RECYCLED BRICKS

A study on how recycled bricks can bring architectural qualities through the design of the façade

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Abstract

The majority of waste in Sweden is generated by the construction industry, where bricks from demolished buildings are often thrown away and ending up in landfills. This indicates that bricks are not a priority in the waste hierarchy. Despite the costs associated with waste management, these building materials are often in good condition for reuse in new projects. The current linear model in the construction sector leads to disposal of old materials and continues the production of new ones. This cycle begins with the extraction, production, consumption and disposal, resulting in a significant negative impact on the environment.

According to the United Nations Agenda 2030, changes are necessary to achieve the outlined goals. Sustainable Development Goal 12 emphasizes responsible production and consumption, including Milestone 12.5 specifically focusing on waste reduction through prevention, reduction, recycling and reuse. Working towards these objectives will enable a shift from a linear to a more circular economy.

Bricks, being a commonly used construction material with significant potential, could be used more sustainably. This can be achieved through three main approaches. Firstly, adopting gentler demolition methods that allows for a higher percentage of material to be reused compared to conventional methods. Secondly, integrating a demolition plan into the initial building project planning, which includes selecting the appropriate mortar for the specific bricks, thereby enhancing sustainability and overall efficiency. Lastly, as suggested in the report *Facade Design Stages: Issues and Considerations* (2019), reducing the variety of materials simplifies the demolition and sorting process, making it easier to reuse and recycle materials. Lastly, as suggested in the report Facade Design Stages: Issues and Considerations by Moghtadernejad (2019),

This thesis aims to challenge preconceptions about recycled bricks by integrating life cycle assessment (LCA) through Environmental Product Declarations (EPD) with the life-cycle cost analysis (LCC), together with architectural qualities and criterias.

Additionally, the project includes a design aspect that incorporates recycled bricks into the planning of a new building for a residential building situated on Tredje Långgatan in central Gothenburg, Sweden. The proposal arises from a comparison between two distinct recycling methods in comparison to using newly manufactured bricks.

Keywords: *recycled bricks, circular economy, design principle, facade design, sustainability, construction details*

Terminology

Load Bearing
refers to structural elements in a building that support its weight and transfer loads to the foundation

Recycled
refers to converting waste materials into reusable products, reducing waste and conserving resources for a more sustainable environment.

Comprehensive strength
refers to a materials' ability to withstand different types of loads and stresses

Stretchers
a brick that is laid flat with its longest side exposed.

Headers
a brick that is laid flat with its shortest end exposed.

Waste hierarchy
It begins with prevention, which involves minimizing waste generation, followed by reuse, recycling, recovery, and, as a last resort, disposal.

Mortar
Mortar is a mixture used in masonry construction to bond bricks together.

Linear economy
A linear economy is a traditional economic model characterized by a "take-make-dispose" approach to resource use and waste management.

Masonry brick
Masonry bricks are laid in courses using mortar to bond them together, forming a durable and load bearing structure.

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01.

INTRODUCTION

This section will offer an overview of this report, explaining its purpose and highlighting the significance of the topic and problem statement. .

Background

The construction industry is responsible for the majority of waste in Sweden (Andersson & Olsson, 2010). Bricks from demolished buildings often end up in landfills at the bottom of the waste ladder. Despite the costly process of waste management, these building materials are often in good condition for reuse in new projects. However, due to the linear model of the economy in the construction sector, old materials are disposed of, and new materials are continuously produced. This model is sometimes referred to as the take- make- waste economy (European Commission, n.d.).

The production of bricks has a significant negative environmental impact (Nordby et al. 2009). The burning of clay requires a large amount of energy to reach high temperatures, resulting in the release of greenhouse gas emissions such as carbon dioxide and toxic gas.

Nevertheless, there is a substantial demand for newly produced bricks due to their cost-effectiveness and ready availability (Baban & Dang, 2010). Cost has consistently been a crucial framework parameter for how buildings are being created, and is frequently a barrier to achieving sustainability. However, including a life cycle perspective is essential in decision- making, and should be automatically adopted to ensure the importance of sustainable solutions (Nordby et al. 2009). According to Nordby (2008), a comprehensive comparison of environmental profiles is only possible when considering the entire life cycle and the overall financial costs, referred to the environmental lifetime.

Transitioning from a linear economy to a circular one requires innovation and education in designing the future built environment (European Commission, n.d.). New technologies and innovative business models play a significant role in this transition.

To reduce greenhouse gas emissions in the construction sector, it is urgent to make thoughtful choices. However, there exists an informational and communicational gap between supply and demand projects (Copeland & Bilec, 2020). Prioritizing and demanding recycled materials for new building designs is therefore crucial and will decrease the use of newly manufactured materials. Transforming new constructions into material banks for upcoming projects helps minimize waste and significantly contributes to the principles of a circular economy.

This research report will therefore focus on the differences between recycled bricks, using two different methods, and newly manufactured ones. It will emphasize the environmental advantages of recycled bricks in a Nordic context. A comparison of the two materials will be presented through life cycle assessment and life-cycle cost analysis. The design part will be showcased through one facade proposal located on Tredje Långgatan in central Gothenburg.

Research questions

Main questions

“ How does the environmental impact of recycled bricks differ from newly manufactured bricks in a nordic context? ¨

“How can recycled bricks be implemented in a facade in central Gothenburg?”

Sub questions

“What is the difference between recycled bricks and newly manufactured bricks from a life cycle assessment and life cost cycle analysis?”

“How can the construction industry move from a linear economy to a more circular one by using recycled brick instead of newly manufactured bricks in today’s architecture”

Aim and purpose

The objective of this thesis is to understand the relevance of recycled bricks in building proposals. By investigating two brick buildings, located in Nordic context and employing different recycling methods, the report aims to highlight the differences compared to buildings constructed with newly manufactured bricks.

This investigation will involve case studies and analysis through life cycle assessment (LCA) and life cycle cost (LLC). Additionally, criteria outlined in the report *Facade Design Stages: Issues and Considerations* by Moghtadernejad (2019) will be considered.

Furthermore, this comparative study can serve as a valuable resource for decision-making in material for new building proposals. The insight gained from the theory and analysis part will serve as a foundation for the design proposal.

Additionally, the aim is to raise awareness and share knowledge about the advantages of recycling bricks, while also challenging existing perceptions about recycled bricks.

Delimitations

This report will analyze life-cost cycle analysis and life cycle assessment data gathered from stakeholders located in the nordic countries. The LCC analysis will just focus on the material, labor and maintenance costs. And the LCA will only calculate the phase A1-A3. The data for specific LCA and LCC in this report is calculated by each stakeholder.

The primary references are mainly from European literature studies. The design proposal focuses exclusively on the facade in a Gothenburg context, Linnéstaden, and does not aim to develop a comprehensive building.

Methods and tools

Literature studies
Reviewing literature on the topic, recycle bricks, for a comprehensive understanding of the material in a sustainable aspect. Additionally, define principles from the report ”Facade Design Stages: Issues and Considerations” to further analyze case studies and work with a design proposal.

Data analysis
Use life-cost cycle (LCC) analysis, which include calculations of material, labor and maintenance costs. Additionally, conducting life cycle assessment (LCA) by using an environmental product declaration (EPD published by the stakeholders.

Research by Design
Use design practice and creative process into the research methodology to deepen understanding and insights. The report also includes an inventory of window and door openings, as well as brickwork details on surrounding buildings on Tredje långatan. Additionally, traditional architectural composition principles such as proportion, geometry, and symmetry will be applied to achieve architectural harmony.

Interviews
Using semi-structured interviews to gain an understanding on how stakeholders in today’s market actively use strategies for a circular economy. These interviews aim to provide background information on recycled bricks and their progress.

The initial interviews were conducted with Lendager Group on November 23rd, 2023, followed by another interview with Bruksspecialisten on November 24th, 2024. Additionally, a workshop was conducted with Brukspecialisten during spring 2024, alongside personal communications with architects and other stakeholders. These interactions laid the groundwork for this thesis and contributed to a more comprehensive

Case Studies
To gain design benefit and aesthetics with reused bricks by investigating facade proposals on already finished building projects. Details such as mortar quality, structural strength, and design flexibility will be investigated.

Schematic

This schematic provides a summary of the progress made throughout the research period.

Evaluation
get familiarized with recycled bricks in a sustainable context. discourse findings and delimitations

Identify
phrase a research question and frame a discourse

Literature review
theory investigation, report reading and case studies findings

Site visits
visit reference projects for the case studies.

Interviews
understand the architects and stakeholders point of view

Case study 1
Villa Lorensberg

Case study 2
Resource rows

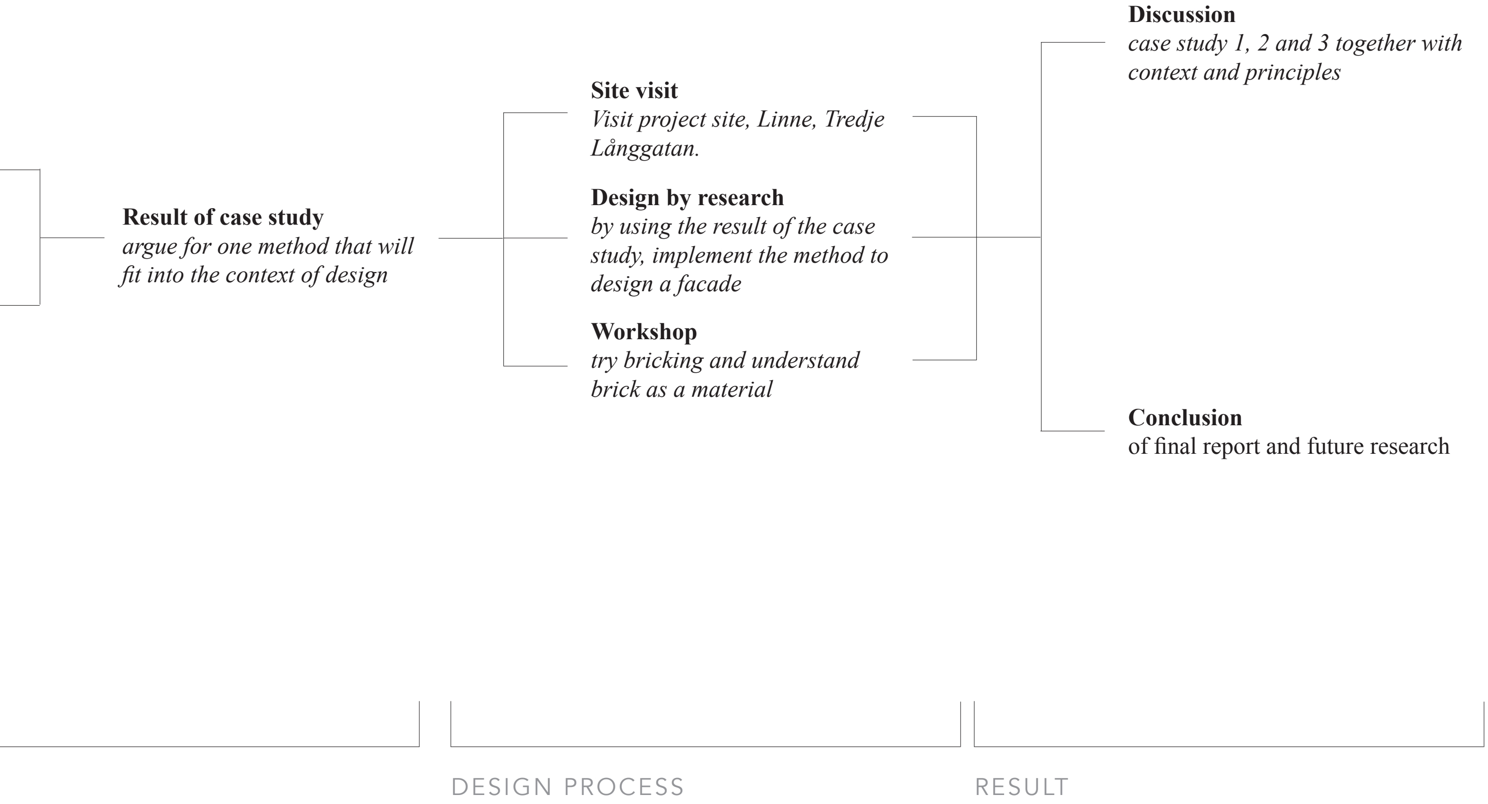
Case study 3
Merkurhuset

Litterature review
find criterias for brick facades and regulations within the nordic context

Critics schedule
as a result of the literature review, find a system how to rate the methods and product

DEFINE

PREPARE AND ANALYZE



Result of case study
argue for one method that will fit into the context of design

Site visit
Visit project site, Linne, Tredje Långgatan.

Design by research
by using the result of the case study, implement the method to design a facade

Workshop
try bricking and understand brick as a material

Discussion
case study 1, 2 and 3 together with context and principles

Conclusion
of final report and future research

DESIGN PROCESS

RESULT

02.

THEORY

This theoretical section will provide background details on the role of bricks in sustainable development and their potential to shift from a linear economic model to a circular one. It will explore three tools, LCA, LCC and EPD - that measure sustainability within the construction sector. Additionally, it will address the issue of waste generated by the construction industry.

From linear to circular economy

The construction industry accounts for up to 40% of global material usage and contributes to 35% of global waste. Today, building materials require large amounts of resources to manufacture and are rarely recycled. Once the material reached the end of the life cycle, it either downcycled or ended up as building waste. Meaning that the value of the material is lost. This shows a linear economy model (Danish Environmental Protection Agency, 2016). See figure 1, page 20.

However, in a circular model, the value of products and materials is maintained for as long as possible (EC, 2015). See figure 2, page 20. According to the European commission, (European Environment Agency, 2023), the need to transition from a linear to a circular economic model is crucial to ensure sustainable growth for the EU. This transition involves minimizing waste and resources use through reuse and creating additional value for products at the end of their life cycle. The resource savings could contribute to reducing climate change by preventing emissions linked to the extraction and processing of new resources (European Environment Agency, 2023).

The following section introduces three methods for comparing newly manufactured materials with reused ones, making it more appealing to shift from a linear economic model to a circular one. These methods focus specifically on building materials like bricks, using product information provided by the companies or producers.

Life cycle assessment

Life cycle assessment (LCA) is a detailed method used to evaluate the effects that a product has on the environment over the entire life cycle (European Environment Agency, n.d.). Through a life cycle assessment, it becomes possible to identify the stage in a building's life cycle where a certain environmental impact is the most significant. The outcomes can be used to design and build with less environmental impact (Boverket, 2019 a).

Environmental product declaration

Environmental Product Declaration is a document that provides transparent and standardized information about the product's environmental impact throughout its life cycle, by measuring the Global Warming Potential (GWP), commonly known as the carbon footprint (Boverket, 2019 b).

The information is the results from a life cycle analysis in a compressed format. An EPD consists of three parts: product data sheet, method choice, results from the environmental impact assessment. These are used in construction as crucial information in the buyer's purchase decision-making process (Climate Earth, n.d).

Life cost cycle

Life- cost cycle (LCC) analysis can be used in both renovation and new construction processes (Offentliga Fastigheter, 2022). The model specifically addresses the initial costs, operation consideration costs and final stages of the material. Using the LCC model provides advantageous decision-making when comparing different materials. By incorporating the LCC model the focus shifts from lowest purchase price to the costs over the entire lifespan of a product, which include the material, labor and the maintenance costs.

Bricks in a life cycle perspective

Understanding the material thoroughly is crucial for analyzing it through LCA and LCC. EPDs often offer information about the specific material being discussed. Below is an explanation of bricks as a material from a life cycle perspective.

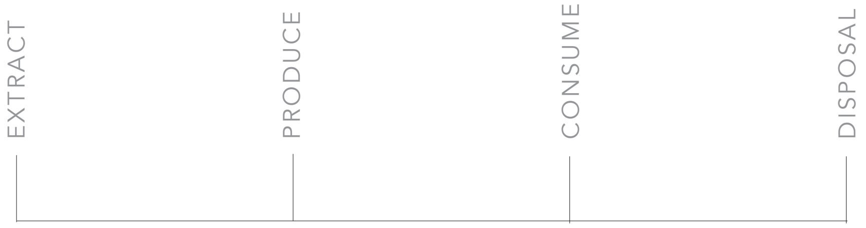
For a long period brick is known for its numerous beneficial properties as a building material. In Sweden, a significant quantity of bricks are imported from Europe, particularly from the Netherlands and Denmark, where extensive brick production occurs (Öhrn & Isaksson, 2014).

The manufacturing process for bricks is relatively demanding and results in a considerable environmental burden. Clay is heated to very high temperatures, requiring large amounts of energy input and leading to the release of CO2 and toxic gases (Nordby et al. 2009). The energy consumption in brick manufacturing varies depending on the desired properties of the brick. For instance, a factory in Denmark uses approximately 0.7 kWh per kilogram of brick during the production phase (Rashid, 2023).

The transportation of bricks from the Netherlands and Denmark, through Kattegat, to Sweden also significantly impacts the climate due to weight and potential need for long-distance transport (Öhrn & Isaksson, 2014). This results in increased emissions, mainly carbon dioxide. Further the bricks are transported to warehouses after additional shipping, making them available for purchase in construction projects.

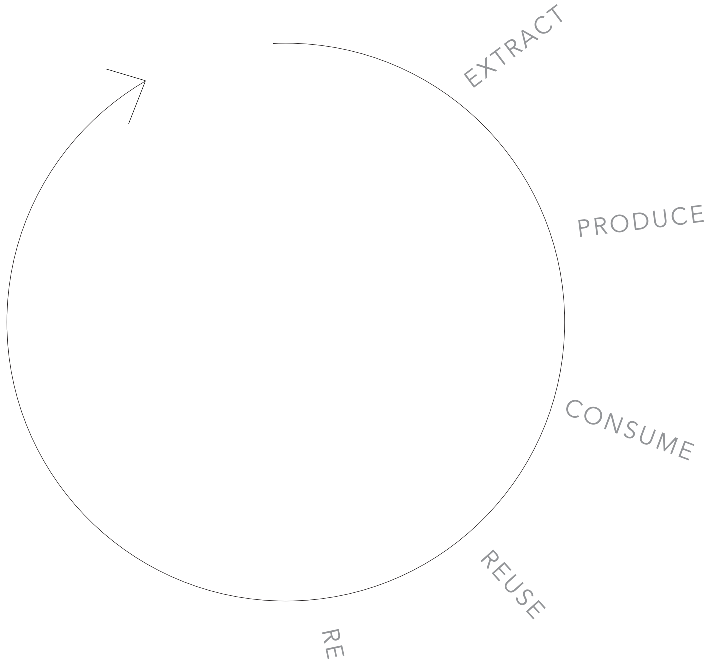
The demolition phase of bricks can vary depending on the method. In the report *LCA of the demolition of a building* (2012), a comparison is drawn between two methods: selective and conventional demolition. The conventional method involves a fast demolition of the building with assistance of machines, resulting in a small amount of recycled materials, sometimes as low as 10% (University of Borås, n.d.). In contrast, selective demolition involves a more careful approach, enabling materials to be more efficiently reused, and roughly 70% of the bricks can be reused. The report indicated that the selective demolition of bricks contributes to reducing the overall environmental impact of the building (Kuikka, 2012).

Nevertheless, there remains a significant amount of waste, including bricks, that ends up in landfills instead of being utilized for new projects.



LINEAR ECONOMY

Figure 1



CIRCULAR ECONOMY

Figure 2

Reuse and recycle building materials

In 2020, Sweden generated a total of 14,6 million tonnes of construction and demolition waste, equating to 1,4 tonnes per person annually. See figure 3. This waste comes from various sources, including construction activities, demolition, and work in other industries and households, with the construction industry accounting for the largest quantity, 14,3 million tonnes (Naturvårdsverket, 2023).

The waste includes soil, concrete, brick, clinker, asphalt and similar materials, collectively referred to as mineral construction and demolition waste (Naturvårdsverket, 2023).

Reusing and recycling construction materials can reduce the needs of new virgin and non-renewable resources while minimizing waste generation. At the same time, the extraction, production and transportation of materials for today's buildings contribute significantly to greenhouse gas emission and other environmental impacts (Gothenburg Stad, 2020).

Addressing this challenge involves transitioning to a circular construction model, where products are designed for disassembly and later to be reused or recycled at multiple stages. This approach considers buildings as valuable material banks, to maintain their value for the future. (Gothenburg Stad, 2020).

The current challenge, according to Strand Nyhlin and Åfreds (2021), lies in the absence of standardized quality control for recycled materials. This lack of standardization creates uncertainty for both contractors and clients regarding the reliability of the recycled materials. Essential certifications such as Conformité Européenne (CE marking), environmental product declaration and product data sheet are often missing, which complicates the understanding of the material's functionality and presence of specific chemical substances. CE marking means that the product meets the EU's health, environmental and safety standards, and it is generally required for products sold within the EU (Svenska Institutet för Standardser u.å). Strand Nyhlin and Åfreds (2021) express concern about the fear that the material is not strong and that it might contain substances that are hazardous to health. Conducting quality control on recycled material can be costly, often requiring the expertise of material specialists. The industry is used to signing warranties, which cannot be applied to material that lacks information (Strand Nyhiln & Åfreds, 2021)

Amounts of waste in Sweden

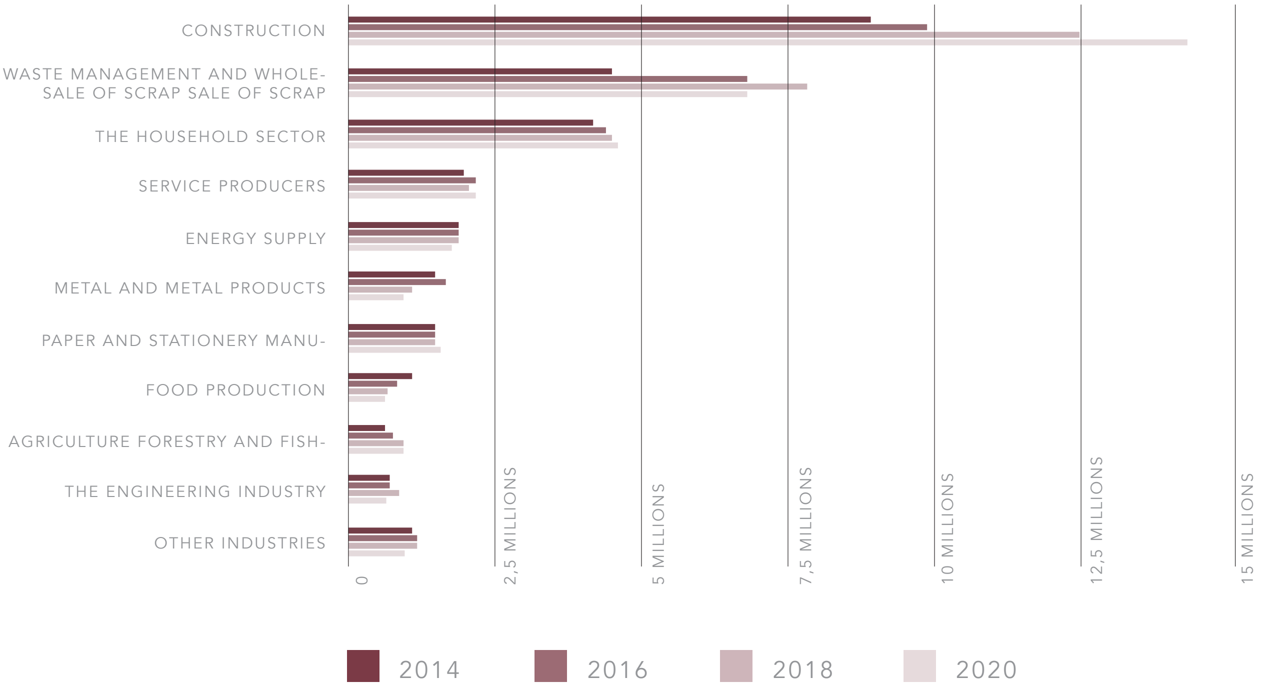


Figure 3, adapted from Naturvårdsverket (2023).

Waste hierarcy

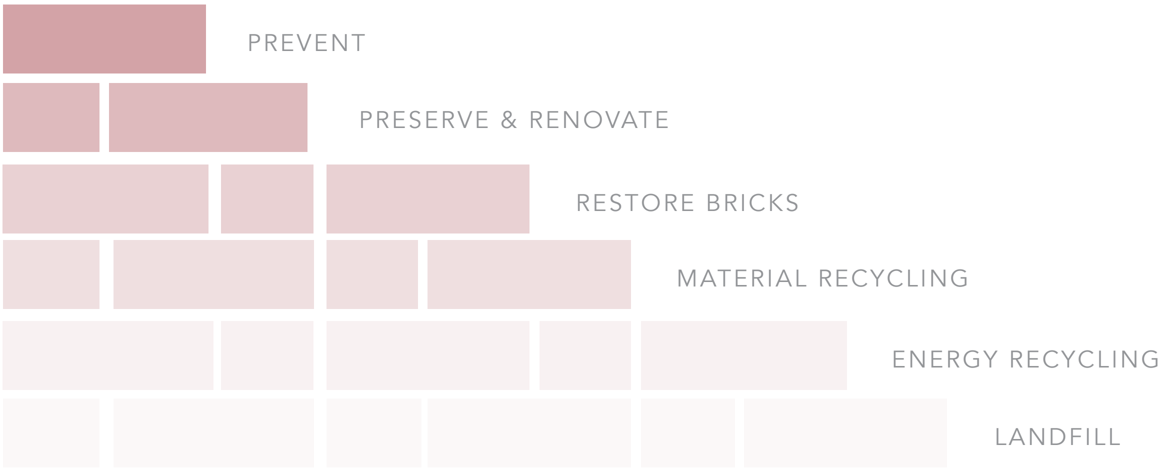


Figure 4, adapted from Brukspecialisten (n.d.)

The brick and its recycle potential

Bricks manufactured in Sweden during the 1900s and up to the million program in the 1965 reached high quality and durability. However, new building technologies developed during the million program aimed to quickly solve the housing crisis, which made reuse of the material difficult. A notable shift from lime to mortar to cement during this period made brick separation more difficult, often leading to breakage. The increased use of glues and chemical binders further contributed to a decline in recycling efforts. In the 2000s, the issue of recycling began to become relevant again in order to reduce waste generated by the construction industry (Strand Nyhlin & Åfreds 2021).

According to the report *Criteria for salvageability: the reuse of bricks* (Nordby et al. 2009), the number of materials that are used in the building also matter to the factor of whether the materials are easy to recycle or not. A lower variety of materials simplifies the process of demolition and sorting, which makes it easier to reuse and recycle the materials. This, in turn, enhances the overall profitability and efficiency of building demolition.

Whether the brick facade is recyclable relies on the compatibility between the bricks and the mortar. If the mortar proves stronger than the bricks, recycling the facade becomes impossible. Below, is a deeper understanding of these two key components.

Compressive strength

Facade bricks, composed of natural clay and sand, rely on the quality of the clay, where ”fat clay”, which is a fine-grained clay, is blended with sand and chamotte to regulate stone shrinkage during drying (Brukspecialisten, n.d. a). The amount of sand directly affects clay density and consequently the brick’s compressive strength. Adding more sand results in a leaner clay and lower compressive strength for the brick. Hard-burnt bricks are known for high compressive strength and significantly reduce water absorption during the process.

A brick with high compressive strength can be combined with weaker mortar and still produce a masonry as strong as one with lower compressive strength and strong mortar. From a recycling perspective that combination is beneficial. It is crucial for the mortar to be weaker than the brick for future reuse, ensuring flexibility and resistance to movements without damaging the brick. Therefore, the choice of mortar is important and should align with the brick’s quality and water absorption for optional adhesion.

The level of recycling increases with higher brick compressive strength, lower water absorption, and suitable mortar. This is because bricks with these qualities withstand the demolition phase better than those with opposite characteristics. Categorizing bricks by compressive strength makes it easier for informed decisions regarding facades lifespan and future reuse, thereby impacting circular and sustainable practices. Higher compressive strength contributes to a stronger, more durable wall, especially beneficial for facades exposed to challenging weather conditions. Furthermore, bricks with higher compressive strength are easier to handle during future demolition and cleaning for reuse (Brukspecialisten, n.d. a).

Mortar

The choice of mortar is crucial for ensuring the resilience potential of bricks throughout their life cycle (Brukspecialisten, n.d. b). In a Nordic context, mortars are classified as M0,5, M1, M2,5 M5 and M10, with M1, M2,5 and M5 being most common.

M1 mortar, commonly used in Denmark, primarily consists of hydraulic lime with possible additions of cement or slaked lime. The mortar is suitable for bricks with compressive strengths up to 35 MPa, M1 exhibits less sensitivity to temperature changes than M0.5, achieves faster strength development, and allows for potential reuse of bricks with strengths between 15-35 MPa. However, weaker bricks may encounter difficulties during demolition due to breakage, which can potentially result in increased waste (Brukspecialisten, n.d. b).

M2.5 is the most common in modern construction, requiring specialized cleaning processes for reuse. Bricks should have strengths over 35 MPa for optimal adaptation with low-absorption stones. The higher cement content in M2.5 mortar enabled better performance with low-absorption stones (Brukspecialisten, n.d. b).

M5 is used when the brick has lower water absorption or when additional strength in the masonry is required. The main difference between M2.5 and M5 lies in the higher cement content of M5 mortar. For premium-class bricks with high compressive strength and low water absorption, M5 mortar, even if cement-based, can be used due to the high quality of the brick (Brukspecialisten, n.d. b).

Method: Individual bricks

The first method to be introduced involves the recycling of individual bricks, wherein each brick is carefully harvested and cleaned. The result is shown in case study 1 on page 44.

When individual bricks are chosen for reuse, the brick must undergo a processing phase in order to ensure guarantee and assess their condition (Brukspecialisten, n.d.). This processing involves quality control checks on the brick, assessments of external influences, identification of the mortar used on the bricks, and removal of old mortar through cleaning methods.

Before receiving bricks and initiating the process, an inventory is conducted to ensure that the bricks meet the required quality standards to become CE marked for potential reuse. Quality control of bricks involves a control of the compressive strength through laboratory tests, particularly crucial for bricks intended for load- bearing structures and normal gentle demolition.

For bricks functioning as facades, a high degree of firing is essential to ensure resistance to external elements like cold, rain, and mechanical impact. Bricks with a lower burning rate might be suitable for internal constructions. Therefore, when reusing bricks, it is crucial to separate those intended for facades from those designed for internal use.

The span for the first tests and controls are five weeks. After that period the appropriate demolition method is selected. Thereafter, the brick that is demolished is transported in containers to the recycling production.

Upon arrival at the recycling facility, bricks are sorted hand by hand on a belt, while a clearing machine vibrates away mortar. Any remaining mortar is manually cleaned by hand, avoiding the use of chemicals or water. After the cleaning process, bricks are placed on a brick pallet and wrapped with plastic foil, ready for reused (Brukspecialisten, n.d.).

Method: Cut brick elements

The second method is made by Lendager, based in Copenhagen. The result is shown in case study 2 on page 52. They stand alone with the unique method to harvest 1 meter by 1 meter brick panels from old buildings across Denmark. In the 1960s, the mortar used between the bricks in constructions was often stronger than the bricks themselves. Facades of this type, in many cases, challenge the possibility to separate the individual bricks from the mortar, this makes the recycling process harder (Lendager Group, 2020).

Lendager has been developing an innovative method that enables the recycling of bricks and reduces the CO2 impact of construction. Cutting out square sections using angle grinders was the only viable option. The brick modules are mounted in steel frames to create an exterior facade- a prefabricated front wall that will later be fixed to a composite concrete/ timber superstructure (Cousins, 2020). In this method, the prefabricated front wall supports its own load. The result is the upcycled brick, an exterior wall construction with a facade composed entirely of reused bricks.

For example the project Resource Rows, brick modules are cut out from historical breweries in Copenhagen, such as Stødpuden and the Matrix Building at Carlsberg (Lendager Group, 2020). Additional brick modules were sourced from two schools in Aarhus and various industrial buildings throughout Denmark.

Material tests

Brukspecialisten (n.d.) conducts initial testing on their products to ensure a CE- mark. This mark indicates that the product has undergone assessment by the manufacturer and meets safety, health and environmental protection standards established by the EU. Additionally, they evaluate substances that might cause environmental and health risks, which can sometimes be found in demolished masonry. These substances can come from constituent components such as mortar, plaster or paint, or they might result from previous activities leading to pollution.

Following material testing, bricks are sorted into different qualities based on compressive strength. This sorting is crucial for making informed decisions about the facade's longevity to ensure future reuse. The quality of the brick and the selection of brick and mortar combination significantly impact the efficiency of a circular and sustainable process.

For Lendager, which harvests and cuts 1 by 1 - meter modules, it is crucial that the material being extracted extracted are certified as non- toxic building material (Fundació Mies van der Rohe, n.d.).

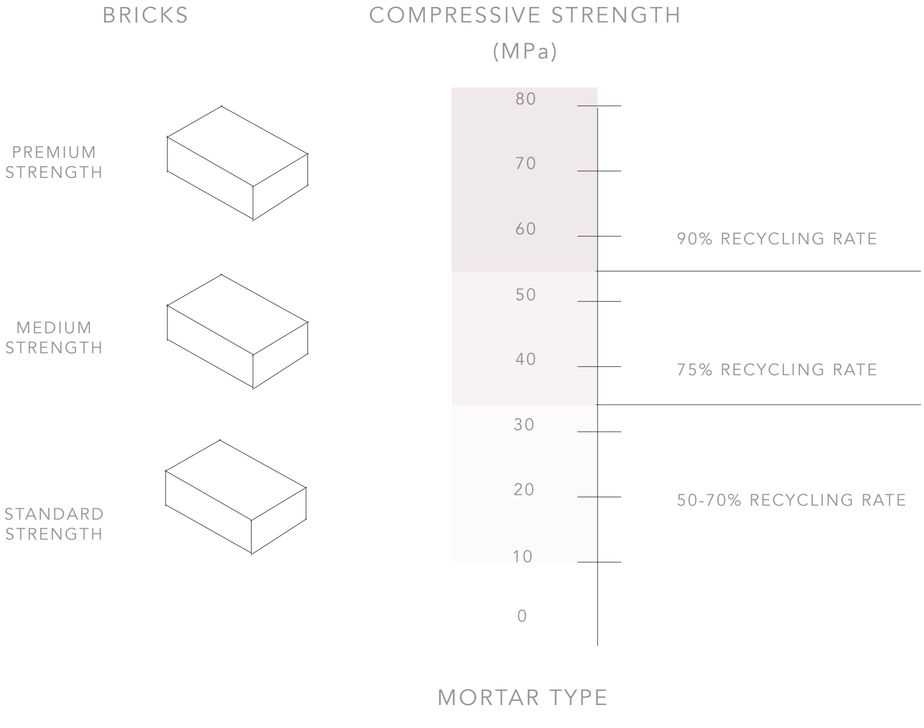


Figure 5, adapted from Brukspecialisten (n.d.)

03.

ANALYSIS

The objective of this section is to analyze two distinct methods of recycling bricks in comparison to newly manufactured ones. This begins with a general understanding of facades, highlighting their diverse characteristics across different historical periods and providing a historical overview of architectural facades in a Swedish context. From there, the focus shifts to the specific context of the design proposal, Linnéstaden. An inventory of the facades surrounding Tredje Långgatan is presented. This section concludes with a case study where three different facades are analyzed based on criterias from on the report ”Facade Design Stages: Issues and Considerations” by Moghtadernejad (2019), as well as life cycle assessment and cost analysis, comprehensive strength, and mortar types.

Facade

The term “facade” has its origin from the French language, referring to the exterior or face of a building, including architectural features on all sides (Moghtadernejad, 2019). Over time, facade materials have evolved, transitioning from clay, stone, wood, and brick to steel and glass to meet various functional and climatic needs, influenced by various architectural styles.

The design of facades play a crucial role in both the aesthetics and the protection of a structure from environmental impacts such as wind and rain (Moghtadernejad, 2019). It sets the architectural tone for the entire building, making the facade a central component in architectural design. Along with the aesthetics considerations, the facade often bears significant gravity loads and must withstand mechanical loads such as seismic and blast loading (Moghtadernejad, 2013).

Brick facades, known for durability and cost-effectiveness, are widely used in both residential and commercial buildings (Moghtadernejad, 2013). Bricks can be molded, shaped, and engraved with ease, and they also offer a variety of colors and shades, adding diversity to the design. In contrast, glass facades, mainly used in commercial buildings, allow natural light and heat. However, they present challenges in predicting their impact on energy performance as their surface area expands. Consequently, the choice between different facade material impacts a building’s appearance, functionality, and environmental performance.

Proportions

Architects are encouraged to follow geometric principles to create desirable structures, considering both visual and practical aspects (Nodeh, 2022). Geometry forms the basis of architecture which can create a desirable architectural structure. By aligning with mathematical principles, particularly in proportions, architects can create facades influenced by nature’s geometry, leading to sustainable achievements in architecture.

In traditional architecture, alongside the golden ratio, modules are employed to make consistent components. The golden ratio helps maintain size harmony, making it easier to organize different parts and create new spaces without major changes (Dewiyanti, 2019). The golden ratio theory allows architecture to be measured in aesthetics.

Over time, aesthetic theories have been developed by studying proportions, providing objective insights into order and harmony. Proportion, including various theories like the golden section, regulating lines, technical orders, and Renaissance theories, becomes a measurable factor for evaluating a building’s aesthetic value.

Basic performance attributes

According to the report ”Facade Design Stages: Issues and Considerations” (Moghtadernejad, 2019) there is an urgent demand for detailed procedures in the creation of durable and sustainable building facades. The diagram, figure 6, shows the different stages in the life cycle of a typical facade system, with each stage potentially consisting of multiple substages. For instance, the design stage may involve conceptual, detailed design, and testing stages. To achieve the desired outcome of an optimal facade system, specific criteria and requirements, such as durability, energy & material efficiency, cost effectiveness, human comfort and structural safety, must be addressed at each stage, and provisions made to meet these standards.

Originally, facades primarily addressed environmental separation and structural protection. In the contemporary context, their key attributes include structural integrity, safety, sustainability, human comfort, durability, and cost efficiency.

These criterias have been implemented and used for further analysis of the case studies in the next chapter, by using the principles as a part of an outlined diagram. See figure 12, page 51.

Durability

Designing tha facade with durability in mind is essential (Morichetto, 2019). Similar to any structural element, facades have a limited service life and will gradually degrade over time. Extending their service life optimality requires a delicate balance between maintenance requirements and the associated cost of repairs. This objective can be achieved through a comprehensive cost cycle analysis.

Energy & material efficiency

In civil engineering, sustainable development involves careful management of natural and manufactured resources throughout the design, construction, and operation phases of a project (Moghtadernejad, 2019). With the present focus on climate change within the construction industry, building facades have the potential to reduce energy consumption (Moghtadernejad, 2019). This can be done by adopting preservation methods that rely on renewable resources, waste reduction and integration of recycled materials.

Cost effectiveness

Expenses are more than the investment costs, as the construction sector in the 1960s introduced the concept of life cycle costs for assets (Morichetto, 2019). Economic calculations including costs associated with design, construction, operation, maintenance and demolition require a larger initial investment to balance out costs during maintenance phases. The financial aspect is significantly influenced by the maintenance demands of the facade, including work such as frequently repainting, washing requirements, replacement parts, among others.

Human comfort

Facades ensure that residents stay comfortable by regulating heating and cooling. They also play a crucial role in enhancing human comfort by protecting them from unwanted visitors and noise from the outdoors. Additionally, facade design can influence social interactions and the level of privacy through outlooks and insight (Morichetto, 2019).

Structural safety

As a self-load-bearing element of a building, facades must withstand significant mechanical and environmental loads, including wind, rain, earthquake, and blast loading (Moghtadernejad, 2019). Additionally, it is crucial for the facade to possess fire resistance, accommodate differential movements caused by factors like moisture, temperature variations, and structural shifts. Another important role a facade has is to provide security by preventing unwanted visitors and keeping children away from the street.

BUILDING FAÇADE LIFE CYCLE

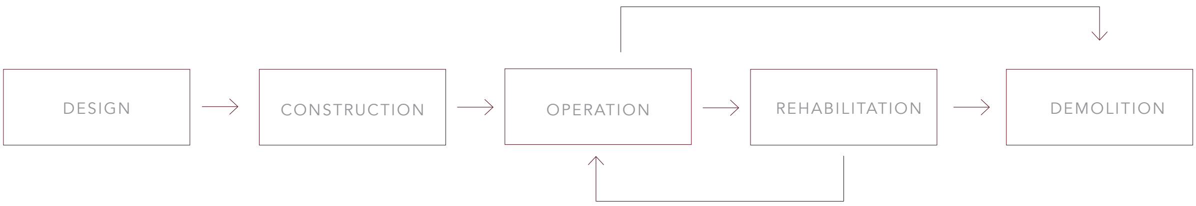
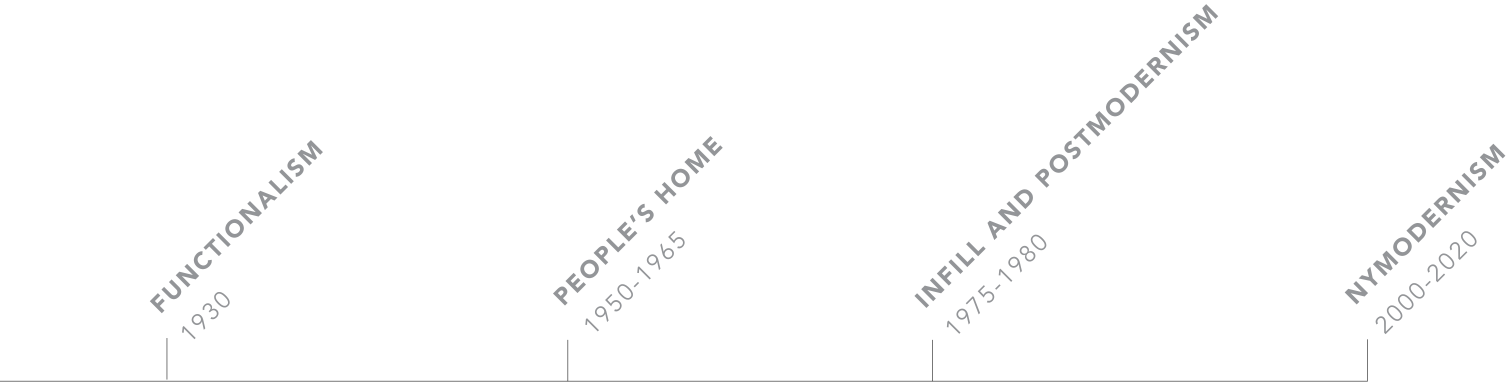


Figure 6

Historical timeline

This timeline showcases the evolution of architectural facade styles in Sweden throughout various periods. The design proposal in this report draws inspiration from the history of architecture, particularly the surrounding buildings on Tredje Långgatan. For a more detailed explanation of the characteristics of the four dominated architectural styles in Linnestaden, see page 30.

Figure 7, historical overview



Historical overview

Many residential buildings, primarily from the 1800s, have been demolished due to their poor conditions. Throughout the 1950s and 1960s, numerous buildings were torn down and replaced to meet modern standards (Björk & Reppen, 2022). However, in Linnéstaden, some buildings have been preserved and recognized as cultural heritage sites, alongside some modern infill and postmodernism structures. Below are some characteristics of the styles that are retained in the area.

Neo-Renaissance 1880

The Neo-Renaissance architectural style is characterized by particularly decorated period decorations on street facades, featuring symmetrically built structures with straight eaves and regularly placed windows, often in an odd number (Björk & Reppen, 2022). See figure 7, page 28. The exterior does not reveal the floor plan or room function, and the height of the houses is adjusted to street width, with wider streets accommodating taller buildings.

The facade structure is divided into three parts: the ground and sometimes the second floor with rusticated cuboid blocks, the middle section (floors three and four) are the most luxurious apartments with vertical elements like pilasters and columns, and the top floor under the eaves presenting a simpler design with fewer decorations. Projecting decorations are achieved through punching bricks from the decade and working them into appropriate shape. Facade decoration varies based on which category of household the house is intended for. A richly decorated relief creating an interplay of light and shadow that changes throughout the day.

The roof is flat with straight unattached eaves that are not visible from the street, and is covered with black-painted corrugated iron (Björk & Reppen, 2022). Windows follow a consistent division with fixed central jambs, tall lower panes, and square upper panes. The entrance is marked by a richly decorated portal, and some houses include a portico for access to the yard. Overall, the Neo-Renaissance style focuses on creating visually dynamic facades that evolve with sunlight and shadow.

Art Nouveau 1900-1910

Art Nouveau architecture style is characterized by nature-inspired lines and a cohesive design approach for both exterior and interior (Björk & Reppen, 2022). See figure 7, page 28. Street-facing residential buildings often include ground floor shops in central locations. The design features smooth arched plaster facades, influenced by the soft and irregular shapes of nature, with detailed relief ornaments of high artistic quality.

The structure of the facade is a mix of symmetry and asymmetry, and windows are rhythmically placed, adapting to room function (Björk & Reppen, 2022). Street-facing windows typically consist of two or three connected louvers. Balconies, bay windows, and protruding roof elements add character and increase natural light. Facades are smooth lime-plastered, painted in warm colors, and roofs can be gabled or mansard, covered in corrugated sheet metal or glazed brick.

National Romantic 1910

National Romanticism is characterized by the building's form, construction, and content with focus on clean lines, flat surfaces, and quality construction (Björk & Reppen, 2022). See figure 7, page 28. Traditional decorations are minimal, using low-key artistic elements in stone, copper, or painted sections. Buildings have powerful volumes, high-pitched tiled roofs, and broken rooflines for additional floors. The facades are asymmetric with bay windows and balconies, creating a sculptural cubism. Bare brick is ideal, with street facades in dark reddish-brown brick and courtyards in bare brick or plaster. Roofs with an upper flat and lower steep slopes are clad with red or glazed tiles and copper sheet coverings. Granite plinths on the ground floor add to the solid impression, and entrances are marked by small gates surrounded by carved natural stone. Windows typically have many small panes with slats.

Infill and postmodernism 1975-1980

The houses are carried out in a rational and cost- effective manner, often with loft corridors serving multiple apartments (Björk & Reppen, 2022). Facade elements, constructed from concrete and painted in various colors, contribute to the aesthetic diversity. These buildings vary in both height and facade appearance, incorporating bay windows and balconies. Lightweight concrete facades are often plastered with plaster, while windows come in various sizes and styles. In some cases, older five storey buildings are replaced with taller seven storey structures within the same roofline. These facades may be plastered or covered with brick. Bay windows of diverse shapes and materials enhance the street facing facades and the windows are made more varied with posts and slats.

The growing awareness of energy efficiency has resulted in stricter standards in new construction projects. Thicker insulation is used in walls, and windows are upgraded to triple glazing for improved thermal performance. This started a trend of installing facade insulation, yet many houses across the country are losing their characteristic architectural facade expressions as they are enveloped in mineral wool and metal cladding (Björk & Reppen, 2022).

Inventory of brick buildings in the surroundings

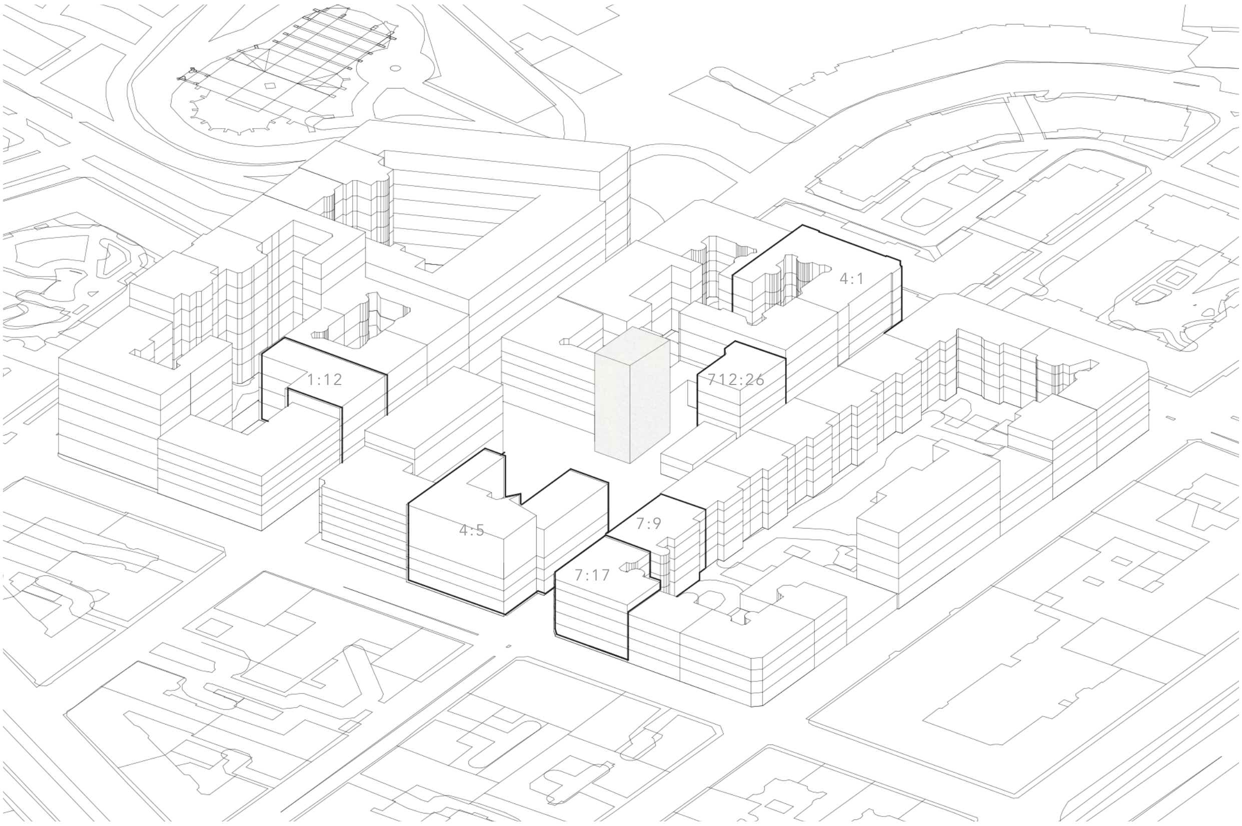
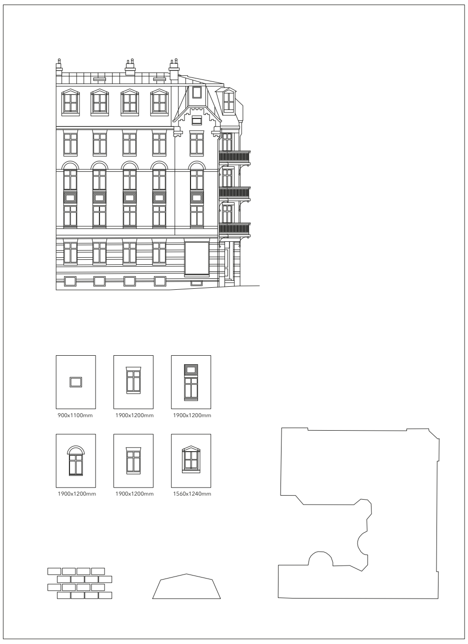


Figure 8, Linnéstaden, Tredje Långgatan

By investigating the area, several findings were made. The focus was primarily on the brick structures nearby Tredje Långgatan, were the findings where different brick bonds in a variety of red brick. The windows seemed to share the same dimensions, while the roof was slightly sloped and included dormer windows. Each floor's height was also studied. The findings from this investigation will inform the design proposal phase.



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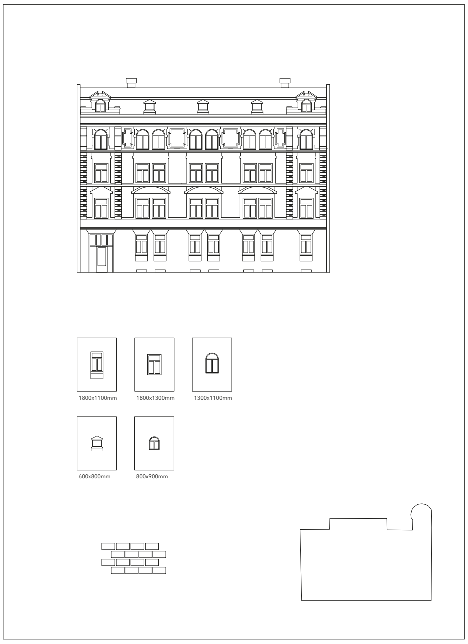

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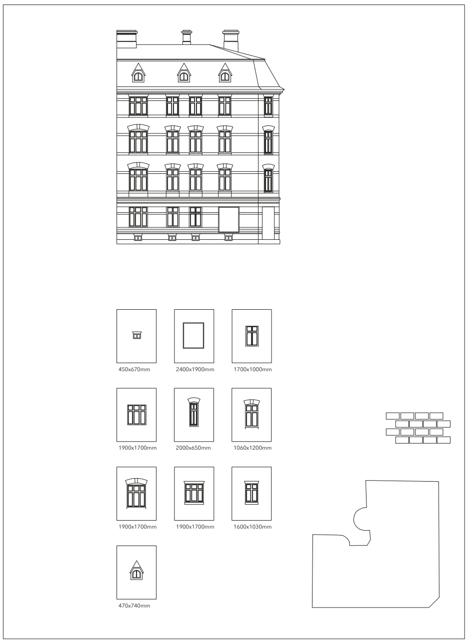

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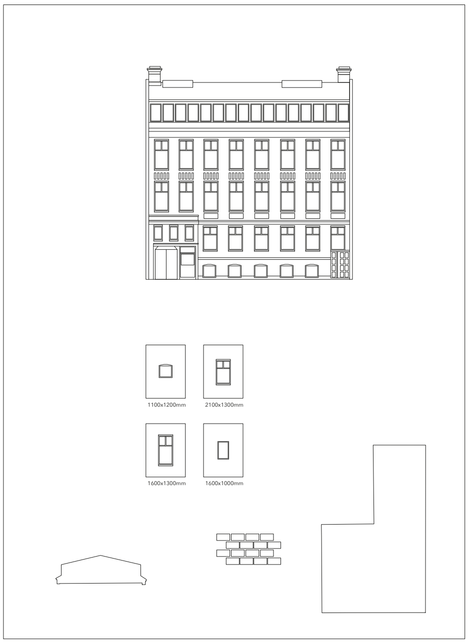

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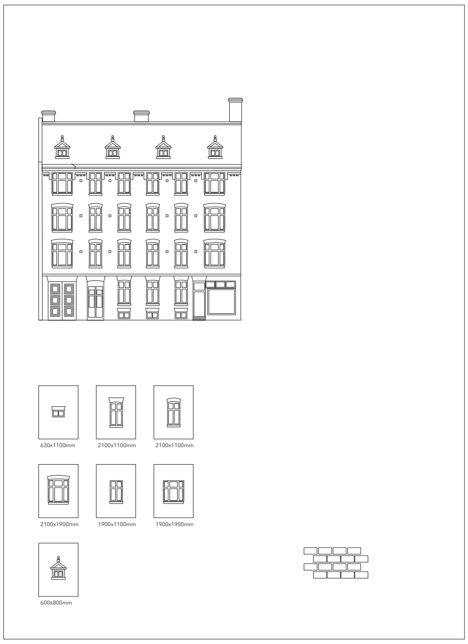

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Case study 1

Villa Lorensberg
Location: Lorensberg, Gothenburg
Year: 2023
Method: Recycling individual bricks

”New building in a sensitive cultural environment. The goal was adaptation to the location but with its own character (Inobi, n.d)”

Villa Lorensberg is located in the middle of Gothenburg and is characterized by brick houses from the beginning of the last century. The vision of the project was to create a character of its own but at the same time interact with the old brick houses in the surroundings (Personal communication, 2024).

The project is designed with inspiration from the earliest days of modernism when the architecture was playful and experimental but still had some characteristics from classicism.

The facade is partially clad in recycled brick that comes from the demolition of a hotel in Nässjö. This is a project where old building materials meet a new home.

Figure 7. Facade from Villa Lorensberg. (Inobi, n.d)

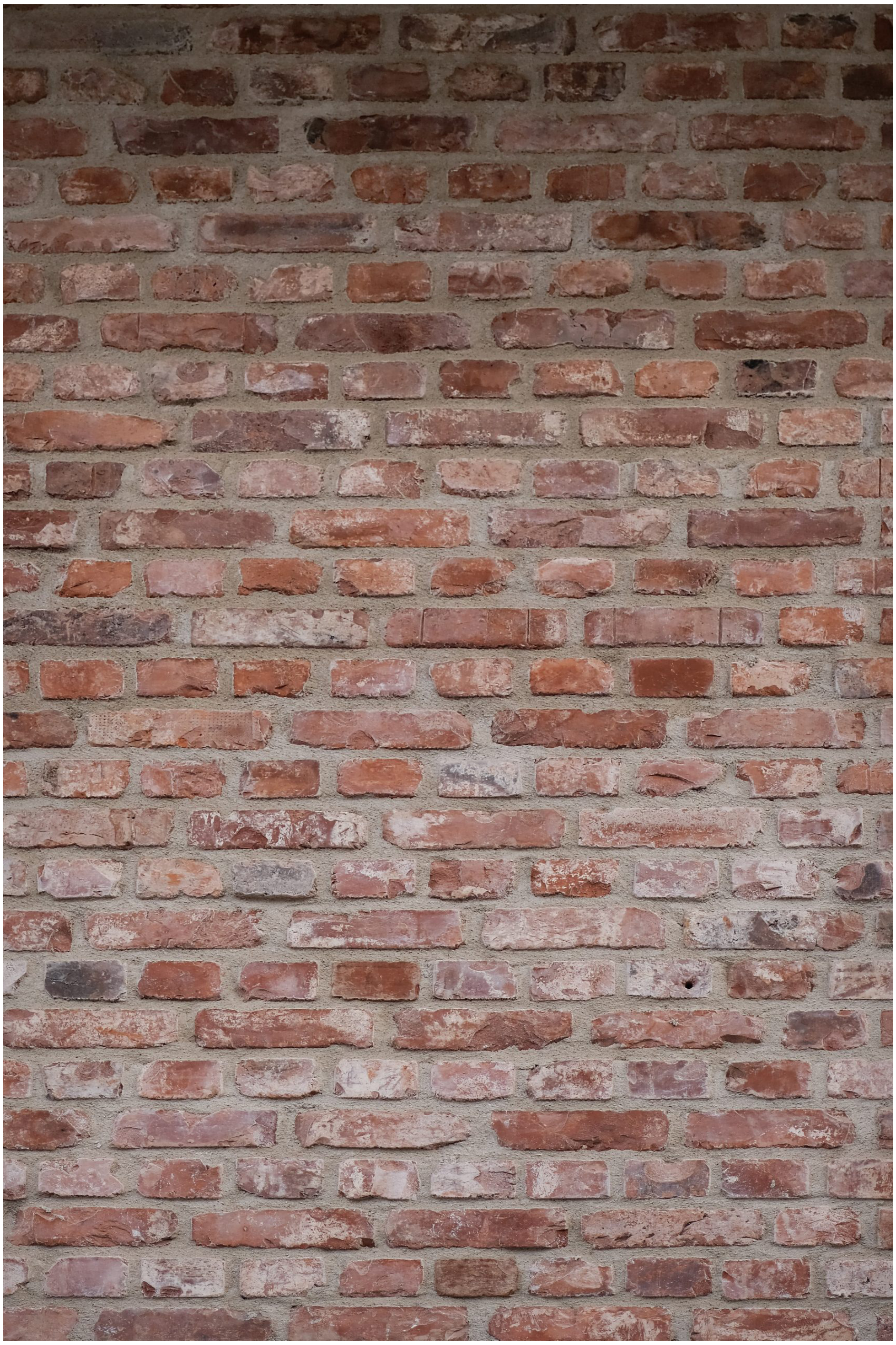


Figure 8. Recycled brick facade. (Inobi, n.d).

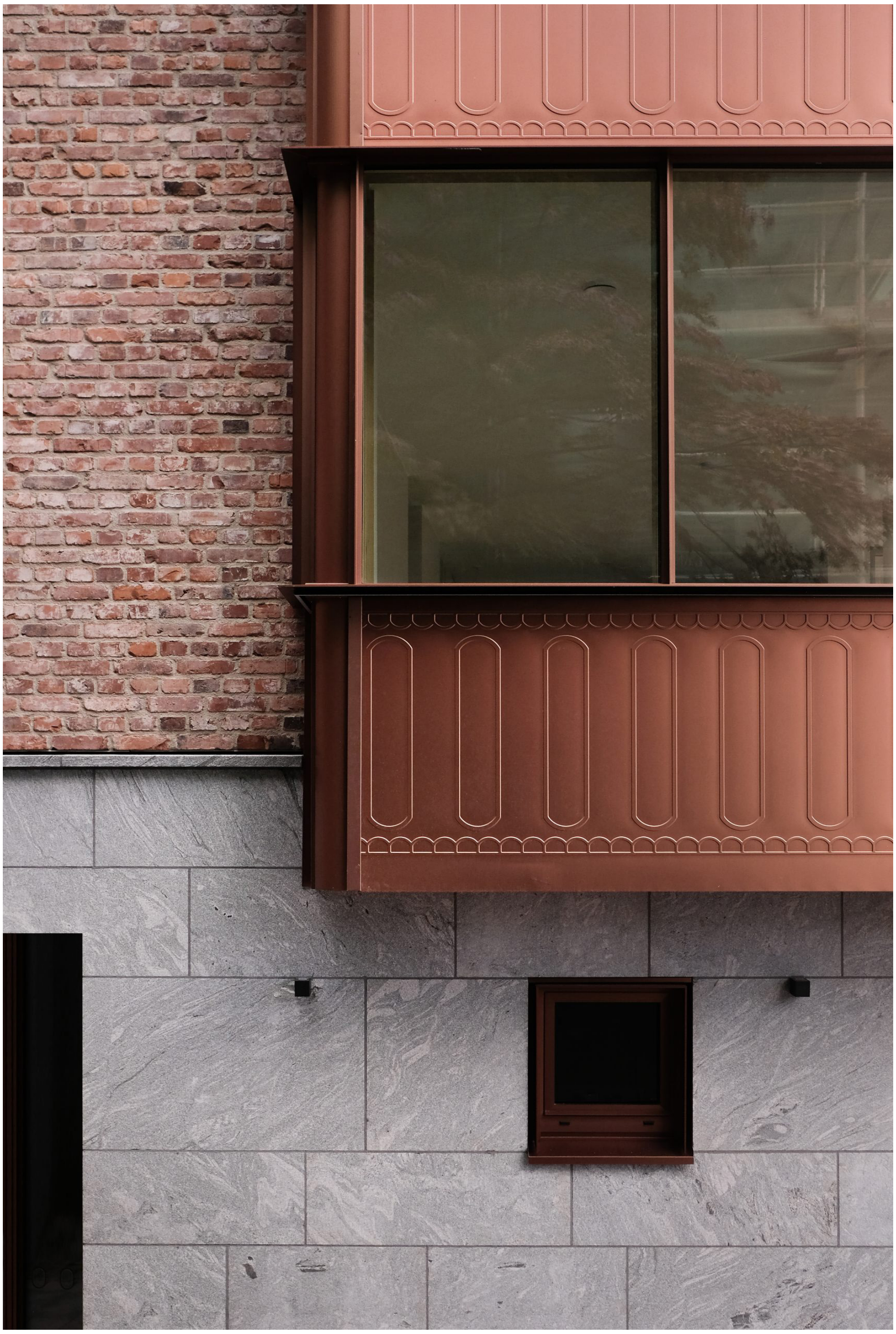


Figure 9. Recycled brick facade integrated with other materials. (Inobi, n.d).

Case study 1: Individual bricks

The brick facade of Villa Lorensberg comes from the old city hotel in Nässjö, owned by Hökerum Bygg. The company recognized the potential of recycling these bricks for an upcoming project in Lorensberg, a residential area in central Gothenburg characterized by its historic stone buildings. According to Inobi Arkitetker (personal communication, 2024) ensuring architectural harmony with the surrounding structures was a key consideration for Villa Lorensberg. Making the use of recycled bricks was a criterion from Hökerum Bygg which made it more advantageous as a design and economical aspect than purchasing newly manufactured ones reaching similar characteristics (Personal communication, 2024).

It was Hökerum bygg's first time to recycle bricks from an old project. According to an employee (personal communication, 2024) the initiative was motivated by environmental considerations ”It felt almost illegal to demolish and destroy such valuable material without recycling it when the opportunity presented itself”.

Despite their limited experience in recycling bricks, there was a willingness to explore its financial and logistical aspects, seeing it as a learning opportunity. They divided the cleaning process, sending 50 percent to Brukspecialisten and the rest to Ulricehamn, where seasonal workers were hired during the summer to manually clean and package the bricks (personal communication, 2024).

The amount of bricks sent to Brukspecialisten was first investigated by material tests. The tests showed an average compressive strength of 43 MPa where the lowest value was 31 MPa, which meet the requirements for CE marking and frost protection guarantees (personal communication, 2024) see figure 11. After approval, the demolition phase started, transporting the material to recycling production in Falkenberg, instead of to the landfill, where it was stockpiled for future use and prepared for delivery to the worksite.

The Global Warming Potential (GWP) for phases A1 to A3, see figure 10, is calculated to be 2.57 E+0.1, equivalent to 25.7 kg CO2- eq per tonne. (See appendix A.) This GWP value for the material is derived from an Environmental Product Declaration calculated according to the latest 2019 standard (15804:2012+A2:2019/AC:2021). The maintenance of the recycled brick facade is the same as it would be newly manufactured brick facade and reached the same standard.

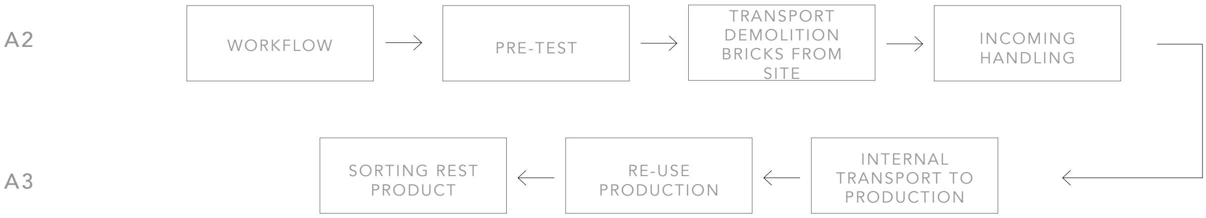


Figure 10,

LCA phases A2-A3, shows the all the phases in a life cycle assessent for a material

In terms of architecture and design, the challenge with recycled bricks, and bricks in general, lies in managing the size openings. Nowadays, many brick buildings only use bricks as a decorative facade element, requiring the bricks to support their own weight. If larger openings are more than 3,6 meters, alternative hanging methods for the brick wall becomes necessary, which potentially restricts design posabilities (personal communication, 2024).

From an economic perspective, it was more cost-effective for the company to handle brick cleaning internally, employing seasonal workers (personal communication, 2024). This approach resulted in a cost of four kronor per brick, compared to the third-party cost of 13 kronor per brick. However, the employee remarked that cleaning the bricks themselves presented logistical difficulties and complexities, making it a more challenging process.

At the project site, mortar M2.5 was used for brick assembly, which was reasonable for bricks' compressive strength for it to be reused again. See figure 11. While there is a high recycling rate for demolished brick buildings, some bricks may not meet frost standards for outdoor use, instead they can be used for interior walling or load-bearing elements. However, there are a lot of storage requirements as the bricks need to be kept dry before, during and after cleaning (personal communication, 2024).

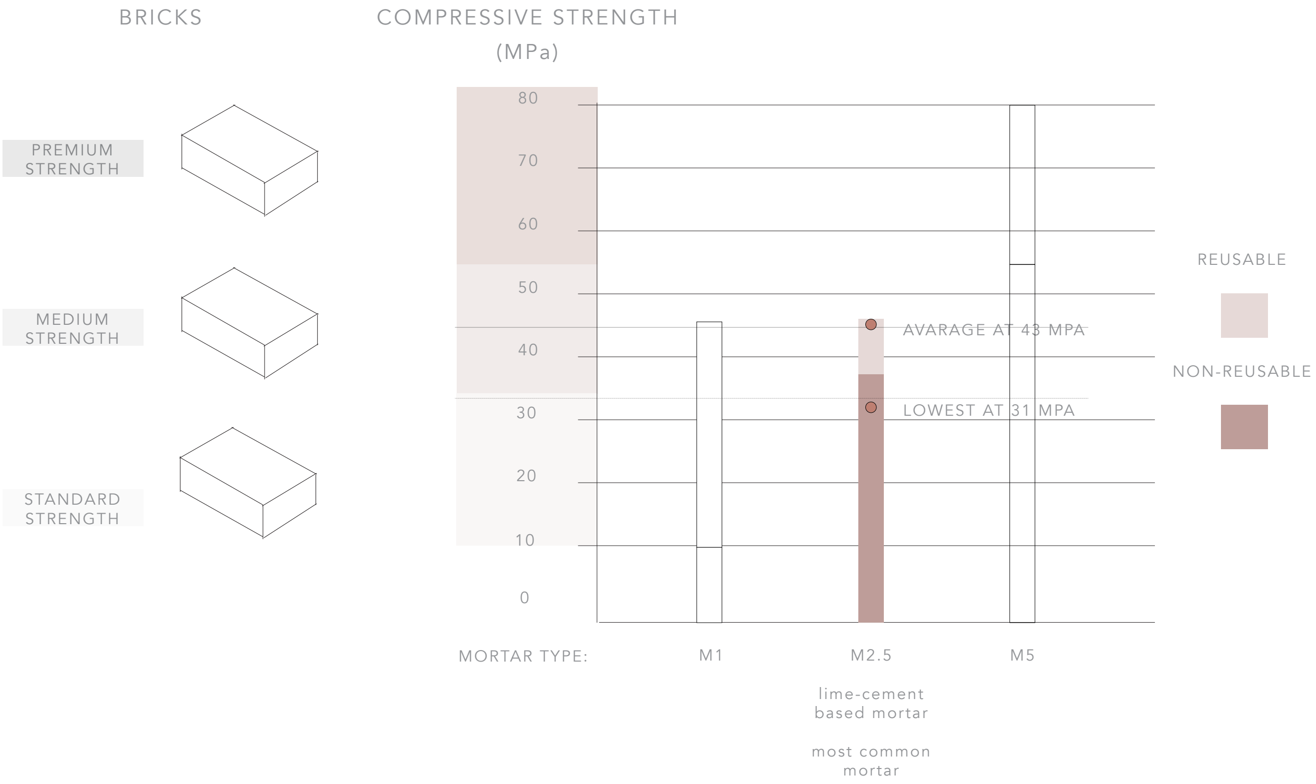


Figure 11,

Showing the compressive strenght of the bricks in Case study 1: Individual bricks, the type of mortar used, and the recycling rate. Adapted from brukspecialisten (n.d).

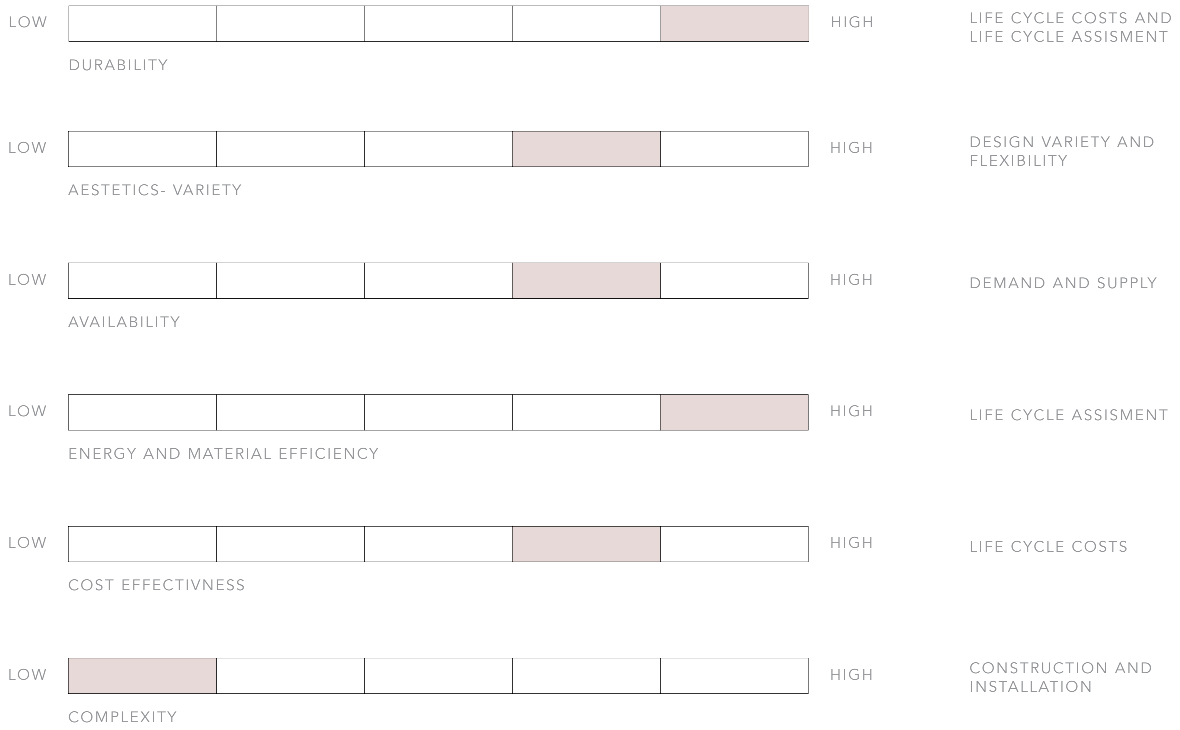


Figure 12,
The criteria for material selection, as outlined in the report ”Facade Design Stages: Issues and Considerations,” for Case study 1: Individual bricks, this serves as a foundation for the discussion on page 67.

Case Study 2

Resource Rows
Location: Oerestad, Copenhagen, Denmark
Year: 2020
Method: Cut brick elements method

” What if we could bring our buildings with us when migrating from the countryside to the city? What if we simply cut down buildings as building blocks and reuse them in the ever-expanding cities? (Lendager, n.d.)

The Resource Rows project used upcycled bricks and waste wood, along with a recycled concrete beam used as a bridge. Old windows and waste wood as rooftop community gardens huts, giving them an allotment garden feel (Lendager, n.d.).

An innovative idea was reusing brick facades from old buildings in the new construction, and cut CO2 emissions by 29% by upcycling only 10% of all building materials (Lendager, n.d.).

Figure 13. Facade from Resource Rows in Oerestad, Copenhagen, Denmark (Lendager, n.d).

Figure 14. Facade from Resource Rows in Oerestad, Copenhagen, Denmark (Lendager, n.d).

Figure 15. Facade from Resource Rows in Oerestad, Copenhagen, Denmark (Lendager, n.d).

Case study 2: Cut brick element method

The panels used in the project resource rows in Ørestad, Copenhagen, are harvested from three different buildings, including Carlsberg Factory and a Steiner School. To enable the reuse of bricks, 1 m² sections were cut using angle grinders, as the mortar bonds were too strong. These brick sections were fixed to welded steel frames and hung from load bearing "I" profile brackets, forming 3 m² facade modules that were mounted on composite concrete/ timer internal walls with insulation. This approach eliminates the need for new mortar, which typically accounts for 20 percent of the facade. The compressive strength of the bricks is not crucial as long as they do not bear loads or support their own weight.

According to the *Sustainability Upcycle Studios & the Resource Rows report* (2020), the modular brick wall archives 94% reduction on CO2 emissions compared to newly manufactured bricks, resulting in 3.1 kg CO2 eq/m² of brick facade. This equates to 19.07 kg CO2 eq per tonne, as detailed in Appendix A. These results are in accordance with the EPD standard 15804:2012 + A1:2013 (Personal communication, 2024).

The Life Cycle Assessment (LCA) calculation covers the production of all new material, potential transport of materials to the brick modular manufacturer, water and energy consumption for cutting the brick facade, and transportation of the brick elements using pallets lifters and trucks. It also includes aggregate production, handling of cut elements and specialized pallets for transporting them.

Maintenance and replacement are necessary for the back wall construction, which includes steel and concrete components. However, maintenance costs for the front wall are comparable to facades with newly manufactured and reused bricks.

The report also outlines the final cost of the brick wall, which amounts to 7116 DKK/m².

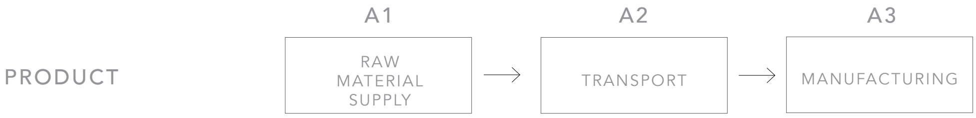


Figure 16,
LCA phases A1-A3, shows the all the phases in a life cycle assessent for a material

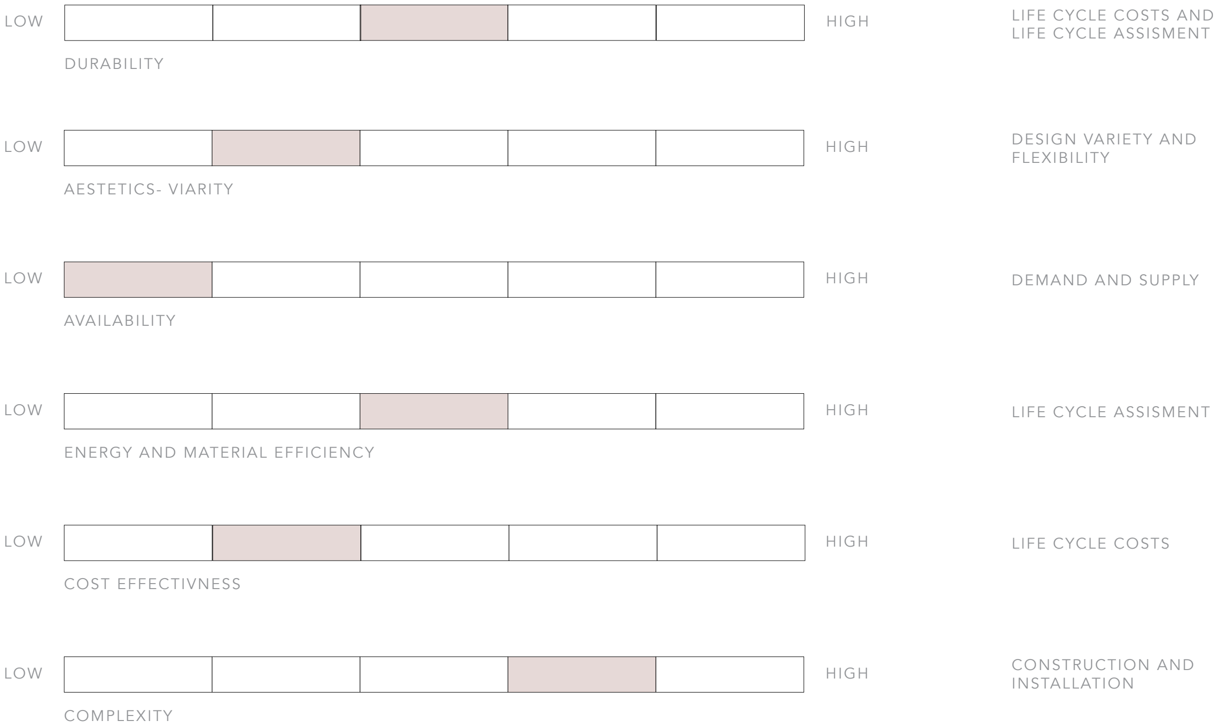


Figure 17,
The criteria for material selection, as outlined in the report ”Facade Design Stages: Issues and Considerations,” for Case study 2: cut brick element, this serves as a foundation for the discussion on page 67.

Case study 3

Merkurhuset
Location: Gothenburg, Sweden
Year: 2022
Method: Newly Manufactured bricks

Merkurhuset is situated inside the old moat in Gothenburg. It is a recently constructed office building with a concept closely tied to the area's oldest house, emphasizing the relationship between new and old (Olsson Lyckefors, n.d). Unlike many other buildings, Merkurhuset focuses on basic architectural elements such as structure, system, material, proportions and light. The brick that is used in Merkurhuset is a newly manufactured brick from Tegelmäster, is a Flensburg format, called D91 and comes from Petersen Tegl (Tegelmäster, u.d).

Figure 18. Facade with newly manufactured bricks (Olsson Lyckefors, n.d)

Figure 19. Facade with newly manufactured bricks (Olsson Lyckefors, n.d)

Figure 20. Facade with newly manufactured bricks (Olsson Lyckefors, n.d)

Case study 3: Newly manufactured brick

Merkurhuset is a project located in central Gothenburg using a decorated facade brick from the Petersen brickyard, a Danish format. with a brick of a danish format called Petersen brickyard. These bricks have a comprehensive strength of 12 MPa, while M2,5 mortar is used for assembling. The product is produced and fired in Jutland and Funen, Denmark, which is Denmark, where the clay is excavated.

The first product stage is A1, which involves the extraction and processing of raw materials, including clay, sand, sawdust, and other natural earth minerals, sourced from quarries located within a five- mile radius of the production facility. Any finished items failing to meet quality standards are recycled into new clay products, ensuring zero waste. The raw materials are crushed and ground to achieve the desired particle size, consistency, and homogeneity. Employing techniques that imitate old, traditional hand-made methods, the mixture is shaped and pressed, enhancing texture and incorporating capillaries and pores that will allow water to expand when it freezes without ruining the clay product.

Following a period of drying, the bricks are heated up to high temperatures during firing, by adjusting the firing temperature the bricks get different textures and various shades of color. Afterwards, the bricks get packaged and shipped in the final stage, A3. According to the EPD standard 15804:2012 + A1:2013, the product's Global Warming Potential (GWP) is measured at 3.03E+02 per tonne which is 303 kg CO2- eq per tonne.

In today's market, a wide range of brick manufacturing options cater to different price groups, offering various qualities and design possibilities without limitation.

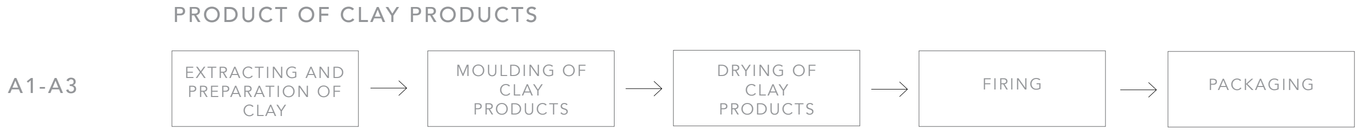


Figure 21,
LCA phases A1-A3, shows the all the phases in a life cycle assessent for a material

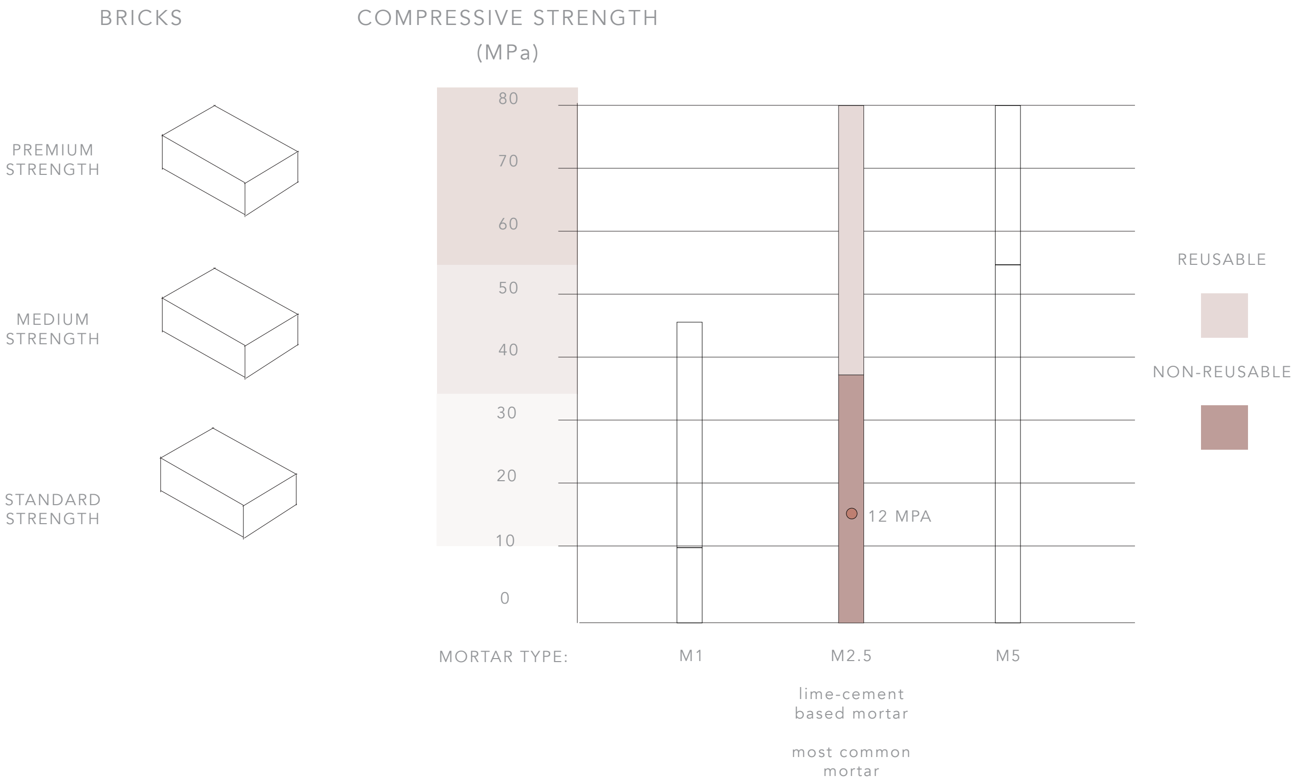


Figure 22, Showing the compressive strenght of the bricks in Case study 3: newly manufactured brick, the type of mortar used, and the recycling rate. Adapted from brukspecialisten (n.d).

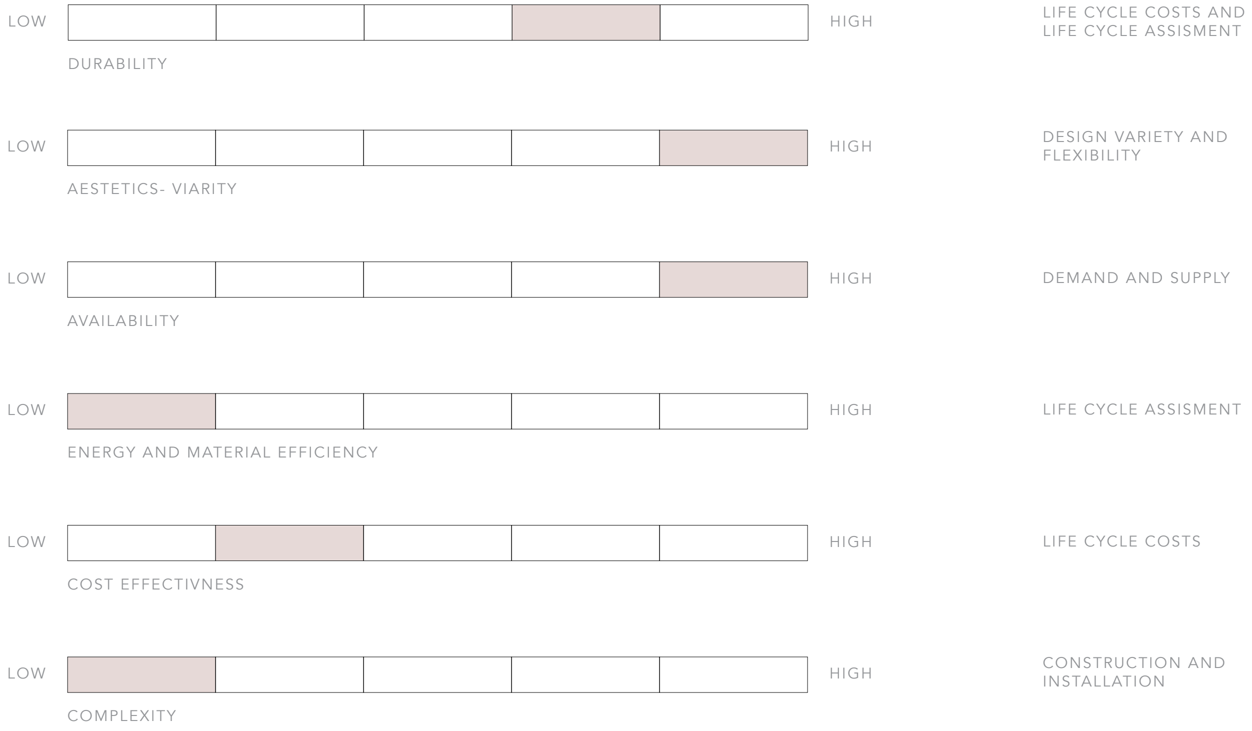


Figure 23,
The criteria for material selection, as outlined in the report ”Facade Design Stages: Issues and Considerations,” serve as the foundation for the discussion on page 67, which provides a summary of all three methods.

Result from case study

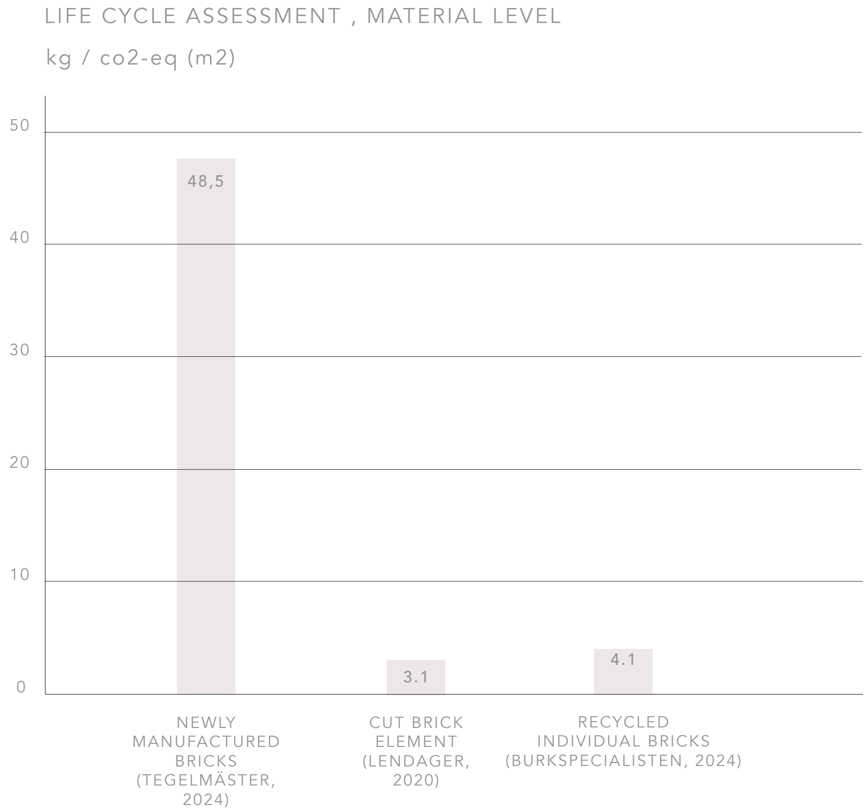


Figure 24

Newly manufactured bricks are calculated by Tegelmästers EPD for the brick Petersen, D91, using a functional unit 1 tonne. See appendix A. for manual calculations conversion from tonne to square meters. The GWP for the cut brick elements by Lendager, is collected by their report sustainability upcycle studios & the resource rows. The GWP for recycled bricks from Brukspecialisten is available in their published EPD. See manual calculations and convert from tonne to square meters in appendix A.

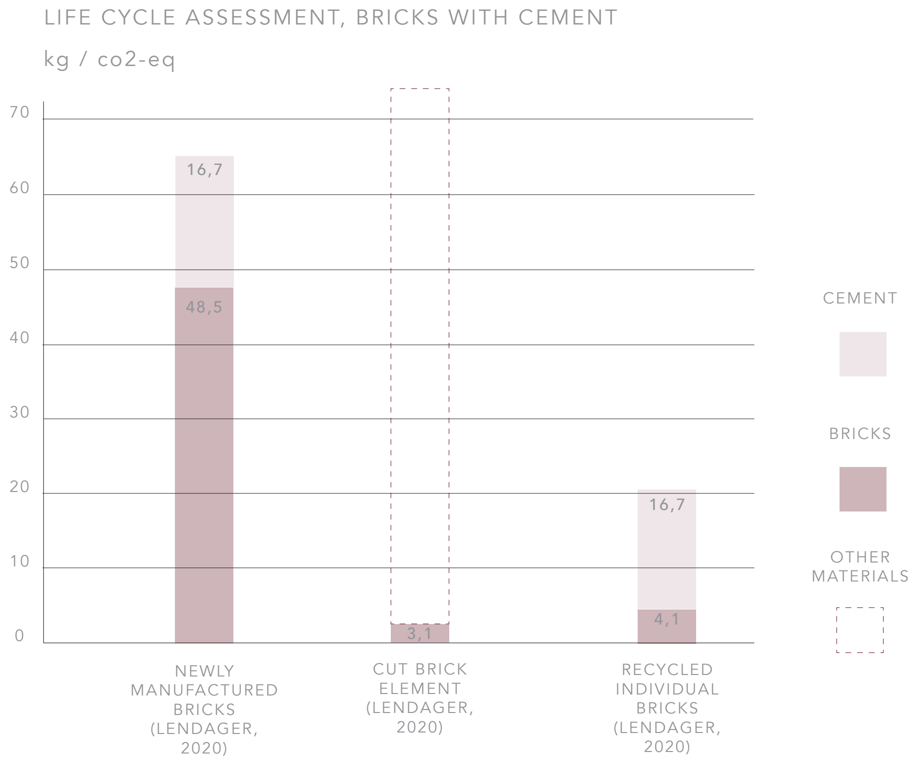


Figure 25

The GWP of cement shows the same results for both newly manufactured bricks and recycled individual bricks as the assembling of bricks are identical. The GWP for the cement depends on the brand; however, the values shown in the diagram are collected from Lendeger's report and verified against other brands for accuracy.

Since cut brick elements require no mortar, the GWP for bricks remains consistent. It is important to note that the cut brick elements are assembled using cement and steel, as shown in figure 27.

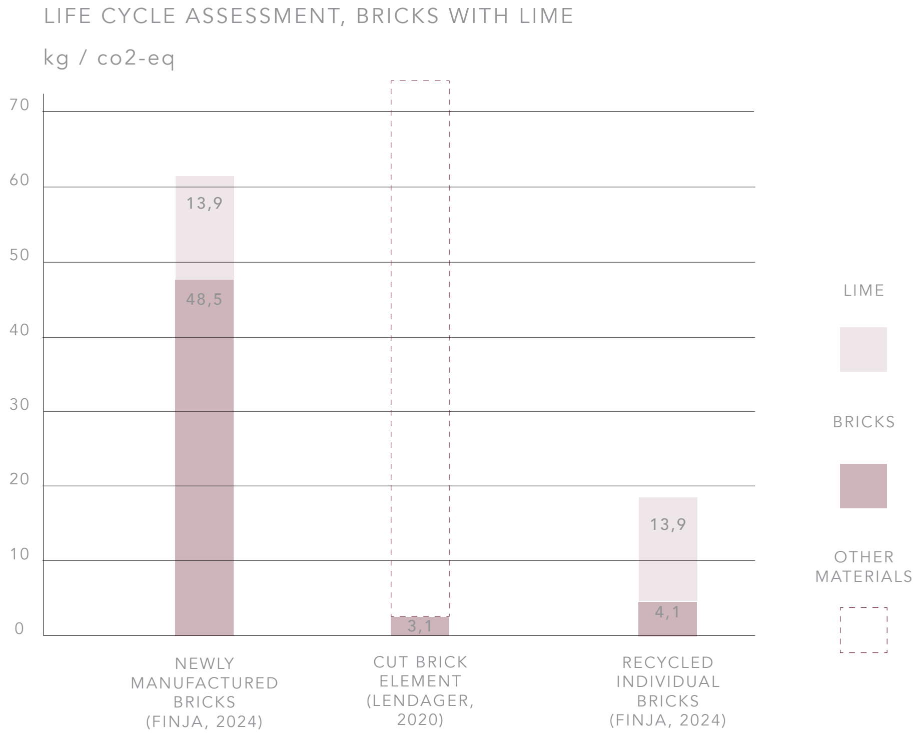


Figure 26

The bricks GWP are similar to the previous diagrams, although in this case, the mortar is lime- based. As the result shows, there is not a substantial difference in GWP between the two mortars. It is worth highlighting that cement mortar demonstrates greater strength than lime mortar.

These calculations are grounded in the EPD of Hydrauliska kalkbruk from Finja Betong AB. See appendix A.

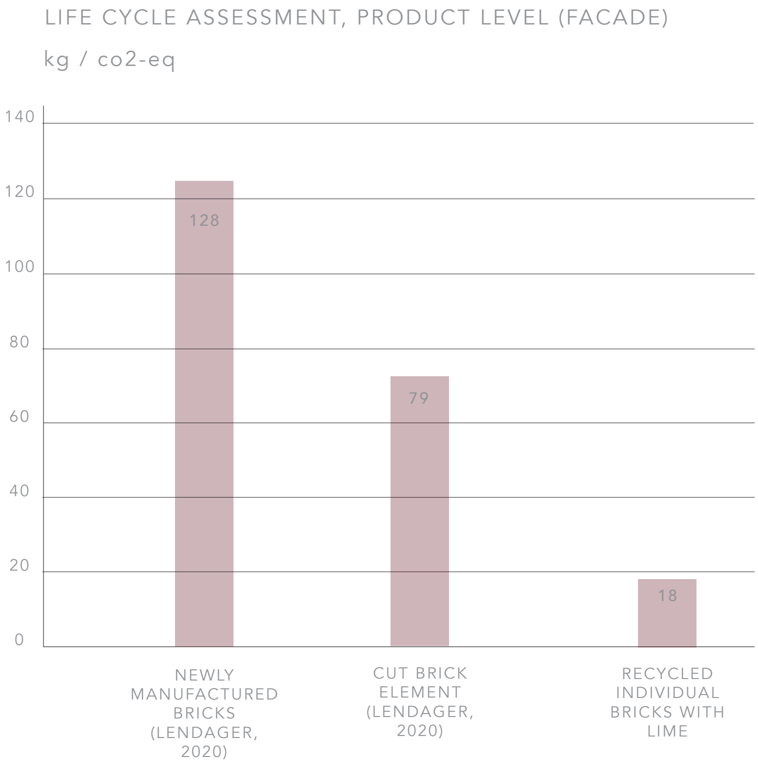


Figure 27

The outcomes of this diagram illustrate a newly manufactured brick wall together with insulation and a load bearing concrete back wall. Additionally, the cut brick wall transformed into an upcycle brick wall including concrete and mounted with steel brackets on a standard wood construction. These data are collected from the report sustainability upcycle studios & the resource rows. And the GWP values for recycled individual bricks with lime are based on previous diagrams, employing masonry brick construction as a method.

The purpose of the diagram is to demonstrate the variation in GWP by using different installation techniques and methods.

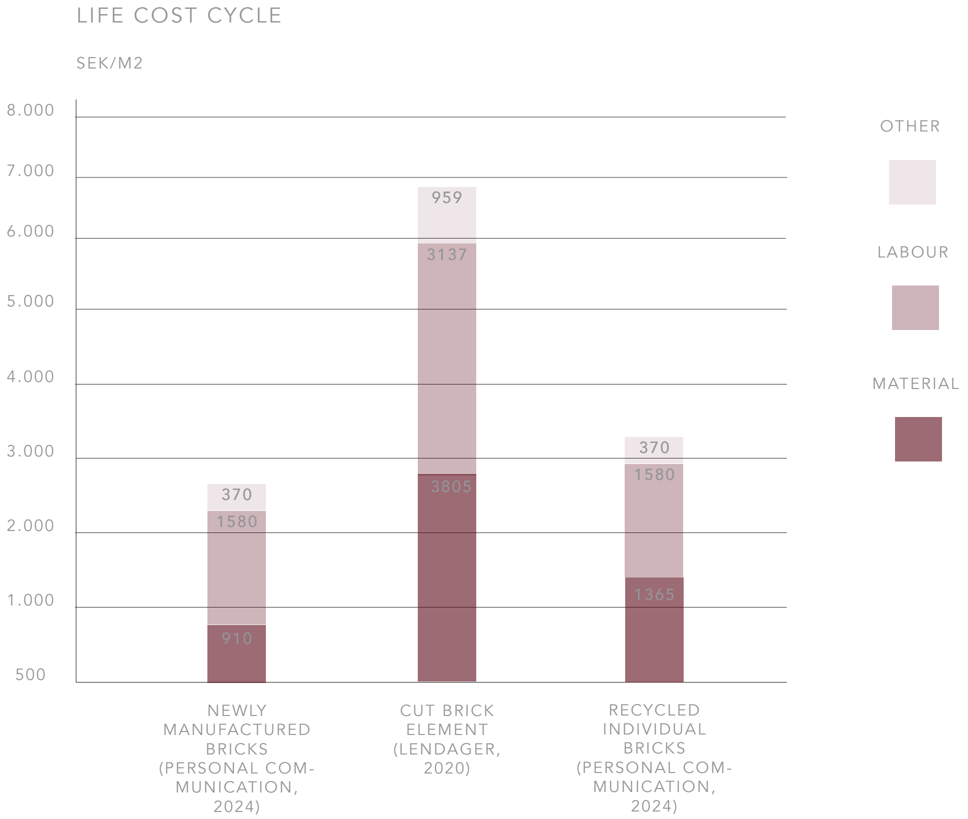


Figure 28

The material cost of newly manufactured bricks and cost of recycled individual bricks are based on personal communication with Brukspecialisten and represent a general cost per brick. The expenses for labor and other associated costs are based on the report *sustainability upcycle studios & the resource rows*. This approach ensures a fair comparison with upcycled brick walls, as both newly manufactured and recycled individual bricks share the same labor and other associated costs. It is important to note that these prices are Danish prices converted to SEK, see appendix B.

The cost analysis for upcycle brick wall is based on data from the report *sustainability upcycle studios & the resource rows*, with prices converted from DKK to SEK.

Discussion from case study

Based on the findings of the case study, it is clear that the recycling of individual bricks offers both cost-effective and environmentally sustainable advantages. In contrast to the cut brick element method, the individual brick recycling approach offers greater flexibility in both construction and design. However, the analysis indicates challenges in obtaining the CE mark for the material from a third party, requiring a comprehensive system and a company capable of managing all necessary certifications. Hökerum Bygg, the owner of the city hotel in Nässjö, managed to clean the bricks themselves for reuse in upcoming construction without the need for CE marks or guarantees. This makes things easier if the builder already owns the bricks.

Analyzing the LCA and LCC diagrams, significant differences in GWP in the LCA are observed between newly manufactured bricks and the other two recycled methods. At the material level, the cut brick element shows 94% reduction in CO2 compared to newly manufactured bricks, while recycled individual bricks show 92% reduction. However, since mortar is 20% of a facade, calculations in diagram 2 are done with bricks together with mortar. The calculations are based on each mortar's EDP and calculated per 1 m2. See appendix A. The differences between cement mortar and lime mortar are not substantial regarding GWP. However, the findings from earlier chapters emphasize the importance of selecting the appropriate mortar for disassembly purposes.

Figure 27 illustrates the facade as an element in the installation phase. The first method involves newly manufactured bricks with insulation and a load bearing concrete back wall, resulting in a total GWP of 128 kg / co2-eq. In comparison, the cut brick element has a GWP of 79 kg / co2 -eq, and the recycled individual brick facade with lime mortar has a GWP of 18 kg / co2 - eq. The method using recycled individual bricks proves to be the most environmentally friendly, although calculations are based upon the wall being a masonry brick construction, which affects brick usage depending on thickness.

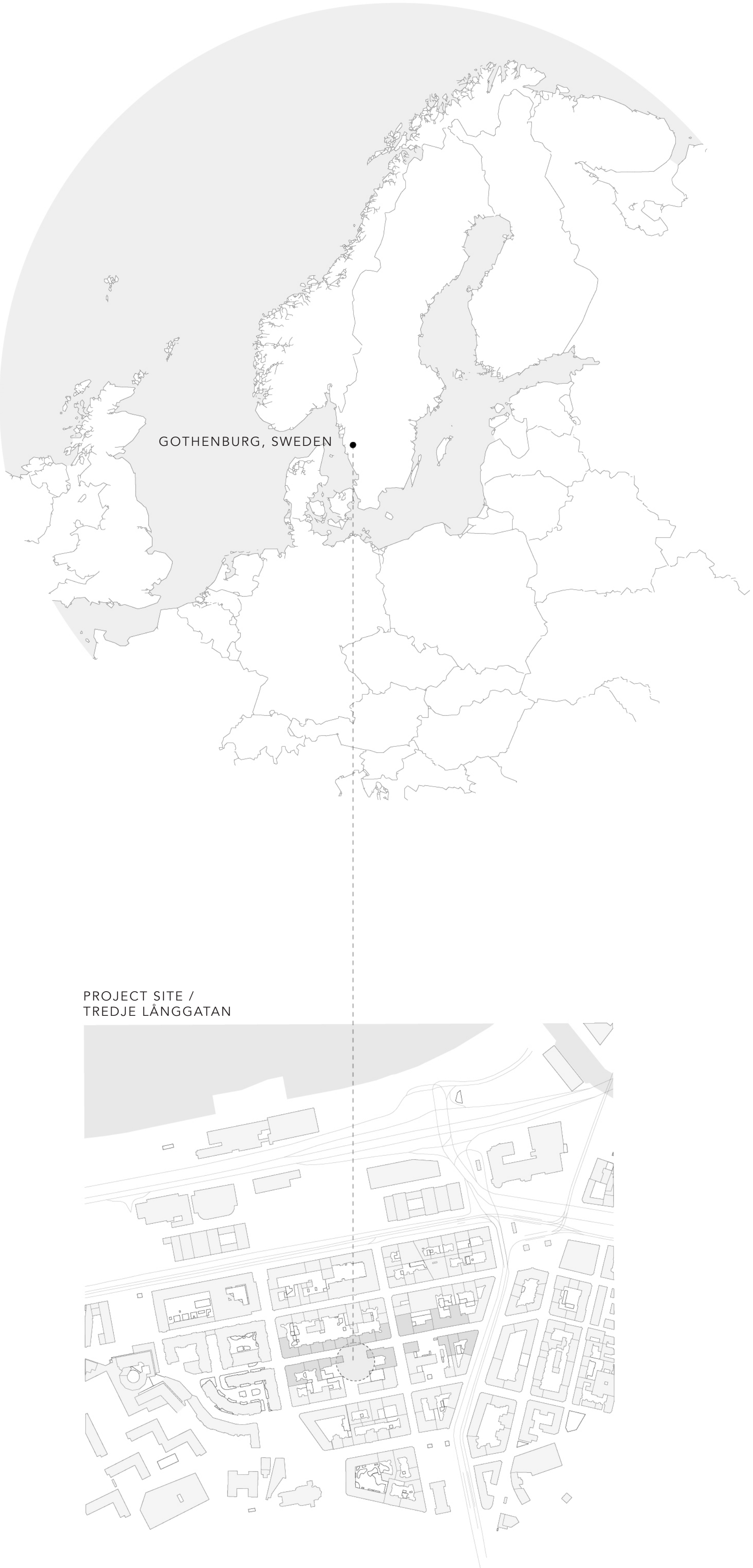
In terms of LCC, newly manufactured bricks are the most cost-effective option, with only a slight price difference compared to recycled individual bricks. The prices for each brick in both options are averaged based on a conversation with Brukspecialisten. The most significant cost difference is the difference between the cut brick element wall and the other two options. This is mainly due to the labor costs and the expenses of materials such as recycled bricks, steel, concrete, and wood.

There is a notable difference between initial price per brick and the cost over its full life cycle, both financially and environmentally. While newly manufactured bricks have the lowest LCC, they incur a very high environmental cost, as highlighted in the LCA. Given the recycled bricks reduce carbon dioxide emissions by at least 94% compared to newly manufactured bricks, is the price difference justified?

In summary, the GWP between newly manufactured bricks and recycled bricks, regardless of method, differs significantly, with up to 94% reduction in CO2 emissions by using recycled bricks. This suggests that a facade constructed entirely from recycled bricks has the lowest environmental impact. While the LCC indicates that the upcycled brick wall (product of cut brick element) is more costly, the differences in cost gap between recycled individual bricks and newly manufactured bricks is minimal. Therefore, the next phase, the design phase, will focus on the method of recycling individual bricks, along with a deeper exploration of the method for assembling individual bricks.

04.

DESIGN PROPOSAL


GOTHENBURG, SWEDEN
PROJECT SITE /
TREDJE LÅNGGATAN

Linnéstaden, Gothenburg

In the 19th century, Linnéstaden was ruined by fire multiple times (Stadshem, n.d.). The events that occurred was an important reason for the plan proposal that was put forward in 1823. The plan proposal highlighted the crucial need for regulating streets, plot quarters and construction methods to proactively address and prevent future fire incidents. This meant, plan proposal with two key measures: incorporation of foundation stone houses in the development, and the construction of four streets from east to west.

In 1866 the area began to expand with stone residential buildings and public buildings such as Oscar Fredrik's church and the fire station in the Briggen quarter. Nevertheless, it was not until the 1920s that the area was fully developed and the development period has played a significant role in changing the architecture.

After that time the stone town began to expand up until 1930. The houses in Linnéstaden were built with five to six floors and some of the finest ones were located closest to Linnégatan.

Today, the district is a residential area with a pulse and atmosphere, complemented with bars, shops and restaurants. The main street, Linnégatan, connects Järntorget in the north with Slottsskogen in the south.

Tredje Långgatan

Tredje Långgatan, situated in Linnéstaden, is one of the four streets that evolved during the 19th century (Stadshem, n.d.). The project is located on this street, between Tredje Långgatan and Fjärde Långgatan. The street differs in character and architecture styles, featuring many stone houses from the turn of the century to the 1930s. Today, the project site is still undergoing construction, and in the coming years, additional projects such as a hotel and a square will be developed close to the project site. A passage is planned on the project site, between Tredje långgatan and Fjärde långgatan to seamlessly connect these two streets.

Figure 29, headers, height 54 mm x width 108, danish format. From personal collection.

Figure 30, strechers, height 54 mm x width 228, danish format. From personal collection.

Masonry bricking

As indicated in the analysis, masonry buildings are no longer standard in construction today, instead they are replaced by other load- bearing elements like concrete (Björk & Reppen, 2022).

Based on the findings from the case study, the proposed design of a building will use recycled bricks for a masonry construction. Using brick as a load bearing element is not a new concept, but rather a traditional practice (Byggnadsvårdsföreningen, 2008). Using a one and a half brick construction for the building's bearing structure, along with an additional insulation layer and brick cladding, archives the U- value required from modern buildings (Boverket, 2020) see figure 31. Specifically, a one and a half brick wall combined with a 170 mm layer of cellular plastic insulation and brick cladding results in a U-value of 0,18, meeting the standards set by Boverket for an outer wall. See Appendix C.

Bonds

The Flemish bond, see figure 32, is a traditional pattern where stretchers and headers are alternately placed in a single course. It is often used for walls that are two bricks thick. Flemish bonds can be replicated in the half-brick outer leaf of a cavity wall by using whole bricks as stretchers, while the headers are created by half bricks called bats or snap-headers (All Brick and Stone UK Ltd n.d.). The project will adopt this bond pattern, serving as an inspiration from one of the old buildings on Trejde Låpnggatan property 4:5, see figure 8, page 32.

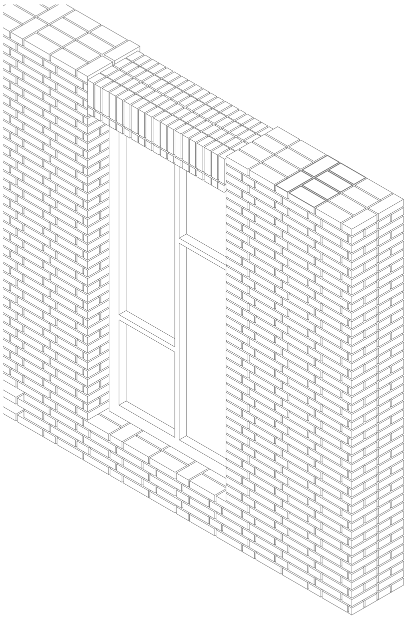


Figure 31, masonry bricking with insulation

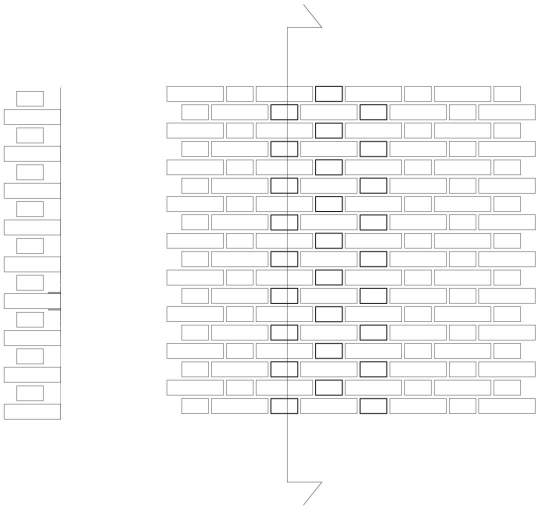


Figure 32, flemish bond

Final proposal

This project on Tredje Långgatan draws inspiration from the surrounding buildings in Linnéstaden. The neighborhood is known for its brick structures and buildings from the 1890s Neo-Renaissance, mostly vibrant red. By using recycled bricks for this project, it aims to complement the historical ambiance of the area while preserving historical heritage.

Compositions

The building's composition follows the same structure of the old buildings, divided into three parts: the ground floor, middle section and the top floor. It embraces the Neo-Renaissance style keeping components symmetrical with straight eaves and regularly places windows in odd numbers, all without revealing the floor plan from the outside.

Material

The building is constructed using masonry recycled brick, with bricks extending in and out from the facade. At ground level, the header bricks extend outward by 50 mm, while the stretchers align with the standard facade line. The windows are crafted from wood, and the roof is covered with red corrugated metal sheet.

Windows

The windows on the middle floor reflect the design of the older one in the surroundings, with their solid central frames, tall lower panes, and square upper panes. However, in this proposal, they are mirrored and rotated from the center to add a touch of modern asymmetry. These windows are slightly recessed due to the thick brick wall, with some bricks protruding out along the facade. This design created an interplay of light and shadow throughout the day, while also maximizing natural light in the apartments.

FACADE


0
1
SCALE 1:200

Roof

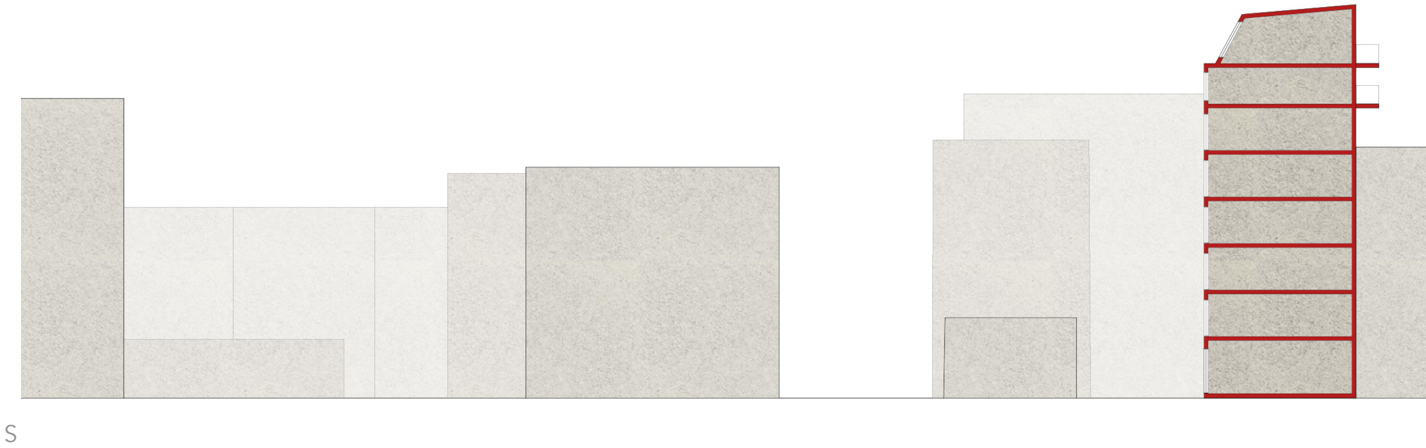
The roof design of the top floor takes inspiration from the dormer windows observed on neighboring buildings. These dormer windows are integrated into the brickwork but extend above the roofline, creating a distinctive feature. The roof itself is constructed using red corrugated metal sheets and includes five skylights.

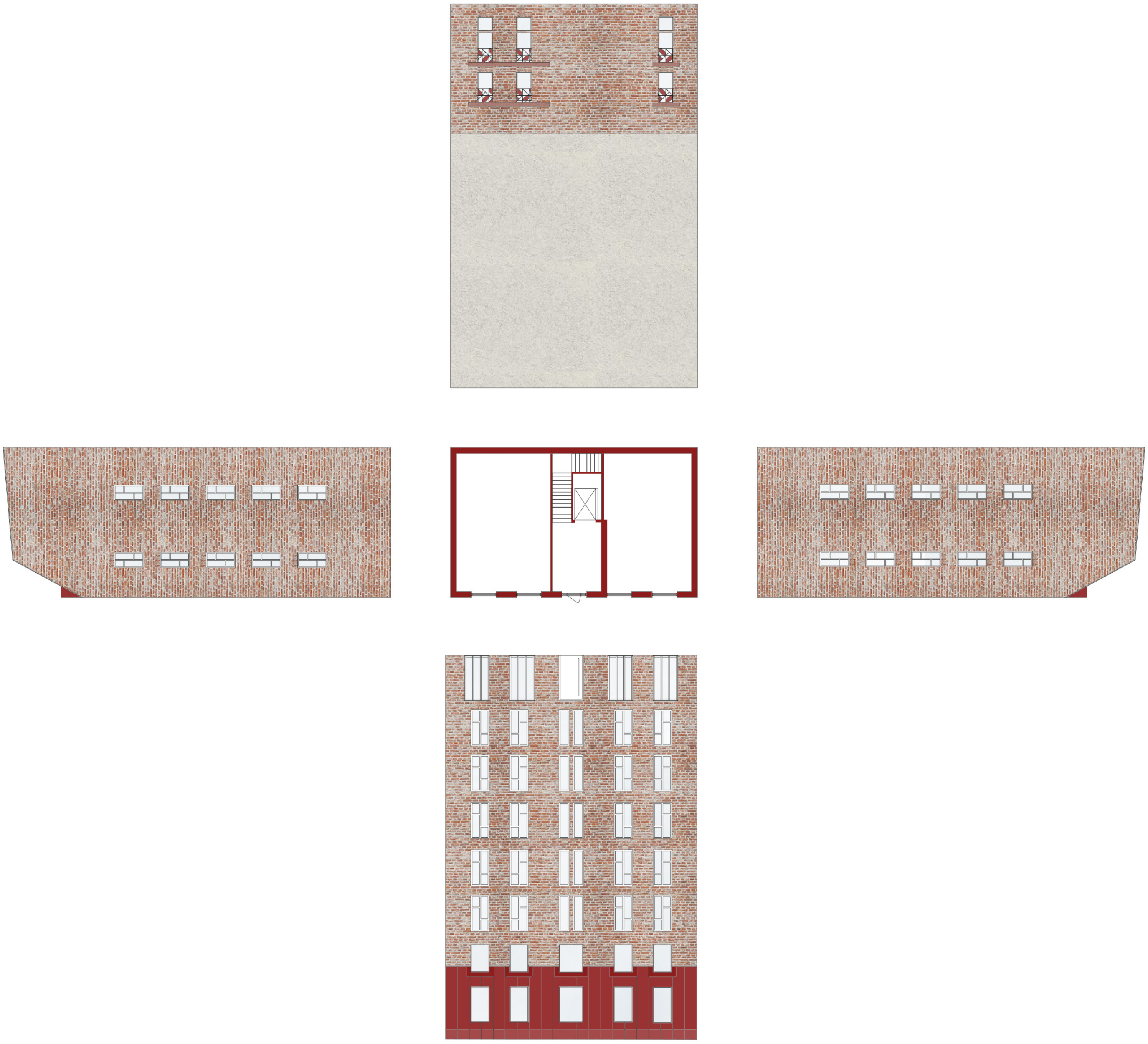
Balconies

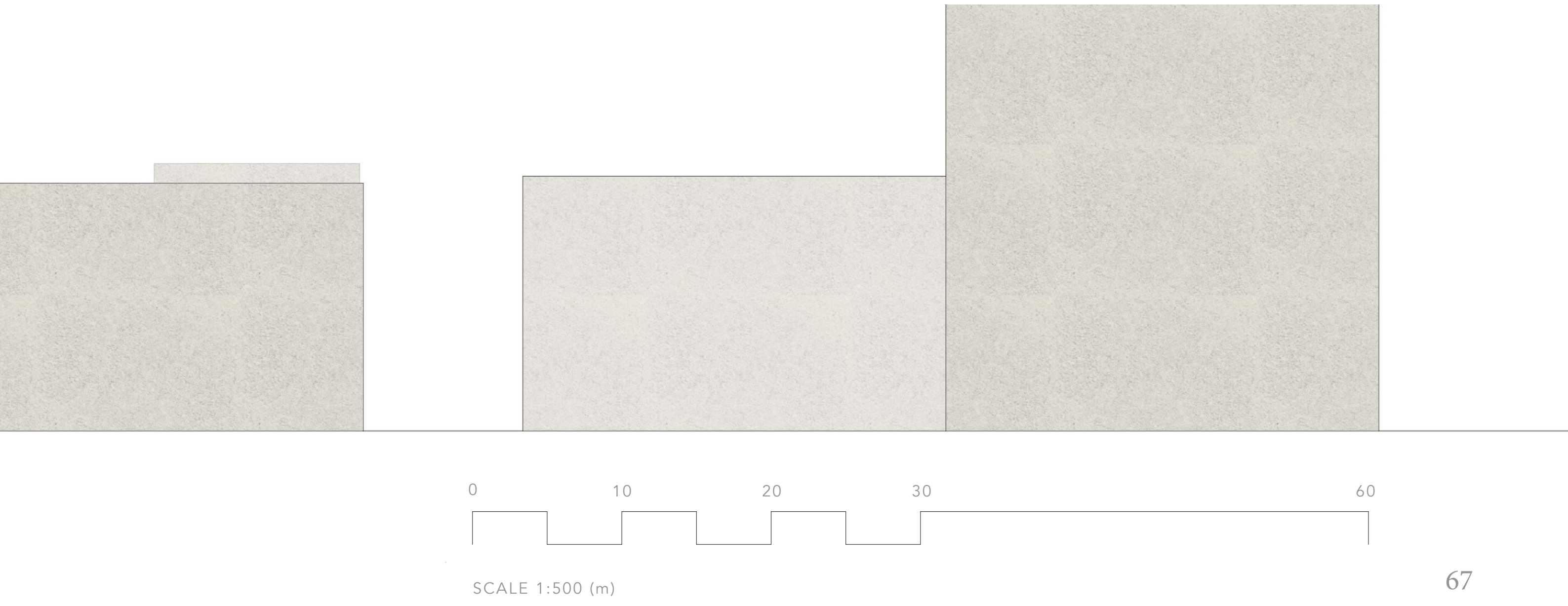
The balconies on the upper floors face south, providing natural light to the apartments and offering outdoor seating areas for residents.

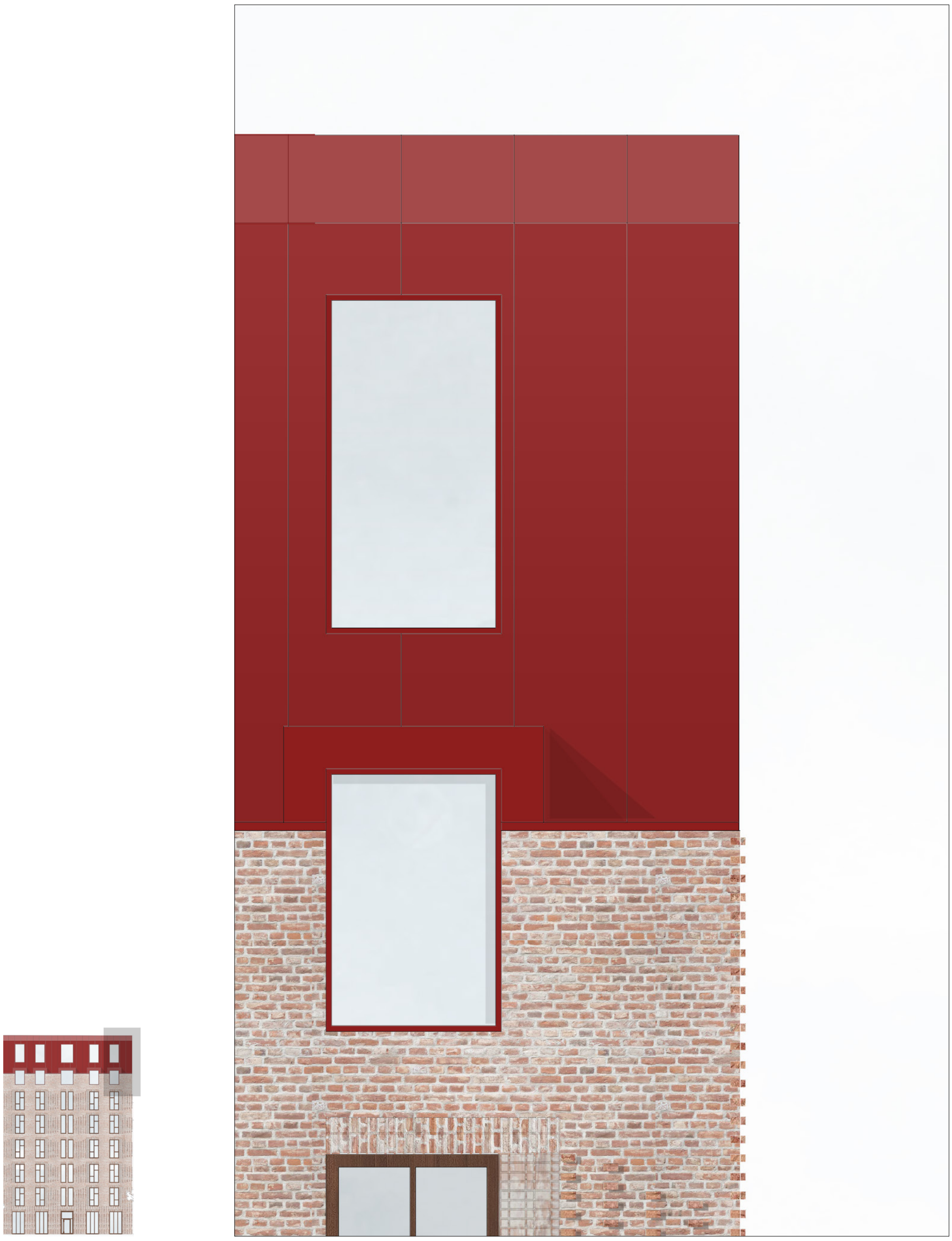
Shadows

On the north, west, and east sides of the facades, the windows are slightly set back, with the bricks protruding along the facade. This design element plays with light and adds depth

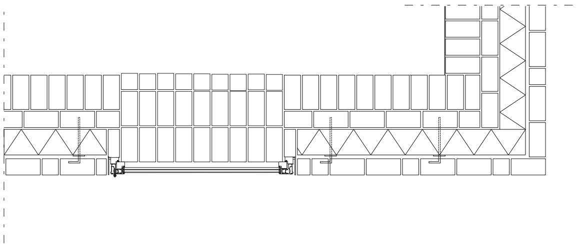




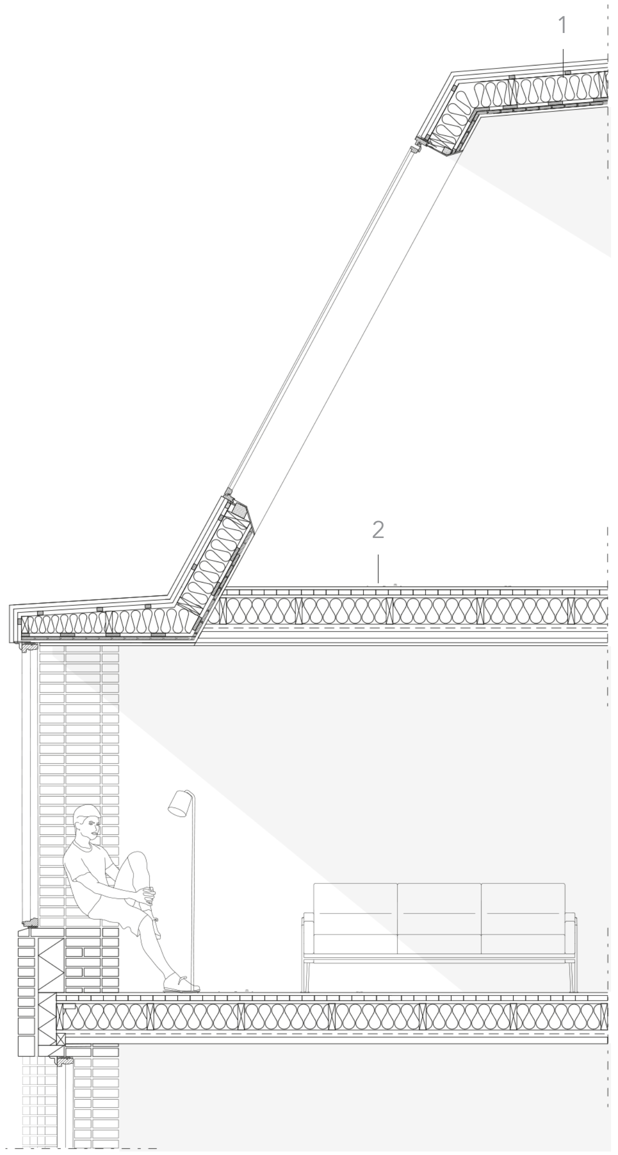

0
10
20
30
60
SCALE 1:500 (m)



FACADE DETAIL 1:50



MASONRY BRICKING PLAN 1:50



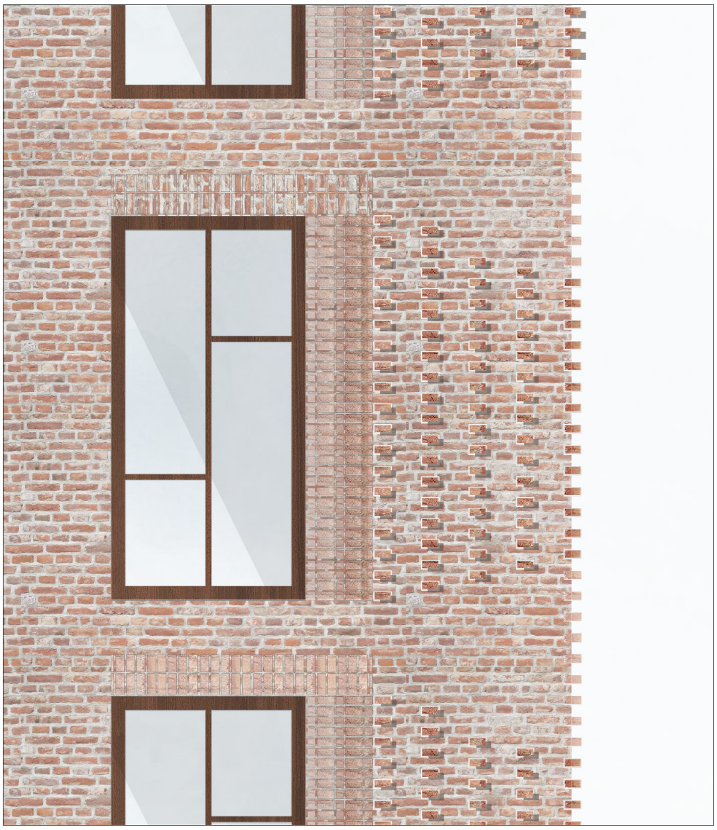
1

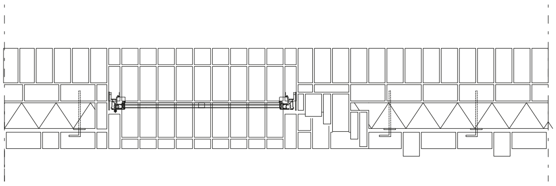
2 mm Sealing layer
Mechanical attachment
80 mm Ceiling board
30 mm Bottom disc
2 mm Air and vapor barrier
200 mm isulation
30 mm Bearing construction of KL wood

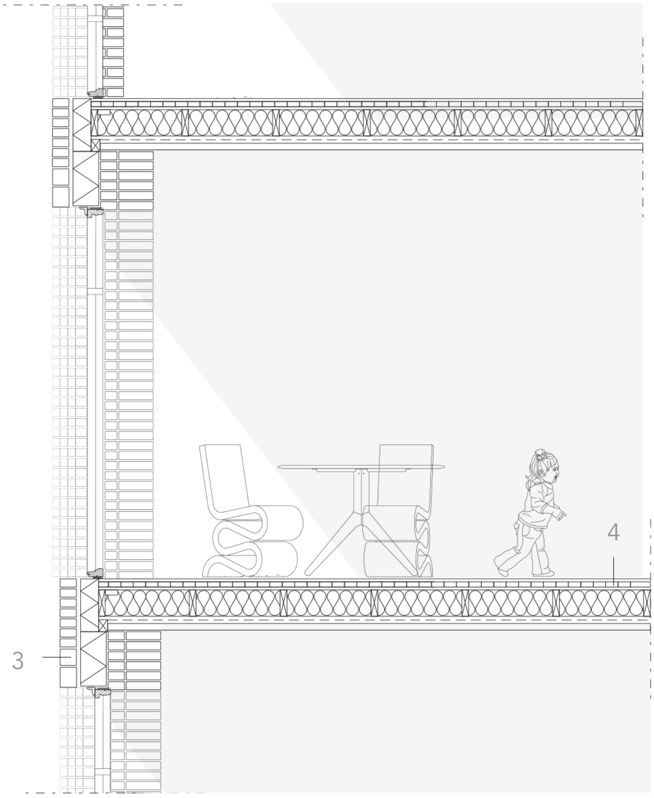
2

15 mm parquet
13 mm floor gypsum screwed
13 mm floor gypsum grooved
22 mm particleboard
soundproofing strip
50 air gap
170 mm mineral wool
170 x 56 glued laminated timber beam
20 wood
13 mm gypsum

SCALE 1:50 (m)







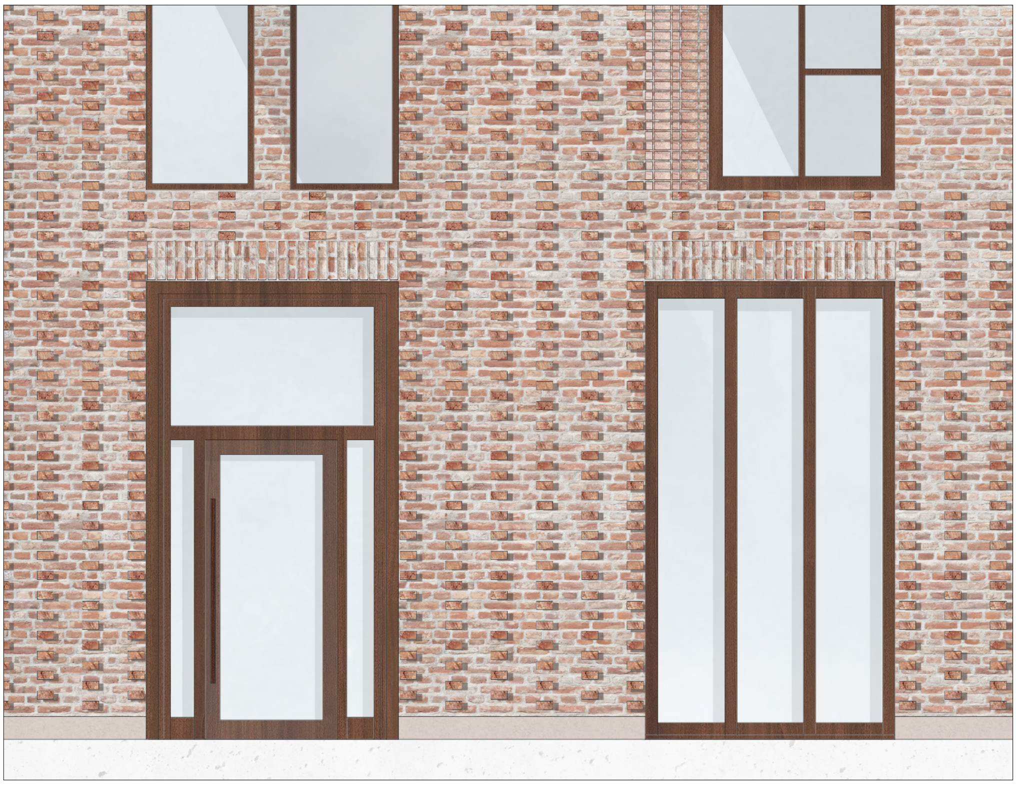
3

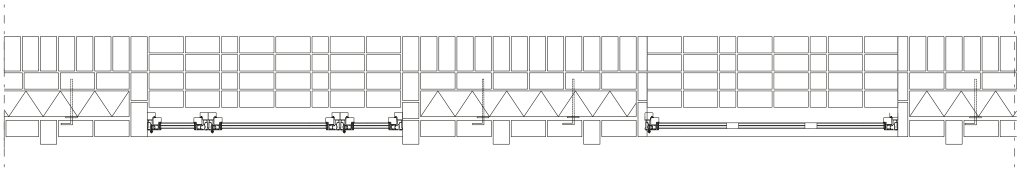
108 recycled bricks
40 mm air gap
170 mm insulation
108 recycled bricks
128 recycled bricks

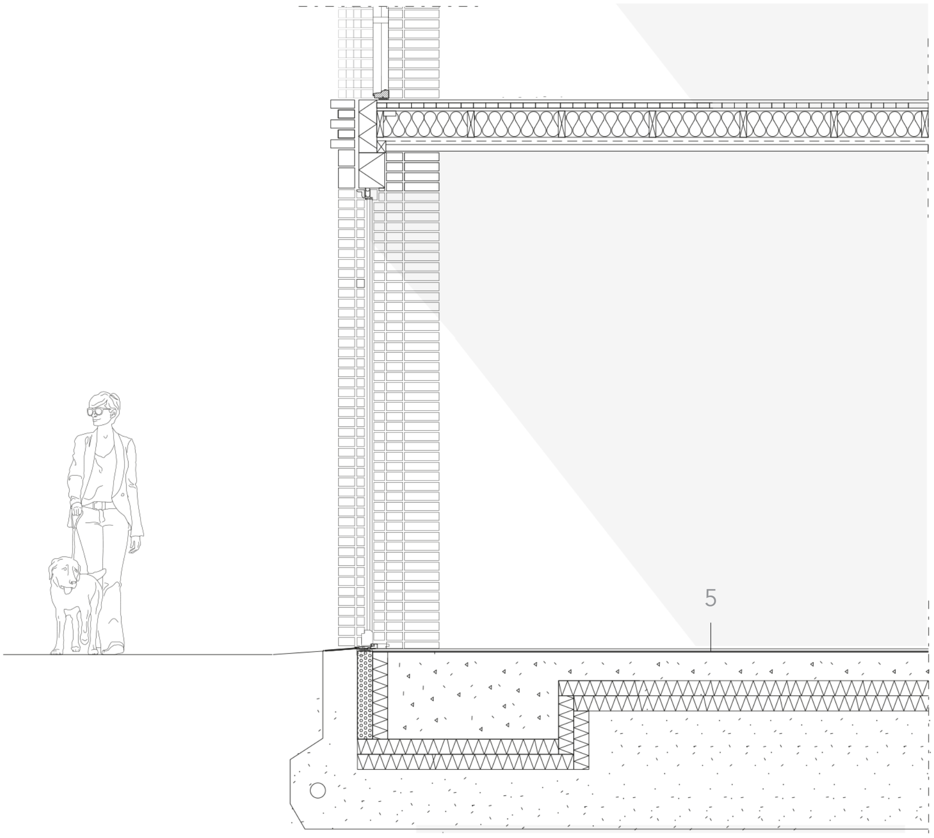
4

14 mm Parquet
Sound insulation foam
22 Particleboard
45 x 170 mm wooden joints
170 mm Insulation
28 x 70 mm Sparse panel
13 mm Plasterboard or Drywall

SCALE 1:50 (m)







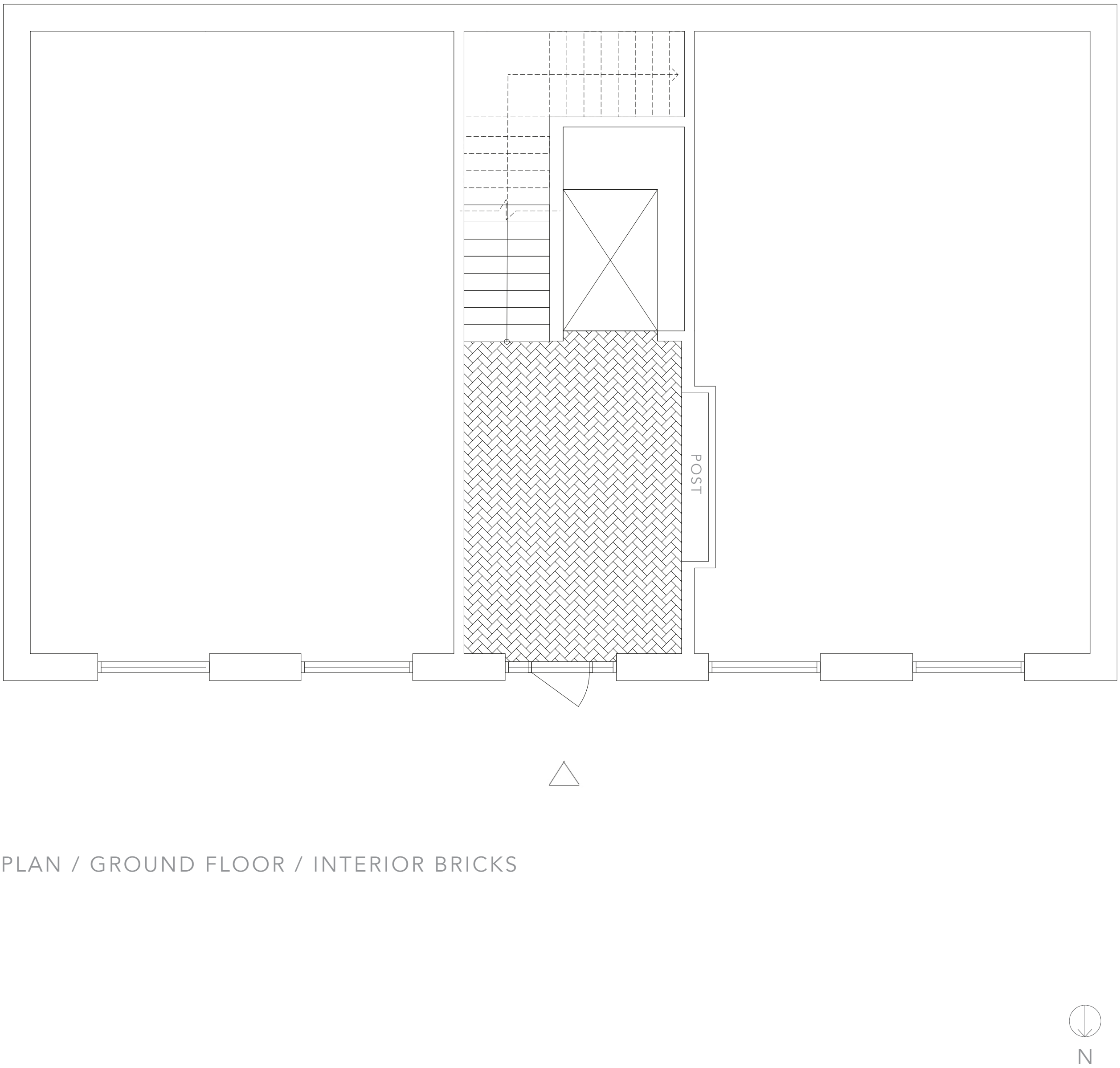
5

14 mm Parquet sound
insulation foam
150 mm Concrete
300 mm Insulation
200 mm Aggregate
Aggregate fabric

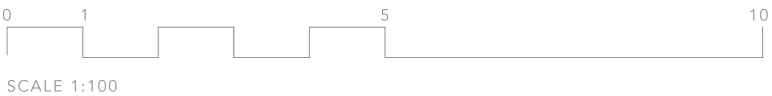
SCALE 1:50 (m)

Indoor bricking

Recycled bricks can also be used indoors, for a better connection between outdoor and indoor areas. The way they seamlessly connect through the windows makes it all feel more cohesive. There is a proposal showing how the bricks can fit in and how it integrates with other materials.



PLAN / GROUND FLOOR / INTERIOR BRICKS



Perspective
window top floor
in progress

05.

DISCUSSION

Discussion and conclusion

This report has contributed to a deeper understanding of bricks as a material. As Louis Kahn famously stated, ”A brick is not just a brick, it wants to be something.” Through a comprehensive understanding of the material, bricks can be fully utilized to their potential. In modern architecture, there are often cheaper alternatives to bricks in terms of initial costs. In our rapidly evolving world, we sometimes overlook the broader life cycle perspective. We tend to focus exclusively on the construction phase and then proceed to the next project, leading to a significant amount of construction materials, especially bricks, ending up in landfills. Yet, these bricks are a resilient material and can be recycled for future building projects.

Therefore, it is crucial to consider a building’s entire life cycle and plan accordingly. Understanding brick as a material involves knowledge of its comprehensive strength and its potential in construction beyond just decorative facades. Brick itself is a robust material, but it often does not reach its full potential and is nowadays primarily used for aesthetic purposes. Consequently, modern brick buildings today do not have a masonry brick construction due to concerns about material efficiency, instead they are replaced with other load-bearing elements like concrete.

This report has investigated the use of recycled bricks as load-bearing materials to optimize their potential. Using bricks as a load bearing element is not a new concept, but rather a traditional practice that has been employed in construction for decades using masonry bricks. By studying the old buildings in Linnéstaden and drawing inspiration from traditional masonry techniques, while also considering the Swedish U-value standard for facades and exterior walls, the use of bricks can be optimized. Implementing a load-bearing construction with one and a half bricks, adding a layer of cellular plastic insulation, and using brick as cladding not only maximizes the use of bricks but also meets the standards for residential buildings.

As demonstrated in the results section, there is a notable difference in global warming potential between newly manufactured bricks and recycled ones. Most of the differences arise from the initial phases A1-A3, which include production, transportation, and packaging. The production of new bricks involves heating the material to high temperatures, often done in Denmark and the Netherlands, requiring long-distance transportation. In contrast, recycling bricks and improving the process can significantly reduce CO2 emissions by minimizing transportation and production. This transition can play a significant role in the transformation from a linear to a circular model.

The comparison between recycled and newly manufactured bricks, as shown by the life cycle assessment and cost analysis, is quite significant, particularly in terms of global warming potential. From a discussion perspective, it is important to understand that the LCA is based on EPDs with different standards (EPD standard 15804:2012 + A1:2013 and 15804:2012 + A2:2019/AC:2021). This inconsistency presented challenges during the research, resulting in values that are not completely accurate, which must be taken into account in the report. Nevertheless, by the end of 2024, EPD standards will be standardized for all products on the market.

However, the results in the report shows that recycling bricks using the cut brick element method results in up to a 94% reduction in CO2 emissions, while the individual brick method achieves up to a 92% reduction by minimizing the production of bricks in phases A1-A3. The data indicates that producing newly manufactured bricks generates 303 kg CO2 eq per tonne, compared to 25.7 kg CO2 eq per tonne for recycled individual bricks and 19.07 kg CO2 eq per tonne for cut brick elements. This demonstrates that the cut brick element method has the least environmental impact. Nevertheless, it is important to consider the additional materials required, such as steel, insulation, concrete, and wood, using that method. For recycled individual bricks, only mortar and insulation need to be accounted for, similar to newly manufactured bricks. In a Nordic context, it is crucial to consider the standards of each country, which means insulation must be factored into these calculations as well.

However, the differences in life cycle cost analysis is less notable. Recycled bricks generally do not usually cost more than newly manufactured ones, as long as they have similar qualities and characteristics. Maintenance and installation costs are generally similar. However, building a load- bearing brick facade, as proposed in this report, requires more labor hours for assembly from scratch. Another challenge arises from the limited availability on the market, as many demolished buildings end up in landfills nowadays. To enhance the attractiveness of this industry and market, architects should demand more recycled bricks or, at least, adapt a hybrid approach, using recycled bricks to the extent of their availability and substituting the remainder with newly manufactured ones. Additionally, it is crucial to consider the entire life cycle of the bricks. Using the correct mortar is essential to ensure the bricks can be recycled again.

From an architectural standpoint, recycling individual bricks, as illustrated in case study one, provides greater design flexibility. Once the recycled bricks pass all tests and receive CE marking, they can be used like newly manufactured ones, in terms of installation and maintenance. However, the second method, recycling modular, presents greater complexity. These modules integrate steel and concrete, each with its own lifecycle, potentially shorter or longer, which can complicate the maintenance. Additionally, the report *Criteria for salvageability: the reuse of bricks* suggests that recycling facades with fewer materials is more beneficial. Otherwise, it could complicate future recycling processes.

Future studies could be about investigating the standard of brick used indoors or as a construction material and not just necessarily the facade. Using recycled bricks for interior purposes increases the recycling rate, as these bricks do not need to meet the same standards required for outdoor use. Through techniques like masonry bricking or channel wall construction, many bricks that would otherwise end up in landfills can be reused in building projects, reducing the demand for new construction materials.

As I started this discussion with a quote from Kahn suggesting that brick has its own aspirations, I believe that brick aims to represent something unique for each era, where the material is timeless and has its own character and potential, which architects should understand and respect. This leads us to think about how the area is shifting from a ’take-make-waste’ approach to a take-use-restore-remake-reuse paradigm and that brick itself can be a part of that shift.

The interplay of light and shadow.

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Images

Figure 3. Naturvårdsverket (2023), Avfallsmängder i Sverige. Adapted from: https://www.naturvardsverket.se/amnesomraden/avfall/avfallslag/bygg--och-rivningsavfall/
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Figure 4. Brukspecialisten (n.d.), Avfallshierarkin. Adapted from: https://brukspecialisten.se/cirkulart-design-stod/ (2024-01-17).

Figure 7. Inobi (n.d). Facade from Villa Lorensberg. [digital image] Retrieved from: https://inobi.se/projekt/villa_lorensberg/ (2024-01-05).

Figure 8. Inobi (n.d). Recycled brick facade. [digital image] Retrieved from: https://inobi.se/projekt/villa_lorensberg/ (2024-01-05).

Figure 9. Inobi (n.d). Recycled brick facade integrated with other materials. [digital image] Retrieved from: https://inobi.se/projekt/villa_lorensberg/ (2024-01-05).

Figure 11. Brukspecialisten (n.d). Showing the compressive strenght of the bricks in Case study 1: Individual bricks, the type of mortar used, and the recycling rate. [digital image] Retrieved from: https://brukspecialisten.se/tegelkunskap/ (2024-01-05).

Figure 13. Lendager (n.d). Facade from Resource Rows in Oerestad, Copenhagen, Denmark [digital image] Retrieved from: https://lendager.com/project/resource-rows/ (2024-01-05).

Figure 14. Lendager (n.d). Facade from Resource Rows in Oerestad, Copenhagen, Denmark. [digital image] Retrieved from: https://lendager.com/project/resource-rows/ (2024-01-05).

Figure 15. Lendager (n.d). Facade from Resource Rows in Oerestad, Copenhagen, Denmark. [digital image] Retrieved from: https://lendager.com/project/resource-rows/ (2024-01-05).

Figure 16. Lendager (n.d). Facade from Resource Rows in Oerestad, Copenhagen, Denmark. [digital image] Retrieved from: https://lendager.com/project/resource-rows/ (2024-01-05).

Figure 18. Olsson Lyckefors, n.d. Facade with newly manufactured bricks. [digital image] Retrieved from: https://olssonlyckefors.se/project/merkurhuset/ (2024-03-04).

Figure 19. Olsson Lyckefors, n.d. Facade with newly manufactured bricks. [digital image] Retrieved from: https://olssonlyckefors.se/project/merkurhuset/ (2024-01-05).

Figure 22. Brukspecialisten (n.d). Showing the compressive strenght of the bricks in Case study 1: Individual bricks, the type of mortar used, and the recycling rate. [digital image] Retrieved from: https://brukspecialisten.se/tegelkunskap/ (2024-01-05).

APPENDIX

Appendix A- LCA calculations

Brick danish format:
228 x 108 x 54 mm

65 bricks / m^2 facade (personal communication, 2024)

Method 2: Cut brick element
GWP (m^2): 3,1 kg CO2 eq/ m^2

GWP (tonne): 19,07 kg CO2 eq/ m^2
1 tonne = 1 000 kg
1 brick = 2,5 kg
1 000 kg / 2,5 kg = 400 bricks
1 m^2 = 65 bricks

1 brick = 3,1 kg CO2 eq/ m^2 / 65 bricks = 0,04769 kg CO2 eq/ m^2

400 bricks = 0,04769 kg CO2 eq/ m^2 x 400 bricks = 19,0769

Brick, merkurhuset
Product: Petersen, D91
Link: *https://www.tegelmaster.se/wp-content/uploads/2021/12/md-19006-en-petersen-tegl.pdf*

Environmental product declaration
Functional unit:
1 tonne
GWP for phase A1 - A3 (tonne):
3,03E+0,2 kg CO2 - eq = 303 kg CO2- eq per tonne

GWP for phase A1 - A3 (m^2):
1 tonne = 1 000 kg
1 brick= 2,5 kg

1 0002,5 kg = 400 bricks
(65 bricks / m^2)

40064= 6,25 m^2 bricks

3,03 E + 0,2 6,25 = 3036,25= 48,48 CO2- eq

Brick, recycled individual bricks
Product: Rebrick
Link: *https://api.environdec.com/api/v1/EPDLibrary/Files/bc72c5dc-bacb-441e-51f4-08dbd569605a/Data*

Environmental product declaration

Functional unit:

1 tonne

GWP for phase A1 - A3 (tonne):

2,57 E + 0,1 kg CO2 - eq = 25,7 kg CO2- eq per tonne

GWP for phase A1 - A3 (m^2):

1 tonne = 1 000 kg

1 brick= 2,5 kg

1 0002,5 = 400 bricks

(65 bricks / m^2)

40064= 6,25 m^2 bricks

2,57 E + 0,1 6,25 = 25,76,25= 4,11 kg CO2- eq

Lime mortar

Product: Hydrauliskt kalkbruk

Link: *https://www.finja.se/produkter/gjuta-mura-putsa-laga/hydrauliskt-kalkbruk?id=5548705*

Environmental product declaration

Amount mortar per m^2:

33 liter/ m^2

Amount mortar generated by:

https://www.finja.se/verktyg/mangdberaknare/mangdberakning-murbruk

Result: 75 kg of the product

Functional unit:

1 kg

GWP for phase A1 - A3 (tonne):

0,185 kg CO2 - eq

GWP for phase A1 - A3 (m^2):

1 m2 = 75 kg

0,185 x 75 = 13,875 kg CO2 - eq

Appendix B- LCC calculations

Exchange rate:
DKK to SEK
1 DKK = 1,503 SEK

LCC
Labor cost:
1 051 DKK x 1,503 = 1 580 SEK

Other cost:
246 DKK x 1,503 = 370 SEK

Upcycle brick wall:
Material cost:
2 368 DKK x 1,503 = 3 805 SEK

Labor cost:
1 563 DKK x 1,503= 3 137 SEK

Other cost:
567 DKK x 1,503= 959 SEK

Appendix C- u value

U- value for a facade with different components

$$\frac{1}{U} = \frac{1}{U1} + \frac{1}{U2} + \frac{1}{U3} + \frac{1}{Un}$$

$$U = \frac{1}{(\frac{m}{\lambda})}$$

λ= insulating capacity

λ for cellular plastic isolation: 0,036
λ for bricks: 0,6

$$U_{1/2\ bricks} = \frac{1}{(\frac{m}{\lambda})} = \frac{1}{(\frac{0{,}348}{0{,}6})} = 1{,}724$$

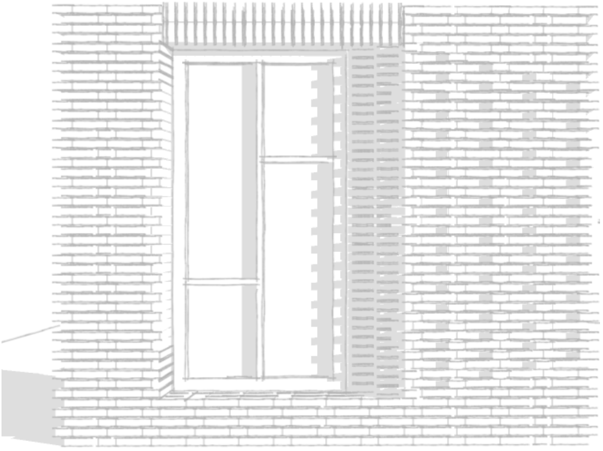
$$U_{cellular\ plastic} = \frac{1}{(\frac{m}{\lambda})} = \frac{1}{(\frac{0{,}17}{0{,}036})} = 0{,}212$$

$$U_{1\ bricks} = \frac{1}{(\frac{m}{\lambda})} = \frac{1}{(\frac{0{,}108}{0{,}6})} = 5{,}55$$

$$\frac{1}{U} = \frac{1}{1{,}724} + \frac{1}{0{,}212} + \frac{1}{5{,}55} = 0{,}58 + 4{,}717 + 0{,}18 = 5{,}577$$

$$u = 0{,}178 \approx 0{,}18$$

Appendix D- sun study



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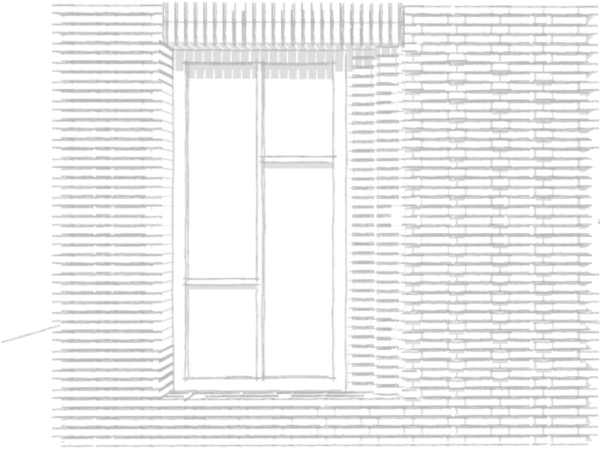

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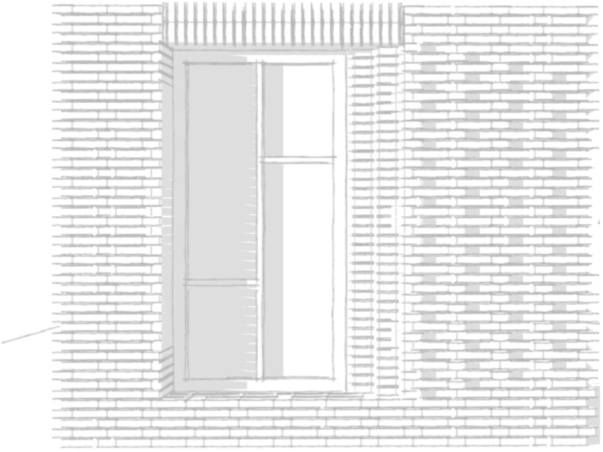

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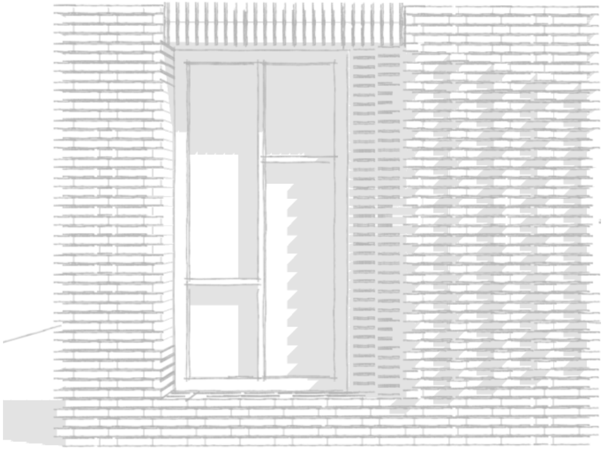

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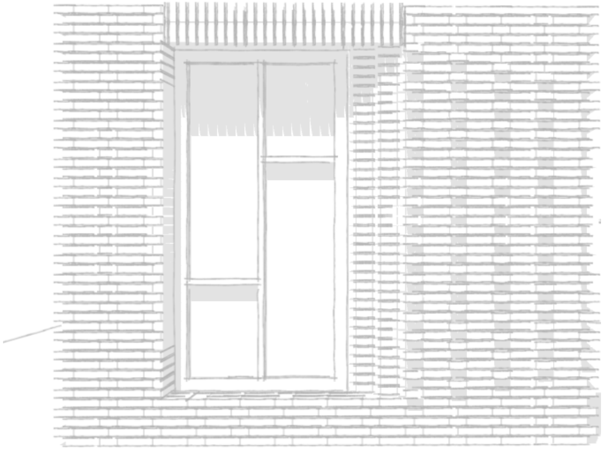

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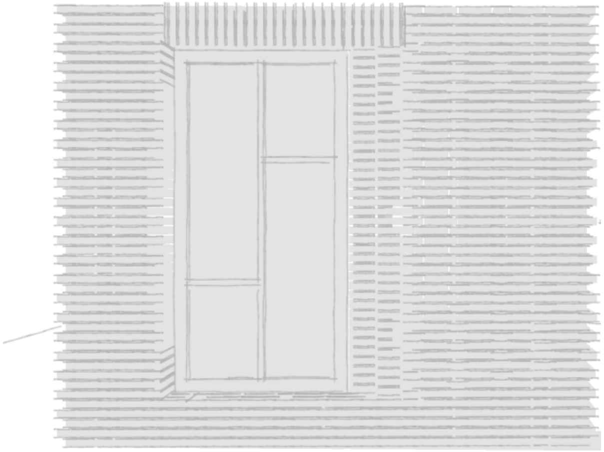

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