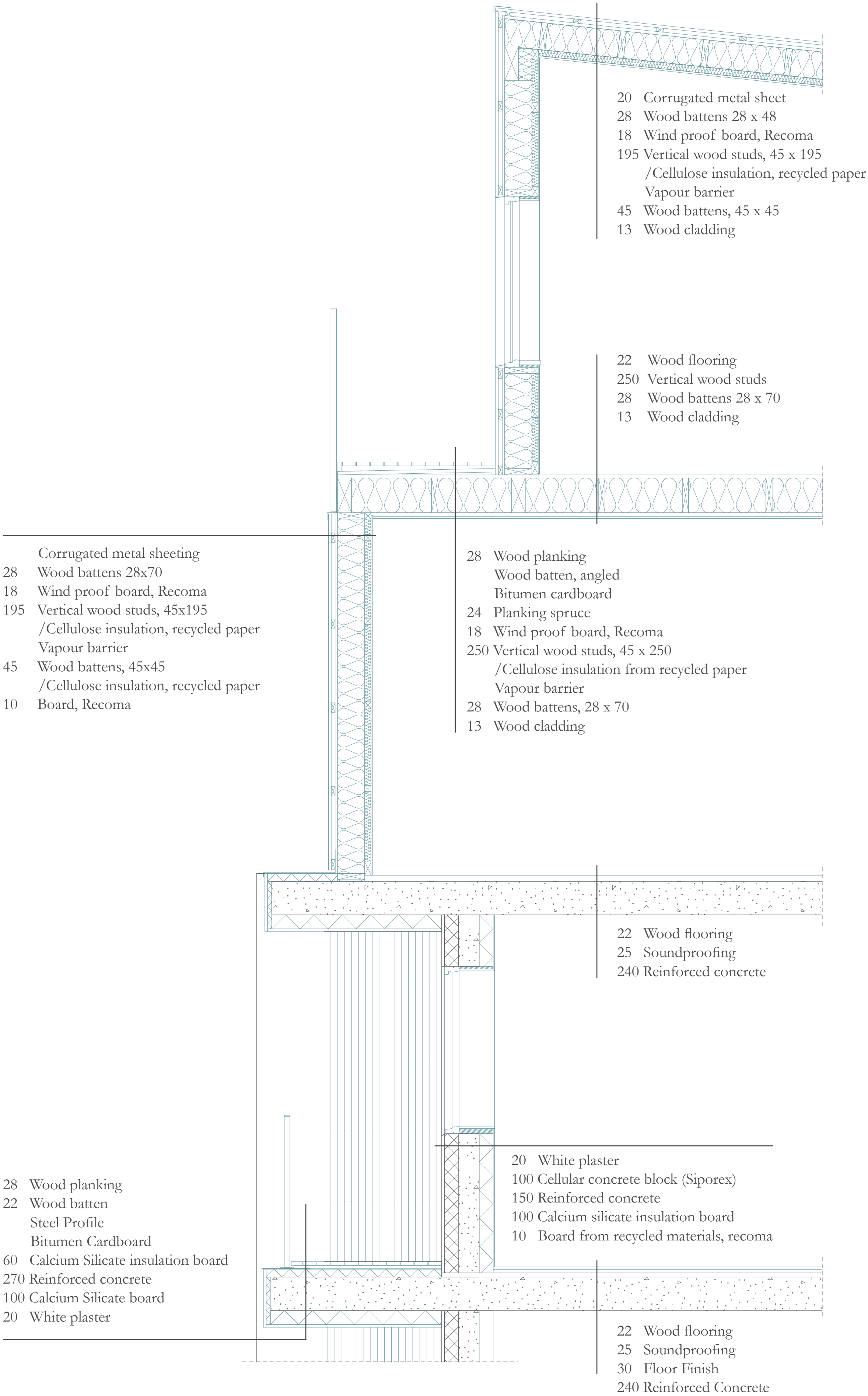
60 x less mass in the new structure vs the existing



III. New structure

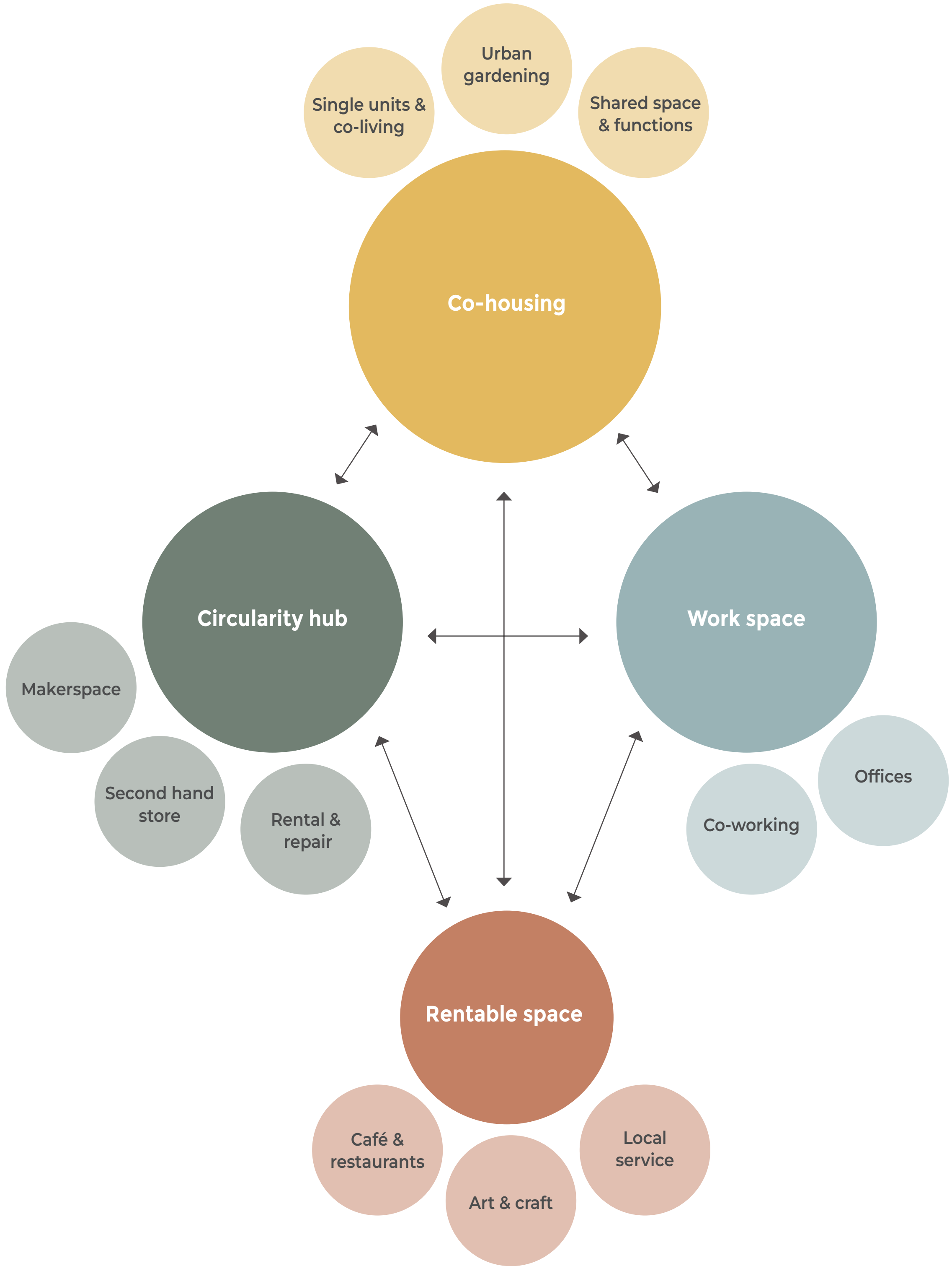
Embodied CO_2: 152 kg CO_2-eq/(m^2NFA)*
Total embodied CO_2: 214 ton CO_2-eq
Total mass: 184 ton

* Embodied CO2 refers to calculations including life cycle modules A1-3 Production and C3+C4 End-of-life, according to EN 15978.



Detail - 1:40 (originally in 1:20)

Detail - North-west facade

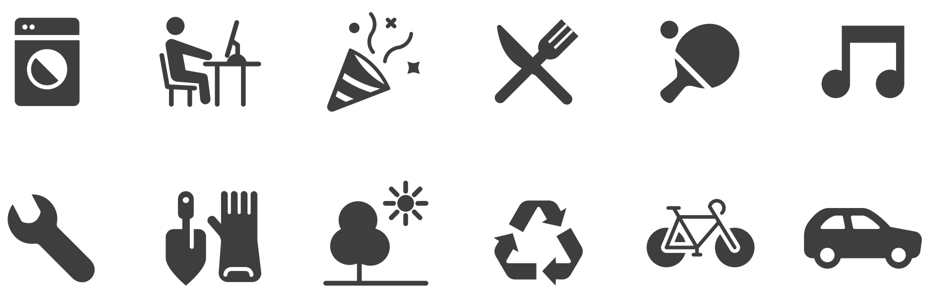


PROGRAM & CONCEPT

The mixed-use program of the building aims to add to the needs and visions identified by the municipality while also contributing to the circular economy by challenging current norms and habits. By promoting more sharing - both of space, equipment and knowledge – the program aims to use resources more efficiently, but also contribute to new synergies and a more resilient community.

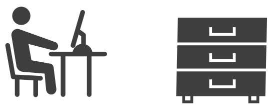
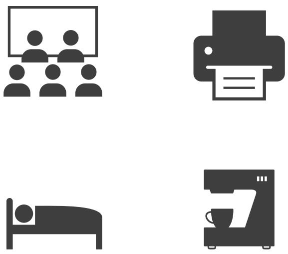
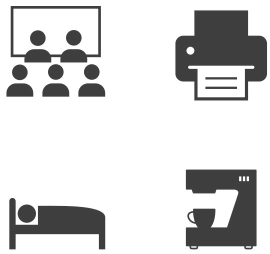
CO-HOUSING

The co-housing offers a mix of smaller studio apartments and bigger shared apartments. The studio apartments are placed in areas where noise regulations only allow for apartments below 35 m². and are perfect for single households or couples. The bigger apartments are designed to be shared among a group of people, such as a generational household, flatmates or two families. All the tenants of the building have access to generous co-spaces that offers extra living, dining and playing space together with shared tools and equipment. By sharing more and owning less the tenants saves both money and resources and gets a more social daily life.

	studio apartments 28 m² 1 bedroom	**shared apartments** 98 -115 m² 3-4 bedrooms
possible tenants	Students Single adults & elders Couples	Generational household Flatmates Group of families
private in apartment		
shared with building		

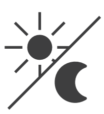
WORKSPACE

The ongoing digitalization and new habits caused by the pandemic have created a demand for more flexible workplaces and the possibility to work in hybrid formats. In order to fit tenants with varying sizes and needs, the workspace can be divided into different office settings. The co-office offers both desks or office rooms for rent and are suitable for freelancers, small businesses and residents working from home. Larger businesses can rent an entire office unit with more private spaces, while still having access to functions that are shared with all tenants in the building. The shared spaces create natural meeting points between tenants, contributing to a more inspiring and innovative environment.

	co-office rent a desk or room	**office** rent a offi ce	
possible tenants	Freelancers, residents working remote, startups and small businesses	Artist collectives, medium - large offices, education	
private			**shared with office**
shared with co-office			
shared with building			

intensify use of space

Office during day. Course, workshops & conference during evenings/weekends



Two different offices might rent the same space - half week each, the rest remote!

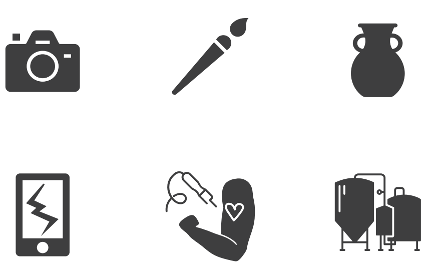
CIRCULARITY HUB

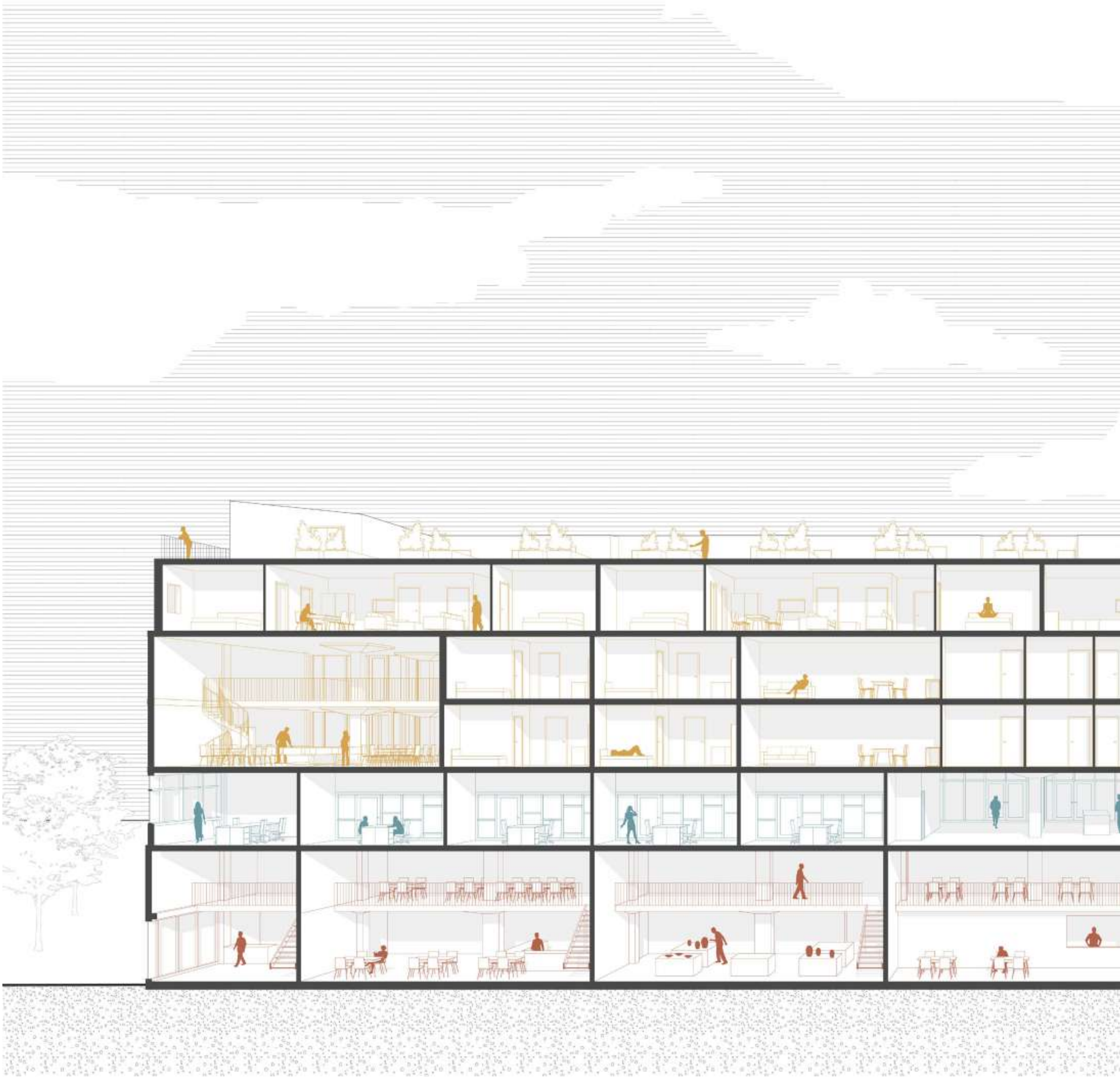
The circularity hub is a space that contains both a second-hand store, maker space and a rental & repair service. It is open both for local residents, visitors, professionals and education, aiming to make Forsåker a more sustainable and attractive place to live and work in and contribute to more circular habits. Users get access to the makerspace through a small daily entrance fee or a membership subscription and can both do projects themself or get assistance from the trained staff.

		function	possible user
	**Maker space**	Tools and equipment for repairs, upcycling and creative projects.	Open for professional craftsmen, local business and offices, residents and schools.
	**second hand store**	Sale of used, repaired or up-cycled furniture, clothes, decorations etc.	Local resident, visitors and offices.
	**rental & repair**	Possible to rent tools and equipment or get things repaired and refurbished by employed professionals	Local residents, visitors and offices.

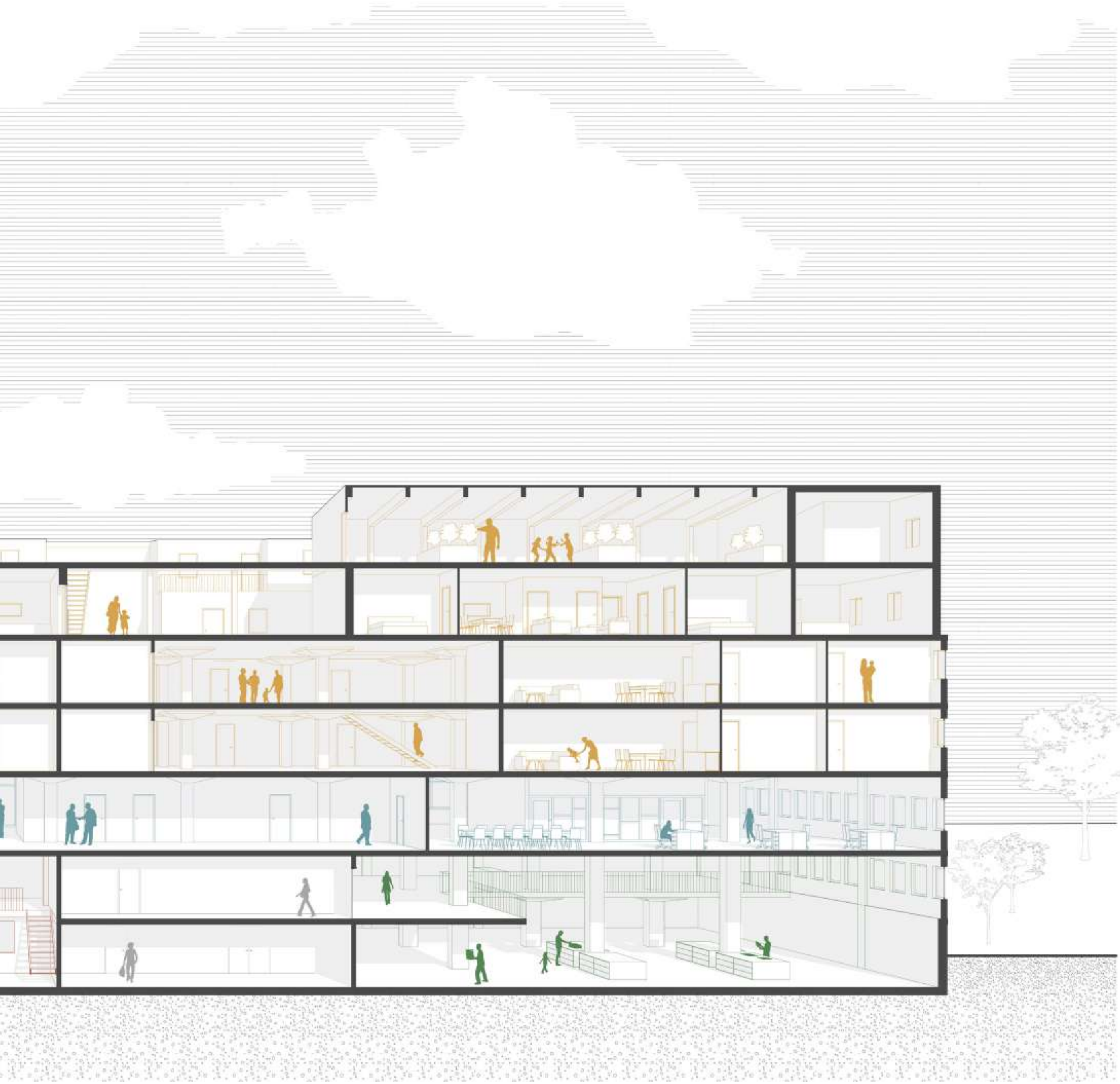
RENTABLE SPACE

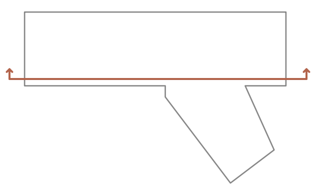
The rentable space initially serves as an affordable and flexible raw space area, suitable for different types of artist and craftsmen. As the site develops and larger flows of people are generated, new business opportunities are created for shops and services that could help activate the spaces even more and expand out to the plaza.

art & craftmanship	shops & services
	

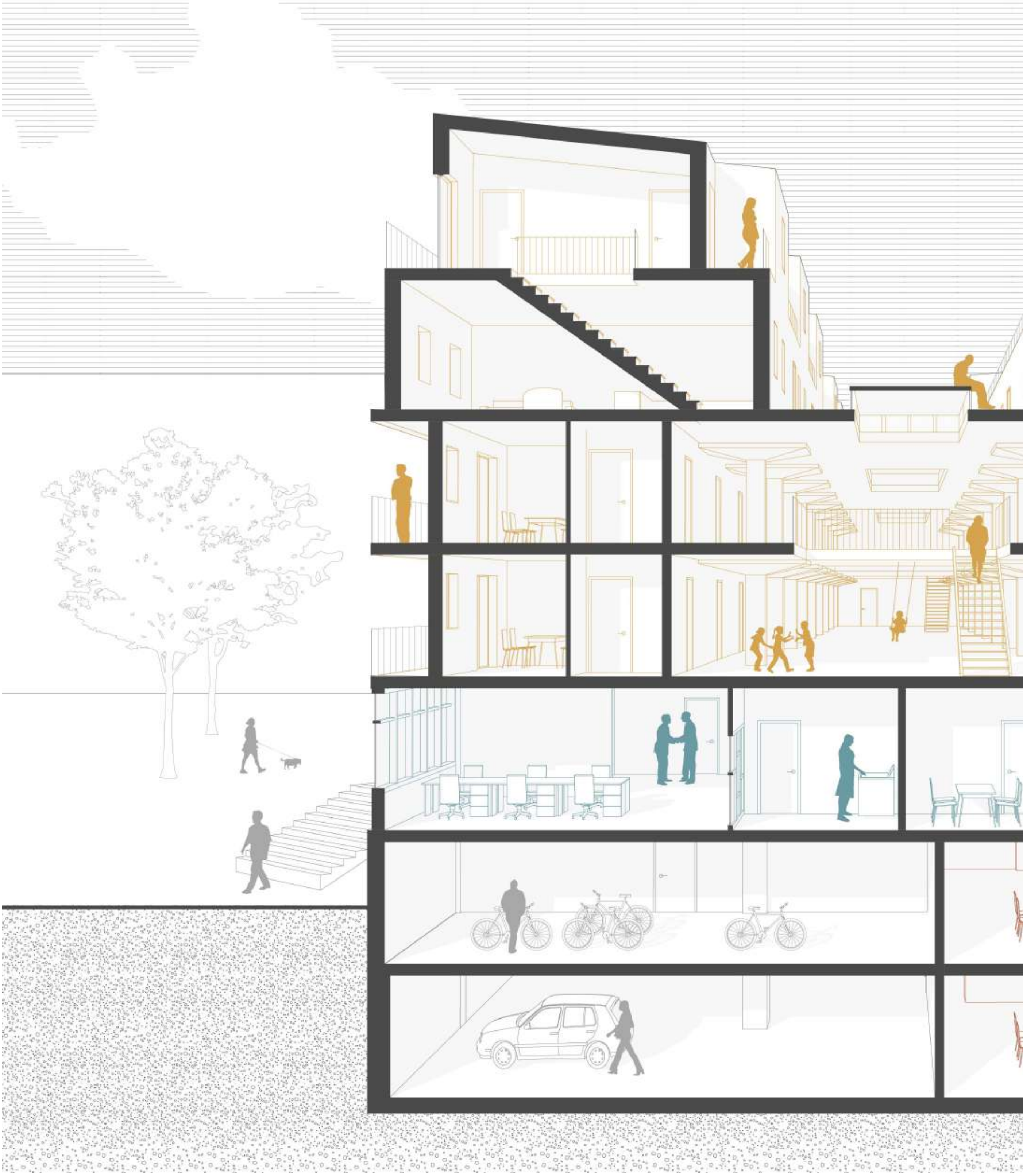


Long Section

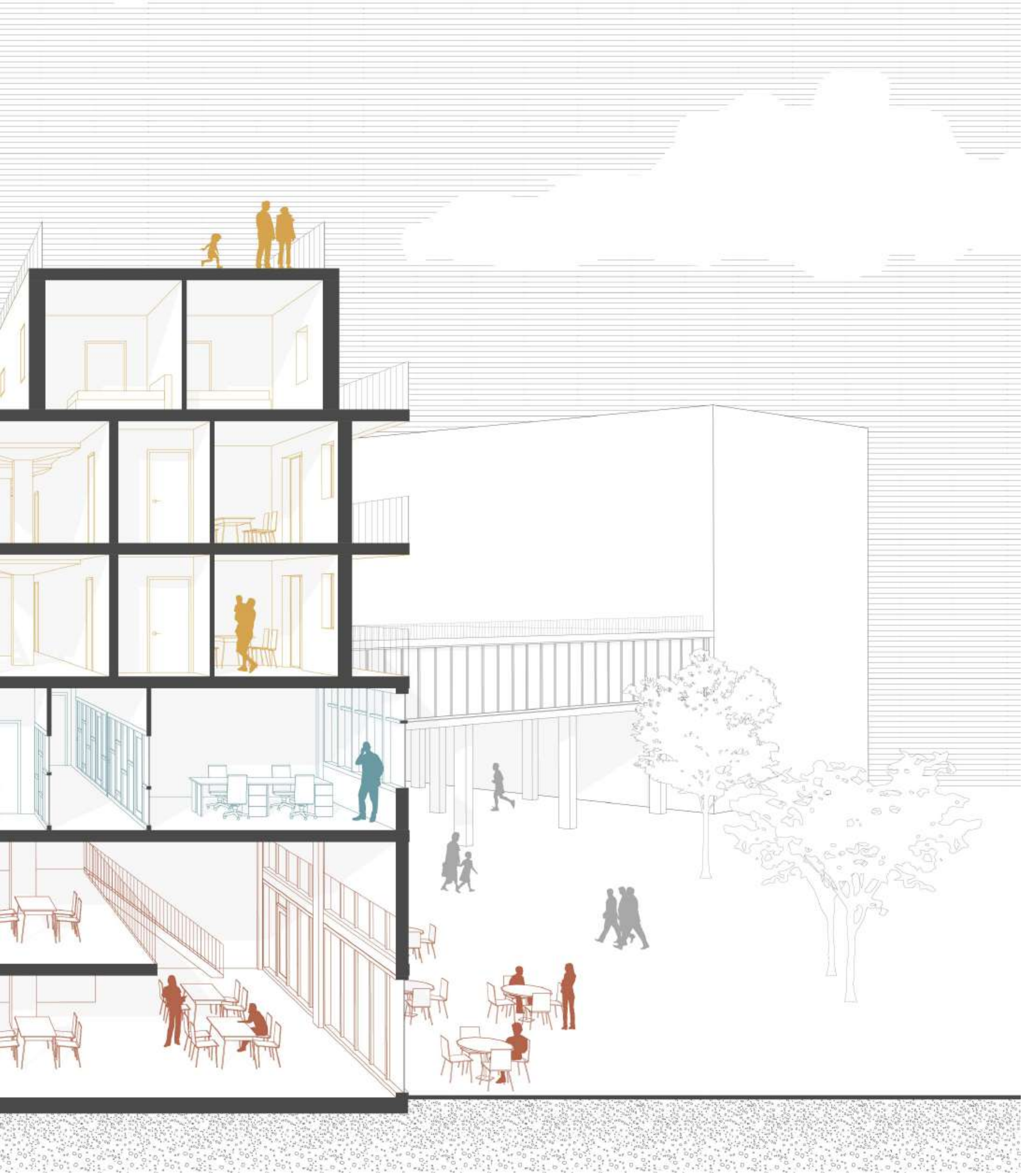


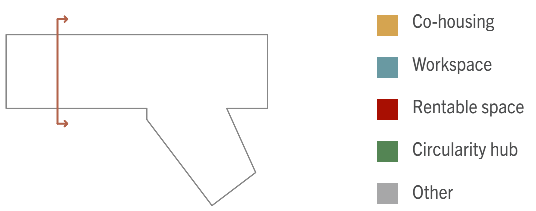


- Co-housing
- Workspace
- Rentable space
- Circularity hub
- Other



Short Section

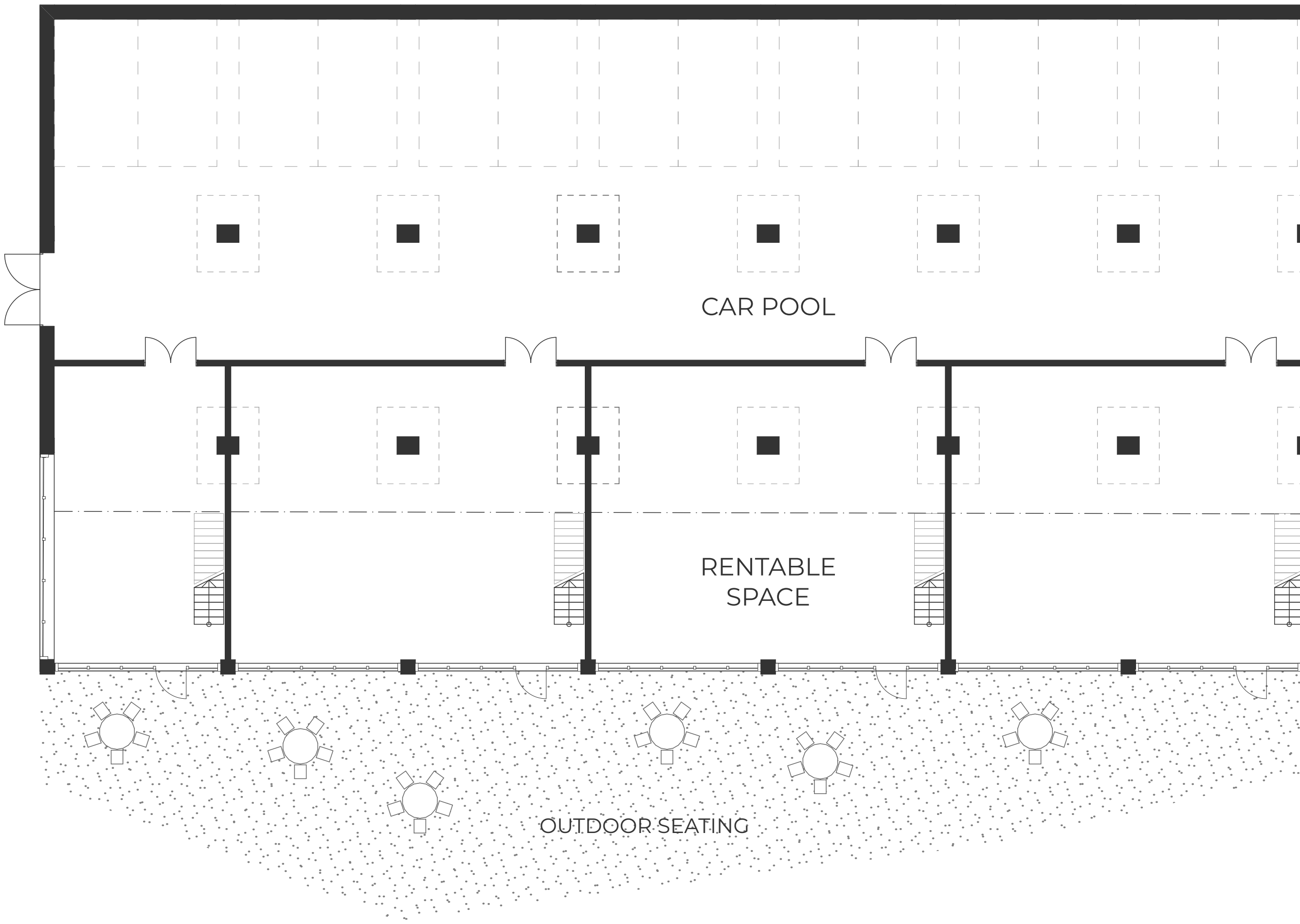




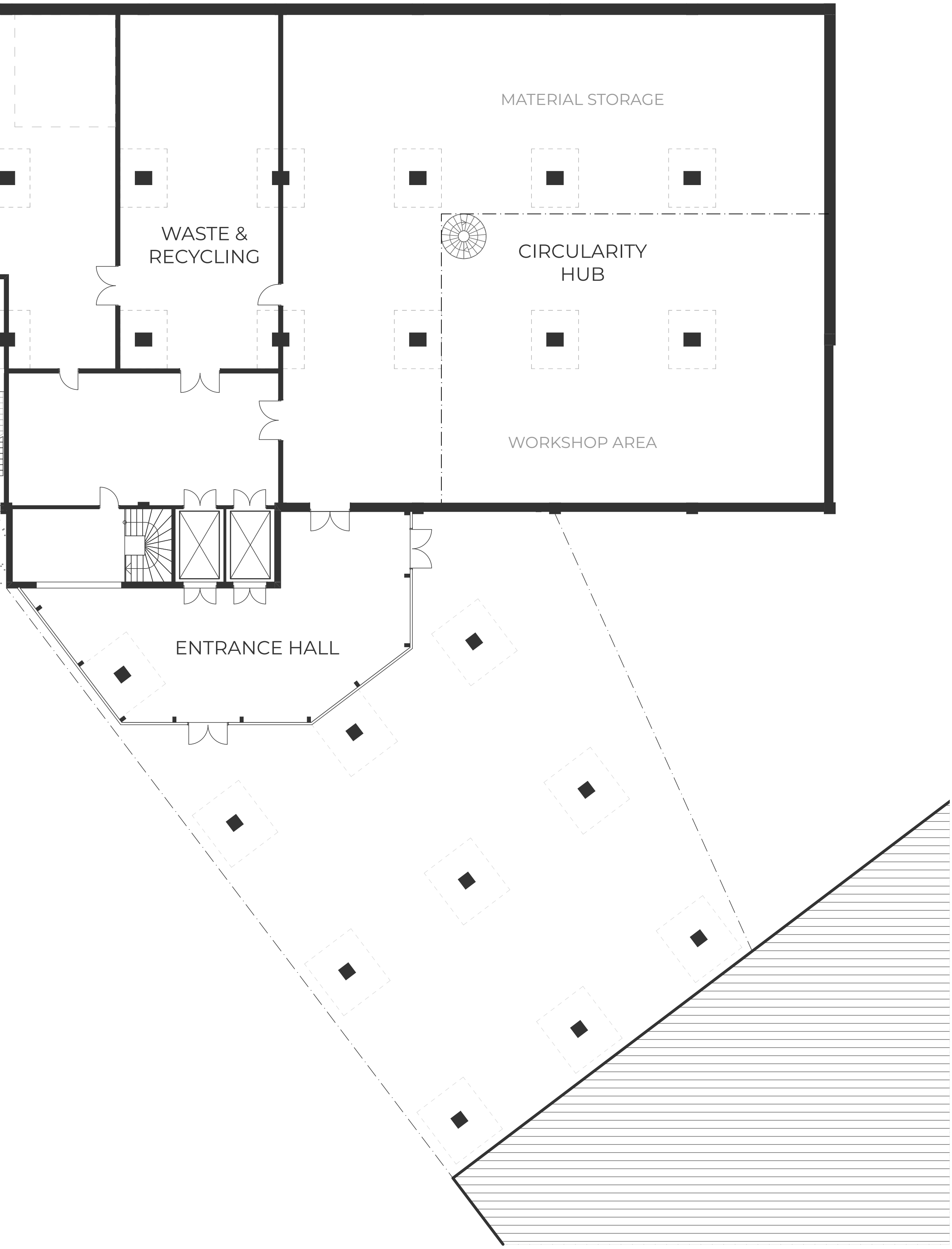
Co-housing
Workspace
Rentable space
Circularity hub
Other

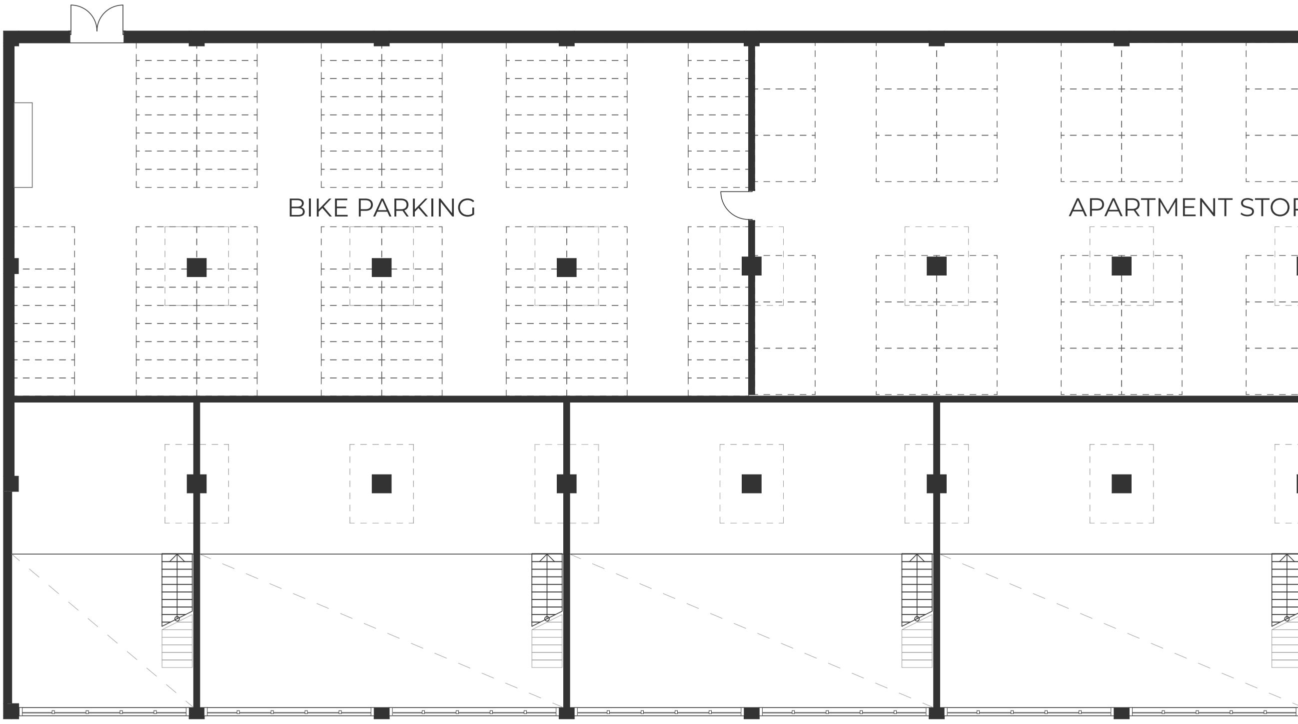
Outdoor square, south-east facade


BAGERI

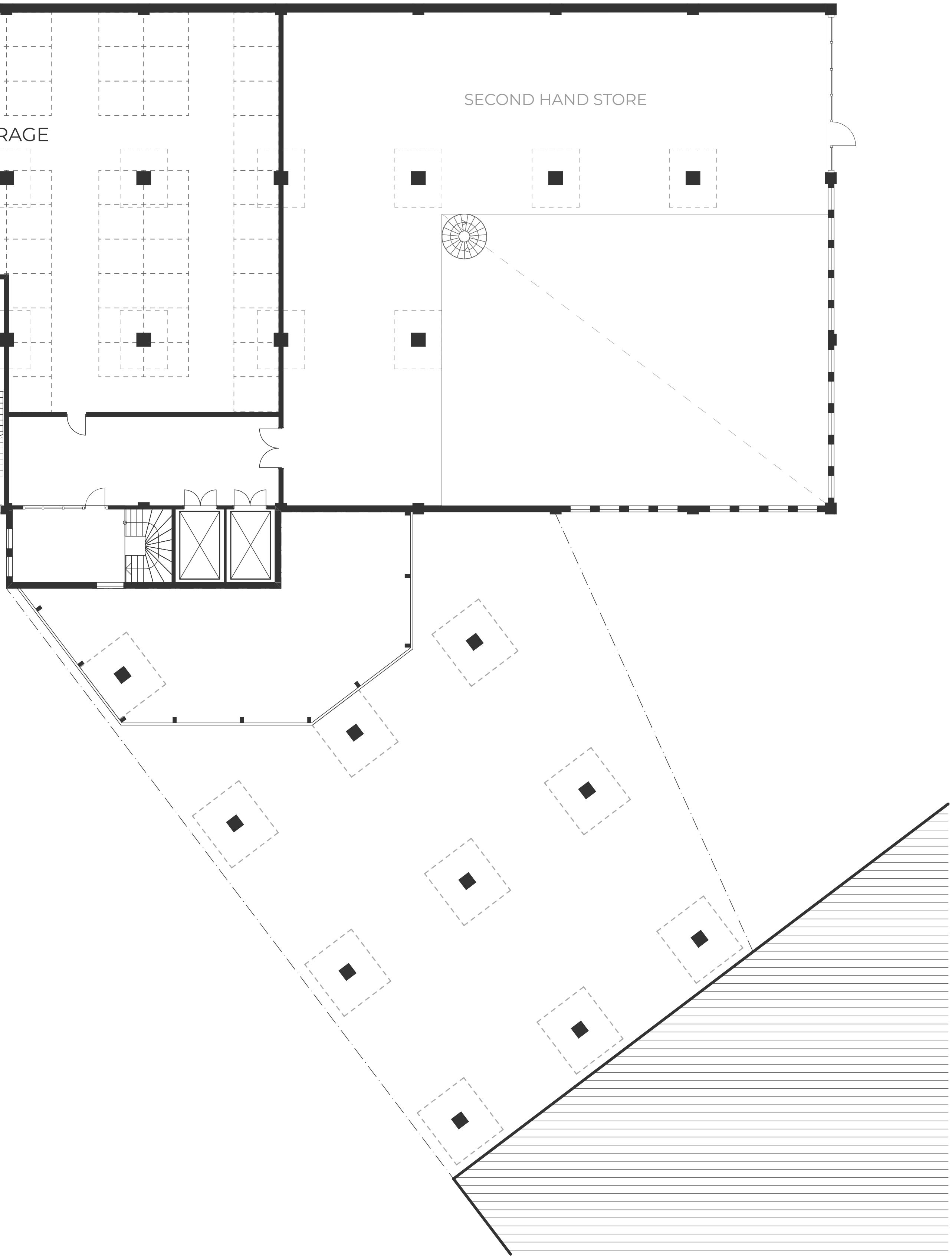


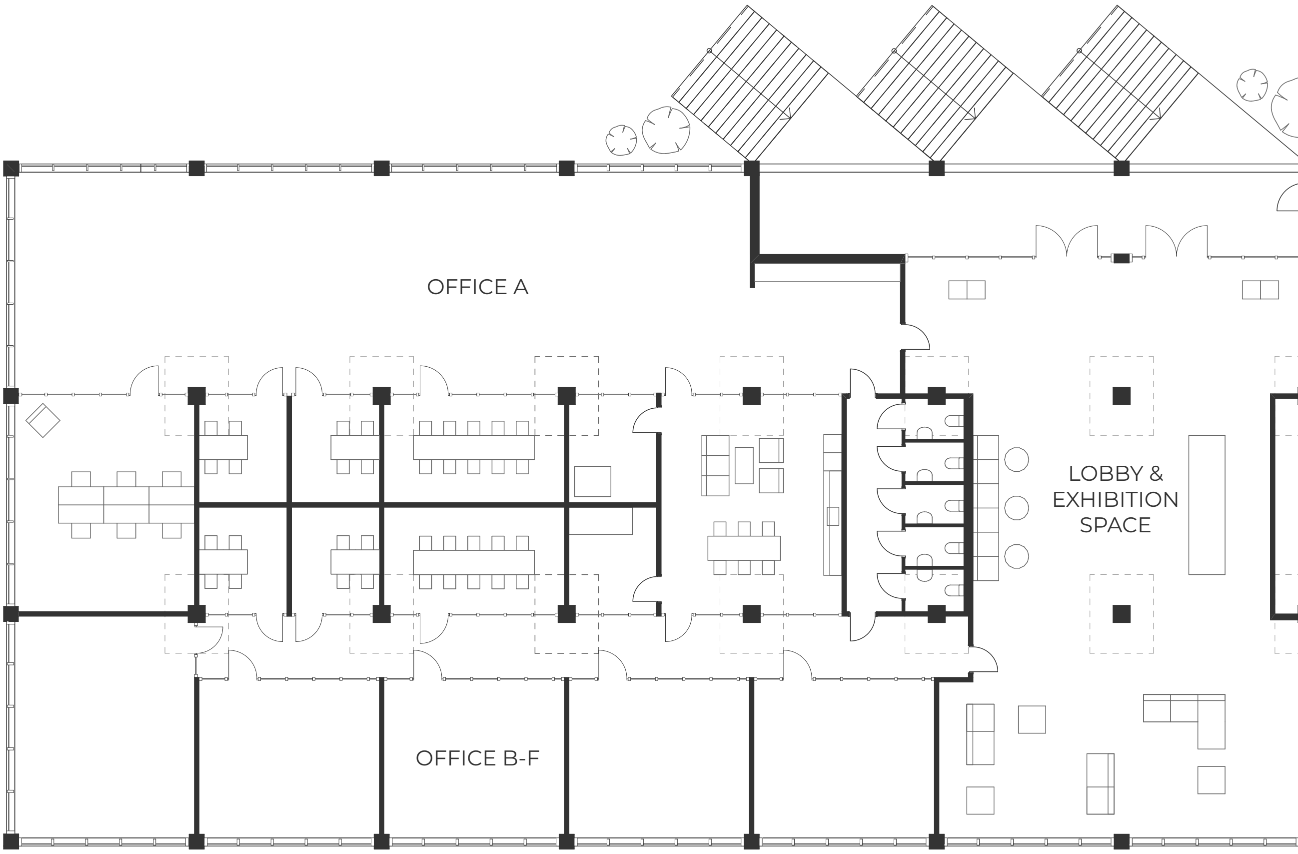
Floor 1 - 1:250


MATERIAL STORAGE
WASTE & RECYCLING
CIRCULARITY HUB
WORKSHOP AREA
ENTRANCE HALL



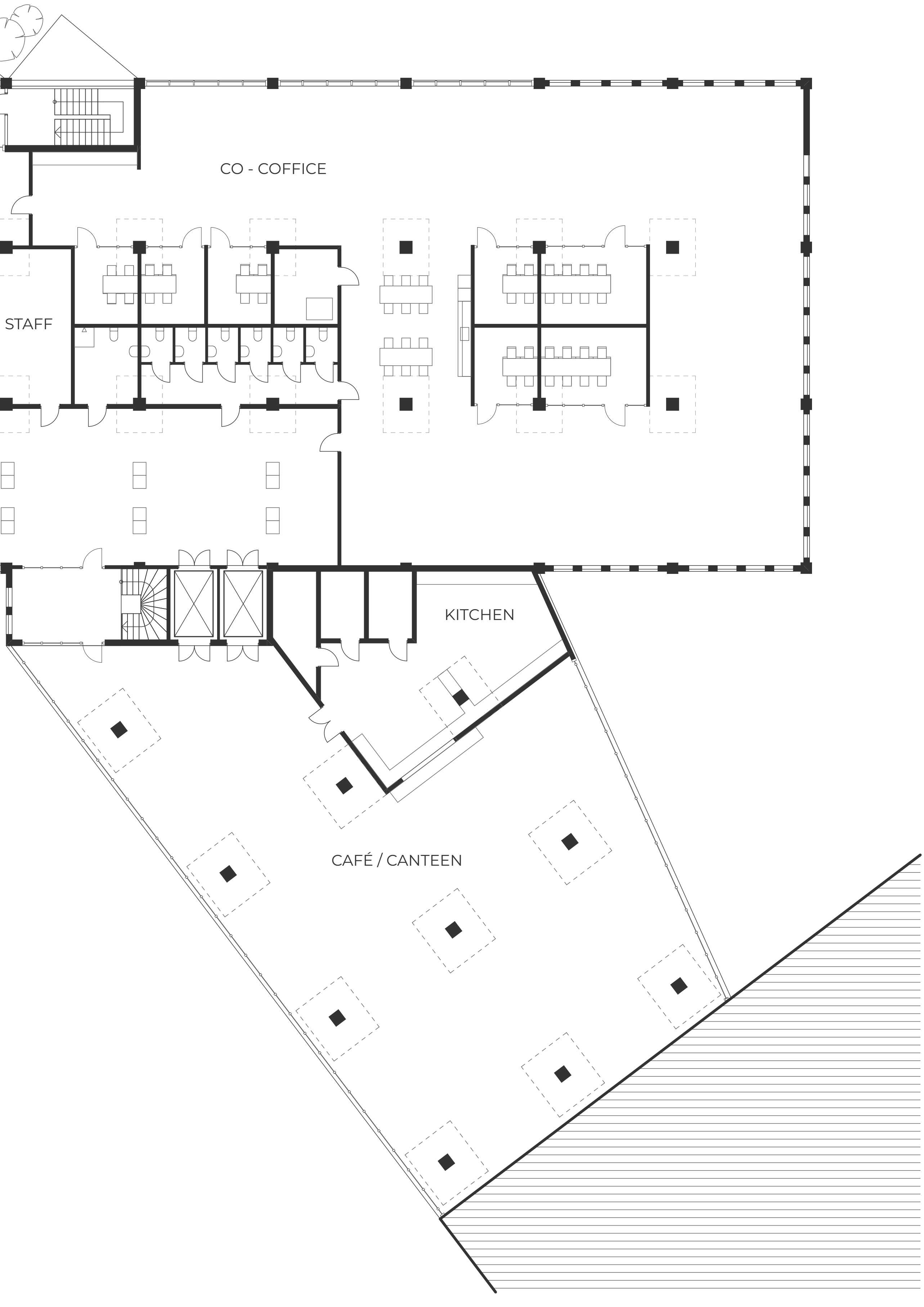
Floor 2 - 1:250


SECOND HAND STORE
RAGE

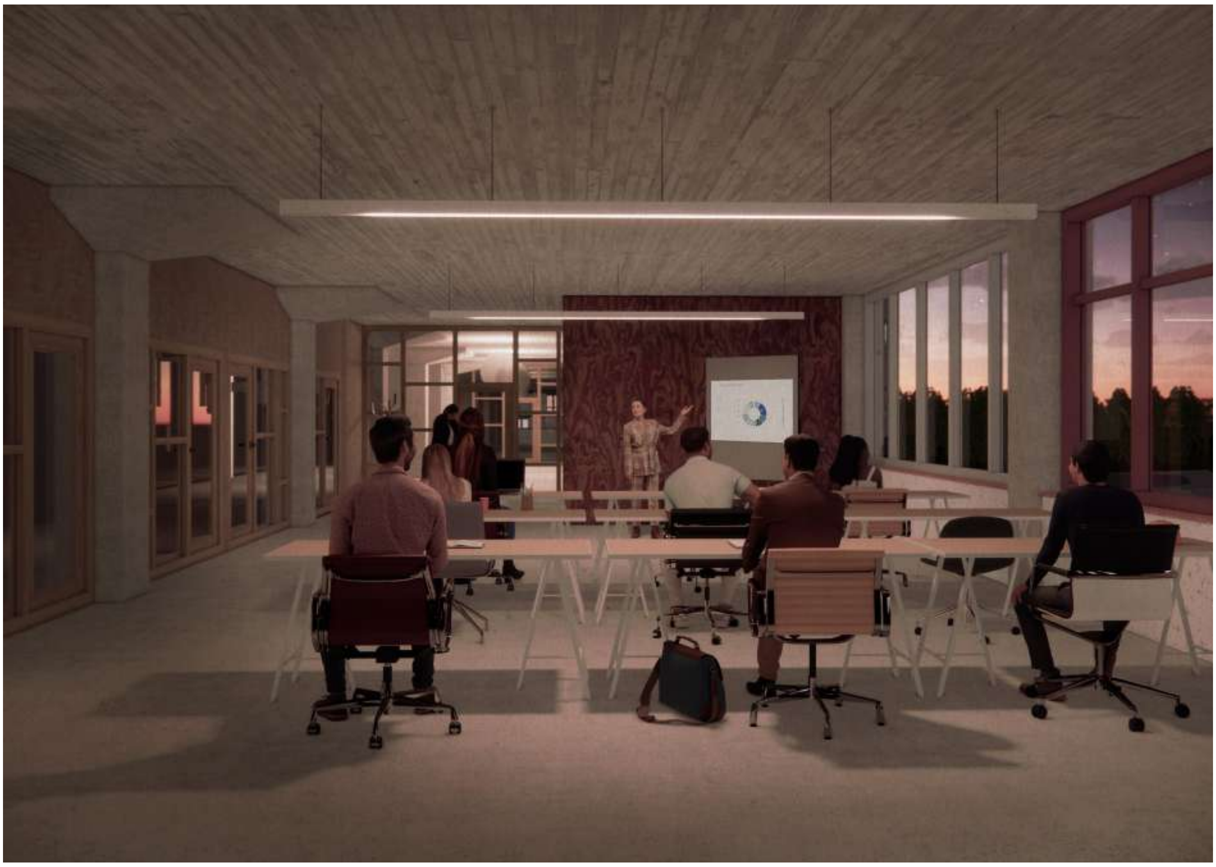


NEVER ENDING STORIES

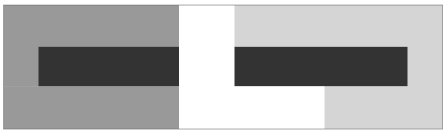
Floor 3 - 1:250


CO - COFFICE
STAFF
KITCHEN
CAFÉ / CANTEEN

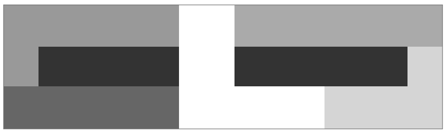
Office - daytime
Floor 3



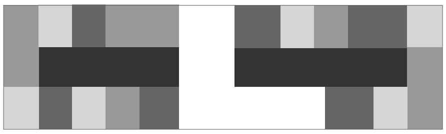
Office - evening time
Floor 3



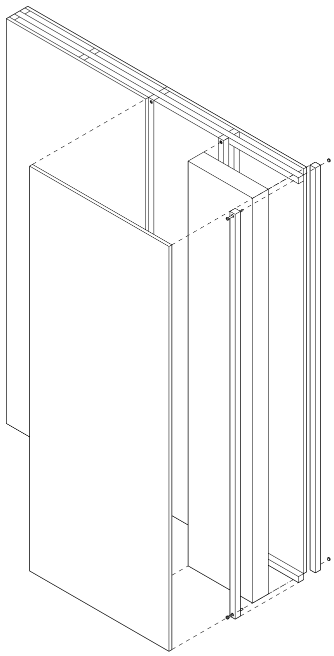
Two tenants



Four tenants



Multiple tenants

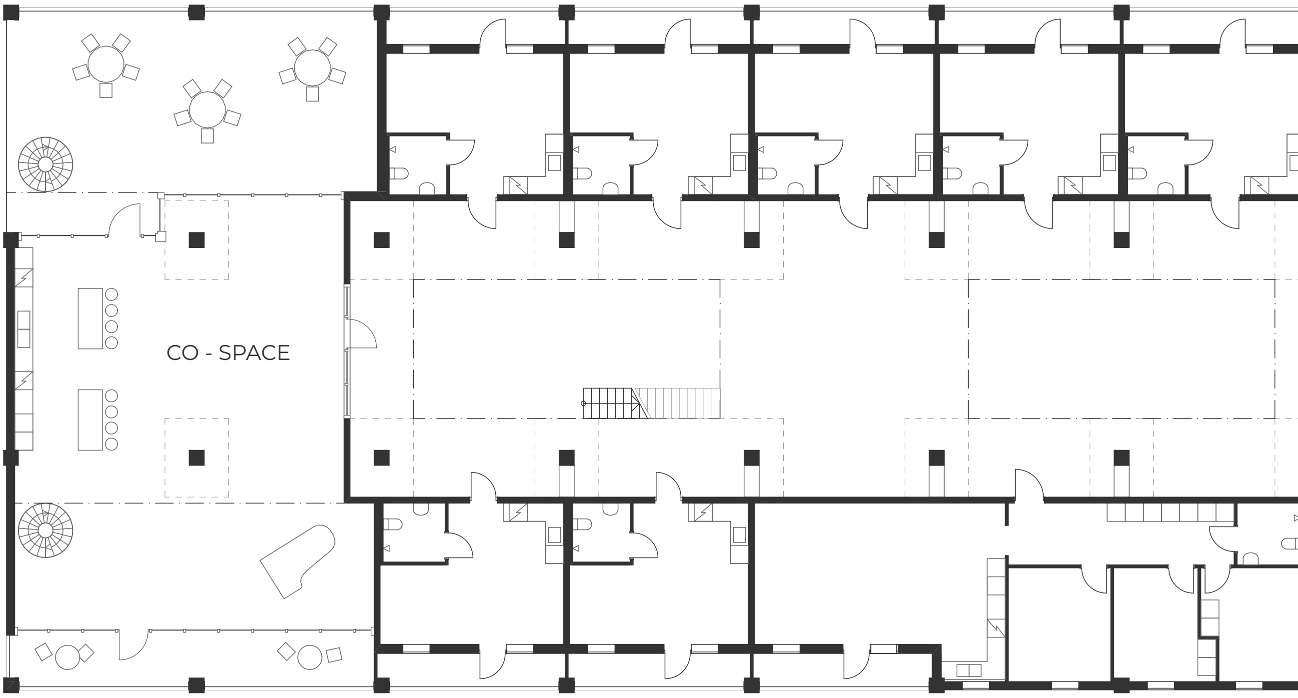


Interior wall concept

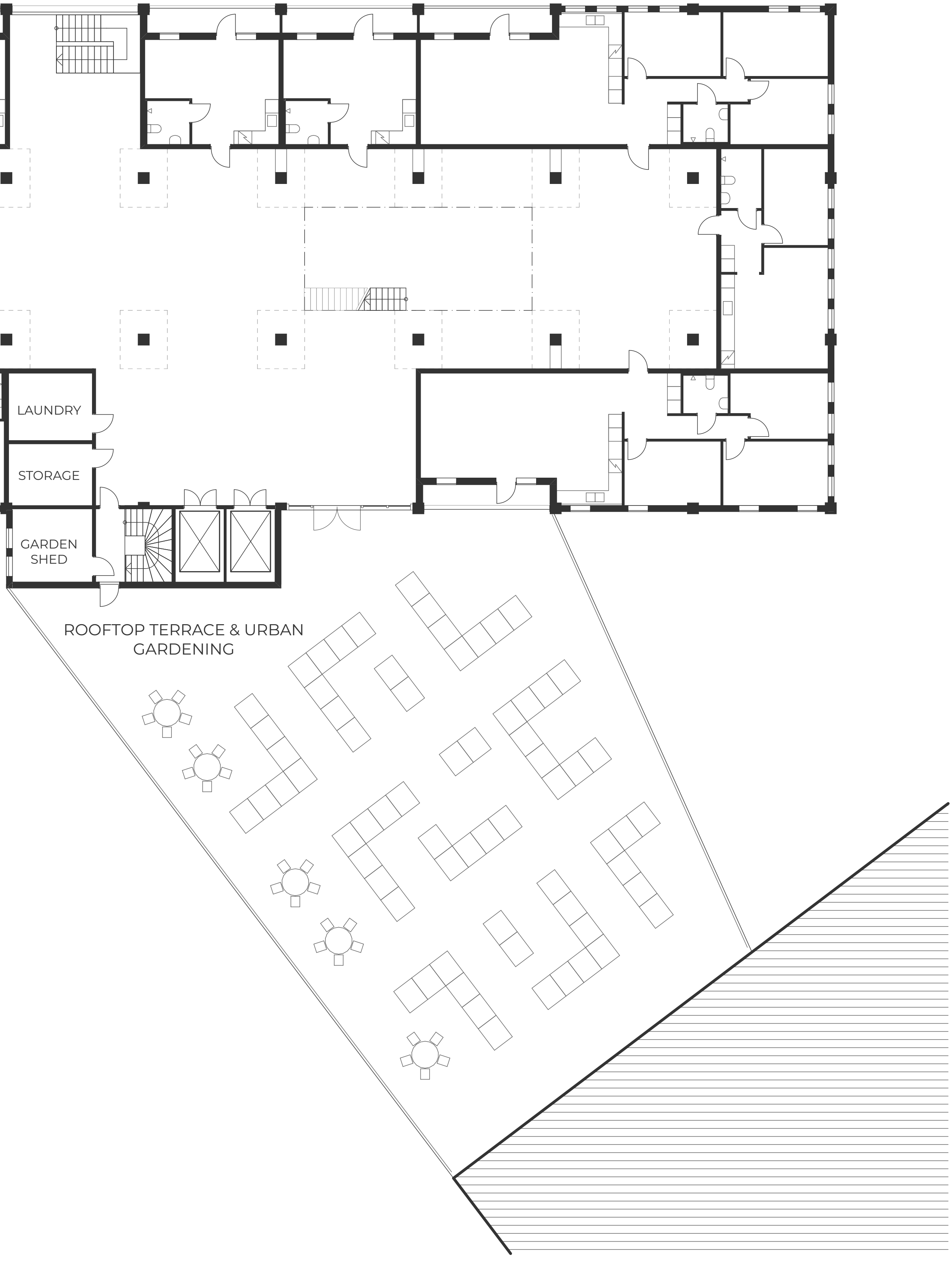
FLEXIBLE & ADAPTABLE SPACES

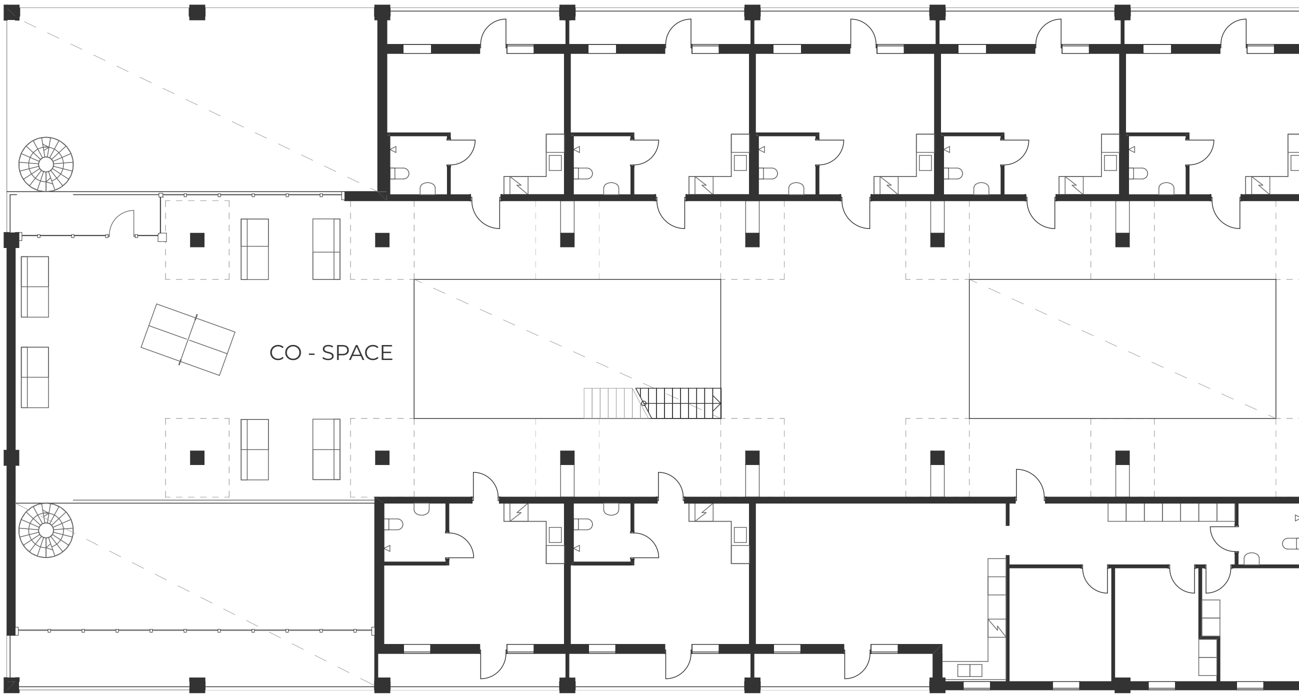
The office space can be divided into many different layouts to fit tenants of different sizes and demands. Interior walls are designed in layers with reversable joints, such as screws and bolts, that can endure repeated assembly and disassembly. This makes it easy to adapt spaces to create different layouts but also contributes to make them reusable in the future.

Multifunctional spaces and the possibility to lock away certain equipment makes it possible to intensify the use of the building and invite new users during evenings and weekends. The workspace together with the café and circularity hub area offers great possibility to arrange anything from courses, workshops, exhibitions, conferences or parties!

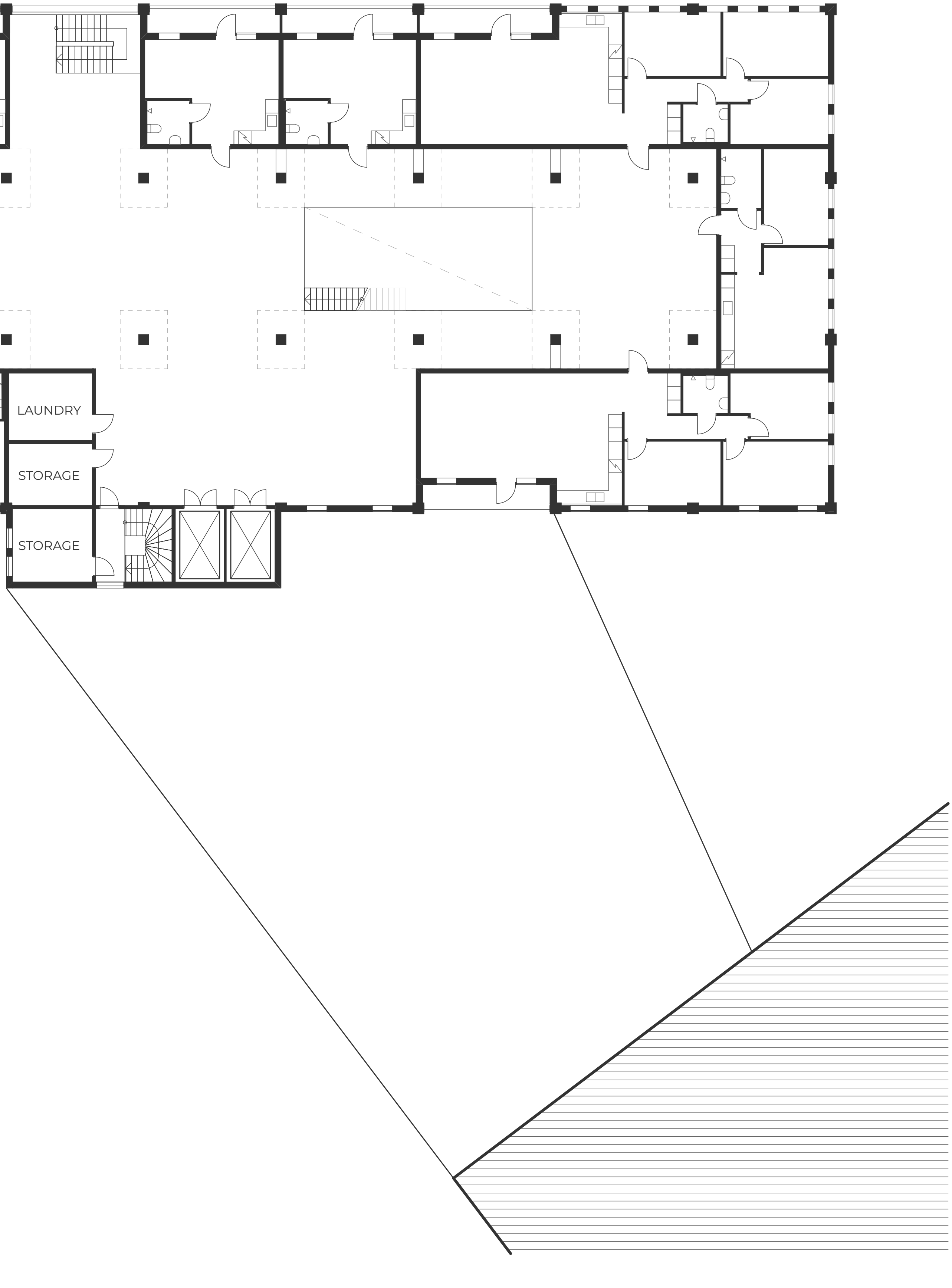


Floor 4 - 1:250


LAUNDRY
STORAGE
GARDEN SHED
ROOFTOP TERRACE & URBAN GARDENING



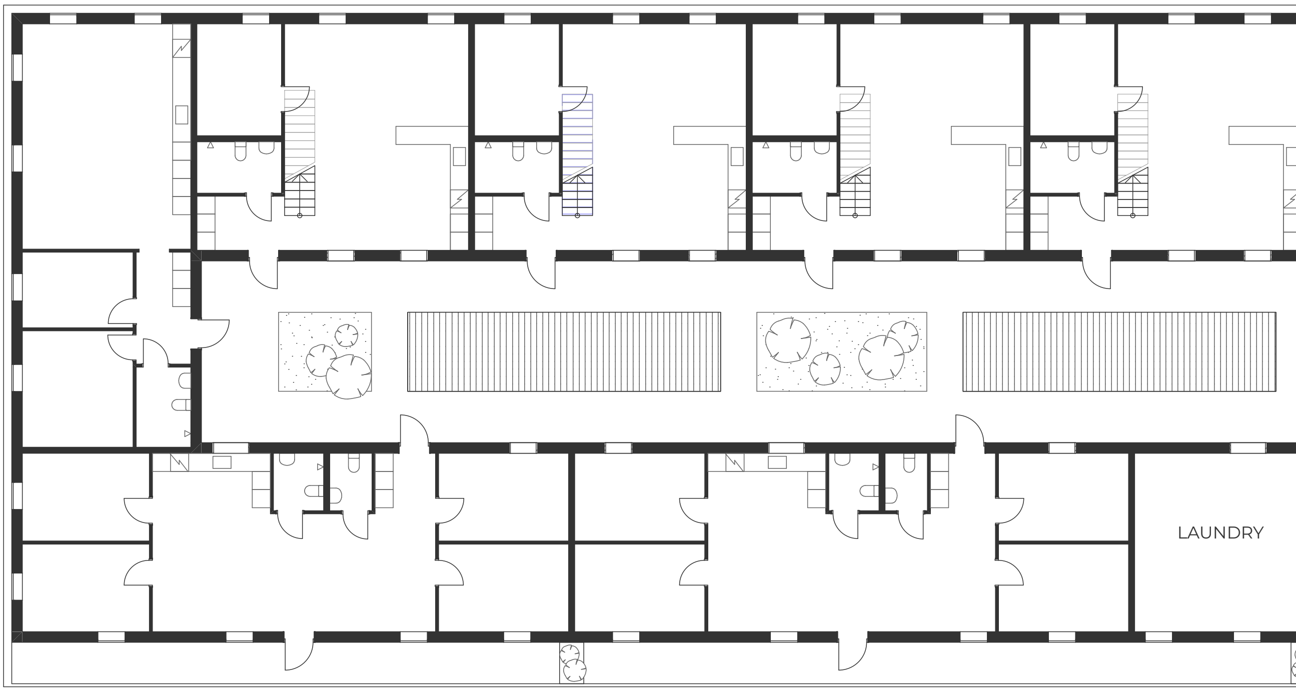
Floor 5 - 1:250


LAUNDRY
STORAGE
STORAGE

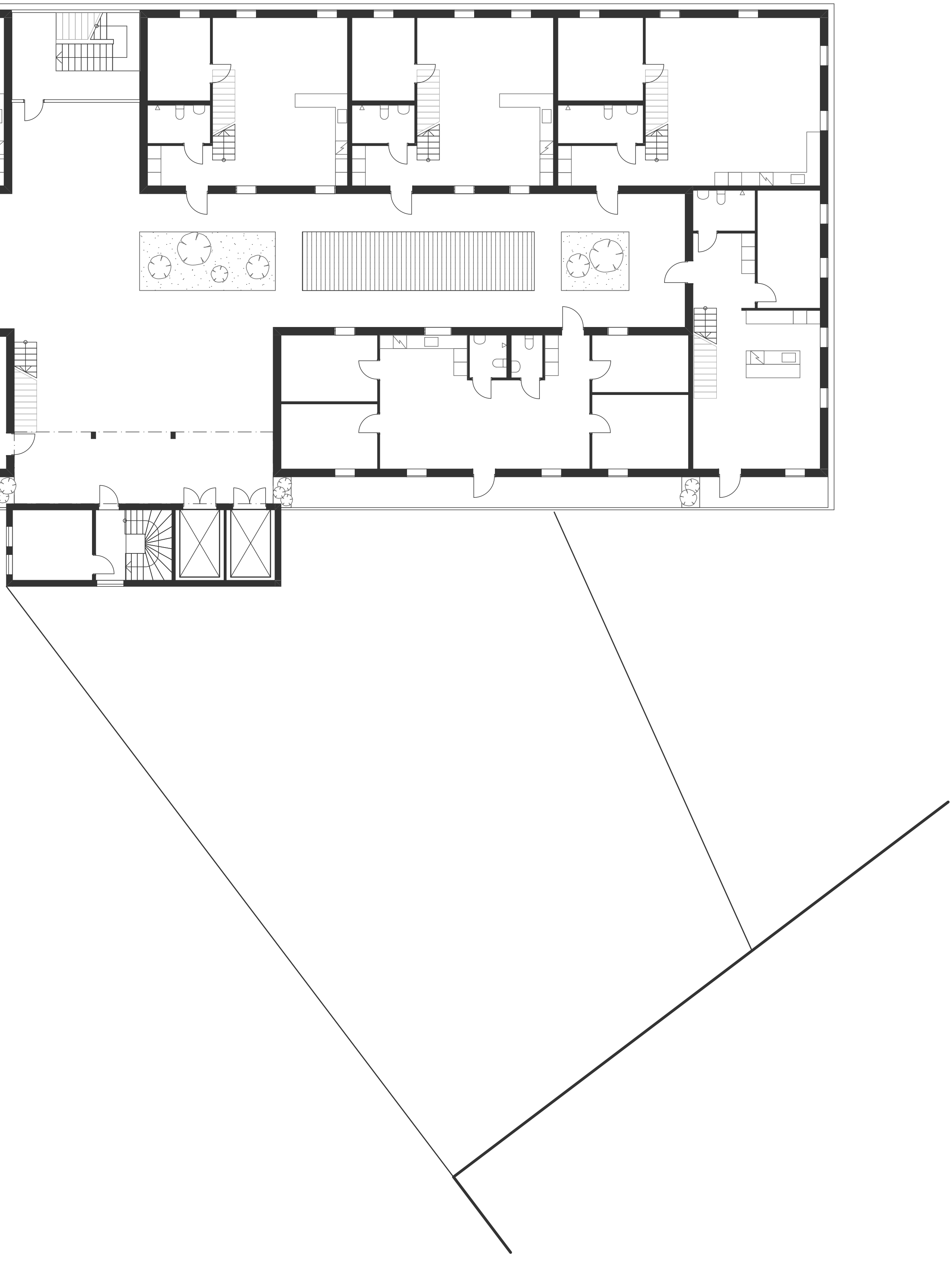
Interior courtyard
Floor 4

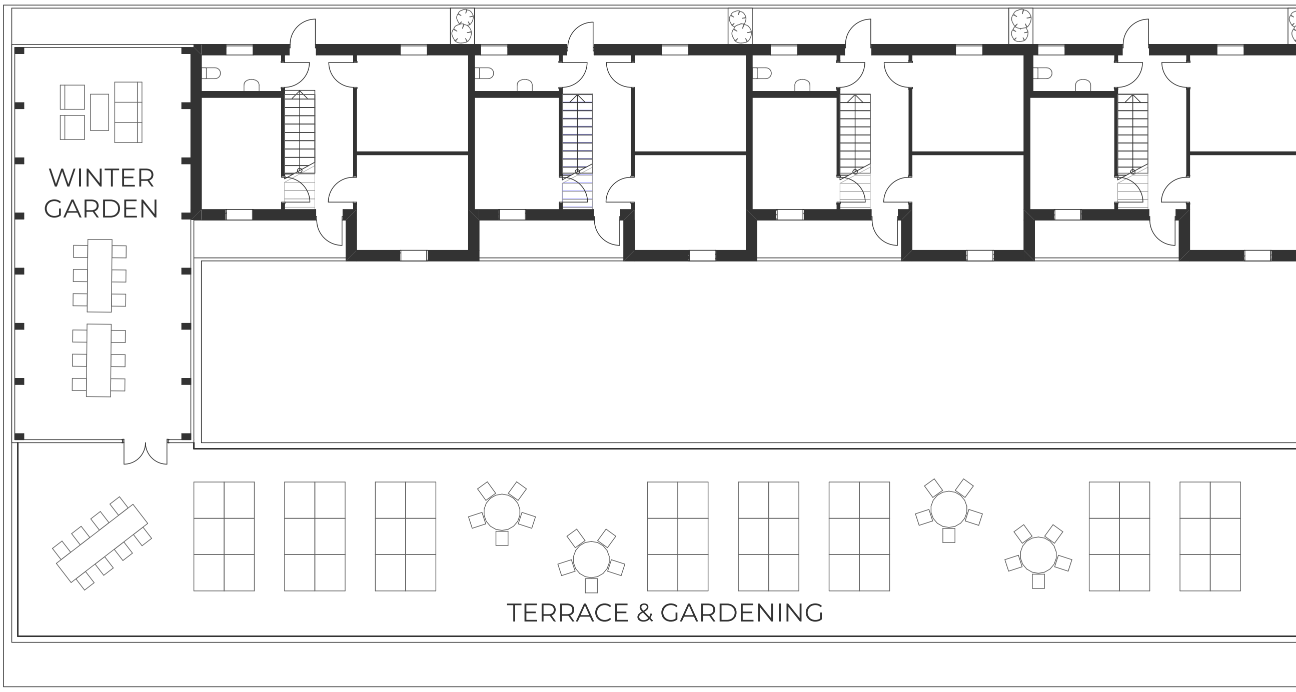

10
11
12

Co-space
Floor 4

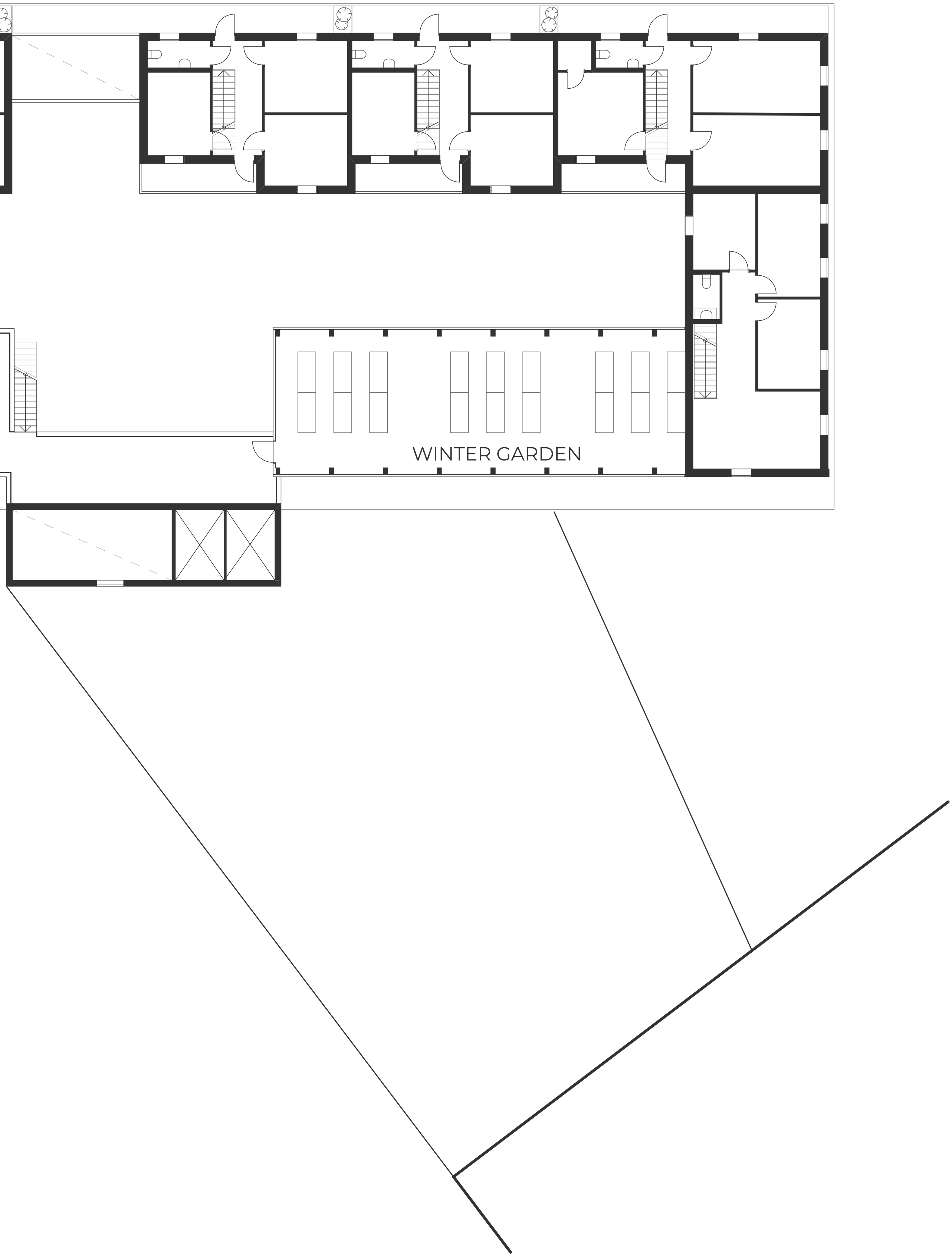


Floor 6 - 1:250

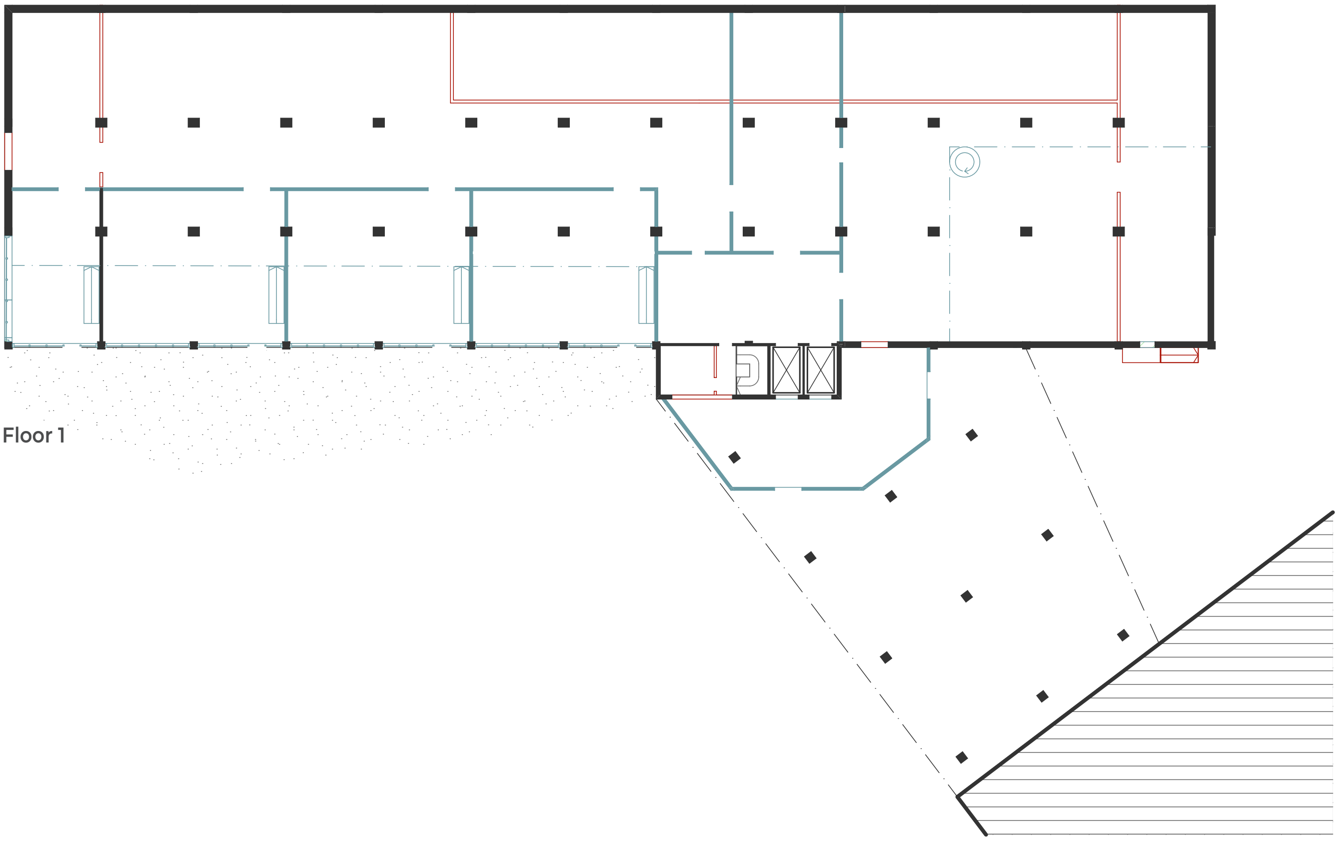




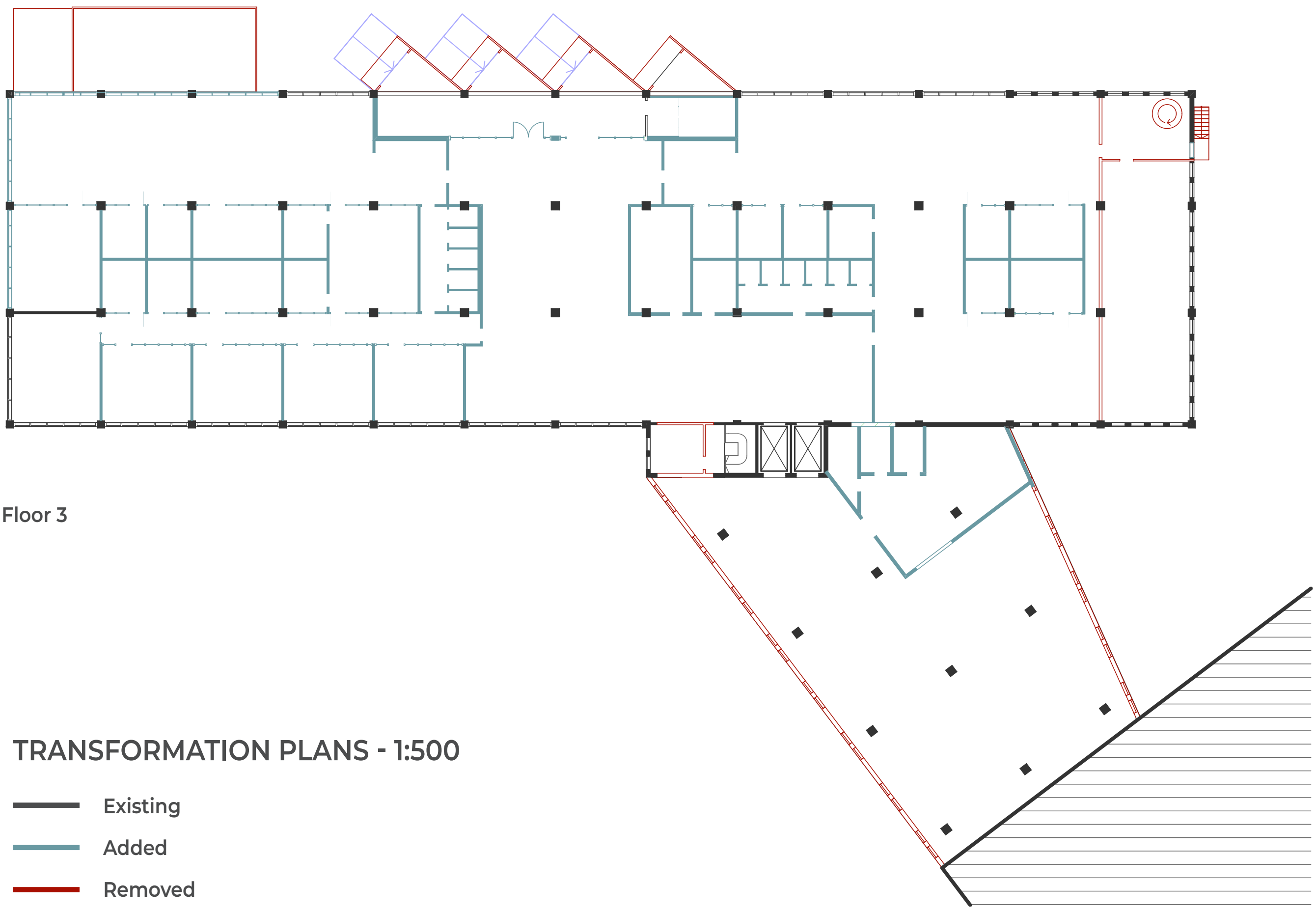
Floor 7 - 1:250


WINTER GARDEN

Exterior courtyard
Floor 6



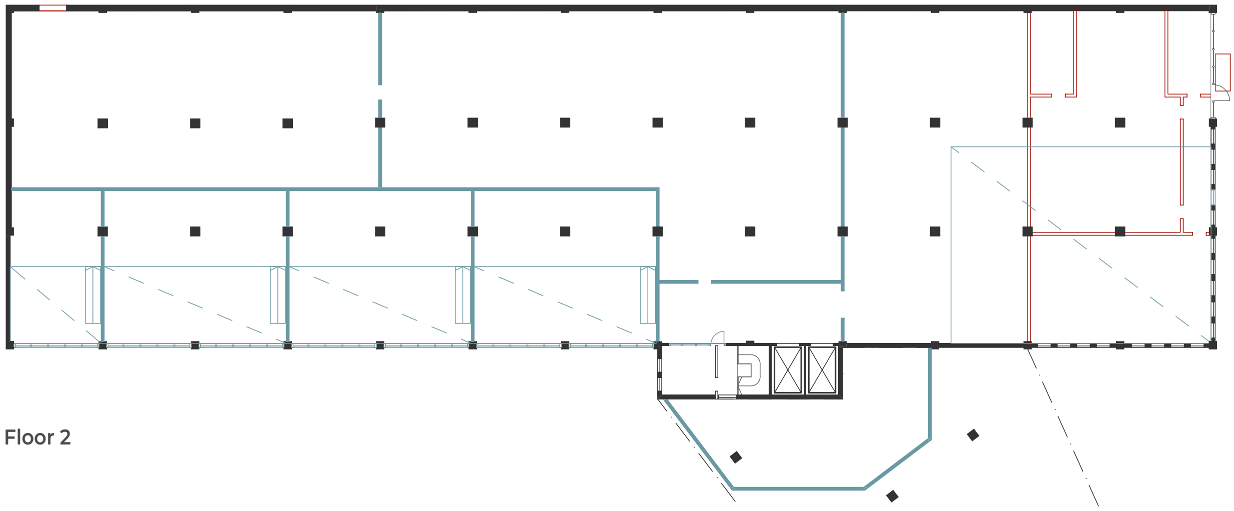
Floor 1



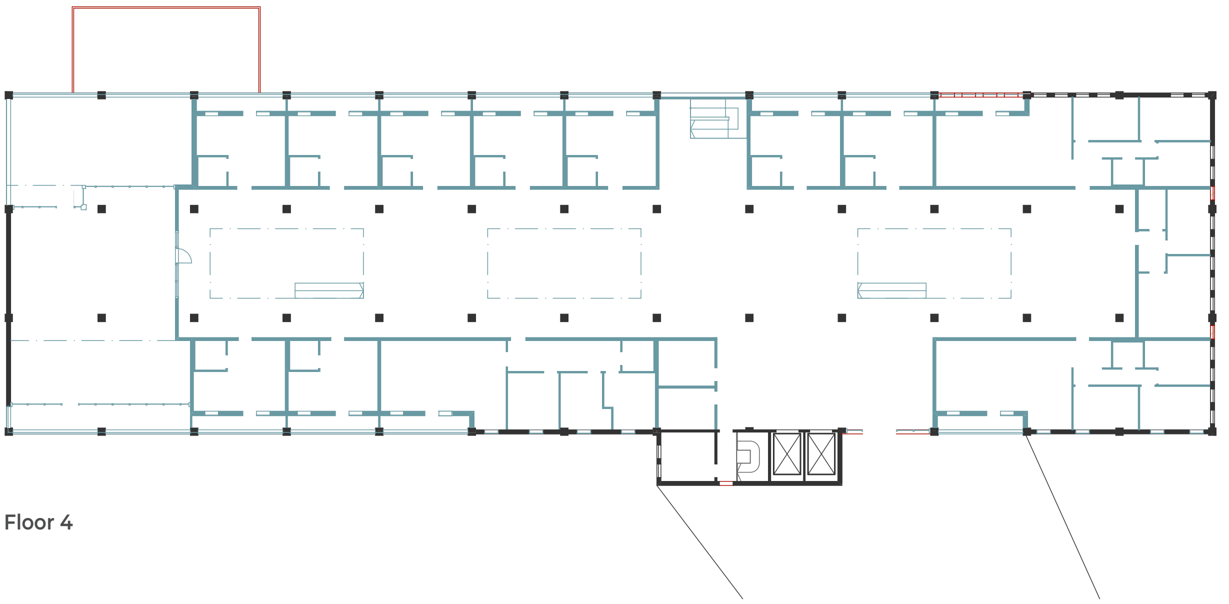
Floor 3

TRANSFORMATION PLANS - 1:500

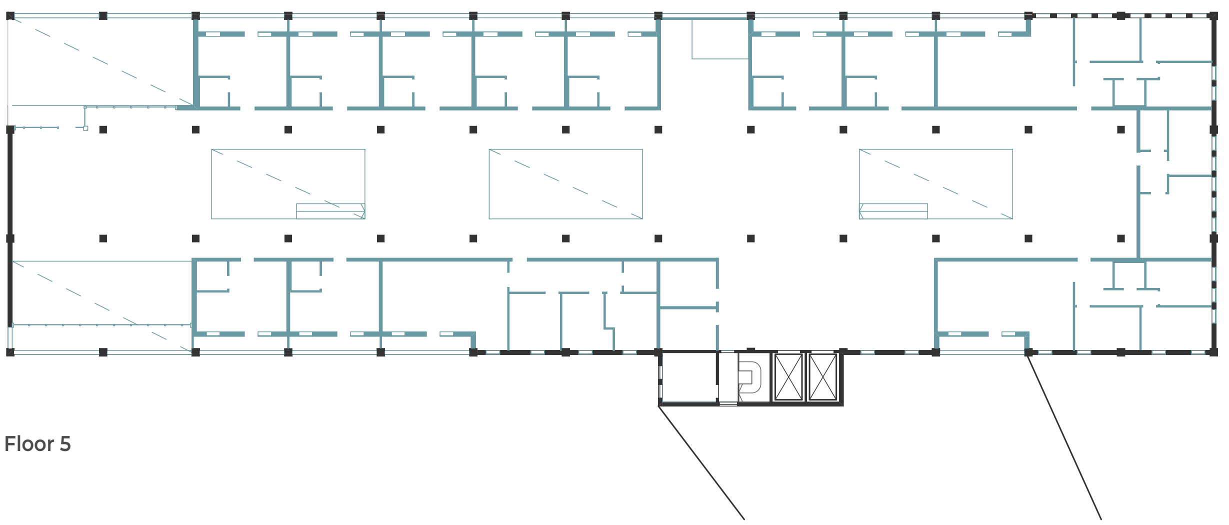
- Existing
- Added
- Removed



Floor 2

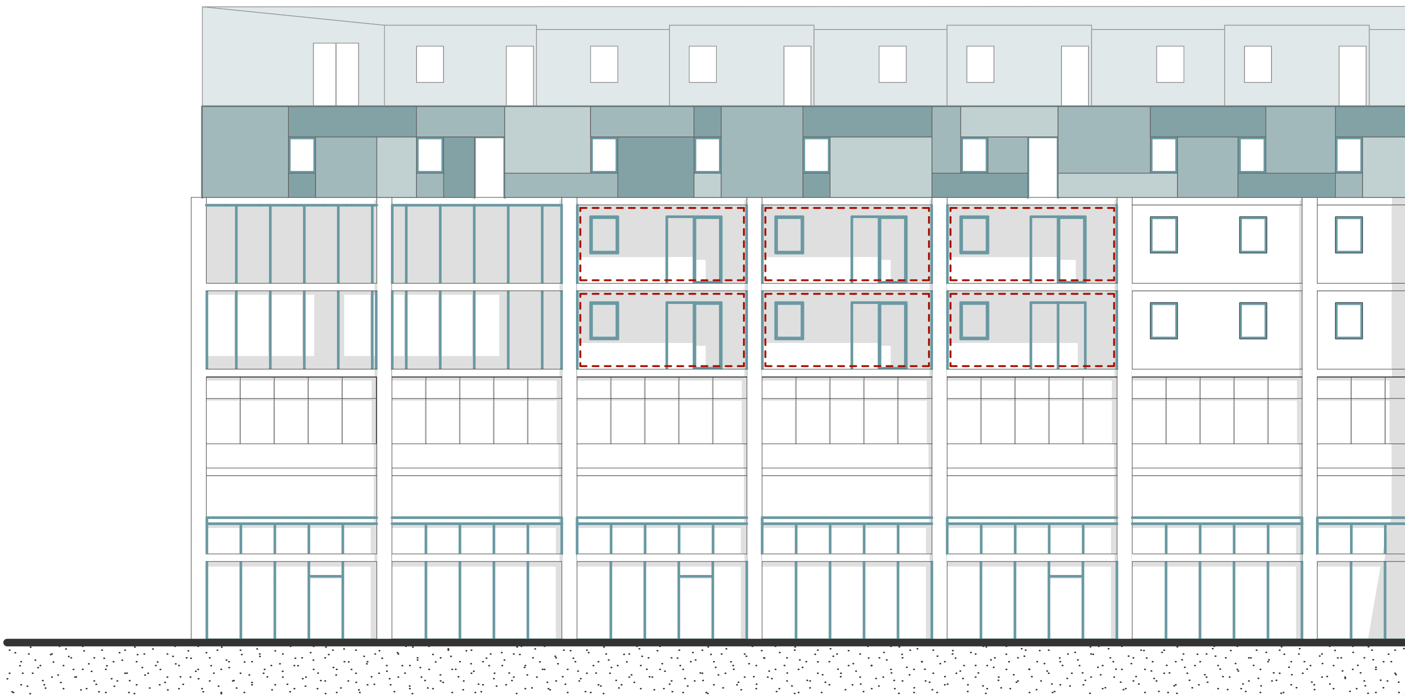


Floor 4



Floor 5

North-west facade



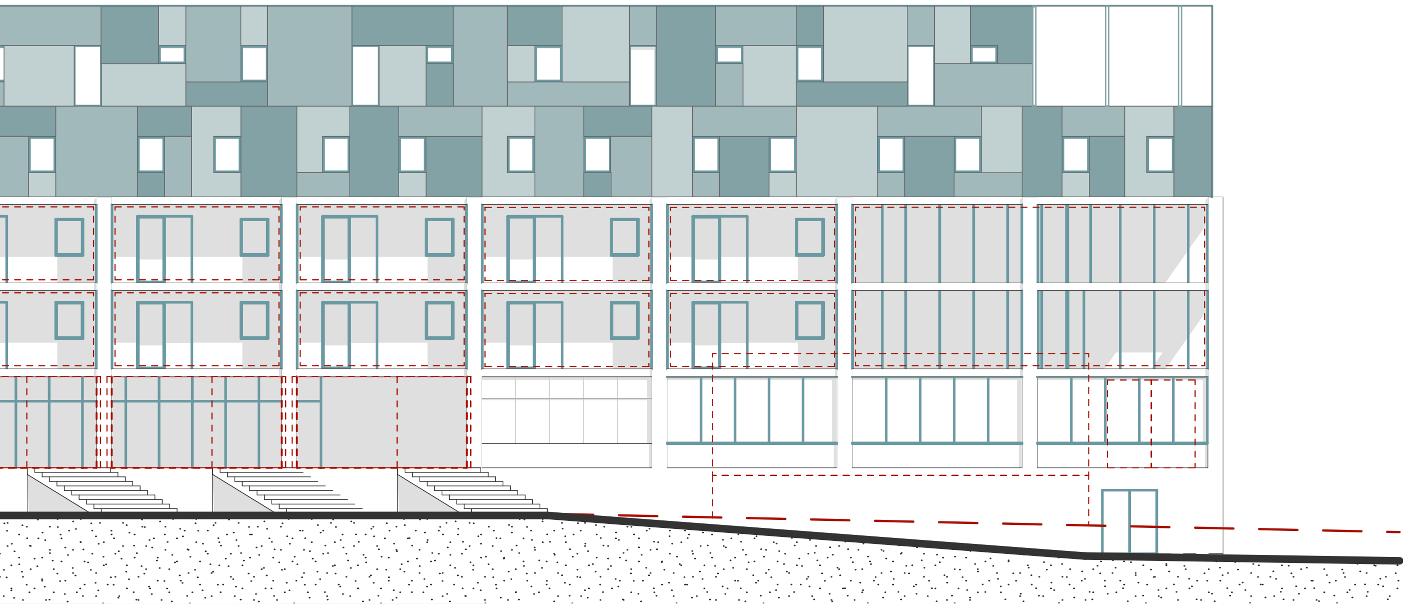
South-east facade

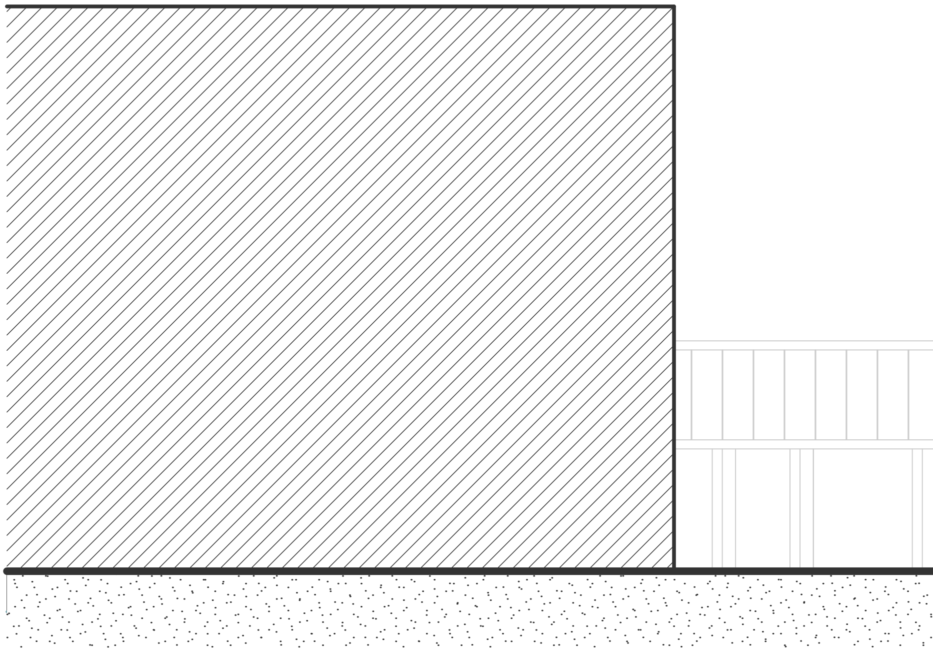
TRANSFORMATION FACADES - 1:250

Existing

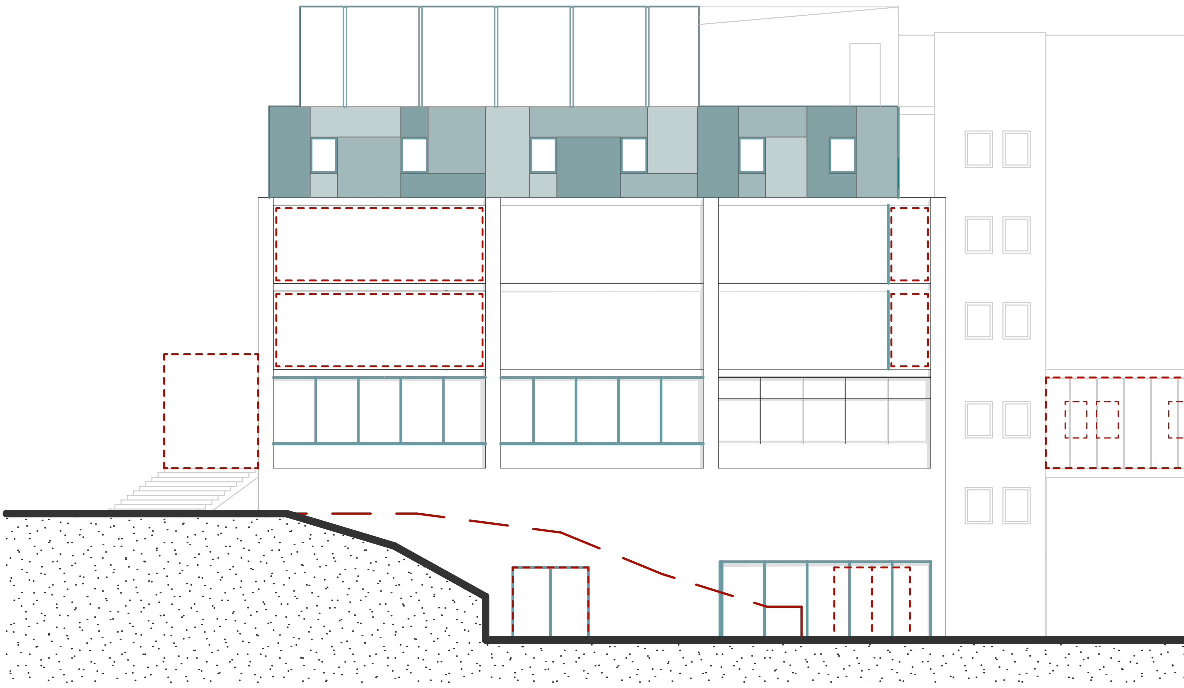
Added

Removed





North-east facade



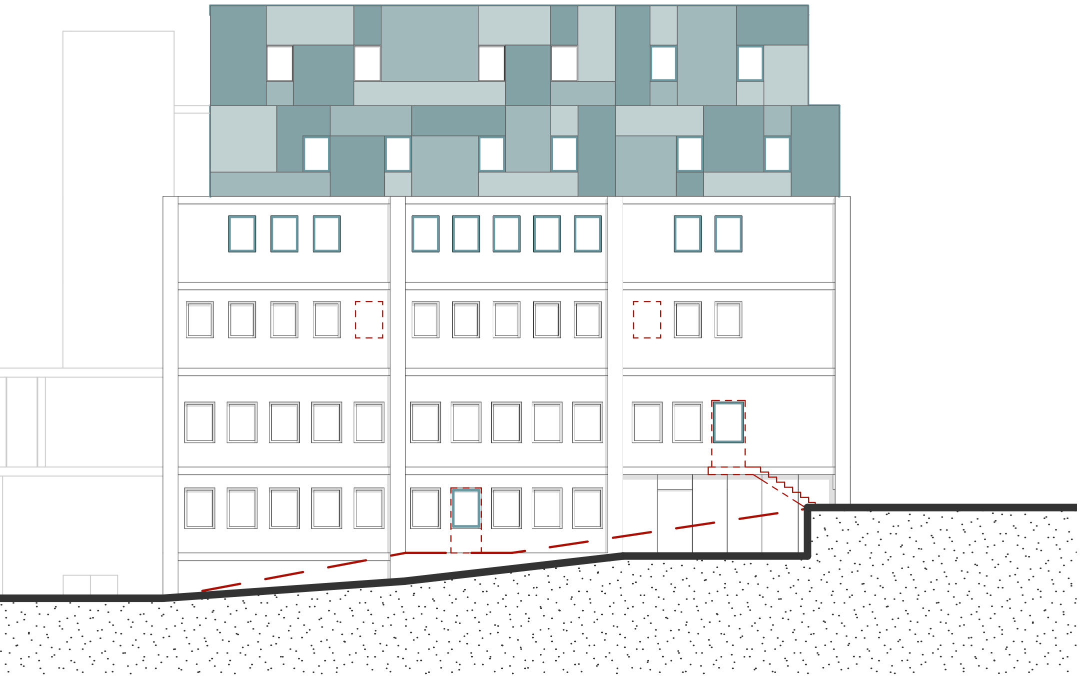
South-west facade

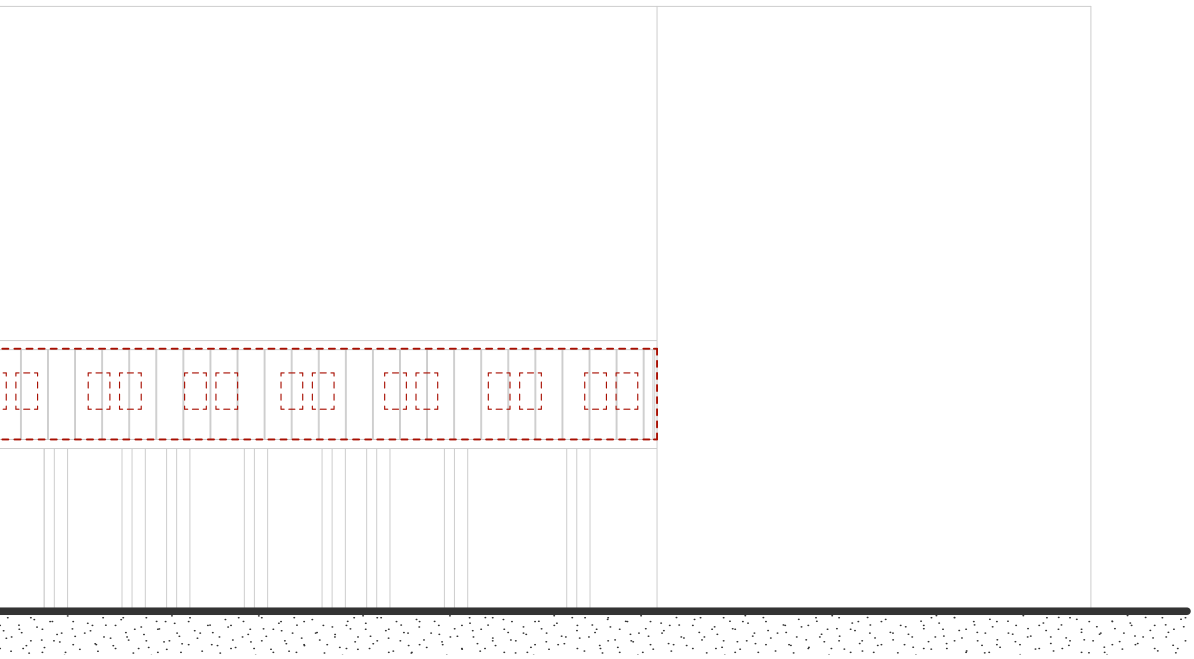
TRANSFORMATION FACADES - 1:250

Existing

Added

Removed





Transformation of building 110

V

V. EPILOGUE

DISCUSSION & CONCLUSIONS

How can a neglected industrial building in Forsåker be transformed into a long-lasting valuable space and help support the transition towards a circular economy?

What qualities can be gained by transforming the building instead of demolishing?
What are the challenges for doing such a project and how can these be overcome?

Working with the research for the questions of this thesis has given us a lot more insight into the complexity of this subject. While it has clearly showed that building transformation using circular principles is both possible and highly beneficial, it has also made us aware that there are a lot of different aspects to consider.

Habits, attitudes and regulations

It is incredibly unfortunate that the framework of the current building industry makes it more profitable to demolish a building with 1390 ton of materials and 10 960 ton of embodied carbon rather than retrofitting it. There is clearly a need for more incitements to make it more attractive to work with the existing building stock and reused materials. Introducing a tax shift to make labour more affordable and material resources more exclusive could perhaps be a good starting point. However, our research show that the main reason for the building industry's hesitation towards reuse comes from habits and attitudes rather than the economic aspects. Habits and attitudes are closely connected to economy though, since insecurities often leads to higher risks for the involved stakeholders. Increasing the competence within the industry by sharing knowledge among stakeholders and include demands of reuse in public procurements are both important strategies that could help shift the industry.

Working with this type of older industrial building has also made us aware of the challenge to fulfil current standards and regulations. Transforming a building that was originally intended for a very different purpose makes it hard to design all spaces as efficiently as in a new production, but it also pushes for new creative solutions that reconsider the conventional ideas of space, material and functions. We also think that the great environmental savings gained from retrofit projects motivates the compromises that sometimes need to be made.

Building heritage and aesthetics

In the debate about building transformation and preservation it is often easy to gain support for older buildings dating from early 1900s and previous than it is for more recent buildings, like the one we have worked with. This is related both to preferences in aesthetics and style but also to what is considered cultural and historically important. However, the majority of our current building stock is not part of this category and if we do not find ways to adapt these, we risk removing both a large part of our built history and also lose an enormous amount of resources. We believe that the urgent climate crisis we are currently in calls for a more pragmatic way of dealing with buildings. We might not always love all the buildings we have, but we simply cannot afford to continue wasting them. Reusing buildings and materials does not have to be a sacrifice to function and aesthetic, instead we strongly believe it can contribute to more rich, useful and enjoyable environments.

Strategies for circularity

Our research has shown that the best way to minimize resource extraction and emissions from buildings are actions that prevents or delay the need for new constructions. Extending the life span of existing buildings by retrofitting them is one of the most efficient ways to do this as it prevents the need for some the most resource intensive building elements, such as the foundation and load bearing structure. Intensifying the use of the building by making spaces adaptable and functional for multiple users is another strategy that can also limit the need for new buildings.

When researching strategies for building circular, a lot of the projects and solutions we found were often focused on making new constructions reusable in the future. Having more buildings designed for disassembly and reuse is in general a good thing, and something we have also tried to do in this project. However, it is still extracting resources and causing emissions. The benefits from these actions will not be gained until an uncertain point in the future, while reusing and retrofitting have a direct positive impact as it limits the pressure on nature today. As the trajectory we are currently on risks leading the planet towards disastrous global temperatures we believe it is important to take action right now in order to avoid irreversible tipping points and stay within planetary boundaries. In this project we have therefor aimed to make new additions both demountable but also based on reused or renewable materials. Even though it is preferable to reuse materials as local as possible we have found that the emissions caused by intermediate storage and transport in most cases are way smaller than the embodied savings from the material, making reuse almost always motivated from a climate perspective.

Life cycle analyses

Analysing buildings through LCA-tools is a very powerful way to highlight the environmental impact of a building. In this project, having quantified data have been a helpful tool for designing and advocating for keeping the building. However, it is important to reflect on the result, since calculations are only as good as the information that goes into them. It is easy to get blinded by data and led into decisions that might not always be the best from a wider perspective. For example, most LCA-tools of today assumes factors such as energy demand and emissions from heating and electricity to be constant over the whole life cycle of 50-100 years. This might lead to over-dimensioning certain elements and adding more materials than necessary. However, speculating about the future and assuming new future breakthroughs and inventions poses other dangers and can just as easily lead to the wrong conclusions. Different LCA-methods can also make it hard to compare results, while standardizing methods in turn can lead to over-simplified models that also cause unfair comparisons. It is therefore important to remember that all LCA-simulations are speculative and simplified models of reality and to be critical towards data results.

Another interesting aspect when it comes to LCA and reuse is the question of who gets the environmental benefits. Currently, the first user of a material is the one who “pays” for the related emissions while a second party reusing the same material can count it as 0. This is the easiest way to calculate, but one could argue that giving the first user a “carbon discount” if they prepare their material for future reuse would create more incitements for creating circular building products. This would of course create other problems (What happens if the product is never reused? What happens if there are multiple reusers?) but we believe that these types of incentives have an important role to play going forward in order to make sustainable choices the default.

FINAL THOUGHTS

We are convinced that the existing building stock is an essential key for reaching a circular economy and fulfilling climate goals. Opting for transformations and reuse rather than demolitions comes with a multiple of benefits that a lot of developers unfortunately fail to see. We hope that this project can highlight the absurdity of tearing down fully functional buildings and showcase the great possibilities one could gain instead.

Our building transformation is saving 1390 ton of materials and 10 960 ton of embodied carbon and creating new value to a worn down and neglected space. The transformation helps amplifying the circular transition by creating spaces and functions that support circular habits and bring the concepts of reuse and circularity closer into people’s everyday lives. By transforming instead of demolishing we are saving a piece of local history but also adding new layers to the story and identity of the area. But more importantly, we are turning an unwanted building into a more beautiful, functional and enjoyable space that can continue to host the never-ending stories of the future. In the end, the most sustainable building is the one that people will use and love for generations to come.

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Images & drawings:

Images and drawings without reference have been developed by the authors of this thesis.

Fig. 1, Göteborg Stad. (2020). Dags att bygga och riva cirkulärt! Slutrapport från projektet Upphandlingskrav för cirkulära flöden i bygg- och rivningsprocessen. https://goteborg.se/wps/wcm/connect/d0600675-8e9c-4522-9984-4783c65d9a07/Slutrapport+Upphandlingskrav+f%C3%B6r+cirkul%C3%A4ra+fl%C3%B6den+i+bygg-+och+rivningsprocessen.pdf?MOD=AJPERES

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Fig. 7, Mölndals Stadsmuseum. (n.d.) DigitaltMuseum. https://digitaltmuseum.se/owners/S-MS

Fig. 8, Mölndals Stadsmuseum. (1929-1964) DigitaltMuseum. https://digitaltmuseum.se/owners/S-MS

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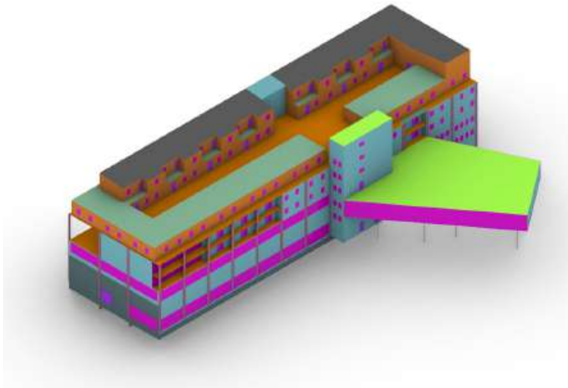
APPENDIX

LIFE CYCLE ANALYSIS

In this thesis the life cycle analyses were made using the tool CAALA, which is a plug-in for SketchUp and Rhino that performs environmental analysis on the basis of 3D models. CAALA includes both life cycle costs, energy demand, and CO2, however cost was not a part of this particular analysis. The tool incorporates both embodied impact and operational impact and it is possible to study the modules A1-A3-Production, B4-Replacements, B6-Operational energy usage, C3-Waste processing, C4-Disposal, and D-Recycling potential. The calculations are made according to EN 15978.



CAALA 3D Model

SCOPE

When performing the Life Cycle Analysis in CAALA the following inputs have been used:

NFA
Existing: 8178 m^2
New: 1408 m^2
Total : 9586m^2

Life cycle modules:
Analysis I-III: A1-3 Production, C3+C4 End-of-life

Analysis IV: A1-3 Production, B6 Energy demand in use phase, C3+C4 End-of-life

Study period: 50 years
Thermal bridges: General 0.1W/m2K
Air tightness: new construction n50 = 4h-1

Analysis IV specific:
No technical systems included.
Mechanical ventilation with heat recovery
Heating:
District heating CHP
Energy sources heat: District heating – Biomass
Primary energy factor: heat 0.2
CO2-Intensity factor heating: 0.06

Electricity
Energy sources Electricity: Hydropower
Primary energy factor electricity: 1.3
CO2 intensity electricity: 0.1
User electricity: 0 / 30 kWh/(m^{2}NFA*a)

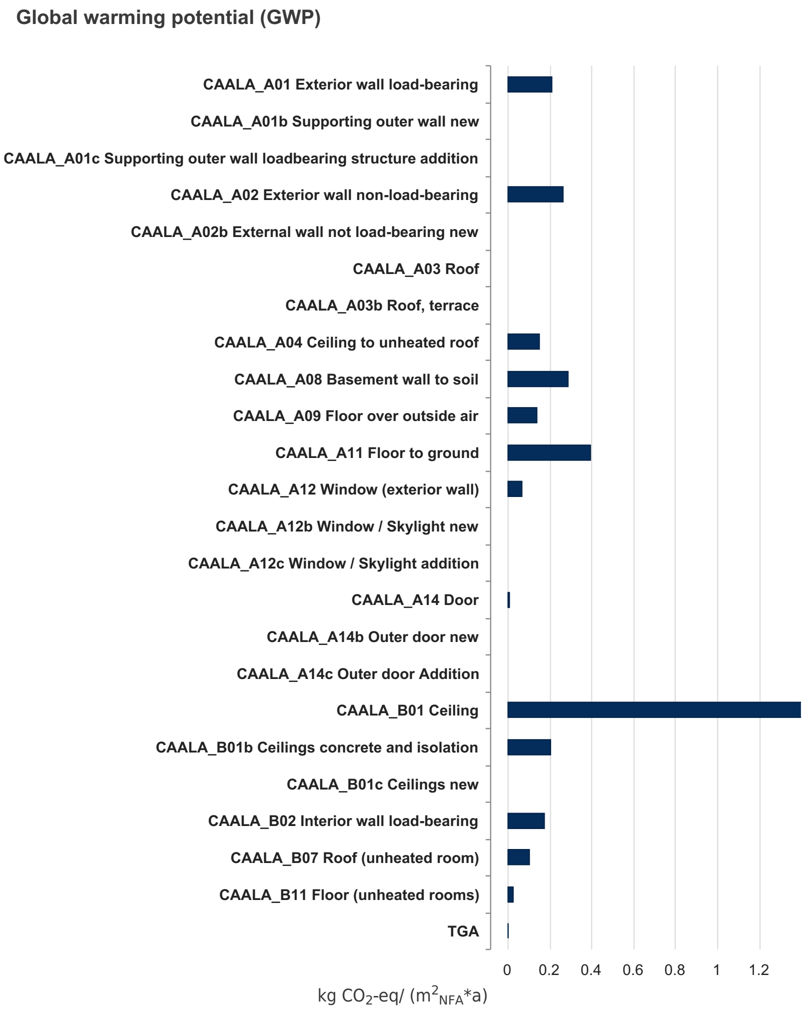
LAYER DEFINITIONS

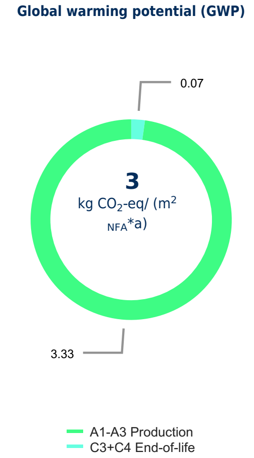
Category	Name in CAALA	Our name / description	Building
Walls	CAALA_A01 Exterior wall load-bearing	Foundation Beams, concrete	
	CAALA_A01b Supporting outer wall new	Exterior walls, wooden stud	additions
	CAALA_A01c Supportingn outer wall loadbering structure addition	Loadbering structure, gluelam	additions
	CAALA_A02 Exterior wall not load-bearing	Exterior walls, concrete	110
	CAALA_A02b External wall not load-bearing new	Stairs, Polycarbonate, heated	110 / addition
	CAALA_A08 Basement wall to soil	Basement walls, concrete	
Slabs	CAALA_A03 Roof	Roof, wooden stud	addition
	CAALA_A03b Roof, terrace	Roof, wooden terrace	addition
	CAALA_A04 Ceiling to unheated roof	Roof 111 & Tower, concrete	111
	CAALA_A09 Floor over outside air	Floor slab, concrete	111
	CAALA_A11 Floor to ground	Foundation slab, concrete	110
	CAALA_B01 Ceiling	Slabs, concrete	110
	CAALA_B01b Ceilings concrete and isolation	Extra isolated slabs, (Balconies, terraces)	110
	CAALA_B01c Ceilings new	Intermediate slab, wooden stud	addition
Windows	CAALA_A12 Window (exterior wall)	Windows, existing	110
	CAALA_A12b Window / Skylight new	Windows, new on existing building	addition
	CAALA_A12c Window / Skylight addition	Windows, new on addition	110
	CAALA_A14 Door	Doors, existing	110
	CAALA_A14b Outer door new	Doors, new on existing building	110
	CAALA_A14c Outer door addition	Doors, new on addition	addition
Structure	CAALA_B02 Interior wall load-bearing	Columns	110, 111
	CAALA_B07 Roof (unheated rooms)	Capitals	110
	CAALA_B11 Floor (unheated rooms)	Capitals	111

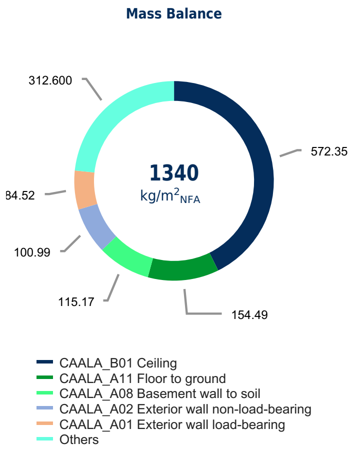
Black = existing
Blue = added

I. EXISTING BUILDING

This analysis is performed on the existing building and is including the elements that is kept in this transformation project. It includes the foundation, exterior walls, slabs, columns and capitals as well as windows and doors.

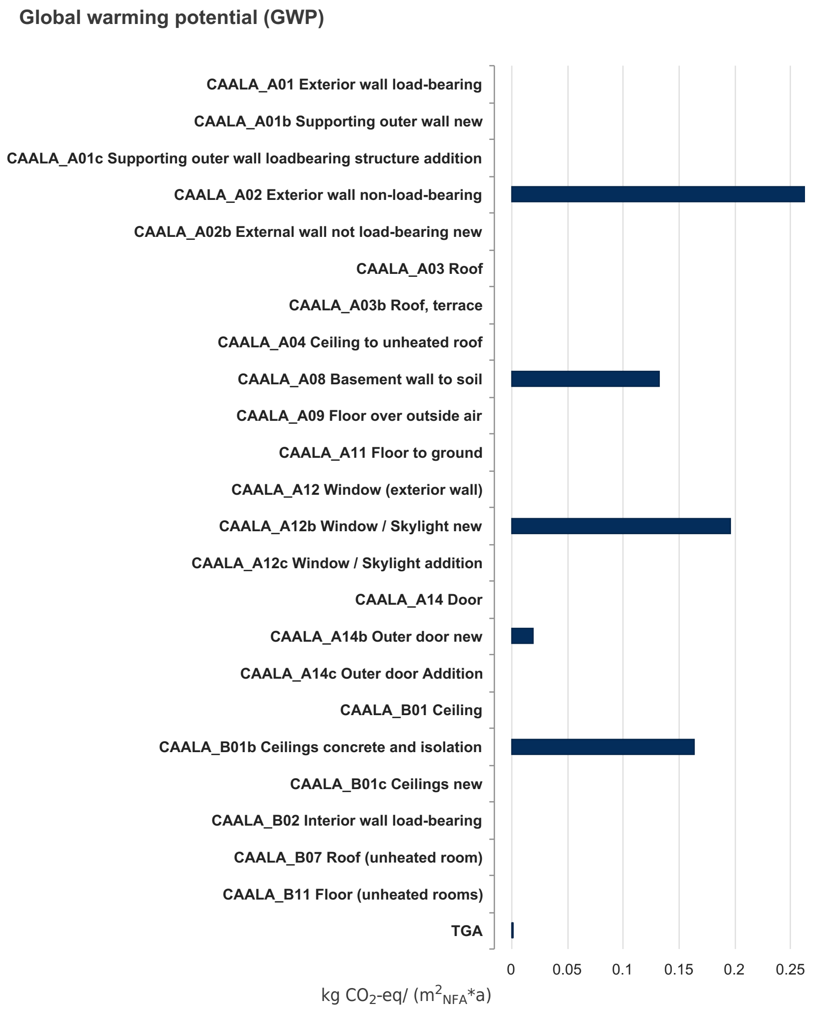


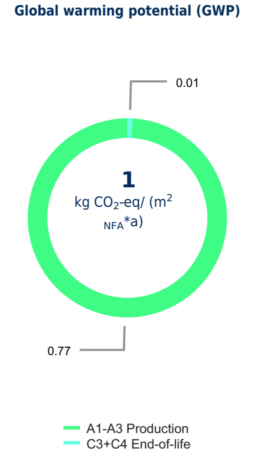


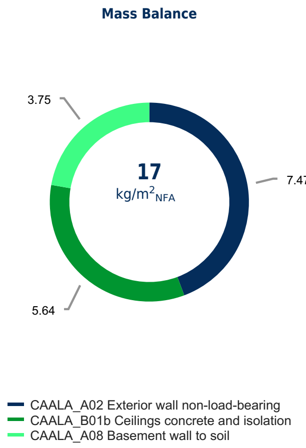


II. ADDITIONAL LAYERS

This analysis studies the impact of the changes made on the existing buildings climate shell. It includes the impact of the additional isolation of the exterior walls and slabs as well as new windows and doors. All impacts from the existing building are set to zero.



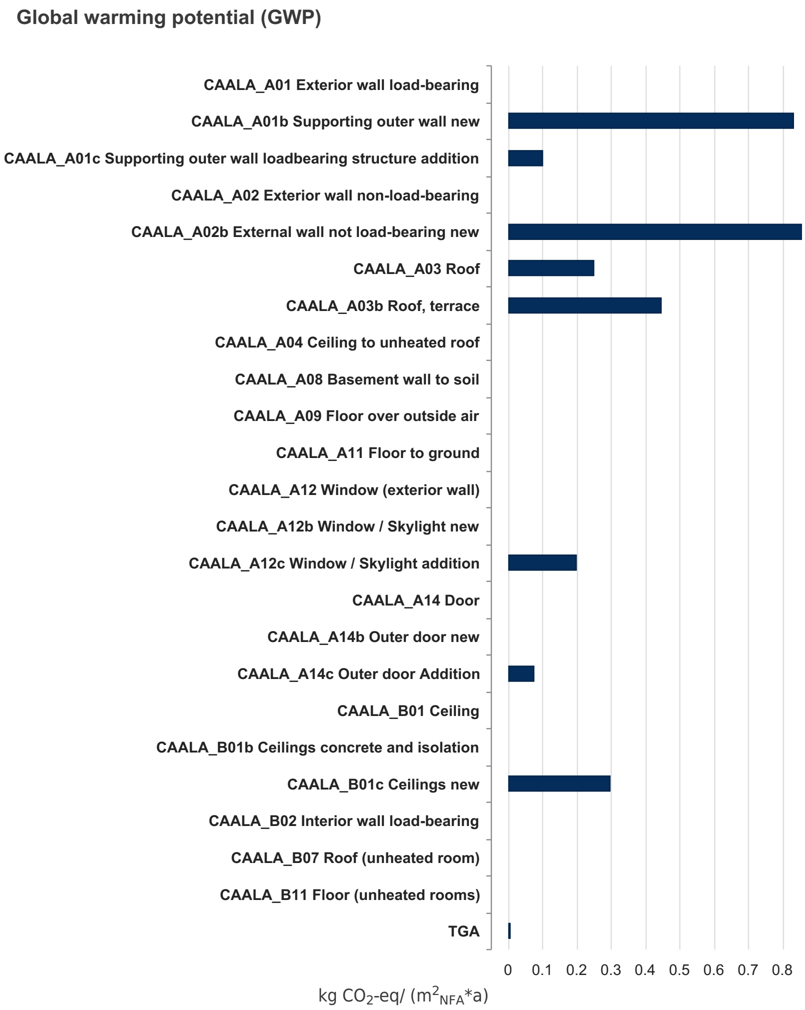


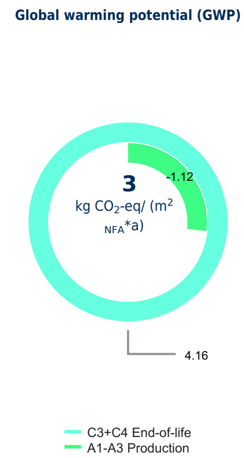


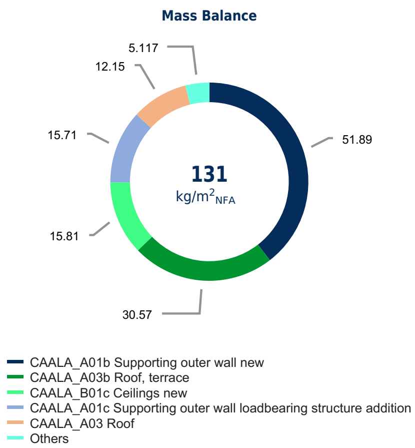
NEVER ENDING STORIES

III. NEW STRUCTURE

Here, the new rooftop addition is studied. The analysis includes the exterior walls, loadbearing structure, intermediate floor slab, roof, windows and doors, as well as the new stairwell. All impacts from the existing building are set to zero.



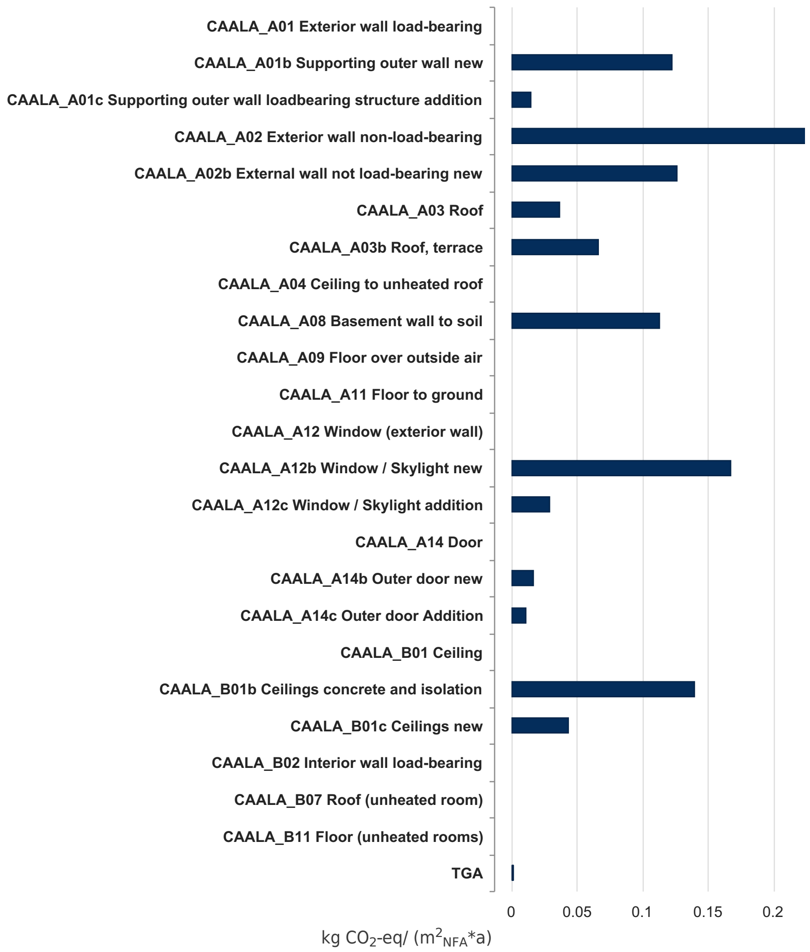


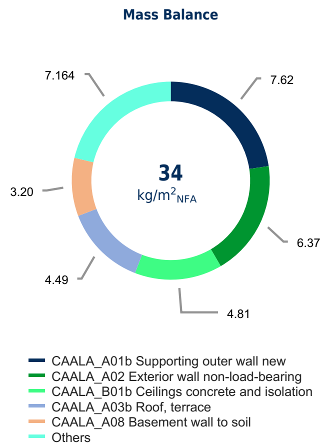


IV. ENTIRE TRANSFORMATION

The final analysis is looking at the impact of all changes made in the transformation. Hence, it is calculating the impact of all additions, including the additional layers and the new rooftop additions. Here the impact of the existing structure and additional reused materials is set to zero. This is a full life cycle analysis including the modules A1-3 Production, B6 Energy demand in use phase, and C3+C4 End-of-life.

Global warming potential (GWP)

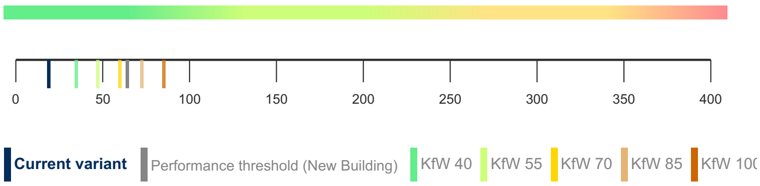




2.1. Primary energy demand

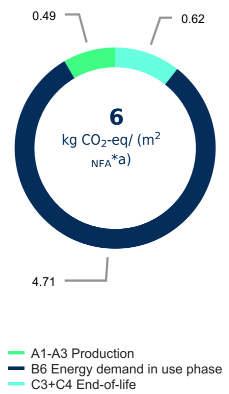
18

kWh/(m^2_{AN}*a)



Excluding user energy

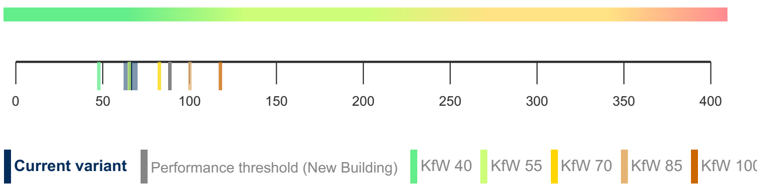
Global warming potential (GWP)



2.1. Primary energy demand

65

kWh/(m^2_{AN}*a)



Including user energy of 30 kWh/(m^2NFA*a)

Global warming potential (GWP)