CHALMERS
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Reuse of bricks
Analysis of challenges and potential in a multifamily residential project

Master's Thesis in the Master's Programme Architecture and Urban Design

JOEL GUSTAFSSON

Examiner: Liane Thuvander

Supervisors: Holger Wallbaum and Shea Hagy

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Master's Thesis ACEX35

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Examensarbete ACEX35/ Institutionen för arkitektur och samhällsbyggnadsteknik,
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Cover:
Deconstruction of bricks from buildings on Drakblommegatan, 2019-01-21, see section 4.1.1.
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ABSTRACT

Global environmental challenges have resulted in efforts from the European Union to reduce waste from the building industry. Accordingly, reduced construction waste is one of the goals in the City of Gothenburg's action plan for the environment. One of the responsible companies for fulfilling this goal is Framtiden Byggutveckling AB, the City of Gothenburg's producer of public housing. Three multifamily residential brick buildings, owned by the municipal company Bostadsbolaget, will be torn down due to radon and the site will be redeveloped with new buildings by Framtiden Byggutveckling AB.

The **aim** of this thesis is to analyse and present solutions to environmental, economic and technical challenges related to the reuse of bricks from the existing buildings in the new buildings. The following questions guide the analysis: How to disassemble, store, transport and reassemble the bricks? What are the liability and insurance consequences? What are the economic costs and potential environmental benefits?

The following **methodologies** are used: A literature study, interviews of Bostadsbolaget, Framtiden Byggutveckling AB and experts in relevant fields, material tests of compression strength, frost resistance, absorption, radioactivity and cleaning possibilities, cost calculations and simplified Life Cycle Assessment (LCA).

The **outcome** is two design concepts for reuse of the facade brick in a new multifamily residential building. The design concepts are presented in this report including drawings and instructions for disassembly, transportation and reassembly as well as rough calculated economic costs and environmental assessment. Additionally, challenges, hinders and solutions to reuse of bricks are presented. The analysis and solutions within this report is intended to support architects, engineers and other professionals in the building industry to reuse bricks for new structures.

Key words: Reuse, Brick, Circular economy, Economic costs, LCA, Demolition.

Återbruk av tegel

Examensarbete inom masterprogrammet Arkitektur och stadsbyggnad

JOEL GUSTAFSSON
Institutionen för Arkitektur och samhällsbyggnadsteknik
Avdelningen för Arkitekturens teori och metod
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SAMMANFATTNING

Globala klimatutmaningar har resulterat i satsningar från EU för att minska avfallet från byggbranschen. I linje med detta är minskat byggavfall ett av målen i Göteborgs Stads handlingsplan för miljön. Ett av de ansvariga företagen för att uppnå detta mål är Framtiden Byggutveckling AB som står för Göteborgs Stads nyproduktion av bostäder. Tre flerfamiljshus, ägda av det kommunala företaget Bostadsbolaget, ska rivas på grund av radon och fastigheten ska bebyggas med nya byggnader av Framtiden Byggutveckling AB.

Syftet med detta examensarbete är att analysera och presentera lösningar på miljömässiga, ekonomiska och tekniska utmaningar relaterade till att återbruka teglet från de befintliga till de nya byggnaderna. Hur ska tegelstenarna demonteras, lagras, transporteras och återmonteras? Vilka är ansvars- och garantikonsekvenserna? Vilka är de ekonomiska kostnaderna och potentiella miljönyttorna?

Följande metoder används: En litteraturstudie, intervjuer med Bostadsbolaget, Framtiden Byggutveckling AB och experter på relevanta områden, materialtest av tryckhållfasthet, frostresistens, sugförmåga, radioaktivitet och rengöringsmöjligheter, kostnadsberäkningar samt en enklare livscykelanalys (LCA).

Resultatet är två designkoncept för återbruk av fasadteglet i nya flerfamiljshus. Designkoncepten presenteras i denna rapport med ritningar och instruktioner för demontering, transport och återmontering samt grova kostnads- och miljökalkyler. Dessutom presenteras utmaningar, hinder och lösningar relaterade till återbruk av tegelstenar. Analysen och lösningarna i denna rapport är avsedda att hjälpa arkitekter, ingenjörer och andra yrkesverksamma inom byggbranschen att återbruka tegel i nya byggnader.

Nyckelord: Återbruk, Tegel, Cirkulär ekonomi, Kostnadskalkyler, LCA, Rivning.

Contents

Preface

This thesis was carried out at the Division of Architectural Theory and Methods, Architecture and Civil Engineering at Chalmers University of Technology between January and May 2019. It was my degree project within the master's programme Architecture and Urban Design and it ends my sixth year of studies of architecture and engineering. I began the studies in 2009 and received a bachelor's degree in 2012. After two years of internships for various architecture companies, I studied structural engineering for two years, graduating with a master's degree in 2016. Between 2016 and 2018, I worked as a consultant within architecture and structural engineering. Over the past year, I have been off duty from my work as consultant to finish my master studies in architecture.

I would like to thank the following for their participation and support during the execution of this thesis:

Cecilia Johannison (Supervisor, Framtiden Byggutveckling AB) and Eva Bengtsson (Supervisor, Bostadsbolaget): For your guidance, encouraging support and making the deconstruction and testing of the bricks possible.

Holger Wallbaum and Shea Hagy (Supervisors, Chalmers): For your careful proofreading of the report and important improvements of my work along the way.

All interviewees: For valuable information about everything from project management to deconstruction methods and brick properties – the fundamental content of this report.

Göteborg, May 2019

Joel Gustafsson

Notations

Abbreviations

ADPE	Abiotic Depletion Potential for non-fossil resources. The chemical element antimony, with symbol Sb, is used as a reference to measure the depletion potential of a specific material
Atemp	Area of interior spaces heated to more than 10 °C
DKK	Danish krone (Denmark's official currency)
EPD	Environmental Product Declaration
FBU	Framtiden Byggutveckling AB, the developer of the new buildings on the site
GFA	Gross floor area
h	Hour, time
LCA	Life Cycle Assessment
MJ	Megajoule, energy
Sb	Antimony, chemical element for assessment of abiotic depletion potential for non-fossil resources
SEK	Swedish krona (Sweden's official currency)

1 Introduction

This chapter explains the background to reuse of bricks. Global environmental challenges have resulted in goals for reduced construction waste, for example in the City of Gothenburg's action plan for the environment. Furthermore, the chapter goes through the thesis' aim and its research questions. The aim of this thesis is to analyse and present solutions to environmental, economic and technical challenges related to the reuse of bricks. Design concepts for how bricks from three case buildings in Gothenburg can be reused in new buildings are developed.

1.1 Background

1.1.1 Global environmental challenges and climate adaptation

The Special Report released from the IPCC (International Panel on Climate Change) in 2018 explains the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways. The report was approved by all the United Nations country representatives and meeting this goal will require drastic changes to our energy, transportation, food and building systems. Even limiting the global warming to 1.5°C puts the Earth at higher risk for severe environmental events like drought and heavy precipitation that will disrupt agriculture, food and water supplies. A global warming of 2°C would significantly magnify these negative impacts (Climate Central, 2019).

Chapter four of the Special Report assesses the related mitigation and adaptation options and several possibilities for the building sector are mentioned. For example, reduced embodied energy in building materials can provide energy savings and reduced greenhouse gas emissions (IPCC, 2019). The 2030 Agenda for Sustainable Development adopted by all United Nations Member States in 2015 has goals for efficient use of natural resources and reduced energy consumption, waste production and greenhouse gas emissions (United Nations, 2019).

1.1.2 European figures and investments for reuse

The use of resources, the energy consumption and waste production are essential environmental challenges also for the European building industry. Statistics from the European Commission show that construction and use of buildings contribute to 50% of the use of raw materials and 50% of the energy consumption within the European Union (EU) (European Commission, 2014). 25-30% of the volume of the total waste generated in the EU originates from the construction and demolition of buildings. This waste consists of for example concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil and many of these materials can be recycled (European Commission, 2018). Constructions and construction work contribute to approximately 10% of the total carbon dioxide emissions in the EU, being the second largest group after the group that includes electricity, gas, steam and air-conditioning (Eurostat, 2018). If you also include the use of buildings, the carbon dioxide emissions amount to 36% of the total emissions within the EU (European Commission, 2019).

To reduce the use of new raw materials and associated carbon emissions, energy consumption and waste production, the European Commission launched an investment package in 2015 for reduced waste (European Commission, 2015). The investment package states that the building and demolition industry within the European Union produces 500 million tons of waste per year, which equates to one ton of construction waste per person and year in this region. To change this, one of the stated investment goals is to stimulate reuse of building materials.

1.1.3 Gothenburg's action plan and reuse of materials

On a local level in Sweden, one document that addresses reduced waste is the City of Gothenburg's action plan for the environment 2018-2020 (Göteborgs Stad, 2018). It includes a target (number 67) for reduced waste in the building industry. The plan guides the work conducted in the City of Gothenburg's committees, boards, departments and companies to create a good living environment and sustainable development in the city.

Reusing building materials to reduce waste has two main objectives (Fröst, 1995): Partly to prevent contamination and reduce the need for new landfill but also to save energy and material resources. Additionally, increasing costs for resources and landfilling bring economic reasons for reusing materials (Thormark, 2008). However, there are many barriers to reuse of building materials (Gorgolewski, 2018): Existing perception towards reused materials, economic considerations, time and scheduling, health and Safety, incentives to deconstruct and reuse, certification of materials, insurance/liability constraints, code/specification issues, material availability, ownership and lack of technical knowledge. These barriers are also present in Scandinavia and are identified in a report from the Swedish construction industry's organization for research and development (SBUF) (NCC, 2017) and in a report from the Norwegian network Nasjonal handlingsplan for bygg- og anleggsavfall (NHP) (Asplan Viak, 2018). Additionally, the IPCC report (2019) shortly mentions the organizational challenges but also indicates the advantages in terms of cost, health, governance and environment. The impact of reuse of building materials on energy use and other environmental issues needs to be assessed (IPCC, 2019).

1.1.4 Reuse of brick for new buildings

Brick is a suitable material to assess with regard to reuse potential for the following reasons:

- Brick is a major part of the construction waste in the EU (European Commission, 2018).
- Brick has high embodied energy and high carbon dioxide emissions (University of Bath, 2011; ÖKOBAUDAT, 2019).
- In contrast to many building products which are laminated and built up by several different materials, brick is a homogenous building component. Additionally, no surface treatment of the bricks is needed, keeping the material clean and hereby easing the recycling process (Nordby, Berge, Hakonsen, & Hestnes, 2009).
- Brick is a modular, highly adaptable building component and therefore suitable for reuse (Nordby et al., 2009).

1.1.5 Buildings on Drakblommegatan

One of the responsible companies for fulfilling the afore-mentioned goal about reduced construction waste in Gothenburg, Sweden, is Förvaltnings AB Framtiden

(Göteborgs Stad, 2018), a business group consisting of several housing companies owned by the City of Gothenburg. One of the companies of the business group is Framtiden Byggutveckling AB (FBU), the City of Gothenburg’s producer of new multifamily residential buildings. After FBU has completed a construction, they hand over the management of the building to other companies in the Förvaltnings AB Framtiden group and one of these companies is Bostadsbolaget.

Bostadsbolaget now owns three multifamily residential buildings on Drakblommegatan which will be torn down, see Figure 1.1. The reason for the demolition is that the buildings contain radioactive light weight concrete and applied actions to lower the levels of radiation have not been successful. Since Bostadsbolaget does not see renovation of the buildings as a possible action, FBU has received the mission to build new buildings on the same site and they have produced early design sketches.

As a way of taking their responsibility for reduced construction waste, FBU and Bostadsbolaget want to study the possibility to reuse materials from the current buildings. FBU and Bostadsbolaget want an investigation to cover what environmental, economic, liability and technical consequences the reuse of a material would have.

In addition to the reasons to reuse bricks mentioned in section 1.1.4, two more motives can be added for the specific case buildings on Drakblommegatan in Gothenburg. The buildings on the site contain a lot of brick which gives the result of the study a large impact. Additionally, brick is a common material in Gothenburg’s building stock from the 1960’s and gained knowledge can be used in other projects.

Figure 1.1 View of the three existing case buildings on Drakblommegatan from northwest (Björlandavägen).

1.2 Aim and research questions

1.2.1 Aim

The aim of this thesis is to analyse and present design solutions to environmental, economic and technical challenges related to reuse of bricks from the buildings on Drakblommegatan. The intention is that this will help developers and consultants to reuse façade bricks in new buildings. Two design concepts for reuse of the bricks of the current buildings in a new multifamily residential building are developed. The design concepts are presented in this report by drawings, illustrations and instructions for disassembly, transportation and reassembly as well as calculated economic costs and environmental assessment. The early design sketches of FBU are taken into account and the developed concepts are customized to fit the extent of these buildings.

1.2.2 Research questions

The main research question of this thesis is: “How to reuse façade bricks?” To fulfil the aim of this thesis, the following additional research questions are used to guide and focus the study. The questions are formulated based on the barriers to reuse mentioned in section 1.1.3 .

- How to disassemble the bricks from the current buildings?
- How to store and transport the bricks between disassembly and reassembly?
- How to reassemble the bricks?
- What are the liability and insurance consequences in reusing the bricks?
- What are the economic costs?
- What are the environmental benefits compared to using new material?

1.3 Method

The methodology of the thesis is divided into three phases, one for preparation, one for analysis and one for design and evaluation. In this way, the gained knowledge during the preparation and analysis can be visualized and evaluated in the design concepts. A mixed method approach with research for design is used, collecting information both in qualitative and quantitative ways.

1.3.1 Phase 1 – Preparation

Literature study

The databases Scopus and Web of science are used to search for information. Relevant literature is also searched for in the libraries of Chalmers University of Technology. The search engine Google is used to find other relevant articles and books available on the internet. The following keywords are used for searches in the databases, library catalogues and search engines: “Återbruk”, “Tegel”, “Reuse”, “Bricks”, “Circular building”, “Rivning”, “Demolition”. No limit for the date of the publications is set to also include old publications which can contain valuable information for this thesis.

Reference projects

Existing buildings constructed with reused bricks have been studied to gain knowledge from the practice. Four projects in Scandinavian contexts, representing different reuse technologies and methods, are studied: Furutorpsparken (Helsingborg), Mellanvångsskolan (Staffanstorp), Magasinet (Göteborg) and The Resource rows (Copenhagen).

Studies of drawings and documents of the existing buildings

The original drawings and documents with describing texts are studied to get information about the structure of the existing buildings on the site and the properties of the brick and the mortar such as frost resistance and mortar content.

1.3.2 Phase 2 – Analysis

Visual inspection of the buildings

A visual inspection is carried out to get an overview of the current condition of the bricks and the mortar and look for damages from for example frost, salt and rust. Common damages to look for is identified from the manual Undvik misstag i murat och putsat byggande (2018), a report from the association Tungt murat och putsat byggande which has members both from the academia and companies working with bricks.

Interviews with Bostadsbolaget, FBU and experts

Qualitative semi-structured interviews are executed with the owner of the current buildings (Bostadsbolaget), the developer of the new buildings (FBU) and experts in relevant sub-fields: Brick construction, structural engineering, assembly, demolition and reuse. The purpose of the interviews is to complement the literature study and give additional information, for example about project management and liability constraints. Both telephone, e-mail and face-to-face interviews are carried out with around a total of 20 interviewees.

Material tests

20 bricks from the Drakblommegatan case study buildings are tested regarding their physical properties and the tests are carried out by Gamle Mursten, a Danish company that is a supplier of reused bricks. Frost resistance, compression strength and absorption properties are tested. The bricks are measured, and the gross density is calculated. The following test standards and methods are used: DS/EN 772-16, DS/EN 772-13:2002, DS/EN 772-11:2011, Murkatalogen 2001: Porefyldningstal efter Norsk Anvisning M1 and DS/EN 772-1:2011. For these tests, 30 brick samples are deconstructed from the buildings and sent to Gamle Mursten. Gamle Mursten also tests cleaning one brick to assess if it is possible to clean the bricks with their machine technology or if the bricks need to be cleaned by hand. Additionally, the bricks are tested on Chalmers University of Technology with a Geiger counter to see if they are affected by the adjacent radioactive lightweight concrete.

1.3.3 Phase 3 – Design and evaluation

Concept development

Two design concepts are developed, each including disassembly, storing and assembly presented in drawings and text.

Economic assessment

Each developed design concept is calculated regarding economic cost and is compared to a similar design with new bricks. The economic calculations are based on cost information from literature as well as interviews with companies specialized in demolition, waste disposal and brick.

Environmental assessment

A simplified LCA is performed regarding embodied energy, carbon emission and use of abiotic (non-renewable) resources for each of the design concepts. As for the economic calculations, the environmental assessment is compared to a similar design with new bricks. The calculations are based on data from three sources: Inventory of Carbon & Energy Version 2.0, an LCA-database published by University of Bath in 2011, ÖKOBAUDATA (2019), an LCA-database from the German Federal Ministry of the Interior, Building and Community, and Ökobilanzdaten im Baubereich, LCA-data from the Association of Public Builders of Switzerland (KBOB, 2019). The databases contain cradle-to-gate data, i.e. covering life cycle stages A1 to A3.

1.4 Limitations

The project has the following limitations:

- Only one type of brick is tested (see method) and applied in the context (even though there might be other types of brick and materials in the building with potential for reuse).
- Only a limited number of bricks are tested due to the limited budget and time of this thesis. However, additional testing will be needed before reusing the bricks in a real project.
- No detailed LCA for the specific brick in these buildings is performed. The environmental benefit assessments are based only on tabulated values from three sources, see section 1.3.3.
- Focus is on reuse of the material in the given context, meaning that the methods, design concepts etc. might not be applicable in environments with other climate zones and regulations for example.

1.5 Reading instructions

The first two chapters of the report present the background, aim, method and limitations of the project as well as four reference projects where bricks have been reused. The description of the case buildings on Drakblommegatan in chapter 3 is followed by detailed specifications of the brick, the mortar and deconstruction in chapter 4. In the following chapter, FBU's ideas for the new buildings on Drakblommegatan are presented as well as an analysis of challenges related to project management, liability, economy and environmental issues. Based on the information presented in the previous chapters, chapter 6 presents the developed design concepts for how the bricks can be reused in new buildings on the same site. The final part of the report consists of discussion and conclusion. The process of the thesis is illustrated in Figure 1.2.

Figures, pictures and tables are courtesy of the author unless otherwise is stated.

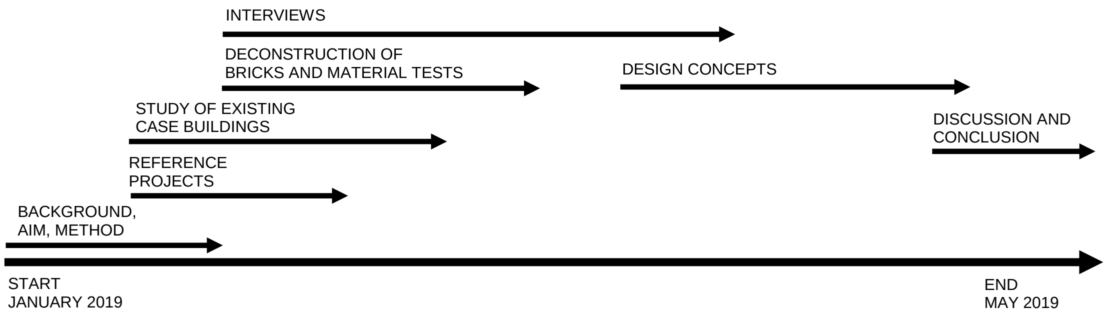

Figure 1.2 Process of the thesis, from the start in January 2019 to the end of the work in May 2019.

2 Reference projects

This chapter presents four buildings where reused brick has been used as façade material. The reference projects cover different methods to reuse bricks: Single reassembled bricks, bricks cast in concrete and bricks disassembled in one square meter modules. The projects are all situated in Scandinavia: Three projects are from Sweden and one is from Denmark.

2.1 Furutorpsparken

Furutorpsparken is a student residential complex in Helsingborg, Sweden, owned by the developer Helsingborgshem, see Figure 2.1. It was completed in 2016 and consists of 160 rental apartments for students. The outer façade material is reused brick in Danish format, 228 mm x 108 mm x 54 mm, which was provided by Gamle Mursten (Brukspecialisten, 2019a), a Danish supplier of reused bricks. The veneer brick structure is combined with a timber frame structure with insulation, see Figure 2.3. Helsingborgshem explains that it was the architect of the project, Arkitektlaget, who came up with the idea to use reused bricks as façade material. Arkitektlaget's ambition was that the reused brick would interact with the older surrounding buildings and that the material would have environmental benefits (Arkitektlaget, 2019). Helsingborgshem found the relatively expensive cost per brick motivated thanks to the positive message sent by reusing a material as well as the appealing material aesthetics (personal communication, February 26, 2019).

Figure 2.1 Furutorpsparken, a student residential complex in Helsingborg. Reprinted with permission from Helsingborgshem.

Figure 2.2 The bricks of Furutorpsparken. The texture is relatively rough and mottled. Reprinted with permission from Brukspecialisten.

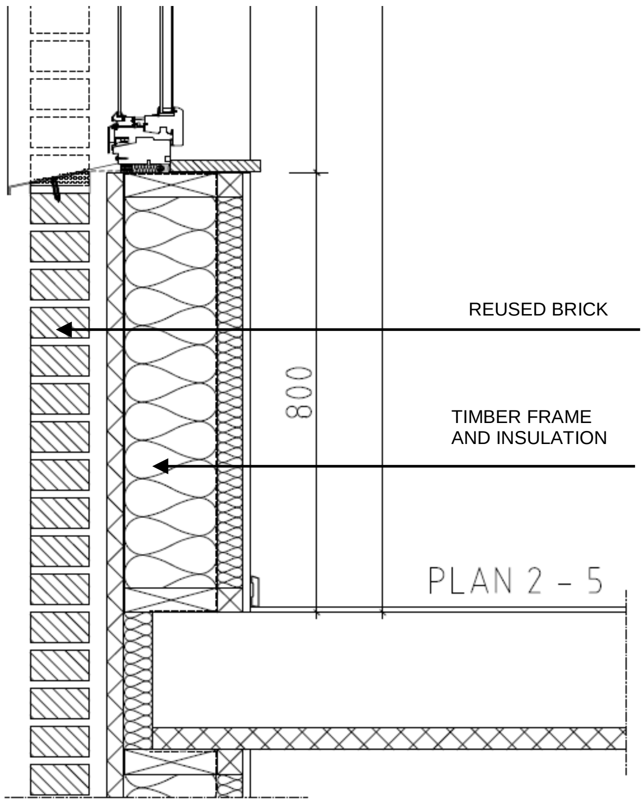

Figure 2.3 Vertical detailed drawing of facade wall of Furutorpsparken. The outer brick layer is combined with a timber frame structure with insulation. Reprinted with permission from Helsingborgshem.

2.1.1 Economy, liability and design

The construction had a turnkey contract and was performed by Veidekke between December 2014 and the autumn of 2016. The total building cost was 88 500 000 SEK (Veidekke, 2019) and 14 070 SEK/m²GFA according to Helsingborgshem. Veidekke estimates the total material cost of the bricks to 875 SEK/m² including transportation and mounting material (personal communication, February 14, 2019) which gives 14 SEK/brick assuming 63 bricks/m². According to Veidekke there was no difference regarding labour cost, material delivery or mortar compared to using new bricks. The only difference was that some bricks had to be discarded due to colour variance from soot. Gamle Mursten offers a material warranty for their bricks and is liable for the material performance (personal communication, February 4, 2019). The bricks have a quite rough and mottled surface which creates a design expression similar to old brick walls.

2.2 Mellanvångsskolan

Like Furutorpsparken, the outer material of Mellanvångsskolan's veneer brick façade wall is reused bricks from Gamle Mursten. Mellanvångsskolan is a municipal school in Staffanstorp, Sweden, see Figure 2.4. According to the architect of the project (personal communication, February 8, 2019) there was no difference in labour time or delivery compared to new bricks.

Figure 2.4 Mellanvångsskolan. Reprinted with permission from Brukspecialisten.

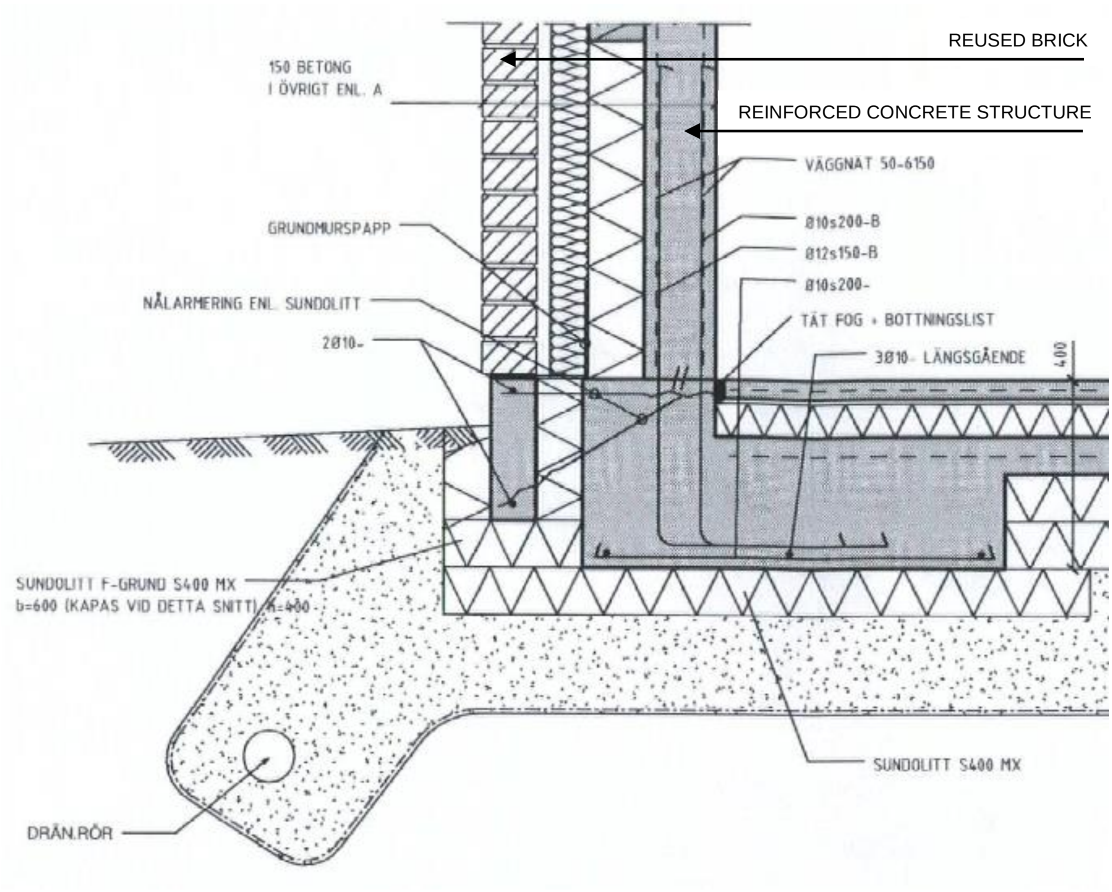

Figure 2.5 Vertical detailed drawing of facade wall of Mellanvångsskolan. Reprinted with permission from Staffanstorps kommun.

2.2.1 Economy, liability and design

The construction had a turnkey contract and was performed by NCC Construction Sverige AB between April 2013 and November 2014. A partnering contract was formed for the project between Staffanstorps kommunfastigheter and NCC (Staffanstorps kommunfastigheter, 2015). The total building cost, including landlord expenses, was around 22 000 SEK/m² GFA which was a relatively low cost from the project manager Anna Russell's previous experiences (personal communication, March 7, 2019). As for Furutorpsparken, Gamle Mursten offers a material warranty for their bricks and is liable for the material performance (personal communication, February 4, 2019). Similar to Furutorpsparken, the mottled and rough surface of the bricks creates a design expression similar to old brick walls. The reason to why reused bricks was chosen as façade material was its associated environmental benefits and its appealing material aesthetics with regard to the financial constraints of the project, according to the architect (personal communication, February 8, 2019).

2.3 Magasinet

On the site where Magasinet was built in Gothenburg, Sweden, there was previously an old factory from the beginning of the 20th century. When the factory was closed in 2001, the developer JM bought the land in 2004 with the intention the renovate it and rebuild it with apartments. Today, Magasinet contains 119 condominium apartments (Byggindustrin, 2014).

To get building permit from the municipality, one condition was to keep the original façade. Due to the bad condition of the original brick walls, JM decided to deconstruct the buildings and build a new structure using the original bricks, see Figure 2.6. The facades consisted of around 200 000 bricks which were all cleaned and sorted by age in three different sections. The bricks were then sent to Strängbetong, a company that produces prefabricated concrete wall elements. Strängbetong cut the bricks in half, put them in a timber frame and joined them with a fluid mortar. On top of the mortar, a layer of structural concrete, insulation, reinforcement and another layer of concrete was placed. JM also considered to construct the outer brick layer on site because cost estimations showed that it was about the same price as casting them into the prefabricated wall elements. In the end, JM choose the full prefabrication method to not have to worry about potential additional costs when constructing the wall on site. A challenge for Strängbetong was to decide which bricks to keep and which to discard. Together with the antiquarian of the project, they developed rules for allowed crack widths and corner damages. To make the joints between the façade elements less visible, Strängbetong mixed the joint sealant material with crushed brick from the discarded material (Byggindustrin, 2014).

Figure 2.6 Magasinet. The connections between the facade elements are visible as vertical and horizontal lines even though the joint sealant was mixed with crushed bricks.

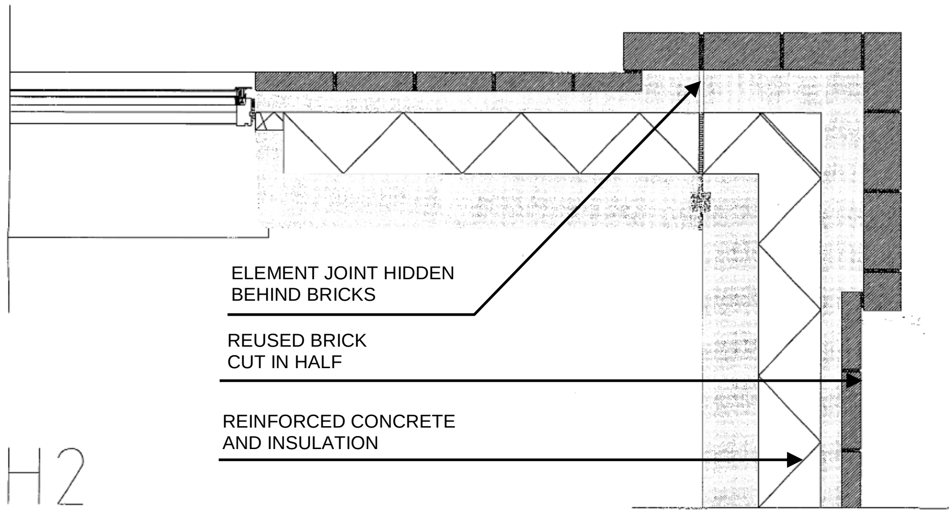

Figure 2.7 Horizontal detailed drawing of Magasinet. The joint between two elements is hidden behind a second layer of bricks. Reprinted with permission from Strängbetong.

2.3.1 Economy, liability and design

The total production cost including landlord expenses was 221 000 000 SEK (Byggindustrin, 2014). Apart from that figure, not much information is available about the project. However, one of the largest suppliers of prefabricated façade elements in Sweden states that a façade element with bricks of approximate size of 18 m^2 costs approximately 3000 SEK/m^2 including transportation approximately 150 km from the factory (personal communication, March 7, 2019). Assembly, including welding, of the façade elements costs around 6000 SEK per element with a mobile crane of normal size (personal communication, March 19, 2019). Another supplier of façade elements states the cost 3500 SEK/m^2 including standard insulation (personal communication, March 19, 2019).

According to Strängbetong, JM has the full liability for material performance of the bricks (personal communication, January 22, 2019). As mentioned above, technical details were designed to make the joints between the elements less visible, see Figure 2.7. Magasinet also features ambitious design elements such as brick vaults above façade openings. In some corners, it is visible that the bricks are cut in half since the shorter side is visible in these positions. Apart from that, it is difficult to tell the difference between this prefabricated façade and a brick façade constructed on site.

2.4 The Resource rows

The Resource rows is a multifamily residential project in Copenhagen, Denmark, that is currently under construction, see Figure 2.8. The project includes 63 apartments divided on 23 townhouses (TCT, 2019). The architect, Lendager ARC, is part of the business group Lendager group, which consists of two other companies, Lendager UP and Lendager TCW (Lendager Group, 2019). Lendager UP is a supplier of upcycled building materials and was started to meet an increased demand for locally produced upcycled products. Lendager TCW is a consulting company, offering analyses, strategies and workshops regarding resource efficiency and material flows.

In the project The Resource rows, Lendager Group aims to reduce the carbon footprint of the buildings by reusing materials for the construction (Lendager & Lysgaard Vind, 2018). Therefore, bricks have been deconstructed from an old brewery, schools and various other buildings in Denmark and reused as façade material in the resource rows. The bricks were then transported to Thisted-Fjerritslev Cementvarefabrik A/S who produced façade elements. In contrast to the project Magasinet described in section 2.3, the bricks for this project was deconstructed in modules of one square meter each and hence keeping the original mortar. When producing the façade elements for the Resource rows, these square brick modules were put in a mould, metal ties were inserted into the bricks and a 100 mm layer of reinforced concrete was cast on top of the bricks, see Figure 2.9 and Figure 2.10. To make a complete façade element, a timber structure with insulation was added to the bricks and the concrete. According to Lendager Group, only some of the original mortar was replaced due to cracks or to get the right colours (personal communication, February 21, 2019). The need for less mortar for the reuse of the bricks naturally contributes to the environmental benefits of this design concept.

Figure 2.8 The facade elements with brick modules during construction. Reprinted with permission from Lendager Group.

Figure 2.9 Brick modules in a mould on which concrete was cast. Reprinted with permission from Lendager Group.

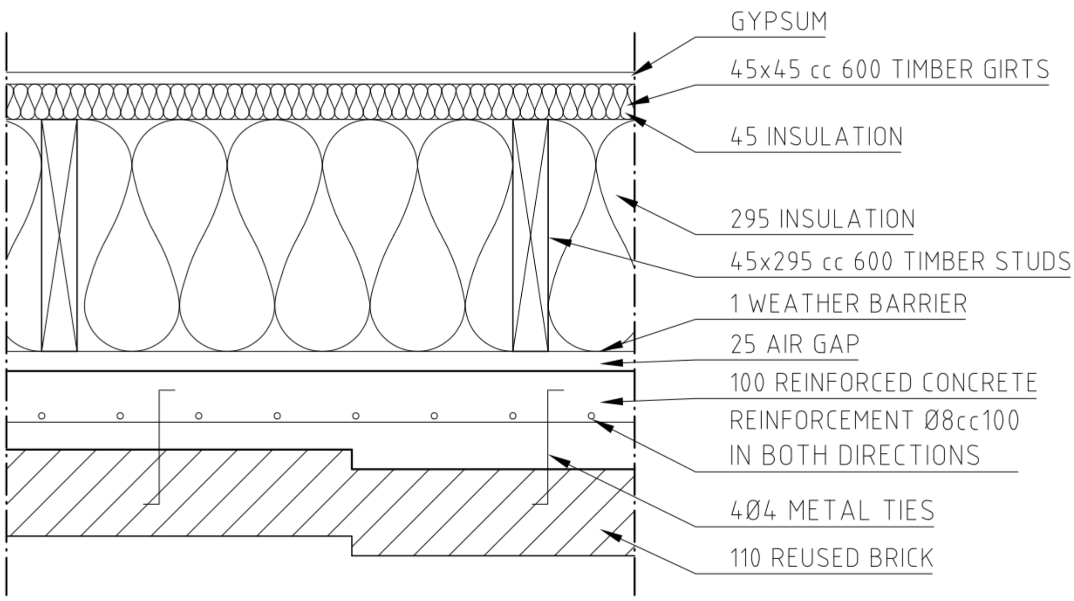

Figure 2.10 Detailed plan drawing of the facade wall of the Resource rows.

2.4.1 Economy, liability and design

According to Lendager Group, the labour time for two workers to deconstruct four brick modules of one square meter each varied from one to eight hours. With a labour cost of 706 SEK/h and 52 bricks per m² this gives the cost 3-27 SEK/brick. The work was highly dependent on power, water supply and accessibility. The work must be planned so that the tools can be connected to a power or water outlet. The buildings were often accessed from the outside where steep hills, trees and bushes can be in the way. With more experience of this deconstruction method, Lendager Group sees that the labour time for two workers can probably be held closer to one hour for deconstruction of 4 m² (personal communication, April 4, 2019). Lendager Group explains that a normal sized truck transported 32 pallets with 4 brick modules each, 128 sqm in total, to the producer of the façade elements (personal communication, February 21, 2019). The contractor of the project, Arkitektgruppen, states that the façade elements were more expensive than a normal sandwich element with bricks on (personal communication, March 12, 2019). Thisted-Fjerritslev Cementvarefabrik A/S states that the cost for the façade elements was 3000 DKK/m² (around 4200 SEK/m²), excluding the cost for the bricks and mounting them in the mould (personal communication, March 1, 2019).

According to Arkitektgruppen, the actor with the liability for the material performance of the bricks is Lendager UP (personal communication, March 12, 2019), i.e. sub-company of a consultant of the project. This contrasts to the previously presented projects, where either an external material supplier or the developer has the responsibility. That the material supplying company Lendager UP takes responsibility for the material performance is a normal arrangement of their projects, according to Lendager Group (personal communication, April 4, 2019).

The brick modules of the Resource rows create a very strong design expression, with modules of varying style and colour. This expression clearly stands out from the other reference projects in the sense that it is very different from common brick buildings. Lendager Group states that they wanted the building design to raise awareness about materials and circularity (personal communication, April 4, 2019).

2.5 Summary of economy, liability and design

In Table 2.1, the costs stated for the reference projects are summarized. Below, Table 2.2 summarizes other gained knowledge from the reference projects, such as contract types, actors liable for the material performance of the brick, incentives to reuse brick and design aspects.

Table 2.1 Summarized costs from reference projects.

	Cost [SEK/brick]	**Cost [SEK/m²***]**
Reused single bricks (Furutorpsparken)	14	728
Prefabricated concrete wall elements with bricks (Magasinet)	-	3000 - 3500
Assembly of concrete wall elements* (Magasinet)	-	333
Prefabricated wall elements with brick modules, excl. Cost of bricks (The Resource rows)	-	4200
Deconstruction of brick modules (The Resource Rows)**	3 - 27	156 - 1400
*Calculated from cost for 18 m² element		
** Assuming a labour cost of 706 SEK/h		
*** With 52 bricks per m²		

Table 2.2 Summary of economy, liability and design of the reference projects.

	Contract	**Brick liability**	**Reuse incentive**	**Design**
Furutorpsparken	Turnkey.	The material supplier.	Environmental benefits and appealing aesthetics.	Rough and mottled, similar to old brick walls.
Mellanvångsskolan	Turnkey with partnering.	The material supplier.	Environmental benefits and appealing aesthetics.	Rough and mottled, similar to old brick walls.
Magasinet	-	The developer.	Condition for building permit.	Joints between facade elements visible. Bricks cut in half are visible in corners. Brick vaults.
Resource rows	-	A material supplying sub-company of the consultant.	Environmental benefits.	Expressive with brick modules of different colours and styles.

3 The existing buildings

This chapter presents the existing case buildings on Drakblommegatan, their context as well as their technical specifications. The first part of the chapter presents the history and the context whereas the technical specifications are presented in the second part. The last part gives information on the radon problems of the buildings.

3.1 History and context

The three buildings are situated on Drakblommegatan 3-25 on Hisingen, an Island in the north part of Gothenburg, in the area Kvillebäcken, see Figure 3.1. Residential housing dominates the area but there are also commercial and service buildings. Kvillebäcken has been developed with several new multifamily residential buildings during the recent years and a market hall was constructed in 2014. At the time for the execution of this thesis, a new multi-story parking garage and several multifamily residential buildings were under construction along Fyrklöversgatan, directly west of Drakblommegatan. In 2012, a three-story building with housing for elderly was constructed east of the site of the investigated buildings. North and south of the site there are two story terraced houses. Drakblommegatan south of the site is a calm pedestrian street and Björlandavägen in the north is a very busy drive connecting Kvillebäcken with the west parts of Hisingen, for example the areas Björlanda and Torslanda.

The four storey buildings (three storeys of brick and a top storey with façade boards) are situated on the property Kvillebäcken 43:1 and were built in 1960, see Figure 3.2. They contain 161 small apartments, most around 35 m², which originally were built for nurses. Bostadsbolaget was the company which built the buildings and is also the company managing them today. The apartments are now not only housing for nurses but are rental apartments available for any Gothenburg citizen to apply for.

Since the construction of the buildings, the windows and the roofs has been renovated and some tests with new ventilation have been performed. Not much has been changed in the buildings apart from those renovations and as a whole the bricks and mortar have not been refurbished.

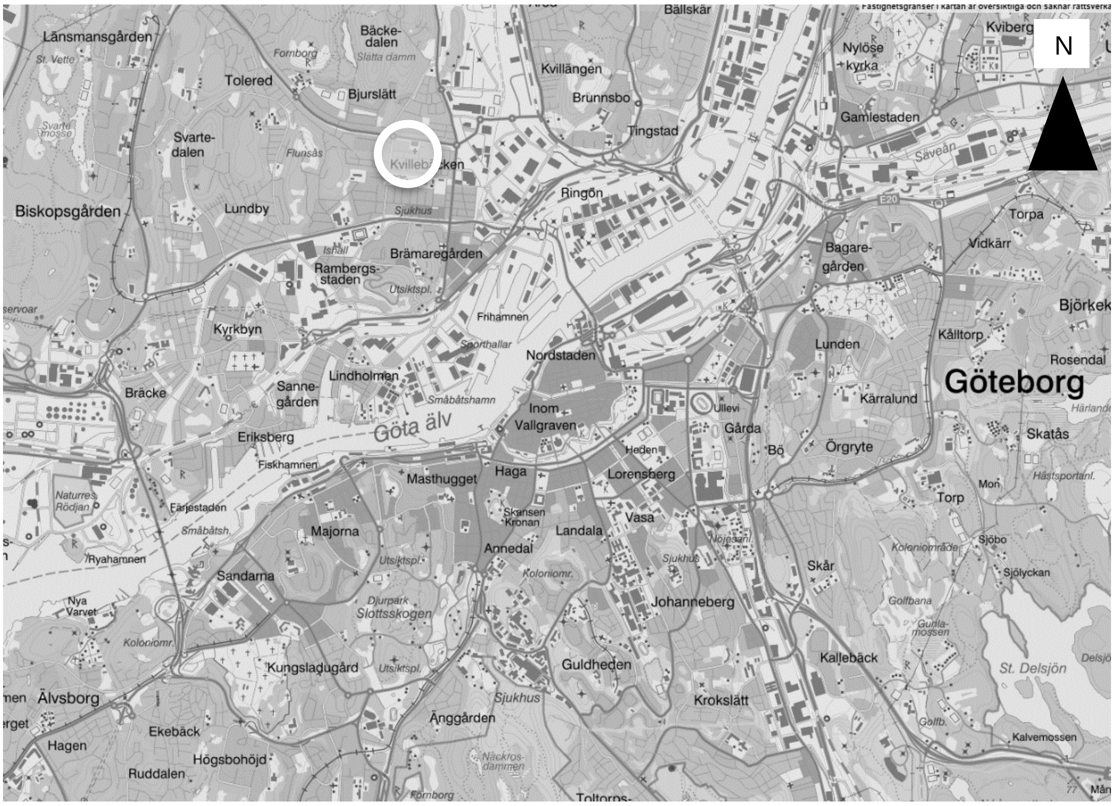

Figure 3.1 The location of the case buildings in Kvillebäcken, north part of Gothenburg, highlighted with a circle in the top (Lantmäteriet© I2018/00069).

Figure 3.2 The existing three buildings on the site.

3.2 Structure and materials

Original building drawings were collected from the city planning office of Gothenburg. The buildings sit on concrete ground slabs supported by concrete piles. Loadbearing inner walls consist of brick and floor slabs are made of concrete. The façade walls consist of a single layer of façade bricks connected to lightweight concrete blocks with four metal ties per m². A section of the building is shown in Figure 3.3 and more drawings are available as appendix D and E.

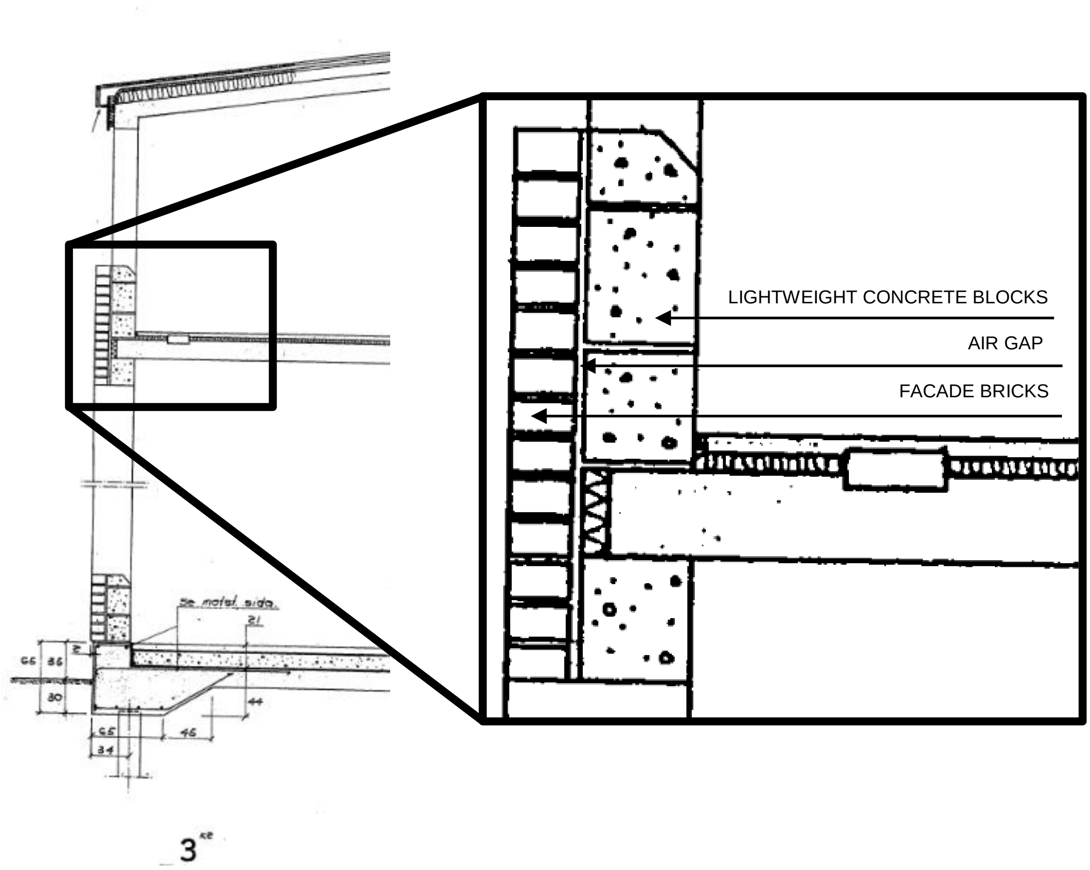

Figure 3.3 Part of original section drawing named "K6" to the left and a zoomed in detail to the right. (Bostadsbolaget).

3.3 Visual inspection

A visual inspection of the buildings was carried out 2019-02-15. All facades of the three buildings were inspected from the ground and damages were located. Common damages to look for was identified from the manual Undvik misstag i murat och putsat byggande (2018), a report from the association Tungt murat och putsat byggande which has members both from the academia and companies working with bricks. Photographs of the facades and located damages are shown in Appendices A-C. The general visual impression is that the brick is in good condition. Cracked bricks were only observed in few locations and the reason for the cracks seems to be related to structural errors rather than being frost or salt related, see Figure 3.4. The mortar is missing or cracked in many positions and this might be because it has not been renovated since the buildings were built in 1960. In some positions, the bricks and the mortar has been replaced, for example above some windows and entrances. Algae were observed on a few bricks and biological growth can be a problem for reuse according Carl Hansson, structural engineer at Brukspecialisten, a supplying and consulting company in the brick industry (personal communication, April 2, 2019). If there is a lot of biological growth on the façade side of the brick, i.e. making it water tight, the brick might suck more water from the mortar during the reuse construction than what it is able to release.

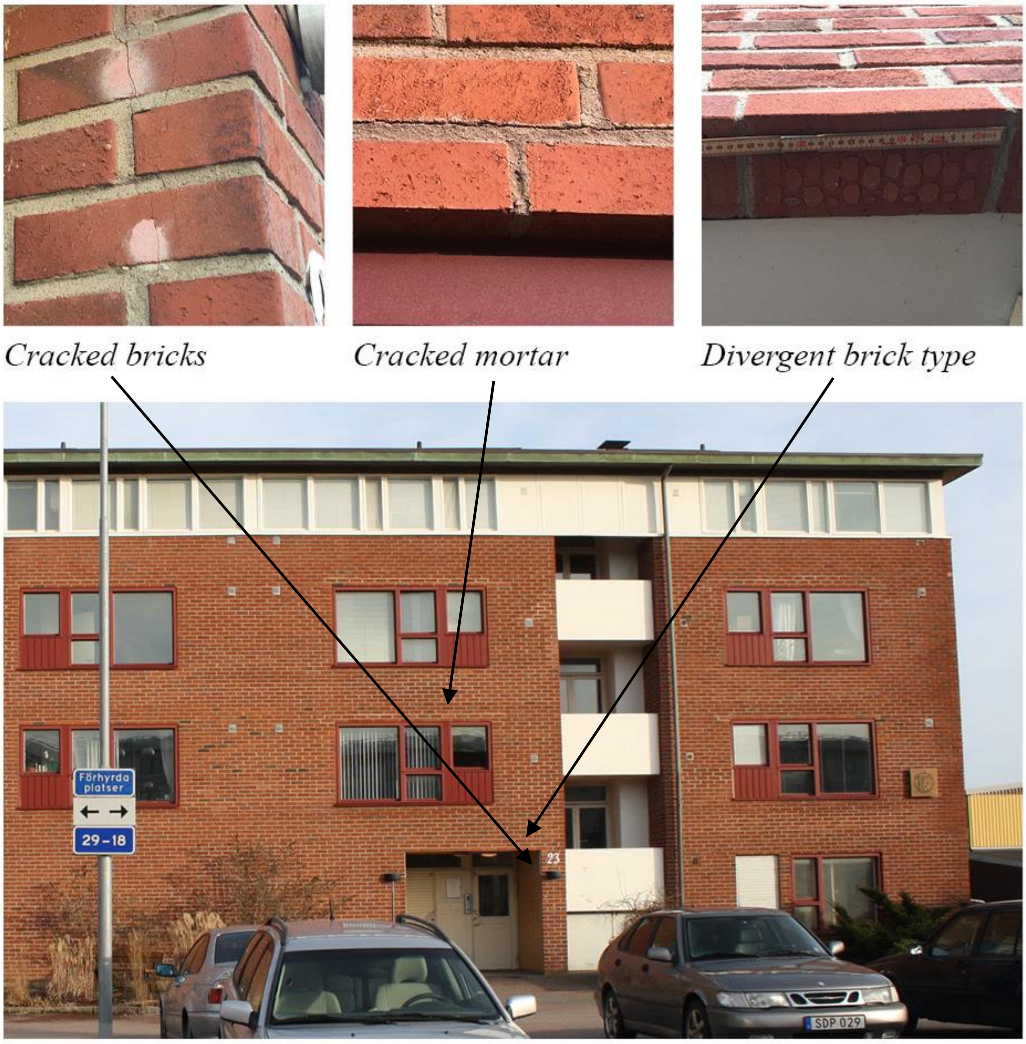

Figure 3.4 Some damages and deviations observed during the visual inspection. More pictures are available in appendices.

3.4 Radon problem and demolition decision

As mentioned in the introduction chapter, the three buildings will be demolished due to problems with radioactive material, the lightweight concrete. Both exterior and interior walls potentially consist of this concrete, called "blåbetong" in Swedish. The radiation has been measured to values between 100-400 Bq/m³ in the apartments on Drakblommegatan (Bostadsbolaget, 2018). If the yearly mean radiation level exceeds

200 Bq/m³ actions need to be taken, according to recommendations from The Public Health Agency of Sweden (Bostadsbolaget, 2018). Measures to decrease the radiation level, such as increased ventilation, that the landlord Bostadsbolaget have undertaken have however not been successful. Hence, Bostadsbolaget has decided to demolish these buildings.

3.4.1 Interaction of bricks and concrete

Even though the façade bricks are located right next to the radioactive lightweight concrete blocks, there is no risk that the brick will be radioactive after it has been detached from the concrete, according to radon experts and Anders Nordlund, Associate Professor and Head of the Subatomic and Plasma Physics Division, Department of Physics at Chalmers University of Technology. The brick cannot be contaminated by the lightweight concrete since the uranium atoms are “stuck” in the concrete. Anders Nordlund explains that the radioactivity in the lightweight concrete stems from uranium and thorium isotopes that are bound in the concrete (personal communication, April 26, 2019). As these decay they will cause radon gas which will escape the concrete. Neither the uranium or thorium or radioactive radiation will contaminate surrounding materials. To verify that radioactive lightweight concrete was properly removed from building blocks, the radioactivity of disassembled bricks from the building were measured with a Geiger counter and the test showed that the bricks were not radioactive, see Figure 3.5.

Figure 3.5 Radioactivity test setup. The Geiger counter to the left and the brick sample to the right. The test showed that the brick is not radioactive.

4 The brick and the mortar

This chapter presents the properties of the brick and the mortar in the current buildings. The properties are retrieved from the original drawings and from material tests. Furthermore, it presents different demolition aspects.

4.1 The brick

The brick is a frost resistant, red façade brick placed in a running pattern in a cavity brick wall, according to drawing K1 in the original drawings, stating the technical specifications of the buildings. The drawing further gives the notation 1,8/1,4/250 for the bricks. What these numbers mean has not been clarified and they do not correlate to any measured values, see following sections for more information. Potentially 1,8 can be the net density, 1,4 can be the gross density and 250 can be the length of the bricks. The bricks have a light texture, and the brick surface type is called "schatterad" in Swedish. Each m² of wall consists of 52 bricks, see Figure 4.1.

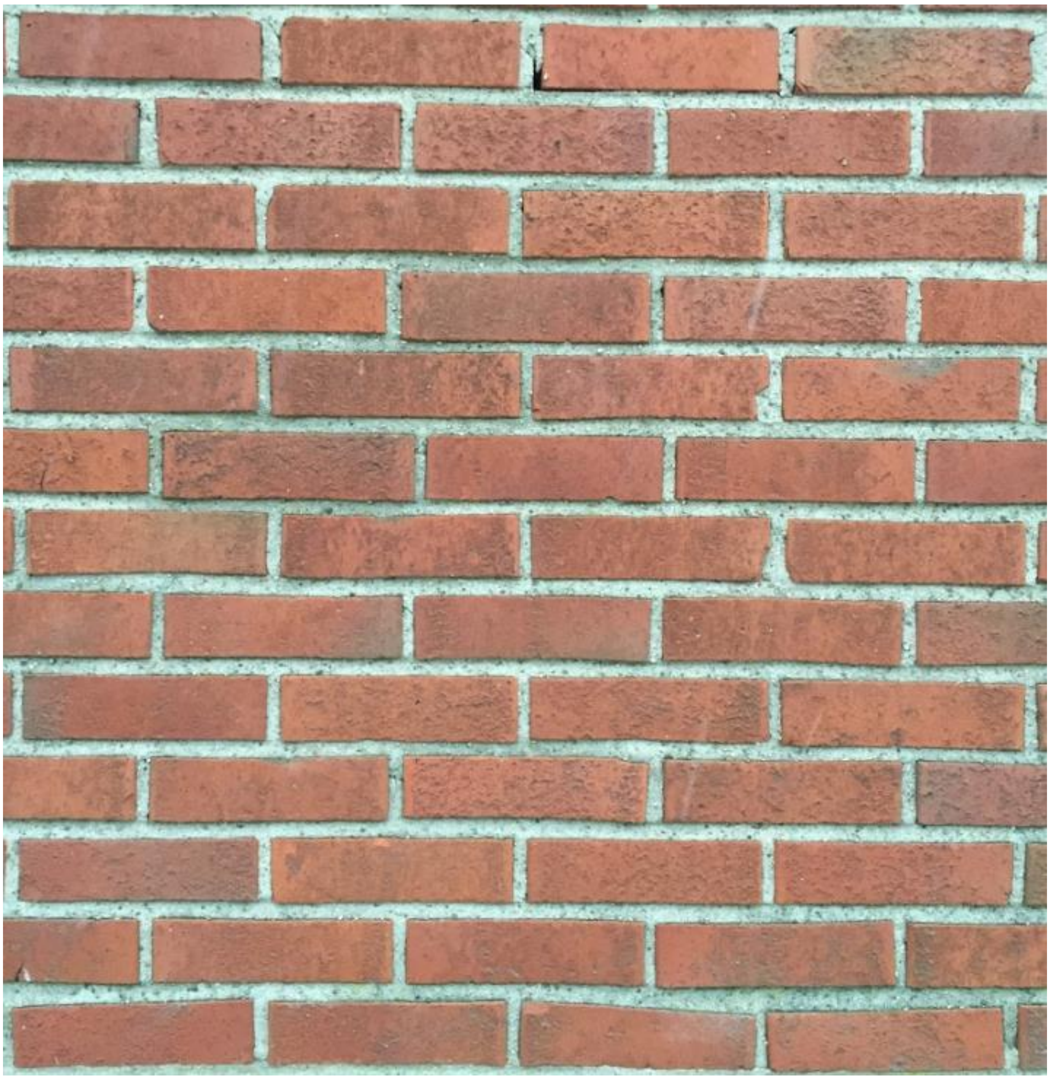

Figure 4.1 The bricks of the existing buildings on Drakblommegatan. The picture shows around one square meter of the wall with 52 bricks.

4.1.1 Deconstruction

Five bricks were deconstructed from the west façade on the westernmost building on 2019-01-21 by a construction company. The purpose of the deconstruction was to get an initial impression of how easy the bricks were to remove from the wall, how easy the bricks could be cleaned from mortar and to confirm the correctness of the original drawings. An electric chisel was used to remove the bricks from the façade, as shown in Figure 4.2. The vibrations from the chisel made the mortar crack and it was only possible to remove single bricks, i.e. not two bricks connected with mortar. One brick including remaining mortar was removed and sent to the company Gamle mursten for a cleaning test, see section 4.2. The overall impression from the deconstruction was that the mortar came off the bricks very easily.

Figure 4.2 Deconstruction of five bricks. The mortar came off the bricks very easily and it was not possible to remove two bricks connected with mortar.

Another 30 bricks were deconstructed from the same position on 2019-03-07. The purpose of this deconstruction was to collect brick samples for further material tests performed by Gamle mursten, see section 4.1.2. A first deconstruction attempt was made on the north façade of the same building 2019-02-26. This attempt failed, and the bricks were not possible to remove from this position with the available tools. The craftsman claimed that the bricks were not possible to remove due to that the back of the bricks were stuck on the lightweight concrete with mortar. For that reason, a new attempt was made on the same position as the first deconstruction which succeeded.

Figure 4.3 The bricks, the air gap and the lightweight concrete.

4.1.2 Material tests

20 bricks have been tested by Gamle Mursten and the results are available in Appendix F and G. The mean width, height and length of the tested bricks are 113 mm, 62 mm and 241 mm and the mean gross density is 1440 kg/m³. This gives a mean weight of 2,4 kg per brick.

Figure 4.4 One of the deconstructed bricks.

The results of the material tests show that the bricks have a high compressive strength, with a mean value of around 40 MPa. According to the structural engineer Carl Hansson, this is a somewhat higher compressive strength than what a normal Danish brick has, the most common brick in cavity brick walls in Sweden today (personal communication, April 2, 2019).

Hansson points out that the absorption, "Minut sug", is rather low, but within the range of what is needed for a normal mortar to reach full adhesion when the bricks are reused. The reason for the variation is that the bricks were not dried before the tests, hence possibly having different moisture content, according to Gamle Mursten (personal communication, April 8, 2019).

The pore size distribution, "porefyldningstal", is equal to or below 0,9. According to the chosen test method, this value should be below 0,8 to indicate frost resistance. However, since the bricks have shown frost resistance in exterior walls of the existing buildings, porefyldningstal below or equal to 0,9 are assessed as sufficient to ensure frost resistance, according to Gamle mursten.

The results of the material tests indicate that the physical properties of the bricks do not prevent reuse in façade structures. The compression strength is high, the absorption is enough for normal mortar and the frost resistance is sufficient. As stated in section 3.3, biological growth can be a problem when reusing bricks, but Gamle mursten noticed no growth on the received samples (personal communication, April 8, 2019). The variation of the geometric size of the bricks is within an acceptable range, according to Carl Hansson.

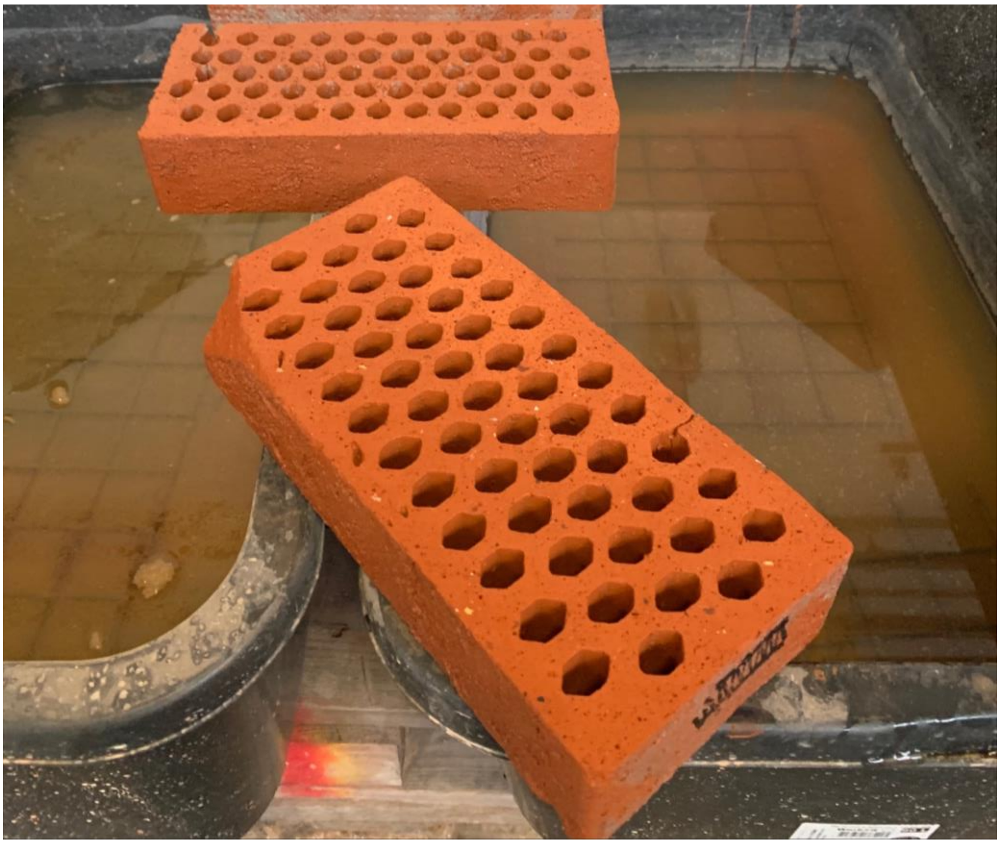

Figure 4.5 Cleaned bricks during the test procedure. Printed with permission from Gamle mursten.

4.1.3 Quantity and additional testing

The quantity of the bricks has been calculated from dimensions of the buildings specified on the original drawings. No extensive damages were observed during the visual inspection and therefore the quantity of available bricks is assumed to be equal to the full brick façade area. However, the bricks also need to be tested regarding contamination. According to Mikael Theorin, Environment & Safety specialist, bricks adjacent to joint sealants can contain hydrophobic contaminants such as PCB for example (personal communication, March 22, 2019) and if so, the bricks might not be allowed to be reused. PCB is used as a plasticizer in building materials such as joint sealants in caulk and window glazing, insulation materials, PVC tiles and bitumen impregnated asbestos coating on metal sidings. Theorin further mentions chloroparaffins (short- and medium chained), PAH and aliphatic hydrocarbons (C16-C35) as possible contaminants since they are commonly present in building materials adjacent to bricks in buildings.

Table 4.1 shows the area of the exterior brick walls, number of bricks and their total weight. The number of bricks has been set to 52 bricks per m² based on the brick dimensions 240 mm width and 65 mm height and 13 mm mortar. The mean weight, 2,4 kg, stated in section 4.1.2, has been used to calculate the total weight. The deconstruction method affects the number of bricks that are able to be reused after demolition and this is clarified in section 4.3.

Table 4.1 Wall area, number of bricks and weight of bricks in façade walls of the existing buildings on Drakblommegatan.

	Wall area [m²]	**Bricks [-]**	**Weight [ton]**
West facade	408	21226	51
North facade	115	5980	14
East facade	404	21018	50
South facade	117	6084	15
Total per building	1044	54308	130
Total of three buildings	3133	162923	391

4.2 The mortar

The dimension of the mortar is highly varying: From around 10 mm to 20 mm. It consists of lime, cement and sand in the volumetric proportion 1:1:8 according to the original drawings of the buildings. With Swedish building terminology this mortar type is called KC11/4. The first numbers indicate the binders (1 part lime plus 1 part cement). The number 4 indicates the proportion of the filler in relationship to the binders, i.e. 4x(1+1)=8 (Dührkop, Saretok, Sneck, & D. Svendsen, 1966). This mortar is classified as M2,5-1:1:8CK today (Boverket, 2016). This mortar belongs to the second strongest mortar type, Class M2,5 (B), which can be seen in Table 4.2 below. The mortar class is used as input to calculate the compression strength of a brick wall. In Table 4.3 below, one can see that a higher mortar class gives a higher compression strength, fk (MPA).

Bricks with mortar containing cement are known to be difficult to clean and in some cases the brick will break before the mortar (Nordby et al., 2009). Cleaning tests performed by Gamle mursten show that the bricks cannot be cleaned in their machines due to too high cement content in the mortar. However, the mortar is relatively easy to remove from the bricks with a hand-held tool like an air or electric chisel hammer (personal communication, February 4, 2019). Tomas Gustavsson, structural engineer with long experience in brick construction, points out that the cement content is not the only decisive factor for how easy the brick is to clean (personal communication, January 28, 2019). Gustavsson explains that the burning temperature that was used during the production of the brick also affects the cleaning possibilities.

Table 4.2 Mortar class *(Boverket, 2016)*. The mortar of the case buildings is a lime and cement mortar called KC 1:1:8 in the second strongest mortar class group, M2,5. Arrows and translations added by the author.

MORTAR CLASS

VOLUMETRIC PROPORTIONS

Tabell H-2 Blandningsproportioner för murbruk

Murbruksklass Bindemedel	**Viktdelar**	**Volymdelar**	**Murbruksklass Beteckning**[1]
Murbruksklass M10 (A)			*Murbruksklass M10 (A)*
Cement	C 100/450	C 1:4	M10-1:0:4C
Kalk, Cement	KC 20/80/400	KC 1:3:15	M10-3:1:15CK
Kalk, Cement	KC 10/90/350	KC 1:4:15	M10-4:1:15CK
Murcement	M 100/350	M 1:3	M10-1:3M
Murbruksklass M2,5 (B)			*Murbruksklass M2,5 (B)*
Kalk, Cement	KC 35/65/550	KC 1:1:8	M2,5-1:1:8CK
Murcement	M 100/600	M 1:5	M2,5-1:5M
Murbruksklass M1 (C)			*Murbruksklass M1 (C)*
Kalk, Cement	KC 50/50/650	KC 2:1:12	M1-1:2:12CK
Murcement	M 100/900	M 1:7	M1-1:7M
Murbruksklass M0,5 (D)			*Murbruksklass M0,5 (D)*
Kalk, Cement	KC 50/50/950	KC 2:1:18	M0,5-1:2:18CK
Hydraulisk kalk	Kh 100/850	Kh 1:5	M0,5-1:5Kh

[1] I beteckningen anges murbruksklass och volymdelar; cement, kalk, sand samt bindemedeltyp.

THE MORTAR OF
DRAKBLOMMEGATAN
KALK = LIME
CEMENT = CEMENT

Table 4.3 Characteristic compression strength, fk, of a brickwork, with increased strength for increased mortar class *(Boverket, 2016)*. For example, a brickwork with bricks of strength class 15 has a compression strength of 4,2 MPa if the mortar class is the same as for the mortar on Drakblommegatan, M2,5.

STRENGTH CLASS

THE MORTAR CLASS OF DRAKBLOMMEGATAN

Hållfasthets-klass	**f_k (MPa) Murbruksklass enligt SS-EN 998-2**				**Tunn-fogs-bruk**
	M10	**M2,5**	**M1**	**M0,5**	
15	5,8	4,2	3,2	1,3	–
25	7,5	6,0	4,5	1,8	–
35	8,9	7,5	5,7	2,3	–
45	10,0	9,0	6,8	2,3	–
55	11,1	10,3	7,8	2,3	–
65	12,1	11,6	8,8	2,3	–

4.3 Deconstruction

4.3.1 Sorting and disposal of the brick

The cavity façade wall consists of lightweight concrete blocks, a 20 mm air gap and a half layer of frost resistant façade bricks, see Figure 3.3. When demolishing this type of lightweight concrete, in Swedish called “blåbetong”, the concrete and the bricks need to be delivered separately to a waste receiving company, according to the demolition company Normans AB (personal communication, March 1, 2019). Hence, Normans AB’s standard demolition procedure would mean that the bricks would be put in one container and the blåbetong in another container, regardless if the bricks were to be reused or not. The demolition company Kolstads Göteborg AB also states that the bricks and the blåbetong need to be separated during the demolition (personal communication, March 4, 2019).

In contrast to the statements of the demolition companies, a large waste receiving company in Gothenburg, says that they can receive blåbetong and bricks mixed in one container as both materials are sorted as aggregate landfill (Swedish: “fyllnadsmassor”) (personal communication, March 4, 2019). The fee for leaving a mixed container is not more expensive than leaving separated containers with blåbetong and brick, given that the blåbetong is not contaminated. Another large waste receiving company in Gothenburg also states that they can receive the blåbetong and bricks in mixed containers, but if the blåbetong is contaminated the fee is higher than for a container with pure brick (personal communication, March 4, 2019). Kolstads AB explains that they paid 700 SEK/ton for leaving blåbetong to this waste receiving company during the demolition of Kärraskolan in Gothenburg 2018 (personal communication, March 4, 2019). For receiving pure brick, a large waste receiving company in Gothenburg charges a fee of 334 SEK/ton (personal communication, March 4, 2019).

Wikells byggberäkningar is a company that produces tools for cost calculations for the building industry. For transportation of waste of bricks and light weight concrete, Wikells byggberäkningar suggests assuming 50% air in each container. One truck can load 18 m³ and costs 5000 SEK per round for a normal transportation distance within a Swedish city (personal communication, March 1, 2019).

4.3.2 Standard demolition

If a lower amount of bricks were to be reused, Normans AB states that a standard demolition can take place, where they sort bricks and blåbetong in different containers, as mentioned in section 4.3.1. In contrast to a careful deconstruction method with a circular saw, see section 4.3.3, a standard demolition uses a demolition truck to scrape the brick of the walls down on the ground, see Figure 4.6. To demolish a brick wall takes around 0,56 h/m², has a labour cost of 200 SEK/h with an overhead expense factor of 3,53 which means 0,56x200x3,53=395 SEK/m² or 395/52=8 SEK/brick (Wikells Byggberäkningar, 2017). 0,56 h/m² is the time it takes to get the bricks from the wall and down on the ground, i.e. excluding time for transporting the bricks from the ground to a container. However, for a project with as many bricks like Drakblommegatan, the working time per m² is probably less than 0,56 h/m² and the stated time can be assumed to include transportation to a container according to Wikells Byggberäkningar (personal communication, March 4, 2019). For a standard demolition process for these particular case buildings, this is a cost that will occur regardless if the bricks were to be reused or not. The final product is bricks sorted in separate containers. Hence, this cost is not an extra expense related to reuse of bricks. From the position in the containers, a cleaning process of the bricks can begin. However, this method will result in a lot of damaged bricks and a smaller amount of bricks able to be reused. Gamle Murtsen estimates the amount of bricks able to be reused to maybe 50-75% (personal communication, February 4, 2019).

Figure 4.6 Truck in use during the demolition of Fixfabriken in Gothenburg, March 2019. 50-75% of the bricks do not brake during demolition and remain reusable.

4.3.3 Careful deconstruction

If the number of bricks that can be reused after demolition of the buildings are to be maximized, a demolition company, frequently involved in demolition projects in Gothenburg, suggests a careful deconstruction method where the bricks are first cut down in modules with a circular saw, then cleaned by hand and finally put on pallets. The company has never practiced this method but gives a rough cost estimation for the procedure, from deconstruction to cleaned bricks: 1000-2000 SEK/m² (personal communication, April 8, 2019), which equals 19-38 SEK/brick for 52 bricks per m². Using a careful demolition, based on the visual inspection explained in section 3.3, this report assumes that 90% of the bricks can be reused. 10% is assumed to be discarded due to existing cracks and other damages.

Figure 4.7 Deconstruction of brick modules using a circular saw. Reprinted with permission from Lendager Group.

4.3.4 Cleaning, testing and storing

To clean the bricks, take around 10-12 seconds per brick, according to Gamle Mursten (personal communication, February 4, 2019). This equals 9-10 minutes per m² brick wall on Drakblommegatan (with 52 bricks per m²). With a labour cost of 706 SEK/h (Wikells Byggberäkningar, 2017), 10 seconds per brick gives the cost 2 SEK/brick. According to the brick construction company Murbiten Tegel & Puts AB the company would charge 7-15 SEK per brick for cleaning and preparation of the bricks (personal communication, March 7, 2019). In addition to the cleaning, 20 bricks per 15000 deconstructed bricks needs to be tested for Gamle Mursten to give warranty for the brick. To test 20 bricks cost around 11 300 SEK (8000 DKK) (personal communication, February 4, 2019).

As can be seen in Figure 3.2, the site is quite spacious and there is a large open area in the west part, currently used for parking. This open area can potentially be used for weather protected storing of the bricks during the demolition process. If the cleaning process takes place on site, a temporary cleaning station can also be set up in this area.

4.3.5 Contract conditions

The above sections of the report conclude that there are many different aspects and methods related to demolition or deconstruction of the buildings and reuse of the bricks. The report Juridik för återbruk – Begagnade byggvaror och returmaterial (English: "Laws for reuse – Used building materials and recycled materials") published by the Swedish National Board of Housing, Building and Planning, Boverket, goes through important conditions to include in the contract between a developer or landlord and a demolition company. It is important to specify that the brick will be reused and clarify the demolition or deconstruction method as well as the procedure of sorting, cleaning, testing and storing. The meaning of demolition is otherwise that the materials will be destroyed (Boverket, 1998).

4.3.6 Cost summary for deconstruction

In Table 4.4 and Table 4.5, the costs related to deconstruction, landfill and tests are summarized.

Table 4.4 Summarized costs for deconstruction, demolition, cleaning and preparation of bricks derived from interviews.

	Cost [SEK/brick]	**Cost [SEK/m²**]**
Careful deconstruction with a circular saw incl. cleaning (Demolition company)	19 - 38	1000 - 2000
Normal demolition with a truck (Wikells Byggberäkningar)	8	416
Cleaning of bricks (Gamle mursten)	2	104
Cleaning and preparation of bricks (Murbiten Tegel & Puts AB)	7 - 15	360 - 780
*Assuming 12 seconds per brick and a labour cost of 706 SEK/h		
** With 52 bricks per m²		

Table 4.5 Summarized costs for tests, transportation and landfill.

	Cost	Cost [SEK/brick*]	Cost [SEK/m²**]
Tests* of bricks [SEK/(20 bricks per 15000 reused bricks)]**	11 300	0,8	39
Transportation of bricks and blåbetong [SEK/(18 m³)]	5000	0,9	49
Landfill of bricks [SEK/ton]	334	0,8	42
Landfill of blåbetong [SEK/ton]	700	-	-
*With mean brick dimension 113x62x241 mm³ and mean density 1440kg/m³			
**With 52 brick per m²			
***Including tests specified in section 4.1.2. Additional tests specified in 4.1.3 are not included			

5 The new buildings

This chapter presents FBU's plans for new buildings on Drakblommegatan. It also presents aspects on reusing bricks related to project management, liability, economy and the environment.

5.1 Plans for new residential housing

FBU has made initial design sketches for new multifamily residential buildings on Drakblommegatan. According to Kristina Hulterström and Anders Jurin, architects at FBU, they plan for buildings in a block formation, creating more defined courtyards, something that is missing on the site today (personal communication, February 11, 2019). Potentially, the buildings can be about six floors towards the busy road in the north (Björlandavägen) and about four floors towards surrounding lower townhouses in the south, see Figure 5.1. There is currently no detailed development plan for this property and an application has been sent to the municipality for information about when the planning process can begin. FBU has not received a response yet but when the planning process starts, FBU will take part as the developer of the site.

Hulterström and Jurin sees potential for the bricks in the current buildings to be reused as façade material for the new buildings. But they also see potential for reused bricks in other building components, landscape architecture and in complementary buildings, for example waste disposal buildings on the courtyards.

A benefit of reusing the bricks from the current buildings is that FBU can see how the bricks look in a complete wall structure (Fritzon, 2002). However, if the bricks are not entirely clean from mortar after the cleaning process the brick wall will have a more mottled appearance (Fritzon, 2002). As mentioned in chapter 4, the developer Helsingborgshem choose reused bricks because they found their appearance appealing. The fact that the number of bricks that will be able to be reused after the demolition is uncertain complicates the design process (Fritzon, 2002).

Figure 5.1 Early design sketch for how new residential buildings can be built on the site. The existing buildings are visible as dashed lines.

5.2 Project management

Hulterström and Jurin point out the importance of making sure that the reuse is within the ambition of the project. For example, if the economic cost of using the bricks from the current buildings is more expensive than using new bricks, this higher cost must be motivated. One way to motivate the higher cost could be to state that reused bricks should be used in the so-called Target document ("Inriktningsbeslut" in Swedish) of the project. Before the project planning phase of a project begins, FBU writes a Target document which states what is important in the specific project and what the project manager must pay attention to. The Target document is approved by the board of FBU before the project planning phase begins and hereby has a strong governing status. By including an instruction to use reuse brick in the Target document for new buildings on Drakblommegatan a potentially higher cost for this material is motivated. Erik Falk, project manager at FBU, agrees on this point (personal communication, February 22, 2019). Falk explains that as a project manager, he needs an instruction from a target document to execute the use of a more expensive solution, for example a higher material price for a reused brick compared to the cost for a new brick. Ulf Östermark, research and development manager at FBU, explains that the goal for reduced waste in the City of Gothenburg's action plan for the environment alone does not have enough governing strength to motivate a higher cost for reused material in a normal project (personal communication, February 11, 2019). Östermark, Falk, Hulterström and Jurin all underline that if there is not a special focus on reuse in a project, the costs need to be within the investment budget to create decent rents for the citizens of Gothenburg.

5.3 Law and liability

5.3.1 Ownership

Builders, construction companies, property owners etc. have full freedom to transfer and sell leftover material according to Swedish law (Boverket, 1998). In legal terms, there is no difference between new and reused material. The law only differs depending on if the material is called waste or not. Since it is up to the owner of the material to decide if the material is waste, Bostadsbolaget has full control of the material and can transfer it to FBU for construction of new buildings.

5.3.2 Liability

If the developer of a site, in this case FBU, decides on a general contract for the project, the conditions specified in AB 92 – Allmänna Bestämmelser för byggnads-, anläggnings- och installationsentreprenader (English: “general conditions for procurement and contracts for construction”) most commonly applies in Sweden. In case the project uses a turnkey contract, ABT 94 (English: “general conditions for construction with turnkey contracts”) applies. For both these contract types, the crucial fact for who (the developer or the contractor) that is liable for the performance of the building material, is the actor that prescribes, demands or proposes the use of the material in the project (Boverket, 1998). If the developer demands that a certain material must be used, for example reused bricks, the developer has the legal responsibility for the material performance. If the developer on the other hand only proposes the use of reused materials but leaves to the contractor to choose the exact product, the responsibility is by the contractor. The contractor is always responsible for the material performance as long as there is not a demand from the developer to use a certain product (Boverket, 1998).

The division of the legal liability between the contractor and the material supplier depends on the contract between these actors. If it is stated by the material supplier that the material is reused, the contractor cannot have the same demands on the material performance as for a new material. The risk for damages due to fungal spores, shorter technical lifetime etc, must be accepted by the contractor as a consumer of the material and that limits the possibility to have complaints. In order for the contractor to be able to have complaints, the material supplier must state that the material has a certain quality, is safe to use, or in another way state that the material can be reused (Boverket, 1998).

5.3.3 Warranty

For new bricks, the material suppliers most often offer a material warranty for fifteen years. In case of reused brick, Gamle mursten is a supplier that can offer material warranty comparable to the warranty for new bricks. Björn Möller, strategic purchaser at FBU, explains that FBU potentially can use reused brick without this normal material warranty, since he sees relatively low risk for material failure of the bricks with regard to the high durability of this material (personal communication, February 11, 2019). Möller assesses the risk to build without material warranty as low but underlines the importance of being able to differ between failures related to the material performance and failures related to the execution of the construction to avoid a litigation with the contractor. According to the structural engineer Tomas Gustavsson, it can be difficult to differ between material and construction failure (personal communication, March 19, 2019). Hence, reusing bricks without material warranty does not seem like an attractive option for FBU. As previously mentioned, a company that can offer material warranty for reused bricks is Gamle mursten. No other company that offers the same warranty has been found during the literature study and interviews carried out during this project.

5.3.4 Particular conditions for the contract

AMA AF is a document with advices and instructions to include in the particular conditions (Administrativa föreskrifter in Swedish) of a contract for building constructions. AMA AF has codes/titles related to specific parts of the construction. Boverket (1998) suggests what codes to pay special attention to and how to formulate these in a project with reused façade bricks for example. For the code AFC.2612 (in AMA AF 98 for a general contract), the following formulation is suggested (translation made by the author from Swedish to English): "*The contract must be carried out with the material specified by the client according to the technical description. The material must be disposed of and stored in accordance with the technical description. Otherwise for this material, liability according to AB 92 Kap 5 § 5 applies.*" As stated in section 5.3.2 this statement would make the client responsible for the material performance and for it to be an attractive option for FBU, a material supplier needs to offer material warranty, see section 5.3.3.

5.4 Economic figures

One of FBU's ongoing housing projects in Gothenburg has calculated building costs of nearly 200 million SEK and a GFA of 10976 m². All facades in the project are planned to have bricks as façade material. In Table 5.1, the influence of various material costs per brick on the total building cost is shown. The material cost per brick used in FBU's building cost calculation is 6 SEK/brick and since the cost statements from experts and reference projects indicate that the cost for reused bricks can be higher, simulations with increments of 6 are made for 12, 18, 24 and 30 SEK/brick for comparison. The only parameter that is changed for the different simulations is the material cost per brick. In case of buying reused bricks from a supplier (e.g. Gamle Mursten), no other expenses related to reused bricks except the higher material cost have been discovered, and therefore all other building costs, such as the cost for labour, mortar, reinforcement and insulation, are not changed.

It can be noticed that a 100% cost increase per brick only generates a 0,9% increase of the total building cost. Thus, a relatively large increase of the material cost of the outer façade material, only generates a relatively small increase of the total building cost. This calculation only includes the building cost, but a developer normally also has other expenses in a project, for example the cost for land acquisition and costs for consultants. If these costs were included in the calculation, or if the bricks did not cover the entire facades (for example only the bottom floor, i.e. having a smaller extent) the material cost increase per brick would naturally have an even lower impact on the total building cost. Nevertheless, it may also be relevant to assume that the cost for consultants will be somewhat increased if the consultant does not have previous knowledge of reuse of bricks. In the case project on Drakblommegatan, it is possible to make cost savings in the demolition phase thanks do reduced cost for landfill, transportation to landfill and transportation of new bricks to the site, which is presented in chapter 6. For the ongoing FBU project, which is not connected to a specific demolition, these potential cost savings are not applied in the calculations.

Table 5.1 Influence of five different material costs per brick (6, 12, 18, 24 and 30 SEK/brick) on façade cost and total building cost based on the studied ongoing FBU project.

Material cost per brick [SEK/brick]	**6**	**12**	**18**	**24**	**30**
Total building cost [MSEK]	196,4	198,2	199,9	201,6	203,4
Facade cost [MSEK]	14,9	16,6	18,4	20,1	21,8
Increase brick cost [-]	-	100%	200%	300%	400%
Increase facade cost [-]	-	12%	23%	35%	46%
Increase facade cost [MSEK]	-	1,7	3,5	5,2	6,9
Increase facade cost/ Total building cost [-]	-	0,9%	1,7%	2,6%	3,4%

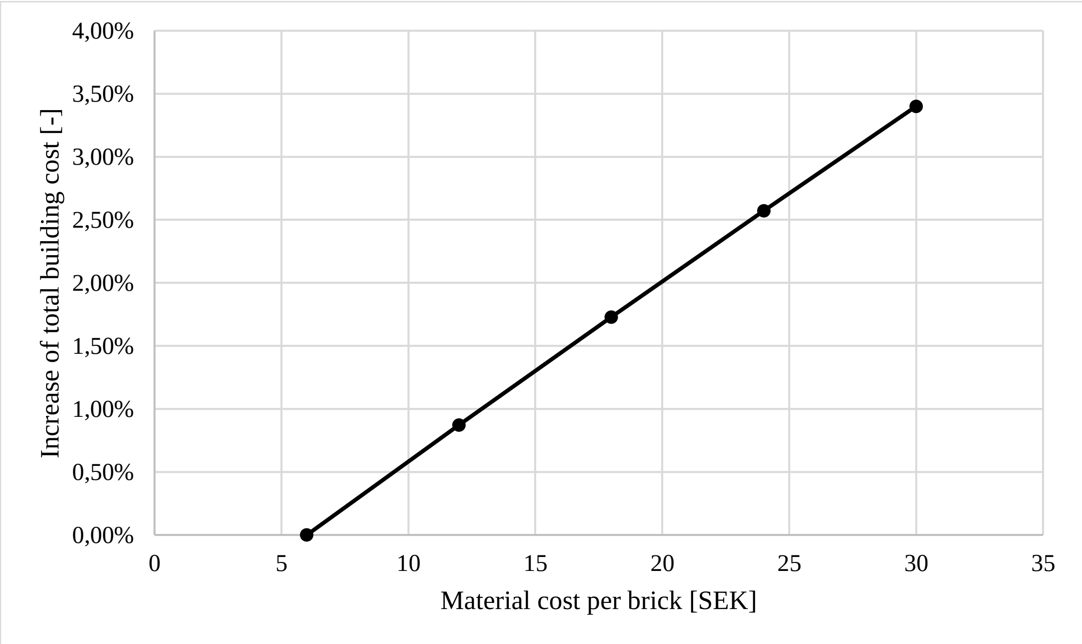

Figure 5.2 Influence of material cost per brick on total building cost based on the studied ongoing FBU project. A material cost of 12 SEK/brick gives an increase of the total building cost of 0,9%.

5.5 Environmental figures

The same FBU reference project as was used to exemplify the economic impact of reusing bricks, is used to exemplify the environmental figures. The façade area of this ongoing project amounts to 4575 m² and the number of bricks per m² has for these calculations been set to 52, which is the number of bricks per m² of the case buildings on Drakblommegatan. This area gives 237 900 bricks in total with a weight of 580 ton. It should be noted though, that according to Table 4.1, the total area of the bricks on Drakblommegatan is 3133 m², without regarding the loss of bricks during deconstruction. This means that reused bricks from other sources would be needed if the entire façade area were to be covered with reused bricks, as is the basis for the numbers in Table 5.2. The numbers for the environmental assessment have been collected from three different LCA sources: Inventory of Carbon & Energy Version 2.0, an LCA-database published by University of Bath in 2011, ÖKOBAUDATA (2019), an LCA-database from the German Federal Ministry of the Interior, Building and Community, and Ökobilanzdaten im Baubereich, LCA-data from the Association of Public Builders of Switzerland (KBOB, 2019). The LCA numbers are then multiplied with the weight of the bricks covering the façade.

The numbers for embodied carbon, embodied energy and abiotic resource depletion potential (ADPE) presented in Table 5.2 is what new bricks would account for covering the entire façade of the studied reference project, i.e. what could be saved by reusing bricks. The numbers include life cycle stages A1 to A3.

Table 5.2 Environmental assessment of bricks in the FBU reference project. The embodied carbon, embodied energy and abiotic resource depletion potential is what new bricks would account for in the project, i.e. what could be saved by reusing bricks.

	ICE v2.0: 0,24kgCO_2eq/kg 3,00MJ/kg	**ÖKOBAUDAT:** 0,30kgCO_2eq/kg 4,77 MJ/kg 4,11E-8 kgSbeq/kg (ADPE)	**KBOB:** 0,375kgCO_2eq/kg
Embodied carbon [kgCO_2eq]	139 200	174 000	217 500
Embodied energy [MJ]	1 740 000	2 766 600	-
Abiotic resource depletion potential for non-fossil resources (ADPE) [kgSbeq]	-	0,024	-
Total weight of reused bricks = 580 ton			

5.5.1 Carbon footprint per heated floor area

To know what the above calculated numbers for the bricks mean for the environmental impact of the entire building of this ongoing FBU project, a calculation of the carbon emissions per heated floor area (Atemp) can be performed. The Atemp area is 9913 m² for the studied ongoing FBU project. Dividing the total embodied carbon of the bricks (from the ICE database) by Atemp gives a carbon emission per heated floor area of 15 $kgCO_2eq/m^2Atemp$. No calculations for the climate impact of the entire reference project has been performed, and therefore LCA calculations performed by the Swedish Environmental Institute (IVL) for two other multifamily residential buildings in Sweden are used for comparison: Strandparken, a building with a timber structure has a climate impact of approximately 170 $kgCO_2eq/Atemp$ and Blå Jungfrun, a building with a concrete structure has a climate impact of approximately 350 $kgCO_2eq/Atemp$ for life cycle stages A1 to A5 (IVL Svenska Miljöinstitutet AB, 2016). The reduction of 15 $kgCO_2eq/m^2Atemp$ for using reused brick instead of new bricks would hence account for a 4-9% reduction of the total carbon emission, compared to Strandparken and Blå Jungfrun respectively.

5.5.2 Transportation

If the bricks are reused locally, as would be the case when constructing new buildings on Drakblommegatan, the reuse will also result in reduced need for transportation of bricks to the building site, life cycle stage A4. ÖKOBAUDAT (2019) provides numbers for the environmental impact of a truck with the following specifications: "*The dataset refers to the transport of 1000 kg cargo on a distance of 1 km by truck (EURO 5) with 20-26 t permissible total weight and 17.3 t payload in forwarding traffic with a utilisation ratio of 85%. The extraction and processing of the fuel is included. The production of the vehicle is not included in the balancing.*" This is the same specifications stated regarding transportation in an EPD from the Danish brick supplying company Randers Tegl (Randers Tegl, 2019), except that the EPD is based on vehicle emission standard Euro 4 instead of Euro 5. The global warming potential specified for transportation of 1 ton load, 1 km is 0,0632 $kgCO_2eq$ according to ÖKOBAUDAT and 0,059 $kgCO_2eq$ according to Randers Tegl (recalculated from stated 2,95 $kgCO_2eq$ for 50 km transportation). If the reuse results in reduced need for transportation, these numbers can be used to calculated additional environmental benefits in reduced carbon emissions. For example, reuse of the 391 ton of bricks from the buildings on Drakblommegatan would mean an additional carbon emission saving of 25 $kgCO_2eq/km$, using the number from ÖKOBAUDAT (0,0632x391=25). A transportation from Gandrup in northern Denmark, where one of Randers Tegl brick factories is situated, to Gothenburg equals a distance of around 740 km and carbon emissions of 19 $tonCO_2eq$ (740x25=19).

6 Design concepts

This chapter presents two concepts for reuse of the bricks from the existing buildings on Drakblommegatan in new buildings on the same site. The two concepts – Single bricks and Brick modules – originate in two different deconstruction methods which give different design implications. The sketches of the new buildings are proposals from the author and are not final designs made by FBU that will be built.

6.1 General

6.1.1 Developed concepts

In the studied reference projects, described in chapter 2, two main assembly directions are identified. In Furutorpsparken and Mellanvångsskolan, the bricks were assembled on site with traditional masonry techniques, brick by brick. In Magasinet and The Resource rows, the bricks are first cast into prefabricated façade elements which are later assembled on site. Chapter 4, mentions two main methods for deconstruction: Standard demolition and careful deconstruction. The standard demolition method results in deconstructed bricks put in a container, from where a cleaning process naturally can begin. Therefore, it goes well together with the first direction of assembly: The traditional brick by brick method of Furutorpsparken and Mellanvångsskolan. Hence, “Design 1 – Single bricks” combines the standard demolition method with assembly brick by brick. The careful deconstruction method results in deconstructed brick modules which are ready to use as they are. To ensure stability and a rational construction process, the modules can be cast into prefabricated façade elements, as the second direction of assembly, exemplified in Magasinet and The Resource rows. “Design 2 – Brick modules” combines a careful deconstruction of brick modules with assembly of prefabricated concrete elements.

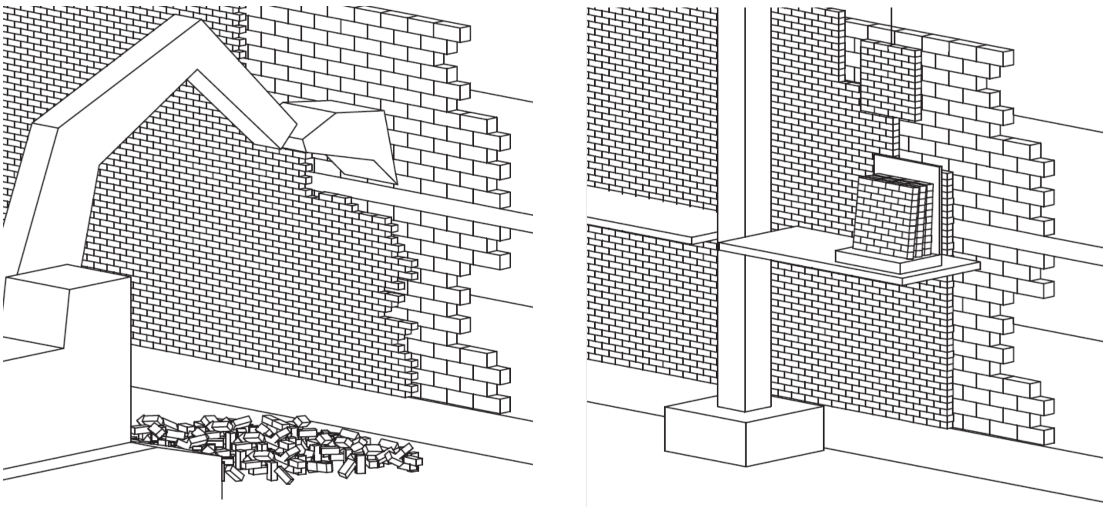

Figure 6.1 The two deconstruction methods for the two developed design concepts. For Design 1, to the left: A standard demolition with a truck. For Design 2: A careful deconstruction in modules to the right.

These two concepts are not the only possible concepts that can be applied for the new buildings on Drakblommegatan. An architect or other actor interested in using reused bricks can combine the information in previous chapters of this report in other ways. For example, it is not necessary to use the standard demolition method for reuse of single bricks. Single bricks can also be deconstructed carefully with the advantage that more bricks can be reused but most probably to a higher economic cost.

Since the amount of available bricks on Drakblommegatan is not enough, both the developed concepts propose designs where only a limited extent of the entire façade area of the new buildings will be covered with these particular reused bricks, see Figure 6.2 and Figure 6.8. Hence, the remaining area has to be covered with another façade material, which can of course be reused bricks from other sources. The design and detailing of this material is not within the scope of this report. For a reference, one can study a residential building on Honolulugatan 1 in Örebro, Sweden, where reused bricks have been combined with new bricks in the same building. The façade with reused bricks has a sign with information about in which building the bricks were previously placed and when this building was constructed.

6.1.2 Economy

In Table 6.1 the costs summarized in Table 2.1, Table 4.4 and Table 4.5 are combined for the two developed designs. The designs are compared with a baseline scenario which includes that the existing buildings are demolished with a standard demolition, all bricks are transported to landfill, and a construction of new buildings are made with solely new façade bricks to a cost of 6 SEK/brick or 312 SEK/m², as in the studied FBU project in chapter 5. In the cost calculation of the studied FBU project, the cost of transportation from a supplier of new bricks to the construction site is 63 SEK/m². This is a cost that can be subtracted from the cost of the design concepts since the bricks are reused on the same site. However, transportation of the modules to the façade element producer needs to be added for Design 2. If the design concepts generate a cost increase compared to the baseline scenario, this is specified with a plus sign (+) and a cost decrease is specified with a minus sign (-). If the designs generate no extra cost, this is showed with a zero (0). Again, the developed design concepts are only two possible combinations of methods and other scenarios can be calculated using the same information from the previously mentioned tables.

Table 6.1 Summarized costs for the two developed design concepts compared to a baseline scenario for demolition of existing buildings and construction of new buildings. A minus sign indicates a saving in relation to the baseline scenario, a plus sign indicated an extra cost and a zero indicates an unchanged cost

	Design 1	**Design 2**
1. Deconstruction [SEK/m²]*	0	-260 to +984
2. Transportation to landfill [SEK/m²]	-49	-49
3. Landfill fee [SEK/m²]	-42	-42
4. Material test [SEK/m²]	+39	+39
5. Transportation to element producer [SEK/m²]**	0	+39
6. Material cost of bricks [SEK/m²]***	-312	-312
7. Transportation from brick supplier [SEK/m²]***	-63	-63
8. Cleaning and preparation [SEK/m²]****	+104 to +780	0
9. Reassembly [SEK/m²]*****	0	0
Total	-323 to +353	-648 to +596
Total excluding savings from step 1-3	-232 to +444	-297 to +687
*Cost for Design 2: Normal demolition subtracted from deconstruction of modules		
**Assumed cost: 5000 SEK/truck (same as transportation to landfill). 128 m² in each truck		
***Based on the studied FBU project		
****Included in the deconstruction cost for the Design 2		
*****Compared to baseline assembly for Design 1 and Design 2 respectively		

Due to decreased costs for transportation to landfill, landfill fee, material cost of new bricks and transportation from a brick supplier, it is possible to make cost savings with both design concepts. For Design 1, the total cost related to the reuse of bricks is -323 SEK/m² (-6,2 SEK/brick) compared to the baseline scenario, when using the lowest costs stated in chapter 4. When using the highest stated costs, the total costs is 353 SEK/m² (6,8 SEK/brick) above the baseline scenario. For Design 2, the corresponding lowest and highest costs are -648 SEK/m² (-12,5 SEK/brick) and 596 SEK/m² (11,5 SEK/brick) below/above baseline scenario.

It is not certain that the cost savings in the demolition phase of the project can be credited for in the budget for the construction of the new buildings on the site. Therefore, the total costs excluding these savings in step 1-3 for the design concepts are also stated in Table 6.1. However, it is assumed that the higher cost for careful deconstruction in Design 2 has to be included in the budget for the new buildings, and therefore it is included in the total cost.

The total costs stated in Table 6.1 are used when calculating the influence of the reused bricks on the total building cost. Table 6.2 and Table 6.4 show how the costs related to the two design concepts influence the total cost of the new buildings. In order to understand the economic influence of reuse of bricks, the total building cost for the new buildings on Drakblommegatan is estimated. According to rough sketches made for this thesis, approximately 20 000 m² GFA can be built on the site. A normal building cost for multifamily residential buildings in Sweden is 18 000 SEK/m²GFA. This gives a total building cost of 360 MSEK and it is used as reference value in the calculations of the economic costs of the design concepts. For the façade areas that are not covered with reused bricks, the calculations of the total building costs assume that new bricks to a cost of 312 SEK/m² is used. A façade material with another cost will of course decrease or increase the cost influence of the reused bricks depending on if the material is cheaper or more expensive than the assumed cost for new bricks.

6.1.3 Liability

For both developed design concepts there are several possible liability scenarios, as described in section 5.3. Who takes responsibility for the material performance of the bricks is not governed by the chosen design concept. For example, both cases allow for a material supplier like Gamle mursten to test the bricks and offer material warranty. As stated in Table 6.1, the cost for material tests needed for material warranty is included in the total cost for the reused bricks. Material warranty for reused bricks is an attractive option for FBU, see section 5.3.3.

6.2 Design 1 – Single bricks

As mentioned in section 6.1.1, Design 1 of the developed design concepts consists of standard demolition to deconstruct the bricks, followed by traditional masonry assembly of single bricks. The standard demolition method generates enough bricks to cover the short sides of the new buildings, see Figure 6.2 and Figure 6.3.

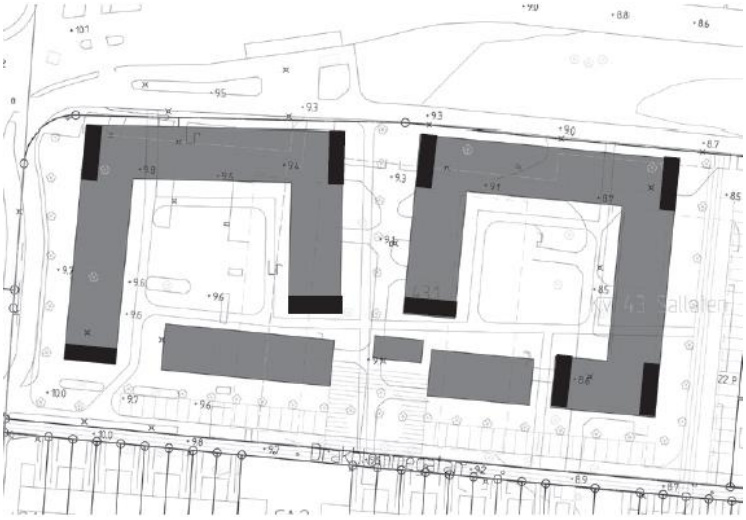

Figure 6.2 The spread of façade areas covered with reused bricks in Design 1, marked with thick black lines. Design 1 generates enough bricks to cover all short sides of the main buildings.

Figure 6.3 The Single bricks design concept with enough bricks to cover the short sides of the buildings with reused bricks from Drakblommegatan.

6.2.1 Concept and design implications

The chosen methods give the following project and design implications for the concept, further explained in section 0, 6.2.3 and 6.2.4:

- A normal demolition is carried out and the bricks are scraped of the lightweight concrete by a truck and 50-75% of the bricks remain whole and reusable, see section 4.3.2. This is enough to cover all short sides of the new buildings, see Figure 6.2.

- The bricks are cleaned and stored on site in a weather protected environment, see section 4.3.4.
- The bricks are reassembled as single bricks with the same traditional masonry procedure as for new bricks, see section 2.1 and 2.2.
- Due to for example cracked corners obtained during demolition, some of the bricks cannot be reused as full brick blocks but as bricks cut in half. Therefore, a bond containing half bricks with both stretcher and header surfaces visible, is suitable, for example a Flemish bond.
- Since the number of bricks available after demolition is very uncertain, the bond type called "vilt förband" in Swedish is beneficial. For this bond type, the masonry worker places header bricks in a random pattern on the wall. The uncertainty of the available bricks and the detailing of the façade on site creates a new workflow and the architect should not decide the exact design of the façade beforehand. The time saved in designing the façade in detail can perhaps be redistributed to potential extra time needed to administrate the work with reused material.
- The surfaces and edges of the bricks will be roughened during the demolition process, creating a texture of the reused bricks that tells a story of their past life before the new buildings, see section 2.1 and 2.2.

6.2.2 Disassembly

During the standard demolition, the bricks are scraped off the lightweight concrete using a truck. 50-75% of the bricks remain reusable after demolition, since some of the brick will brake during the process. 50% of the bricks is enough to cover all the short sides of the façade of the new buildings, about 1300 m², illustrated in Figure 6.3. After the bricks have been deconstructed from the walls, they are put in containers and a cleaning process can begin. After they have been cleaned, the bricks are put on pallets, waiting to be reused.

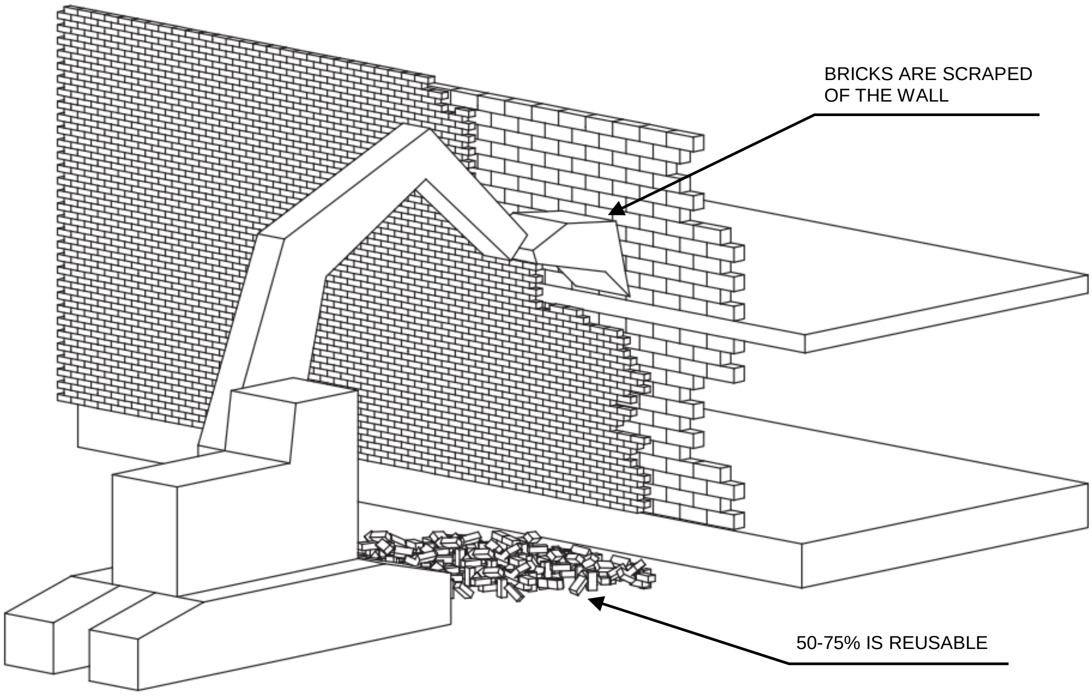

Figure 6.4 Approximately 50% of the bricks can be reused after a normal demolition process where the bricks are scraped off the lightweight concrete blocks using a truck.

6.2.3 Transportation and storage

Since the bricks in this case will be reused on the same site, there is no need for transportation of the bricks that will be used in the new buildings. Around 150 bricks need to be sent to a company for material tests, but this is a relatively small need for transportation. Additionally, since up to 50% of the bricks will need to go to landfill, there is need for transportation related to this. Nevertheless, this need for transportation is certainly lower than if all bricks needed to go to landfill. The bricks are stored on site in a weather protected environment, for example under a plastic cover. The large open space in the west part of the site, can be used for storage of the bricks.

6.2.4 Reassembly

The bricks are reassembled with traditional masonry methods. To increase the number of reused bricks, bricks with damages on one side is used as headers in the wall, as previously mentioned. This header and stretcher bond, together with the roughened textured obtained during the demolition process, will result in a façade wall with a design differing from the existing buildings, telling a story of the reuse process, see Figure 6.6.

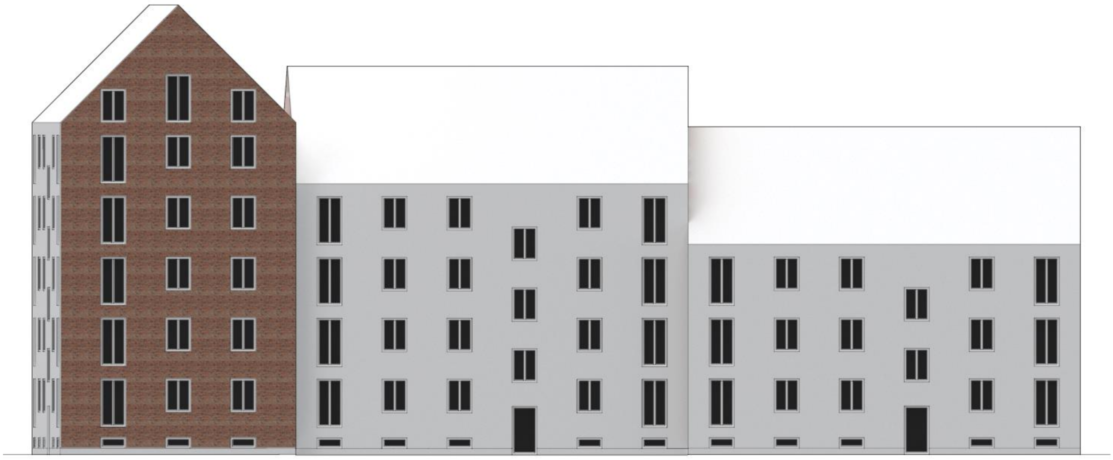

Figure 6.5 West facade of the new buildings. The short side is covered with reused bricks from Drakblommegatan and the remaining facade area (coloured grey) must be covered with another material.

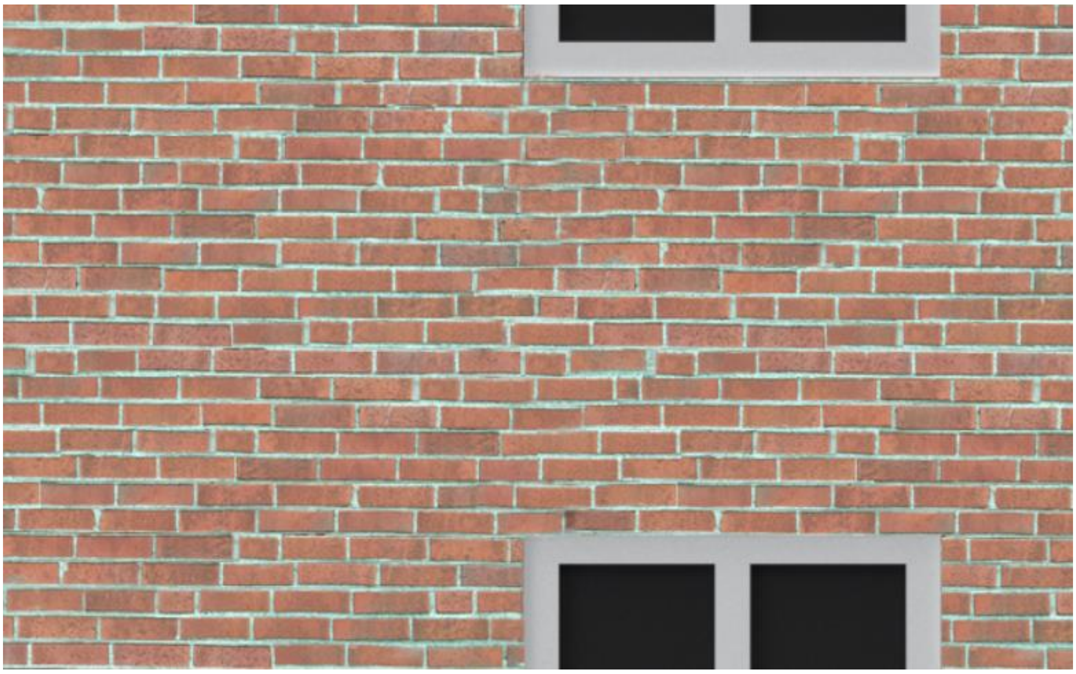

Figure 6.6 To increase the amount of reused bricks, the bricks are put in a pattern that has both header and stretcher surfaces. Header bricks are placed in a random pattern decided depending on the available brick quantity.

The bricks can be combined with various façade systems. In the ongoing FBU project studied in chapter 5, a steel frame system is used and detailed economic costs for each element in this structure has been obtained from FBU. This steel frame system is used in the economic assessment, see section 6.2.5. A detail of the façade structure is shown in Figure 6.7. The absorption properties of the bricks were assessed to be sufficient for normal mortar to be used, see section 4.1.2.

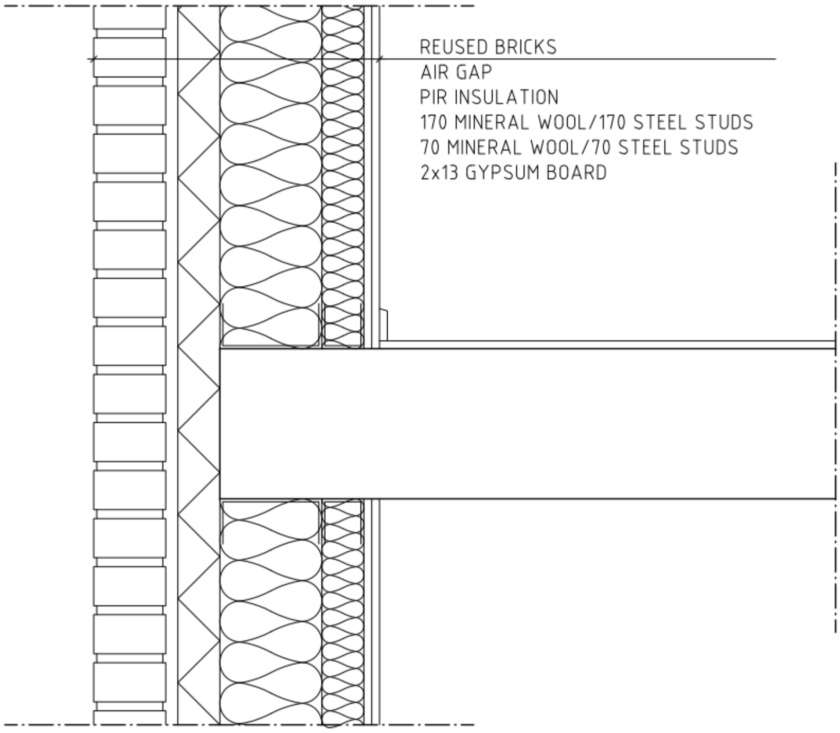

Figure 6.7 Vertical detailed drawing of Design 1. The bricks are attached to a steel frame system with insulation.

6.2.5 Economic assessment

Including savings in the demolition phase, this design concept generates a 0,23% decrease or a 0,02% increase of the total building cost, depending on if the stated low or high costs are used. Excluding the potential savings in the demolition phase, the concept will generate a 0,20% cost decrease or a 0,05% cost increase of the total building cost. The relatively small effect on the total building cost can partly be explained by the fact that only a small part of the entire façade consists of reused bricks.

Table 6.2 Economic costs of the single bricks concept.

Building cost for facades with reused bricks (1300 m²)* [MSEK]	3,3 - 4,2
Building cost for facades with reused bricks excluding savings related to demolition (1300 m²)* [MSEK]	3,4 - 4,3
Building cost for facades with new bricks (6200 m²)** [MSEK]	19,8
Building cost for all facades with new bricks (7500 m²)** [MSEK]	23,9
Potential cost effect due to use of reused bricks*** [%]	-0,23% to +0,02%
Potential cost effect due to use of reused bricks excluding savings in demolition phase*** [%]	-0,20% to +0,05%
*Based on costs in Table 6.1	
**Based on 6 SEK/brick	
***Compared to using new bricks on all facades (7500 m²)	

6.2.6 Environmental assessment

Compared to using new bricks, using reused bricks on the concerned façade areas (1300 m²) generates a reduction of 1% of the building's total carbon footprint. However, since cement based panels has lower amount of embodied carbon, the decrease of carbon footprint is only 0,1% when comparing reused bricks to this façade material. The embodied carbon, embodied energy and abiotic resource depletion potential of the corresponding amount of new bricks is stated in Table 6.3.

Table 6.3 Environmental assessment of the single bricks concept.

	Bricks: 38 kgCO_2eq/m² 604 MJ/m² 5,21E-6 kgSbeq/m² (ADPE)	**Cement based panel:** 7,2 kgCO_2eq/m² 139 MJ/m² 4,59E-3 kgSbeq/m² (ADPE)
Embodied carbon [kgCO_2eq]	49 400	9 360
Reduction of carbon footprint* [-]	1%	0,1%
Embodied energy [MJ]	785 200	180 700
Abiotic resource depletion potential for non-fossil resources (ADPE) [kgSbeq]	0,007	5,967
Based on 1300 m² of reused bricks, 52 bricks/m² and with a mean weight of 2,4 kg/brick		
*Compared to if all facades used new material. Assuming footprint 350 kgCO_2eq/Atemp (Blå jungfrun).		

6.3 Design 2 – Brick modules

Design 2 of the developed concepts consists of careful deconstruction of the bricks in modules followed by an attachment to prefabricated façade elements which are assembled on site. The careful deconstruction method generates enough bricks to cover the long sides of the new buildings, see Figure 6.8 and Figure 6.9.

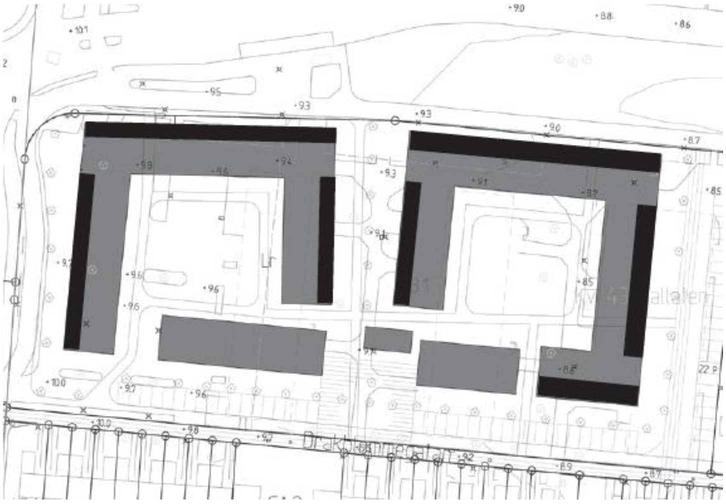

Figure 6.8 Thanks to the module deconstruction of Design 2, a larger façade area, all long sides of the main buildings facing the surrounding streets, can be covered with reused bricks from Drakblommegatan.

Figure 6.9 Perspective along Björlandavägen. The available bricks after a careful deconstruction are enough to cover all long sides of the buildings.

6.3.1 Concept and design implications

The chosen methods gives the following project and design implications for the concept, further explained in section 6.3.2, 6.3.3 and 6.3.4.

- A careful deconstruction of brick modules is carried out and 90% of the bricks remain reusable after disassembly, see section 4.3.3. Parts of the 10% discarded bricks are used in joint sealants to make them less visible, see section 2.3. The amount of reused bricks is enough to cover all long sides of the buildings facing the streets, see Figure 6.2.

- The modules are transported to a producer of prefabricated facade elements, see section 2.4.
- The finished facade elements are sent back to the construction site for assembly, see section 2.3.
- Since the bricks are carefully deconstructed in modules, their texture or bond remains the same as in the existing buildings. However, some additional mortar is needed to fix cracks for example, see section 2.4.
- By varying the orientation of the modules, a façade pattern that diverges from traditional brickwork is created. The pattern connects the existing buildings with the new buildings and raises awareness about reuse of building materials by the observer, see section 2.4.

6.3.2 Disassembly

The bricks are deconstructed from the wall by a careful deconstruction with a circular saw. 2500 m², 90%, of the bricks, are reused since 10% of the bricks are assumed to be discarded due to for example existing cracks. The deconstruction workers access the wall via a sky lift or a scaffold system, see Figure 6.10. The 1 m² modules are put on pallets with 4 modules per pallet.

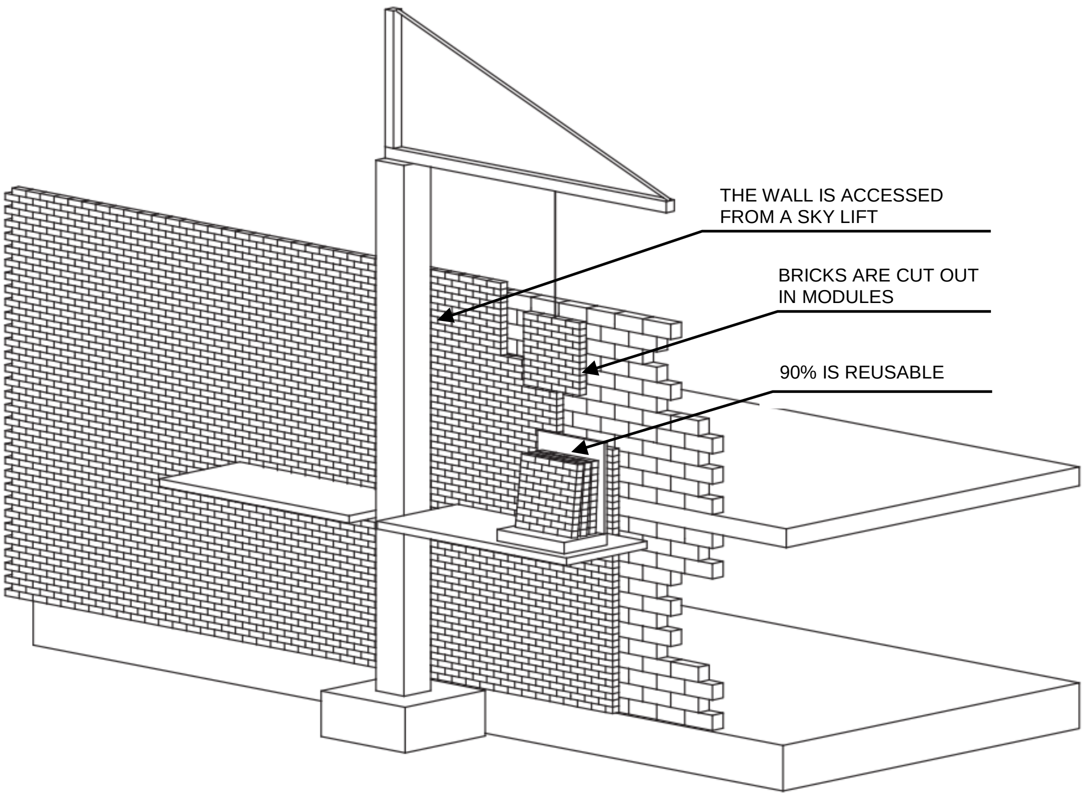

Figure 6.10 Approximately 90% of the bricks can be reused after a careful deconstruction. 10% of the bricks are assumed to be discarded due to for example existing cracks.

6.3.3 Transportation and storage

After disassembly, the brick modules are transported to a facade element producer. A truck is able to carry 128 modules where 4 modules are placed on 1 EU sized pallet, see section 2.4.1. The modules need to have temporary supports on the pallets, for example consisting of a timber stand and plastic ties that keeps the modules in place. No on-site storage is needed since the elements are delivered to the construction site directly from the façade element producer.

6.3.4 Reassembly

The prefabricated facade elements are assembled on site using a crane, see section 2.3. The 2500 m² is enough to cover all long facade walls facing the streets (not the courtyard), see Figure 6.11. By varying the orientation of the brick modules, a pattern differing from traditional brickwork design is created, see Figure 6.12.

Figure 6.11 West facade. The reused bricks are enough to cover the long sides of the facade.

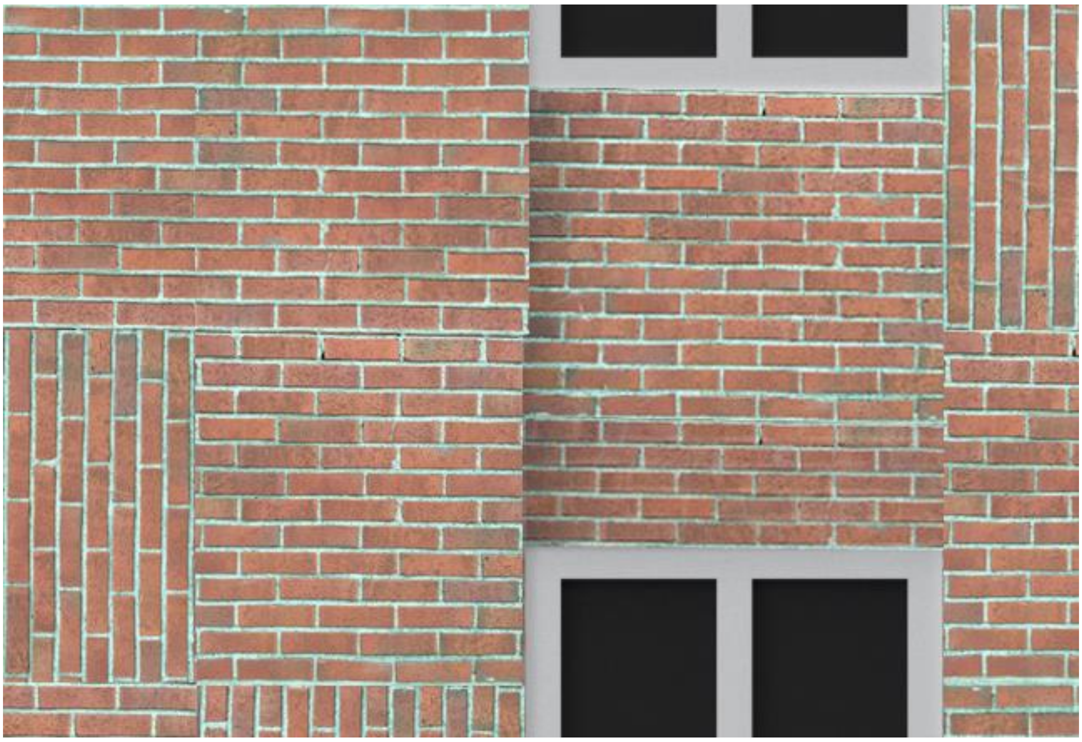

Figure 6.12 By varying the orientation of the brick modules, a pattern differing from traditional brickwork is created.

The bricks can be combined with various façade systems. In the reference projects Magasinet and The Resource rows, described in chapter 2, the bricks are combined with a concrete structure and it is applied in this design concept as well, see Figure 6.13. However, steel and timber structures are also possible to combine with this concept, but they need further development which is beyond the scope of this thesis. It should be mentioned that The Resource rows only uses concrete in the outer façade layer while the rest of the structure is made of timber. But no Swedish producer of such façade elements has been found and therefore a full concrete element is presented.

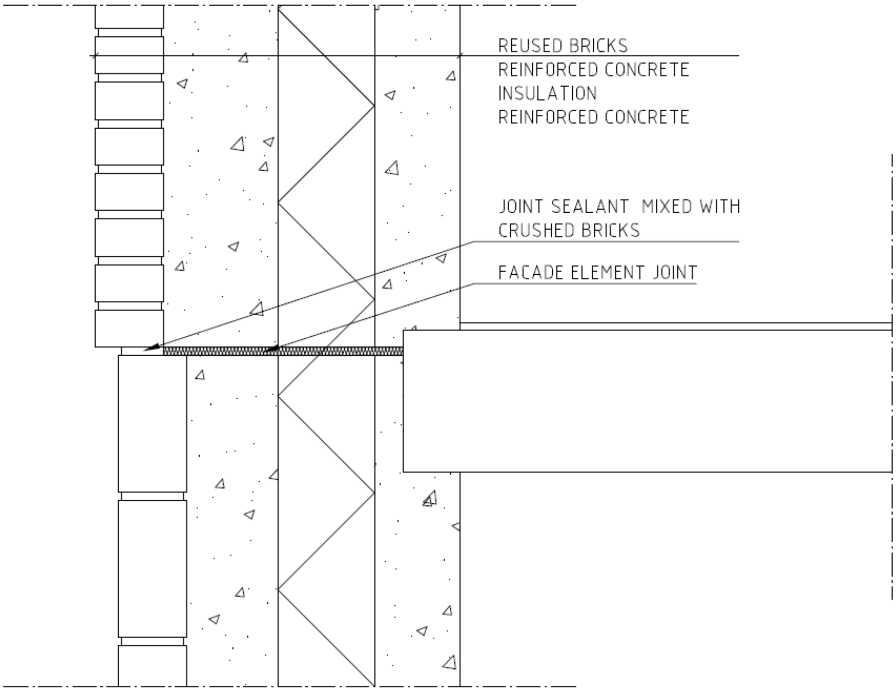

Figure 6.13 Vertical detailed drawing of Design 2. The varying orientation of the brick modules is visible in the outer façade layer.

6.3.5 Economic assessment

Including savings in the demolition phase, this design concept generates a 0,44% decrease or a 0,38% increase of the total building cost, depending on if the stated low or high costs are used. Excluding the potential savings in the demolition phase, the concept will generate a 0,19% cost decrease or a 0,44% cost increase of the total building cost. The relatively small effect on the total building cost can partly be explained by the fact that only a part of the entire façade consists of reused bricks.

Table 6.4 Economic costs for the brick modules concept.

Building cost for facades with reused bricks (2300 m²)* [MSEK]	7,2 - 10,2
Building cost for facades with reused bricks excluding savings related to demolition (2300 m²)* [MSEK]	7,5 - 10,4
Building cost for facades with new bricks (5200 m²)** [MSEK]	19,9
Building cost for all facades with new bricks (7500 m²)** [MSEK]	28,8
Cost effect due to use of reused bricks*** [%]	-0,44% to +0,38%
Cost effect due to use of reused bricks excluding savings related to landfill*** [%]	-0,19% to +0,44%
*Based on costs in Table 6.1	
**Based on 6 SEK/brick	
***Compared to using new bricks on all facades (7500 m²)	

6.3.6 Environmental assessment

Compared to using new bricks, using reused bricks on the concerned façade areas (2300 m²) generates a reduction of 1,4% of the building's total carbon footprint. When comparing reused bricks to cement based panel façade material, the decrease of carbon footprint is 0,3%. The embodied carbon, embodied energy and abiotic resource depletion potential of the corresponding amount of new bricks is stated in Table 6.5.

Table 6.5 Environmental assessment of the brick modules concept.

	Bricks: 38 $kgCO_2eq/m^2$ 604 MJ/m^2 5,21E-6 $kgSbeq/m^2$ (ADPE)	**Cement based panel:** 7,2 $kgCO_2eq/m^2$ 139 MJ/m^2 4,59E-3 $kgSbeq/m^2$ (ADPE)
Embodied carbon [$kgCO_2eq$]	87 400	16 560
Reduction of carbon footprint* [-]	1,4%	0,3%
Embodied energy [MJ]	1 389 200	319 700
Abiotic resource depletion potential for non-fossil resources (ADPE) [kgSbeq]	0,012	10,557
Based on 2300 m² of reused bricks, 52 bricks/m² and with a mean weight of 2,4 kg/brick		
*Compared to if all facades used new material. Assuming footprint 350 $kgCO_2eq$/Atemp (Blå jungfrun).		

Both Magasinet and The Resource rows use reinforced concrete as a supporting structure of the bricks. It is fully possible that this concept is also possible to combine with another type of structure, made by for example timber or steel, which might have a lower environmental impact than concrete. However, this environmental assessment only considers the brick, i.e. the skin of the façade. It is also relevant to look at the entire façade structure, but it is not covered in this report. Another aspect that has not been taken into consideration, is the fact that the brick module concept means that less new mortar is needed compared to Design 1.

7 Discussion

This chapter discusses the results achieved in this study and is divided into three sections: Results, method and data. The effect of the data quality and chosen method on the results is discussed. Furthermore, it elaborates on various limitations that occurred during the study period.

7.1 Results

The results are very dependent on the interviews performed with experts. The information gained about the reference projects, the disassembly and reassembly methods has strongly influenced the results. A few important data are listed below:

- Standard demolition is significantly less expensive than careful deconstruction. However, only deconstruction of brick modules can be less expensive than standard demolition.
- 50-75% of the bricks remain reusable after a standard demolition and therefore it is an applicable method in a reuse project.
- The bricks and the radioactive lightweight concrete are normally not mixed, meaning that separating these materials to enable reuse of the bricks is not a costly factor that will make the project more expensive.
- The tested bricks are frost resistant and have high compressive strength and therefore they can be reused as façade material and do not have to be downcycled to serve as other building components.

This thesis is only one case study of reuse of bricks from existing buildings on Drakblommegatan in new buildings on the same site. More similar case studies are needed for wider knowledge about reuse challenges and potential for other types of brick, other types of façade structures and other type of buildings in other locations. In a Gothenburg context, assuring the frost resistance is important, whereas it is not relevant in warmer climates. However, the procedure of inspection, deconstruction methods, transportation and reassembly is applicable globally and can be used for any other project.

Many reports and books about reuse of brick states that it is problematic to clean bricks where mortar with cement content has been used. In contrast, this report shows a case where it is fully possible and relatively easy to clean the bricks despite the cement mortar. The content of the mortar is not the only decisive factor for how easy the bricks are to clean which this report exemplifies and that is an important contribution to previous perception about reuse of bricks.

The environmental assessment of the design concepts uses fibre cement façade panels as a reference material for comparison with brick. The comparison shows that the carbon emission reduction by reusing bricks is significantly lower when comparing with cement panels than when comparing with new bricks. However, it must be taken into consideration that the technical lifetime of the cement panel is most probably shorter than the lifetime of the bricks, something not covered in this report.

Since this is a common façade structure from the 1960's, both in the Gothenburg building stock and nationally in Sweden, the results of this report go beyond the specific case on Drakblommegatan. Even though this particular type of radioactive lightweight concrete (blåbetong) is not common in other parts of Europe, several sections of the report are valid for many buildings with façade bricks. The exact total impact that reuse of bricks can have in Gothenburg, Sweden, Europe or even globally has to be assessed considering an inventory of brick buildings, as proposed in chapter 8.2. However, it is clear that there are environmental benefits with reuse of bricks and that these most probably generate a higher economic cost. Developers, politicians and consultants can use the results to evaluate reuse of bricks in comparison to other possible environmental measures in construction projects.

7.2 Data

The data for this report has been collected from a limited number of sources. The costs for deconstruction and preparation of the bricks, summarized in Table 2.1, Table 2.2, Table 4.4 and Table 4.5 and combined in Table 6.1 are information from interviews. Most costs are only based on one source which makes it possible to question their credibility. The interviewees are all professionals that might be involved in the Drakblommegatan or other similar reuse projects and therefore their answers are of course very valuable. But in order to strengthen the data it should be complemented with data from more sources.

It can also be questioned if the interviewees had enough experience from previous related projects in order to make correct estimations of the costs. Their previous experience was not verified in most cases. For example, it is not clear how much experience of cleaning and preparation of bricks that the company Murbiten Tegel & Puts AB has. The demolition company stating the cost for careful deconstruction and preparation (1000-2000 SEK/m^2) did not have any previous experience from that kind of work and the cost was a very rough estimation.

The cost data used for the deconstruction of brick modules in Table 6.1 is based on rich experience from Lendager Group. But it has a wide variation from 156 SEK/m^2 to 1400 SEK/m^2 and it is not clear if it only includes the time to deconstruct the modules or also the time to put the modules on pallets and load them into the truck. Most probably, the cost for renting the needed sky lift or scaffolding system is not included and thus, this has to be added to the cost of Design 2.

The interviewees were shown a few drawings and descriptions of the case buildings on Drakblommegatan to give correct answers. But they did not do a site visit or any detailed studies of the buildings and therefore their answers can be questioned due to missing information.

No data for the transportation of modules to the façade element producer was found. Therefore, the cost was assumed to equal the cost for transportation of 18 m^3 brick (with 50% air), stated in Table 4.5 but it is not certain that this is correct.

Since the cost data is the basis for the economic results, the accuracy of the findings, such as the potential cost effect due to reuse of bricks can be questioned. It is difficult to say if other companies will be able to deconstruct and clean the bricks for the same costs as are stated in this report and therefore the results are uncertain.

During the interviews, a recurring concern has been if the reuse of bricks will result in increased time consumption by consultants and other people involved in a project due to lack of previous knowledge. This data has not been collected and it might be difficult to measure. In future reuse projects, the client can ask the consultant to report their consumed time for reuse related tasks as a separate post in order to map the potential extra time needed.

7.3 Method

The study of the reference projects is a useful part of the report in the sense that it shows that reuse of bricks is realizable. Unfortunately, the study only covers the new construction of the buildings, i.e. the reassembly of the bricks. It would have been useful to also have references on how the bricks were deconstructed from their previous buildings, potentially complementing the data obtained from for example demolition companies. From studies of deconstruction projects, information on additional cleaning methods other than the ones covered in this report, could possibly have been derived. Also, cutting edge cleaning and deconstruction technology, such as robotics could possibly also have been investigated as a possible method. It is possible that new cleaning technologies will increase the potentials to reuse bricks by lowering the costs.

The visual inspection was carried out by the author, looking for common damages specified in a Swedish manual. Since the author has limited experience from brick construction and related damages, it is possible that important information was not noticed during the inspection.

The material tests were performed by Gamle mursten in Denmark. If a company able to perform the tests in Sweden, closer to Gothenburg, the need for transportation would decrease. Also, the test standards and methods that were used were proposed by Gamle mursten, since these are what the company use for their material certificates. However, another testing company might suggest other test standards and methods. The absorption properties of the bricks were considered to be sufficient in order for normal mortar to be used. But some of the interviewees raised concerns that the adhesion of the mortar might still not be sufficient, so this could be investigated more in detail.

For the environmental assessment, LCA data was collected from one Swiss, one German and one British database. In order to gain results more accurate in a Swedish context, it would have been beneficial to use a Swedish database. However, no such database was found, and the other databases were used in lack of such.

8 Conclusion

Global environmental challenges call for reduced use of natural resources and related carbon emissions and energy consumption. Goals for reduced construction waste have been set up within the EU, for example implemented in The City of Gothenburg's action plan for the environment.

This report shows that reuse of bricks can reduce the environmental impact of construction of a multifamily residential building, its related carbon emission, energy use and consumption of abiotic resources. For bricks with the same density and pattern as the studied buildings on Drakblommegatan, approximately 40 $kgCO_2eq$ and 600 MJ can be saved per m^2 of reused brick wall. In a studied ongoing FBU project, with bricks on the entire façade area, the calculated reduction of carbon emission was 15 $kgCO_2eq/m^2Atemp$ of the entire building. The saved abiotic resource depletion potential per m^2 of reused brick wall is around 5E-6 kgSbeq.

Reuse of bricks can implicate higher economic costs, for example approximately 14 SEK/brick in the studied reference project Furutorpsparken compared to around 6 SEK/brick for new bricks. However, a large, 100% cost increase of the material cost per brick was found to generate a small increase of the total building cost of below 1% in the studied FBU project. Additionally, cost assessments show that reuse of the bricks on Drakblommegatan can also potentially generate a cost decrease compared to a baseline scenario. For the developed concept Design 1, the total building cost effect of reuse of bricks varies from a decrease of around 300 SEK/m^2 of reused brick wall to an increase of around 350 SEK/m^2 compared to a baseline scenario of demolition and construction of new buildings.

Regarding liability and insurance consequences, several options are possible. The studied reference projects show examples of different liable actors: The developer, the consultant and the material supplier. For material warranty of reused bricks, an attractive solution to the developer FBU, no other material supplier than Gamle mursten has been found that offer this.

Another important project condition for the developer FBU, is that the project should have a clearly expressed focus on reuse. Otherwise, it is difficult for the project manager to accept a potentially higher cost for reused bricks compared to new bricks. The focus can be stated in the so-called Target document where FBU lists what is important to fulfil in a project.

When reusing single bricks, the texture of the bricks will be roughened during the cleaning process. The uncertainty of available bricks after a standard demolition implicates that the design should be flexible in its extent and bonds with header bricks allow for partly damaged bricks to be reused as well. The deconstruction and reassembly of brick modules bring the possibility to create a pattern with a strong contrast to traditional brickwork.

An important conclusion of this report is that bricks constructed with cement mortar also have potential to be reused, not only bricks connected with pure lime mortar. The content of the mortar is not the only decisive factor for the possibility to clean the bricks, but the burning temperature of the bricks also affects this.

Another important finding is that some demolition conditions suggest that the bricks are sorted separately in a container even though they are not supposed to be reused. In the studied case on Drakblommegatan, the standard procedure is to separate the bricks due to the radioactive lightweight concrete in the existing façade walls. Many buildings in Sweden consist of this façade structure and the bricks from these buildings could beneficially be reused since the standard procedure is to separate the bricks, easing the reuse process.

8.1 Answers to research questions

How to disassemble the bricks from the current buildings?

With a standard demolition (for example scraping of the bricks with a truck) or with a careful deconstruction (for example with a circular saw).

How to store and transport the bricks between disassembly and reassembly?

The bricks can be stored on site in a weather protected environment. If they are to be put in façade elements, they can be stored by the element producer, waiting to be delivered to the construction site.

How to reassemble the bricks?

The bricks can be assembled in the same way as new bricks using normal mortar.

What are the liability and insurance challenges in reusing the bricks?

One challenge is that not many actors offer warranty for reused bricks, which is often demanded from developers. Another challenge is that it can be difficult to tell who is responsible for a failure in brickwork structures, since material and construction failure can be difficult to differentiate.

What are the economic costs?

One example from a reference project is 14 SEK/brick (including mounting material and transportation) compared to around 6 SEK/brick for new bricks. The economic assessment for reusing single bricks on Drakblommegatan shows a potential decrease of 6,2 SEK/brick and a potential increase of 6,8 SEK/brick in the total building cost, depending on what cost data that is used.

What are the environmental benefits compared to using new material?

About 40 $kgCO_2eq$, 600 MJ and 5E-6 kgSbeq ADPE saved per m^2 of reused brick wall. The carbon footprint of a building fully covered with bricks can be reduced by approximately 15 $kgCO_2eq/m^2Atemp$.

8.2 Future research

A wide variety of areas can be suggested for future research related to reuse of brick.

Material flows

An inventory of brick buildings in a certain area, for example Gothenburg, and a prediction of future material flows can be made in order to map the need for storage for example. Can the municipal reuse central in Gothenburg, Återbruket, or other actors receive bricks and distribute these to building projects? For inspiration, one can read Deniz Ergun and Mark Gorgolewski's article "Inventorying Toronto's single detached housing stocks to examine the availability of clay brick for urban mining".

Bricks available after demolition

Since it is very uncertain how many bricks that are available after a normal demolition, a study of demolition projects can be made to map how the bricks are affected by the demolition. How many remain in one piece? How many get a damaged corner? How many are completely crushed?

Social aspects

Several projects have involved unemployed people in cleaning of bricks for reuse. These projects can be studied and a report with guidelines for how to include social sustainability in a brick reuse project can be established. Förvaltnings AB Framtiden has responsibility for social sustainability development in Gothenburg. Can an increased building cost due to reused bricks be motivated if it is also a social investment?

Supporting structure for the brick modules

The design concept with brick modules suggests a concrete structure to stabilize and carry the bricks in the façade elements. Since this concrete solution might have environmental disadvantages, other supporting structures can be developed, for example of steel or timber. One can study the IRCAM-building in Paris for inspiration. This alternative structure might also increase the possibility for a second reuse by design for disassembly.

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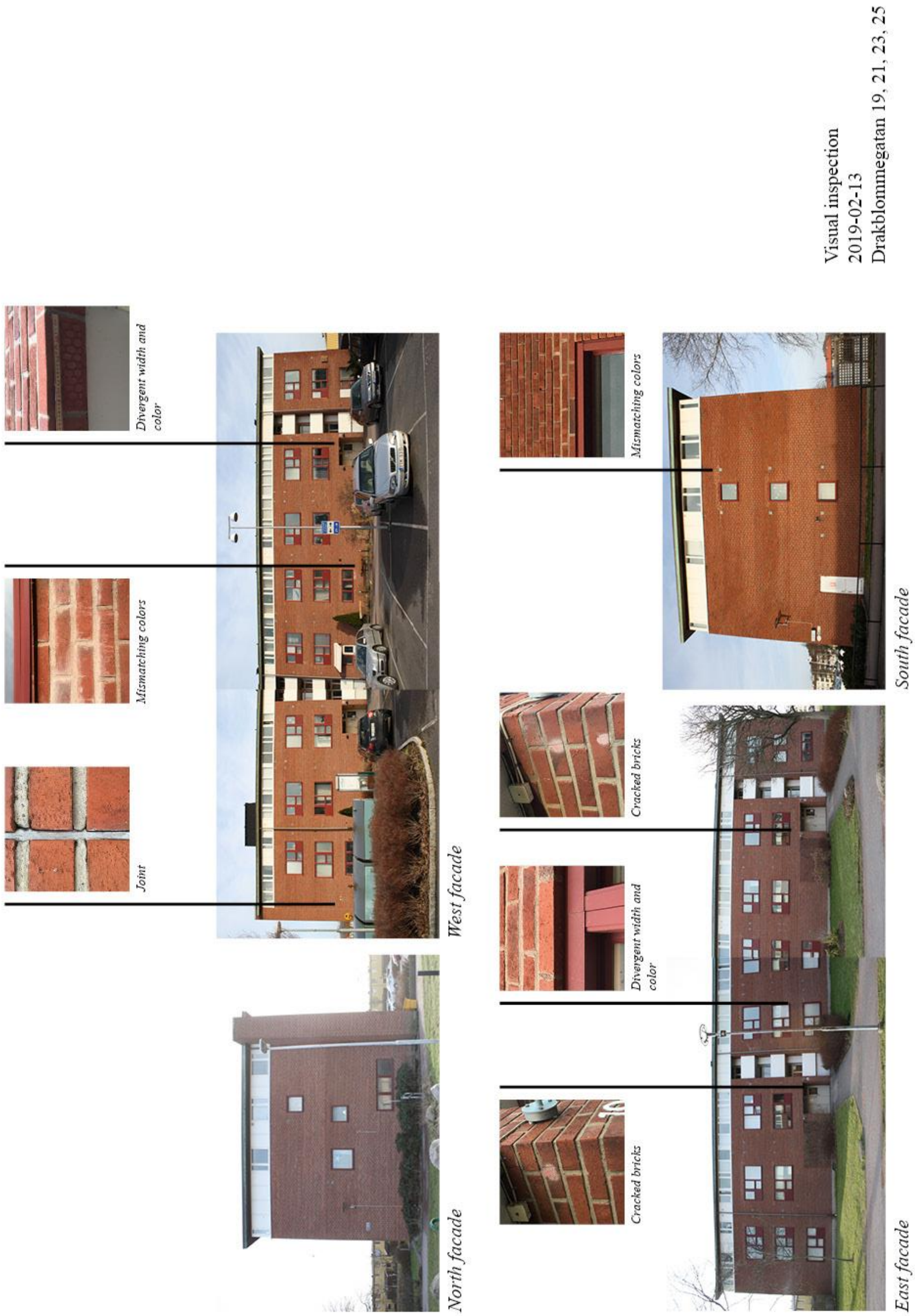
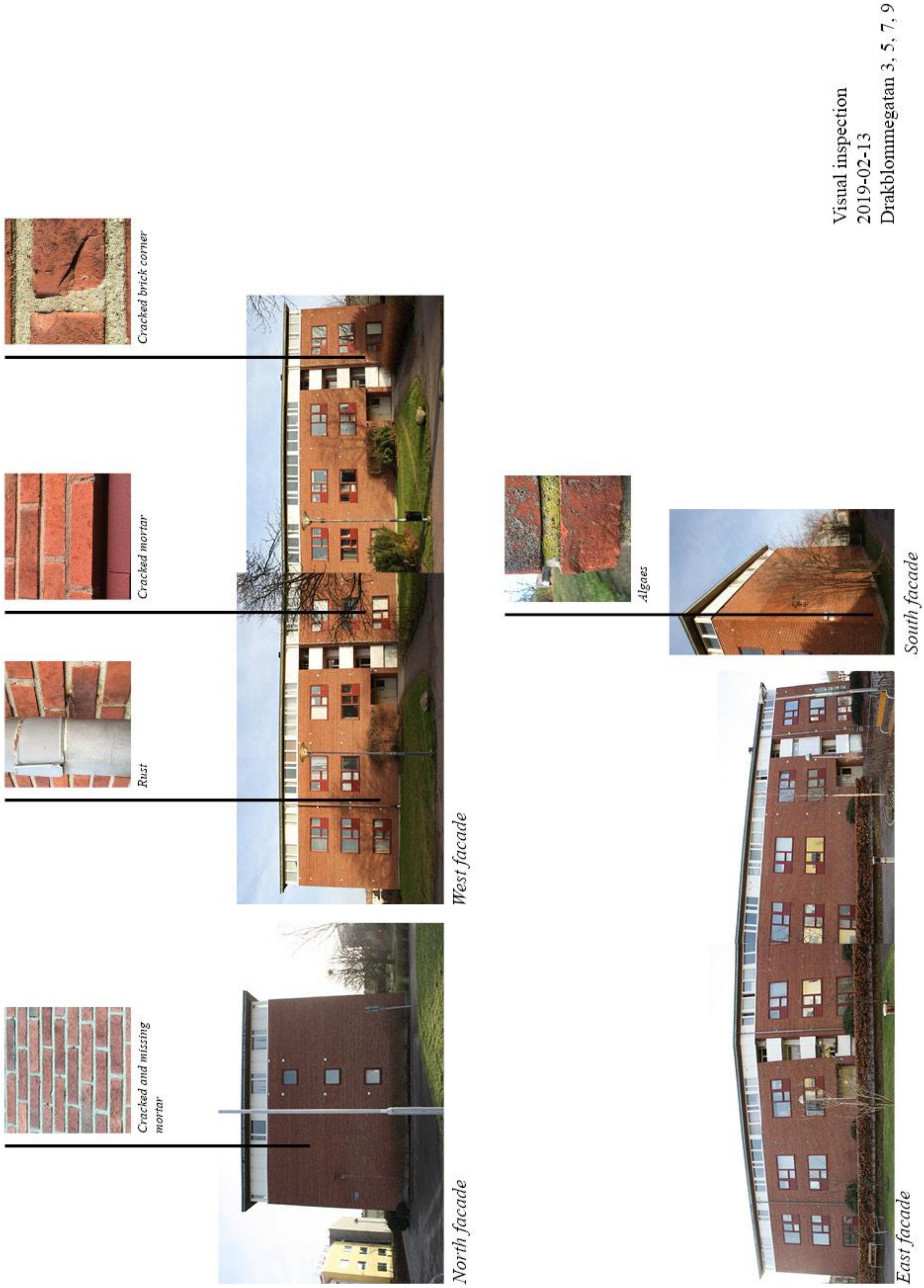
Appendix A – Visual inspection Drakblommeg. 19-25

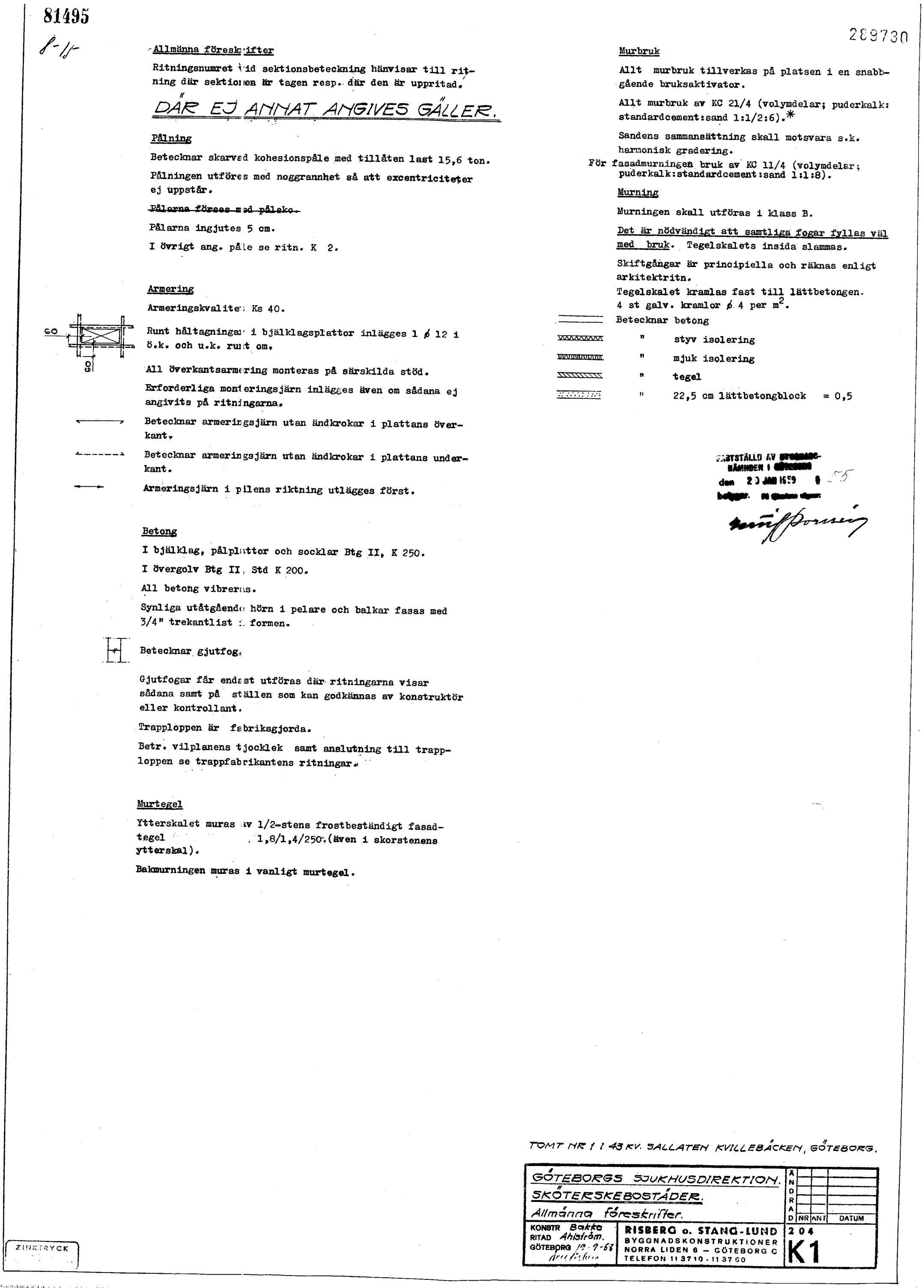


Appendix B – Visual inspection Drakblommeg. 11-17

Appendix C – Visual inspection Drakblommeg. 3-9



Appendix D – Original drawing K1


81495

8-11

289730

Allmänna föreskrifter

Ritningsnumret vid sektionsbeteckning hänvisar till ritning där sektionen är tagen resp. där den är uppritad.

DÄR EJ ANNAT ANGIVES GÄLLER.

Pålning

Betecknar skarvad kohesionspåle med tillåten last 15,6 ton.

Pålningen utföres med noggrannhet så att excentriciteter ej uppstår.

~~Pålarna förses med pålsko.~~

Pålarna ingjutes 5 cm.

I övrigt ang. påle se ritn. K 2.

Armering

Armeringskvalitet: Ks 40.

60

60

Runt håltagningar i bjälklagsplattor inlägges 1 ø 12 i ö.k. och u.k. runt om.

All överkantsarmering monteras på särskilda stöd.

Erforderliga monteringsjärn inlägges även om sådana ej angivits på ritningarna.

Betecknar armeringsjärn utan ändkrokar i plattans överkant.

Betecknar armeringsjärn utan ändkrokar i plattans underkant.

Armeringsjärn i pilens riktning utlägges först.

Betong

I bjälklag, pålplattor och socklar Btg II, K 250.

I övergolv Btg II, Std K 200.

All betong vibreras.

Synliga utåtgående hörn i pelare och balkar fasas med 3/4" trekantlist i formen.

Betecknar gjutfog.

Gjutfogar får endast utföras där ritningarna visar sådana samt på ställen som kan godkännas av konstruktör eller kontrollant.

Trapploppen är fabriksgjorda.

Betr. vilplanens tjocklek samt anslutning till trapploppen se trappfabrikantens ritningar.

Murtegel

Ytterskalet muras av 1/2-stens frostbeständigt fasadtegel , 1,8/1,4/250.(även i skorstenens ytterskal).

Bakmurningen muras i vanligt murtegel.

Murbruk

Allt murbruk tillverkas på platsen i en snabbgående bruksaktivator.

Allt murbruk av KC 21/4 (volymdelar; puderkalk: standardcement:sand 1:1/2:6).*

Sandens sammansättning skall motsvara s.k. harmonisk gradering.

För fasadmurningen bruk av KC 11/4 (volymdelar; puderkalk:standardcement:sand 1:1:8).

Murning

Murningen skall utföras i klass B.

Det är nödvändigt att samtliga fogar fyllas väl med bruk. Tegelskalets insida slammas.

Skiftgångar är principiella och räknas enligt arkitektritn.

Tegelskalet kramlas fast till lättbetongen.

4 st galv. kramlor ø 4 per m^2.

Betecknar betong

" styv isolering

" mjuk isolering

" tegel

" 22,5 cm lättbetongblock = 0,5

STÄLLD AV

NÄMNDEN I

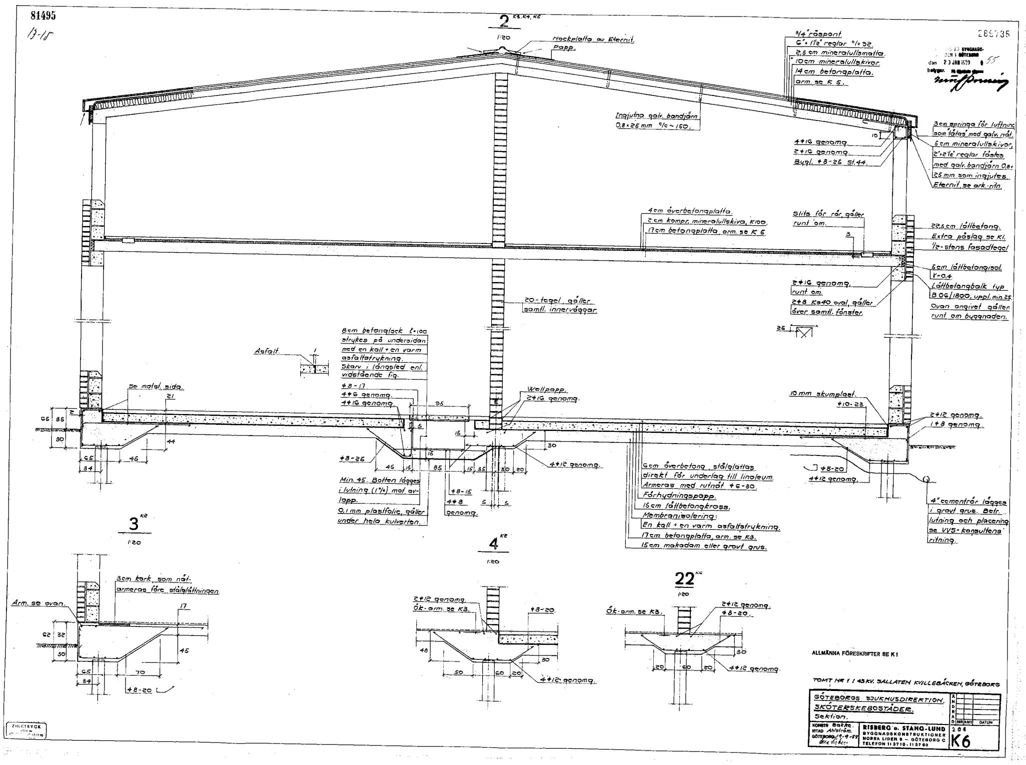
den 23 JAN 1959

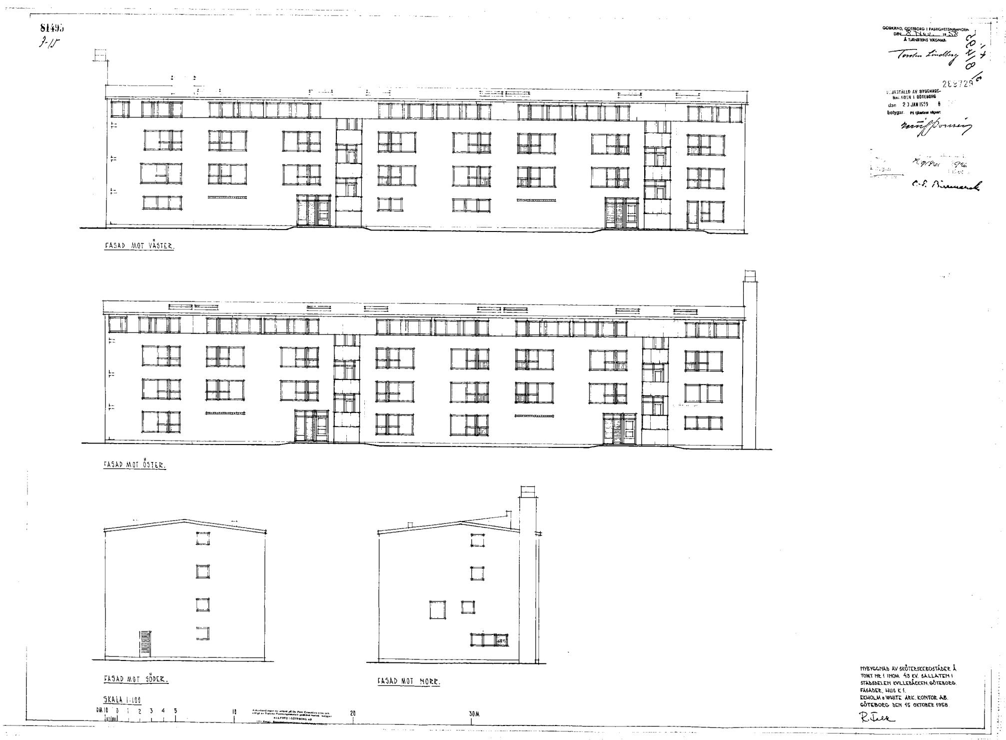
TOMT NR 1 I 43 KV. SALLATEN KVILLEBÄCKEN, GÖTEBORG.

GÖTEBORGS SJUKHUSDIREKTION. SKÖTERSKEBOSTÄDER. Allmänna föreskrifter.		ÄNDRAD	NR	ANT	DATUM
KONSTR Bakke RITAD Ahlström. GÖTEBORG 19-9-58	RISBERG o. STANG-LUND BYGGNADSKONSTRUKTIONER NORRA LIDEN 6 – GÖTEBORG C TELEFON 11 37 10 - 11 37 60	204 K1			

ZINKTRYCK

Appendix E – Original drawings K6 and 88640





Appendix F – Material test results, page 1

GAMLE MURSTEN

Prøvningsrapport

Materiale:	20 Cellesten Stentype: Facademursten
Udtagning:	Prøvematerialet er modtaget urenset i papkasser.
Metode:	DS/EN 772-16 Metoder til prøvning af byggesten til murværk – Del 16: bestemmelse af dimensioner DS/EN 772-13:2002 Prøvningsmetoder for byggesten til murværk – Del 13: Bestemmelse af netto- og bruttotørdensitet (undtagen natursten). DS/EN 772-11:2011 Prøvningsmetoder for byggesten til murværk – Del 11: Bestemmelse af Teglbyggesten vandabsorption(Minutsug) Murkatalogen 2001: Porefyldningstal efter Norsk Anvisning M1 DS/EN 772-1:2011 Prøvningsmetoder for byggesten til murværk – Del 1: Bestemmelse af trykstyrke.
Periode:	Prøvningen er gennemført 19-03-2019 – 26-03-2019.
Resultater:	Resultaterne fremgår af side 2. NB! For hurtigt at kunne få resultater, er stenene ikke tørret til konstant vægt før opstart af analyserne, Format - Densitet –Minutsug og Porefyldningstal.

Gamle Mursten Dato 26.03.2019

Direktør Claus Juul Nielsen

Bende Andersson

Appendix G – Material test results, page 2

Sten nr.	Bredde i mm	Højde i mm	Længde i mm	Densitet kg/m3	Minut sug		Porefyld ningstal <= 0,9	Norma-liseret Trykstyrke (MPa)
1	112,1	59,2	234,7	1515	0,15		0,88	52
2	111,4	59,4	241,0	1447	0,30		0,78	37
3	113,5	62,2	239,2	1458	0,22		0,73	32
4	113,5	65,6	243,4	1386	0,36		0,68	36
5	112,6	61,9	239,6	1397	0,37		0,77	50
6	110,0	61,6	246,4	1476	0,52		0,85	35
7	110,4	65,3	241,7	1425	0,22		0,84	39
8	113,8	62,0	243,3	1403	0,65		0,70	31
9	113,2	61,1	238,0	1454	0,07		0,90	37
10	114,2	61,4	241,5	1401	0,51		0,84	43
11	113,6	61,3	240,5	1458	0,51			39
12	114,1	64,2	242,3	1420	0,36			19
13	112,8	62,4	239,3	1473	0,30			56
14	112,5	60,8	237,1	1459	0,30			47
15	115,3	62,5	243,1	1464	0,29			52
16	118,4	63,3	246,4	1329	0,82			27
17	114,4	60,6	241,7	1425	0,36			34
18	113,2	61,5	238,9	1443	0,22			26
19	111,3	60,9	240,2	1503	0,30			37
20	112,0	64,2	239,3	1459	0,45			48
middel	113,1	62,1	240,9	1439,7	113,1		0,8	38,7
spredning (STD AFV s)	1,8	1,7	2,9	42,9	1,8		0,1	9,7
spredning i % af middel	1,6	2,8	1,2	3,0	1,6		9,5	25,1
min	110	59,15	234,73	1329	110		0,68	18,7
max	118,42	65,61	246,44	1515	118,42		0,90	55,6