Danmarks Tekniske Universitet

Bachelor Thesis

Implementing Material Efficiency Strategies in the Early Design Phase

Life Cycle Assessment of an Alternative Design Proposal

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Abstract

Optimisation of material efficiency represents a large potential in energy consumption reduction. This project studies which environmental benefits implementation of material efficiency strategies in a design proposal may result in. A renovation project in Stavanger represents the case where the strategy of direct re-use of materials is implemented in the design stage. The project thereby challenges the established mindset of building design, which in traditional views is designing a building and producing materials to fit the design. Our case relies on the existing materials to set the restrictions of the new building's form and shape.

Architecture is all about finding limitations and setting constraints for the design. In reality, only laws of physics and economy limits the possibilities for the architect. By striving for optimum material efficiency, a natural motivation occurs and a challenging aspect arises in the development of new design proposals.

A LCA has been made to evaluate the environmental benefits and impacts resulting from a design strategy relying on the existing materials to set the restrictions. The LCA of our alternative design proposal is subsequently compared with more conventional design approaches relying on more or less complete replacement of the existing structures.

This project intends to inspire a new approach to building renovation cases, and encourage building designers to realize the possibilities in the existing structures and materials, and hence minimize the demand for producing virgin materials.

Terms and Definitions

LCA
LCA is short for Life Cycle Assessment. LCA is a strategy to assess environmental impacts associated with all the stages in a product's life.

CEN/TC 350
CEN/TC 350 is a European comity responsible for the development of standardized methods for the assessment of the sustainability aspects of new and existing construction works. CEN/TC 350 have issued several standards for sustainability evaluation of buildings and building materials.

DGNB
DGNB (German Sustainable Building Certification) is a German certification scheme, which is the german council for sustainable buildings.

Ökobau 2013
Ökobau is a German building materials database, as a standardized database for ecological evaluations of buildings and assessment of global ecological effects.

Environmental categories and indicators
The environmental categories and indicators are potential environmental impacts and resource consumption.

Environmental profile
The environmental profile is a profile over the results given from a building's LCA, based on environmental categories.

Embodied energy
Embodied energy is all the energy required to produce a material.

Upcycling
Upgrading a product to materials that have higher value.

Downcycle
Converting a valuable material into a less valuable raw material.

Recycle
Reusing the materials in its original shape.

Direct reuse
Reusing building elements directly as they are.

Quantis Suite 2.0
Quantis Suite 2.0 is a LCA software tool based on sustainability.

LCAbyg
LCAbyg is a LCA – tool developed by the SBI administration. With LCAbyg it is possible to calculate a buildings environmental impacts and resource consumption. LCAbyg is based on the German database for building components, Ökobau.

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Contents

Introduction

Sustainability in the building industry was firstly focused around the new development of buildings. However, existing building masses poses an interesting assessment of buildings overall contribution to environmental impacts. Renovations with energy optimization as the motivation factor are not seldom, however in this project the concept of architectural renovation is of great interest. If an architectural renovation is an alternative to demolishing old buildings and building new, could this strategy be more sustainable?

In this project there is created an alternative renovation proposal to challenge the mindset of the building industry. It wishes to shift the design approach from producing materials to fit the building to designing the buildings to fit the materials. This method challenges the mind in creative thinking based on a limited spectrum.

Research Topic

This project takes a case-study area to lay the basis for where the design strategies are implemented. The environmental benefits following re-use of materials will be assessed using the LCA method. Different elements in the LCA such as system boundaries and lifespan of buildings will be discussed to whether they contribute in creating the correct assessment of the sustainability of the design proposal. Lastly the results of the refurbishment proposal will be compared with new developments, in order to put the project in perspective.

Readers guide

The structure of the project is built under the classical conditions; Introduction, Methodology, Results and analysis, Discussion and Conclusion. However, there is implemented sections concerning theoretical background and case-study background to provide the reader with an overarching knowledge which is referred to throughout the project.

The section "Theoretical Background" describes the meaning behind sustainability and material efficiency, introduces and describes the LCA method, and give the reader insight in different recycling methods.

The section "Case-study Background" starts with describing the city where the area is situated. The section then focuses on the architectural firm Helen & Hard before zooming in on the specific site of which the project has its focal point.

The methodology section describes the methods applied in the different sections. An overall description of the methodological approach is given, an the focus of the project is explained. The section "Methodology" then divides into two subsection. Each describing different aspects of the project. These sections are: "Quantification of Materials", "Union Canning" and "Warehouse". More on the methodological approach will be described in this section.

The results and analysis chapter is divided into two sections: "Quantification of Materials" and "Union Canning". "Quantification of Materials" presents the results and analysis of the materials present at the site. In the following section "Union Canning" shows the results of the design method and the environmental assessment. The warehouse will not have a result and analysis section. This is explained under the methodology for the warehouse.

The discussion section provides a thorough discussion of the results and analysis reached in the previous section. This section also includes a discussion to the method used in assessing scenarios set up for the warehouse.

Further discussion as to experience working with the program LCAbyg, and of the general methodological approach is also to be found under this section.

Lastly the project provides a conclusion, summarizing and rounding up the project for the reader.

Theoretical Background

The theoretical background forms the overarching framework of the Union Canning assessment. The aim of the theoretical background is to supply the reader with background information about the knowledge gained during the research period. "Sustainability and Material Efficiency" describes the overall meaning of sustainability and provides the reader with insight to the motivation behind the project. "LCA" describes the theory of which the analysis method is built upon. The section "Recycling and Re-use" describes the different methods of recycling different building materials.

Sustainability and Material Efficiency

"*Sustainable development is development that meets the needs of the present without compromising the ability of future generation to meet their own needs.*"[30]

In today's society sustainability is a hot topic. When discussing the matter this quote is often used to describe the meaning of sustainability. The saying originates from the report "Our common future" also known as "the Brundtland report" which came in 1987 and addressed the concern and necessity for a sustainable future.

Society's immense development over time has driven it towards an explosive consumption of resources. Therefor has it been necessary to increase focus on a more long-lasting development on wards. Sustainable development shall secure best possible conditions for mankind and the environment for both now and in the future.

Three Dimensions of sustainability

The Brundtland report [30] describes three aspects covered by the term sustainability. These are social, economy and environmental, see figure 1. Sustainability in the building sector is used to comprehend a buildings environmental, economical and social abilities.

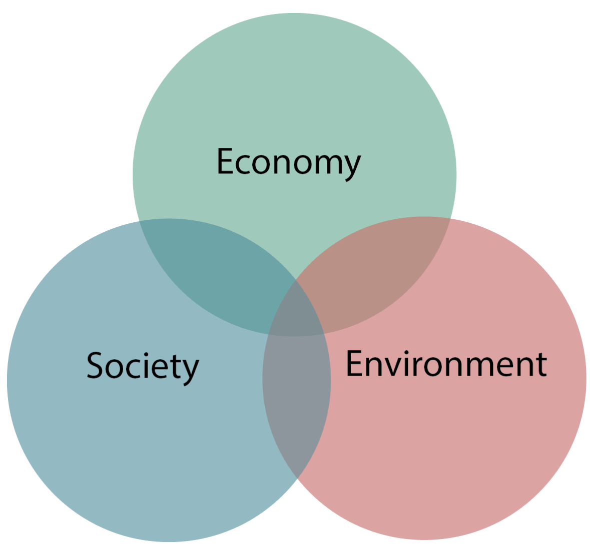

Figure 1: Diagram representing the three dimentions of sustainability

Social sustainability is about creating buildings and environments that enhances our quality of life. Aspects of this dimension could be: diversity, comfort, well-being, welfare, diversity, accessibility, culture, architectural qualities, among other things.

Economical sustainability secures long-term economical interests and investments in buildings that create stable conditions for a sustainable development and optimisation of resources.

Environmental sustainability is about securing that buildings minimizing the affect on the environment throughout the lifespan of the building.

Sustainability in the Building Sector

The general increased focus on sustainability has also been transmitted over to the building sector. The building industry represent a big consumer of resources both in terms of energy and material consumption. At first sustainability was mostly seen as relevant on new development projects. However, energy optimization of existing buildings has proven to be a huge potential in minimizing the environmental impact from the building sector.

The environmental impacts of material production and processing, particularly those related to energy, are rapidly becoming critical. In this case, it is material efficiency, rather that energy efficiency that represent the biggest opportunity[2]. Material efficiency means to deliver the same required services with less primary production. In other words getting the most out of the material without enhancing the use of resources.

There are four main strategies to reducing material demand through material efficiency[1]:

- Longer-lasting products
- Modularisation and remanufacturing
- Component re-use
- Design products with less materials

The benefits behind recycling have often been questioned as to whether the environmental benefits exceed their environmental impacts[6]. This is very probable if the recycled product does not require a lot of energy in the primary production phase. If this is the case it is highly likely that the energy spent recycling exceeds the energy saved avoiding primary production. However, in the building sector there are many materials which require a lot of energy in the primary production stage.

It is important to focus on which materials will have greatest effect by optimizing when determining which materials to prioritize.

Figure 2 describes the distribution of energy consumption contributing to Global Green House Gas (GHG) emissions. (of equivalent annual CO_2 emissions, i.e. they show the effects of other greenhouse gas emissions translated into units equivalent to CO_2).[2].

The chart A. to the left describes the division of global GHG emissions. They consist of two sectors. Two thirds of the total emissions are the emissions emerging from burning fossil fuels to generate energy and those released directly by industrial processes. Emissions emerging from changes in land use (primarily deforestation) and from agriculture contributes to approximately one third.

The pie chart in the middle, chart B., shows the main drivers of CO_2 emission emerging form energy production and industrial processes, the largest segment of the left chart. It is seen that the largest sector contributing to emissions is what arises in industry by making goods, buildings and infrastructure. While the emissions resulted by building use is roughly 30% of the total emissions.

The last pie chart (C.) shows the industrial carbon emissions categorized by materials. The biggest sources of impact are namely five materials that together are responsible for 55% of global CO_2 emissions from industry. The five materials with greatest impact are: steel, cement, paper, plastic and aluminium. There are several strategies to improve material efficiency in these five key materials. Steel is mentioned as the worst of the top five materials[2].

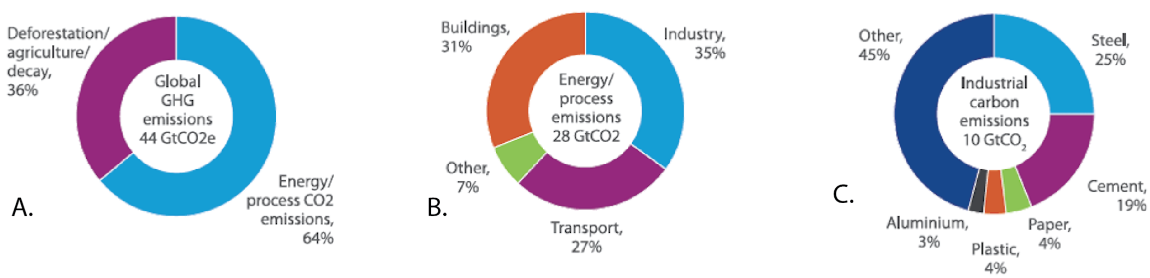

Figure 2: Distribution GHG equivalent emissions [2]

Today the tradition of recycling steel is effective and well functioning. The current rates for recycling steel is 65%[1]. In a demolition process, steel is usually sent for recycling which means melting it. From a life cycle objective this initiative prevents the phase of extracting raw materials which is very positive. However, the melting process is an energy-intensive process which could be avoided if old components could be directly re-used instead. Steel in construction is one of the biggest potential assets, as the beams from dismantled building are usually recycled rather than being reused directly. “When you take a building down, the steel girder is totally reusable. All you need to do is unbolt it and clean it, because steel doesn’t degrade with use. Re-use means we can avoid all the energy of melting, casting and re-rolling old steel.” [1]

LCA

The LCA method

LCA is short for Life Cycle Assessment and is big part of the process when assessing the environmental impacts associated with all the stages in a building’s life cycle. The method is furthermore a help for the actors working with assessing the environmental sustainability of a building, by ensuring fundamental knowledge of which parameters are reasons for the consumption of resources and the environmental impacts in the buildings lifecycle. LCA is therefore an important tool in developing a sustainable and environmental friendly design of buildings.

A LCA can be used in the optimisation of a building, and point out the most critical phases in the lifecycle. The LCA can emphasis the perspectives on certain phases, such as pointing out phases with most critical impact, or the part of a building with the most critical impact and furthermore, how the optimisation can be done to reduce the critical impacts.

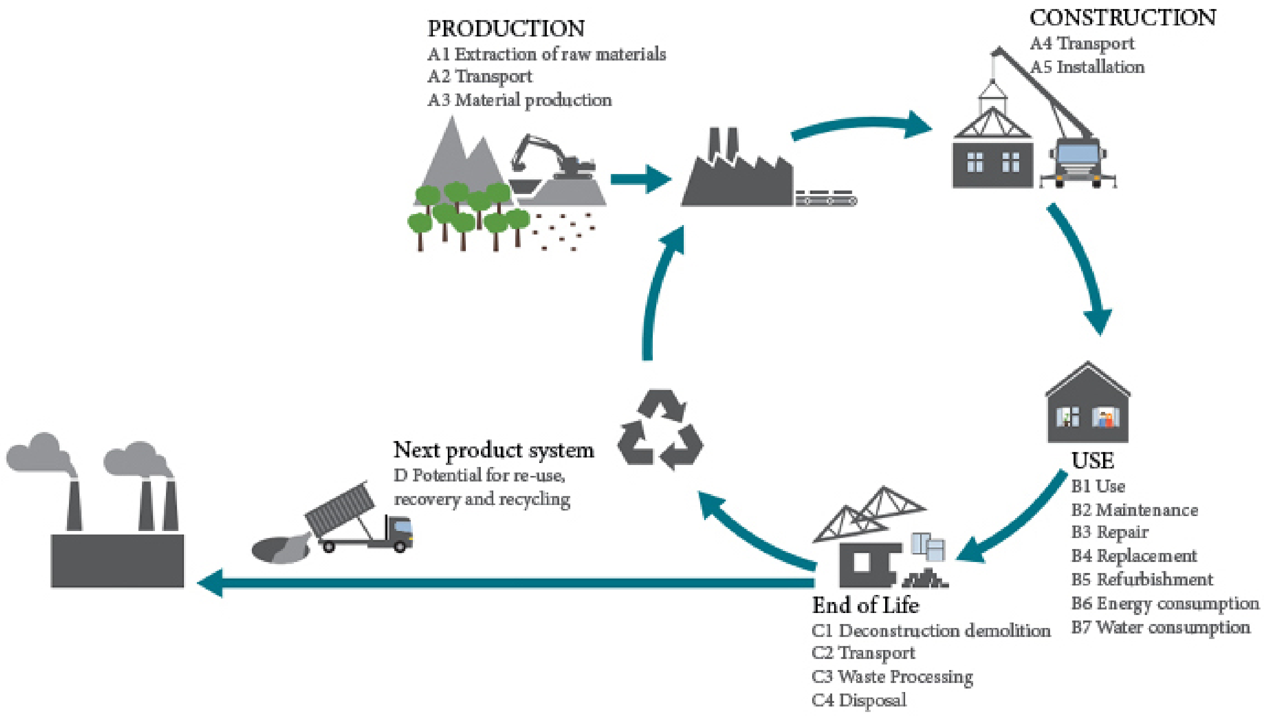

Figure 3: Life cycle stages of a building as described in the european CEN/TC standards.[25]

The LCA is divided into five phases; production, construction, operational (use), end of life and next product system. The life cycle phases are illustrated in figure 3. The first two phases are the most easy to approach, because obtaining knowledge is more feasible, whereas the last three phases are more based on assumptions, such as usage of the building, maintenance and demolition.

Furthermore, the LCA is also divided into process modules, also called system boundaries. The system boundaries are an important parameter, when a LCA is to be conducted. The process modules are a more detailed description of the five phases, as mentioned above. The process modules indicate which phases are implemented in the specific LCA. This is beneficial when results from a LCA are to be assessed by an outsider. However, it is not always the case that all the process modules are implemented in the LCA, this could occur because of lack of information or if a simplified LCA is made. If these circumstances occur, it is important to clarify which phases of the process modules are included.

The production phase includes process module A1 and A2, and is where the materials needed for the building is gathered. This includes extracting the materials and transporting to manufactory. From the production phase, the produced materials are transported to the construction site where the materials are installed etc. until the building is finished. The Construction phase includes process module A4 and A5. When the building is constructed, it is ready for usage. This is the Use phase, process module B1, B2, B3, B4, B5, B6 and B7. This phase is based on the buildings service life. When setting up this stage, assumptions are made based on expectations about how the service life would evolve. The processes involves consumptions for use of energy and water, and furthermore maintenance of the building and the need for repair, refurbishment and replacement. When the building has fulfilled its service life its ready for demolition, also called End of life. Process module C1, C2, C3 and C4 are included in this stage. This phase is - like the use phase - based on assumptions. Assumptions of how the materials are handled after the demolition process, such as waste handling and disposal, and furthermore how transportation in this phase is proceeded.

Process Module D seen in 3 describes the potential environmental benefits/impacts resulting after the buildings lifespan, when the materials enter a new product system. For example when crushed concrete is re-used as landfill under road construction. The waste processing is under phase C3, but the environmental benefits (avoiding extraction of gravel) and impacts (possible emissions of heavy metals) arising belong to process module D. The results from process module D shall be reported separately from the other modules according to the DS/EN 15978 standard [9]. This is due to the large uncertainties occurring when predicting the future for the disposed materials. If process module D was to be included in the overall LCA of the building is a great risk of accounting the environmental benefits/impacts two times. After years of service life there is a depreciation of the embodied energy to the building part. If the expected lifespan of a building is 100 years, it will take the full lifetime of 100 years for the embodied energy to be fully depreciated. In other words the environmental impacts due to its production phase shall still be accounted for if the building does not outlive its lifetime expectancy. If a new building wishes to use recycled materials, it is discussed whether the embodied energy shall be a part of the new buildings life cycle.

The DGNB approach of the LCA method

The DGNB approach is a simplified version of a full LCA. The DGNB includes only 3 stages; product stage, operation stage and EoL & Next product system stage. The stages not included from the recommended LCA approach given in the CEN/TC 350 standard, are excluded from the assessment not only as a simplification of the method but also because they are considered less important.

- **In the product stage**, phases such as raw materials supply, transport and manufacturing are implemented. If some of the materials appears not to account for more than 1%, the certification order accepts these materials to be left out, though by expecting the final results to be multiplied with 1,1.
- **The operation stage** includes two phases; replacements and energy use.
- **The Eol & Next product system stage** includes two phases; replacements and energy use. is influences by the last three phases waste processing, recycling/reuse and disposal.

System boundary

A system boundary determines the processes that are taken into account for the object of assessment [9]. DS/EN 15978 described the system boundary for an assessment of a new and existing building. For a new building, the system shall include the life cycle stages A-C shown in figure 3. For an existing building, only the stages representing the remaining service life and end of life stage shall be included in the system boundary.

Environmental impact categories and indicators

When making a LCA, there are several environmental impacts, which potentially can have an influence in the lifecycle of a building. These environmental indicators are divided in several categories, where each category are a source to a different environmental impact. The environmental categories are set in the European standards for sustainability of construction works – CEN/TC 350[25]. Nine categories are pointed out to being the most typical environmental impacts affecting the life cycle of a building. These are the current categories implemented in the Ökobaus database. These categories are to support the assessment and to highlight the critical environmental impacts and the consumption of resources.

The nine environmental impact categories and indicators are as follows[5]:

Global Warming Potential (GWP) – CO2 - equivalent When the amount of greenhouse gasses in the atmosphere grows, the down-to-earth air layers heats up with following climate changes.

Ozone Depletion Potential (ODP) – R11 - equivalent Depletion of the stratospheric ozone layer, which protects flora and fauna against the suns harmful UV-A and UV-B rays.

Photochemical Ozone Creation Potential (POCP) – Ethen - equivalent Contributes in consideration to UV – rays to create down-to-earth ozone that among other things are harmful for the airways.

Acidification Potential (AP) – SO2 - equivalent Reacts with water and falls as "acid rain", which i.a. contributes to disintegrate root systems and wash out the plants nutrients.

Eutrophication Potential (EP) – PO4 - equivalent To big amounts of supplements of nutrients, increases unwanted vegetation in sensitive ecosystems.

Abiotic Depletion Potential, Elements (ADPe) – Sb - equivalent A large use of abiotic resources can contribute depletion of obtainable resources, such as metals and minerals.

Abiotic Depletion Potential, Fossil fuel (ADPf) – MJ A large use of abiotic resources can contribute to depletion of obtainable energy, such as fossil fuels.

Total Primary Energy Consumption (PEtot) – MJ or kWh A large use of resources in primary form of energy from fossils and renewable sources can contribute to depletion of natural resources.

Secondary fuel (Sek) – MJ or kWh Secondary fuel, such as waste, is principally a limited resource, and therefore a large use of secondary fuel can indirectly lead to lack of resources.

Recycling and Re-use

Concrete and reinforcement steel

Today there is not many alternative ways of reusing reinforced concrete. One of the reasons for this is the way reuse of concrete is managed today, i.e. used for landfill, is an efficient and effective method and based on established technique. Concrete waste has several good qualities, such as its density value, high durability, and reusing is cheaper than manufacturing new concrete. These benefits makes concrete waste a wanted landfill material[29]. However, this would be to downcycle the building material. Downcycling is a process where waste materials are crushed/demolished and used in new materials, which converts a valuable product into a less valuable raw material[20]. This is a less desirable way of handling products, compared to upcycling (upgrading a product to materials that have higher value). Although it is important to keep in mind that downcycling is a better for the environment compared to no reuse or recycling at all.

Currently there is no route to creating new cement from old cement[1]. Nevertheless, there are potentials in creating new reuse possibilities for concrete waste, with sustainability as the driver.

As mentioned above, there is not many ways of reusing reinforced concrete, and the efficiency of the method for recycling as landfill is not the only reason. The Concrete elements are hard to reuse, because the elements are often dimensioned for a specific structure, and furthermore they are hard to separate because they typically are jointed together by reinforcement steel. However if the concrete elements are jointed together by steel wires, it would make them separable and therefore easier for reuse. Such construction has to be designed and incorporated already at the construction of the restructure that later on will be demolished and reused. This method is sometimes used when constructing silos. Options for developing reusable concrete elements is therefore not completely infeasible.

Creating new design concepts for concrete panels, that makes it easier to separate the panels with no damage consequences should be considered. This could be done by designing more flexible joints, for instance by creating concrete panels, which are gathered by bolts. This would make it possible to demolish and separate the panels. If this would be possible the old concrete panels are to get renovated and ready for reuse as new concrete panels.

Another solution could be reuse by keeping the original shape of the building to a greater extent, in the sense of maintaining the bearing construction, while the indoor rooms and building's façade could be renovated despite this seem to be in the opposite direction than the current evolution[8].

On the other hand, there is potential in using crushed concrete in situations where the requirements lies on the finished product and less on the specific input of resources in the product. This could be paving stones, concrete tiles etc.

Steel reinforcement has no potentials in recycling, because it is made of 100% steel scrap[1], which makes reuse opportunities of the concrete elements more convincing.

These suggestions could help to reduce the exploitation of the nature resources and the environmental impact.

Foundation

It is possible to reuse the foundations of the old constructions directly where the building is demolished. However, when reusing old foundations there are considerations to be made. The existing foundation is constructed to bear the specific old building. When the old foundation shall bear a new building, the constructions of the new building cannot derivate much from the old. However, if it is desired to build a new building with a different construction an assessments of the reuse possibilities by a structural engineer is required. Based on the construction of the new building, the engineer would have to create new plans for the foundation caused by either the design of the new building or the bearing capacity of the old foundation that may be insufficient. Consequently, additions to, change of reinforcement of the old foundation is required. Ultimately, the old foundation may have suffered damage in such a way that it is not suitable for rebuilding.[28]

These considerations about the reuse of the existing foundation, can cause extension of the investigation and design process, because solutions have to provide a robust basis for the decision on whether the old foundation is sufficient or if establishment of a new foundation is needed.

Bricks

Bricks manufacturing process is very energy consuming and resource demanding. On the other hand the durability quality of bricks is very strong, which improves its recycling possibilities of the bricks.

Therefore, by recycling, a lot of CO_2 emission and use of raw resources could be reduced. When reusing bricks, they have to be cleansed before use. This can be handled by machine or by hand. Both ways gains an environmental profit, because it will not be necessary either way to produce new because even cleansing by machine result in significant less CO_2 emission than new production.

The hand cleansed method is a gentle process, which typically is done on bricks from very old houses. When reusing old bricks it is best if they are to be reused on properties containing similar old bricks. It may therefore be necessary to compare the demolished bricks with other old bricks and it may be difficult to find a perfect match. The hand cleansing process is in this case better than the machine wash, because of the big difference in the brutality degree of the handling process.

In the construction of new brick buildings in the sixties the bricks started to get pasted together by cement mortar instead of lime mortar[13]. This makes it harder separating the bricks without causing damage. Our building is from the early 1900, which means bricks are pasted together with lime mortar. Union Canning will therefore have no bigger problems in the separating process.

Even though cement mortar made the process easier for the builders, lime mortar is a more sustainable material, and has better qualities. First quality, as mentioned above, it is easier to separate. Another two qualities of lime mortar is that it is free of harmful substances and the leftover lime mortar from the cleansing process can be reused within new mortar[4]. It is crushed and ready for use in the new lime mortar which reduces the use of sand.

If bricks are not to be maintained as a part of the exterior wall, there are other solution for reuse such as using the bricks as an indoor wall sheathing or as facing for the outside exterior wall, covering for instance the boring current plaster facing. The bricks could also be used as tiling for a playground, driveway, sidewalk etc.

When using bricks for these alternatives, it has to be ensured that they are completely clean of toxic substances. In 1950 it became very popular using PCB in the grout and paste when building up a construction. PCB has a high insulation capacity and has good qualities in the sense of fire-resistance and durability. Later on, in 1977, PCB was examined to be toxic and very dangerous for the human body, which made it illegal for use. It is therefore important today, to test the bricks for PCB, if a building is build by old bricks or renovated in the spectrum of 1950-1977[7]. PCB has an ability to wander from the materials it was mixed with to the materials adjoining, which is the cause for PCB's infiltrating in the bricks.

Even if bricks have been in use for hundreds of years, they still maintain their good qualifications. Furthermore, by reusing old bricks you save a half kilo of CO2 emission for every brick used, compared to using a new brick[13].

Steel

Steel is a very durable and sustainable material that can be reused time after time, without losing its good qualities. It can be reused 100%, which is a help for protecting our environment and preservation of natural resources. Reuse of steel will at the same time saved a significant amount of energy, because production of new steel is heavily dependent on energy including extraction of iron ore[14]. Another good quality of steel, in the recyclable sense, is its magnetism, which makes it easy to separate from other materials.

The recycling process of steel can be handled in two ways. It can be melted and then used in new production, or it can be reused directly as it is. By reusing the material directly, it won't have to go through a steel production process, and its good qualities would still be remained. Direct reuse is typically done on steel beams from buildings or on steel sheets piles from building projects. When using the steel sheets piles in building projects reused as they are and only if or when they are damaged they will be melted in new steel production.

Steel from vehicles, other parts of buildings, infrastructures and daily life equipment contribute also to recycling steel.

Today it is possible to up-cycle steel[26]. When a steel material has lived its service life and ready for recycling, it is possible to upgrade the steel qualities. This is possible because the technological development has made today's steels qualities better than 50 years ago.

Windows/Doors

It is possible to reuse windows directly. However, windows from before the 1950'ies may have been painted with leaded painting. White lead is a toxic material that may have negative impact on the human body. Lead can be obtained by inhalation of lead-containing dust. Therefore, it is important to test the windows for lead, because lead painting may be invisible to the naked eye or hided in-between layer of several of other layers of painting. When the lead painting on the windows is removed or the test result shows that the windows do not contain any lead, they are ready to be directly reused. Direct reuse of windows and doors is typically done by using them in a new building, or by using them as an indoor room reparatory.

Another way of handling old windows is by recycling the materials. Manufacturing glass is a very energy consuming process. When producing glass, up to 90% of the glass can contain old glass[15]. Beside energy the recycling of glass by using is as raw materials in production of new glass reduce the use of raw materials such as sand and water, remarkably[22].

Wood

Reuse of timber is possible but as always and especially when it is 100-years-old testing of the wood's condition has to be made before reuse. The timber may be attached by dry rot. If this is the case, dry rot may have spread out from the old timbers to the new building as well. However, if there is no sign of dry rot old timbers normally have a higher breaking threshold than new wood[21], because the old timber are often produced from hard tree, i.e. trees with longer growth period. This would in certain cases make the old wood more suited than new wood.

Using old timber as an energy resource by obtaining the calorific value from incineration may be an option. However, there are criterions for the woods condition before it can be incinerated, such as no impregnation, no dry rot etc. These conditions has to be handled before incineration, if possible.

Case-study Background

The Case-study Background gives background information to the thesis. The chapter is divided in the following sections: Stavanger, Helen & Hard and The site - "Vindmøllebakken"

Stavanger

Stavanger is Norway's fourth biggest city and is situated on the south-western coast of Norway. As well as bearing the title: "the Oil Capital of Norway", Stavanger is also known for it's beautiful nature and interesting history. Stavanger can boast of it's beautiful nature and is surrounded by breathtaking fjords, mountains and white beaches.



In Norway, the term "Olje eventyr", (directly translated to "The Oil Fairy Tale") is used to describe the transition of the country and economy. Before Stavanger became a central part in this transition, the city was know for being a small canning city [12]. The uprising of fishing herring represent an interesting and proud aspect of Stavanger's history. The trade resulted in an upturn of the economical situation in 1800 and ensured Stavanger's continuous growth. The city's tradition of fishing herring resulted in other industries such as the shipping and canning industry to grow, providing jobs and income for the citizens.

Figure 4: Herring fishing

Helen & Hard

Stavanger marks the city where the two architects Siv Helene Stangeland and Reinhard Kropf founded the architecture firm Helen & Hard. Today the firm has offices in both Stavanger and in Oslo (the capital city of Norway) and has a youthful staff of 26 employees[3].

Helen & Hard has the philosophy of relational design creating architectural solutions that serve and inspire people to a sustainable life. By combining the aspects of manifold and complex relations the company supports architectural development. It is their goal to move towards relations in physical, social, cultural and economic context.

One of Helen & Hard's main objectives is to inspire people to a sustainable life. Developing a more sustainable building with a mind-set of creativity is an inspiration of achieving this goal. Areas that are to be improved and help the sustainable way of thinking are by improving concepts, the organization process, construction, fabrication etc. Furthermore Helen & Hard has been exploring another way of improving their buildings by a co-dependency of spatial, materials, human organization. By working on design skills in these different areas the company develop more sustainable projects.

Helen & Hard philosophy is that the design of a building is not just a solution, but it's also a part of a sustainable development. The goal is to take advantage of the projects potentials.

Figure 5: Cabin situated in Norway made by Helen & Hard

The site - "Vindmøllebakken"

The case-study area is confined to the site "Vindmøllebakken". The site is located in the eastern part of Stavanger, which is one of the city's most interesting neighborhoods at the moment. What used to be known at Stavanger's "backyard", has now become an important asset in developing the city of Stavanger[27]. Currently the site consists of: Helen & Hards old office building; the Union Canning building and a warehouse from the 80's, see image 6. Helen & Hard owns the property together with the entrepreneur company "Kruse Smith"[17].

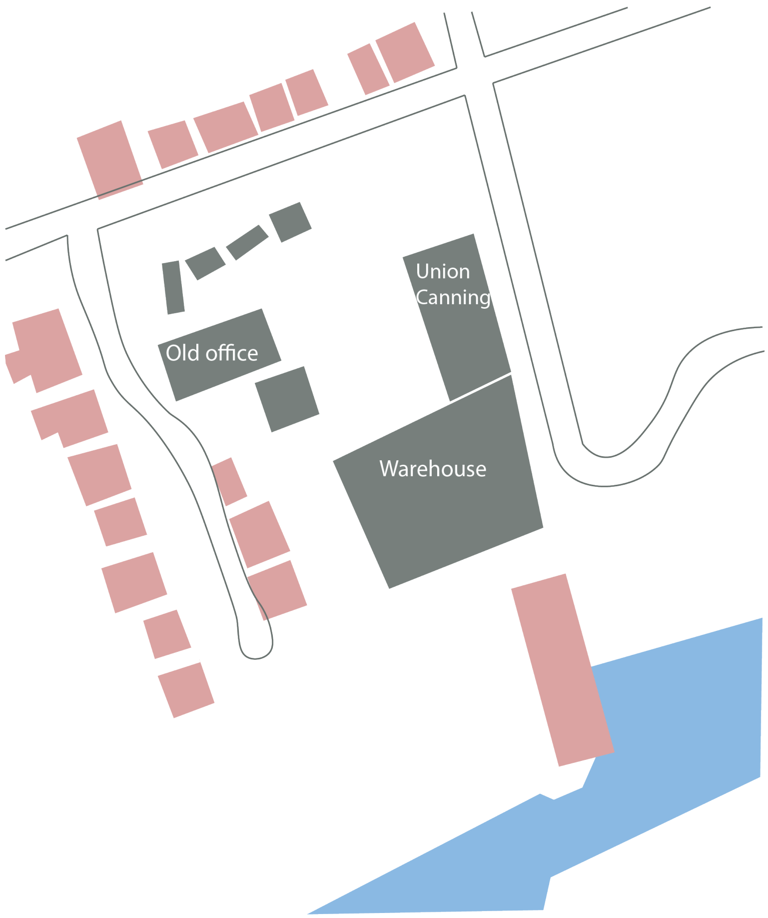

Figure 6: Overall plan drawing of the site "Vindmøllebakken"

Helen & Hard's vision for the site is to create the opportunity for sustainable living conditions. The strategy to obtain this vision is through collective housing. An opportunity arises to minimize the housing imprint, by introducing the concept co-living. The area is planned to have a collective consisting of 34 apartments of different sizes with a shared common area. The housing solution shall secure privacy for the residents, whilst securing the right conditions for creating a social community among the residents. In figure 9 the green area marks approximately where Helen & Hard's new area of housing will be situated. Figure 8 gives an idea of what such a design proposal may look like.

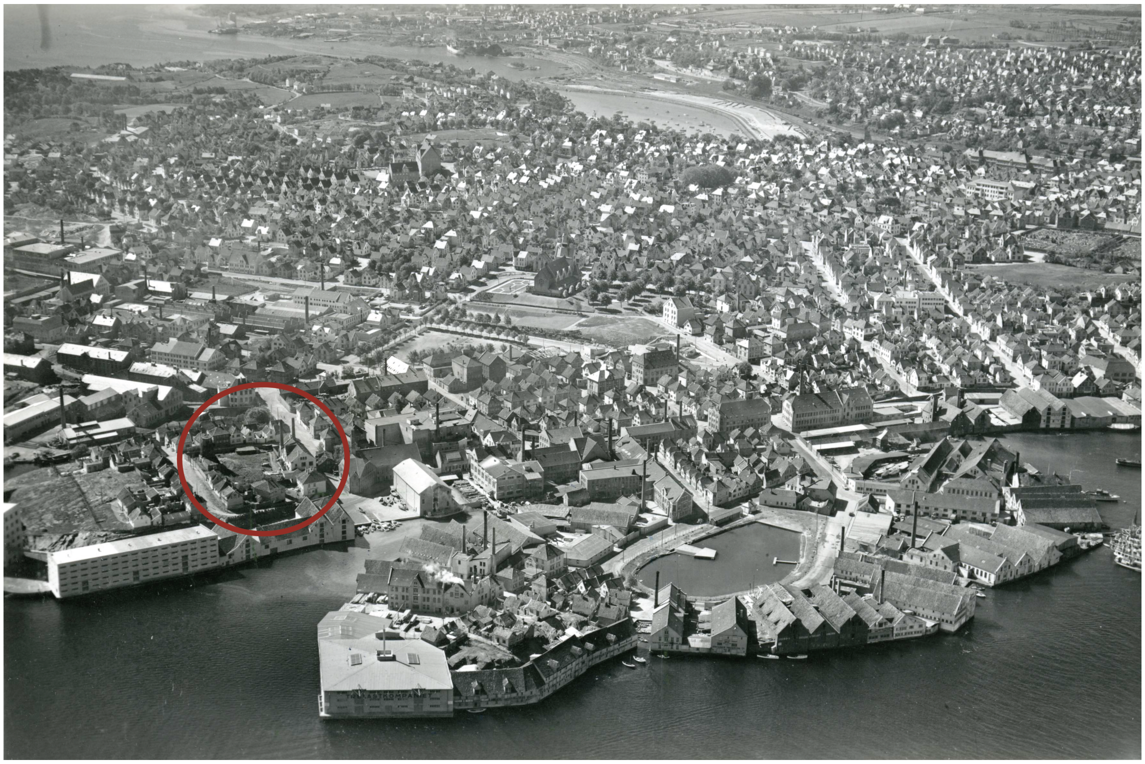

Figure 7: Historical photography of Stavanger where the case-study site is marked

Figure 8: The picture shows Helen & Hard's idea for the site

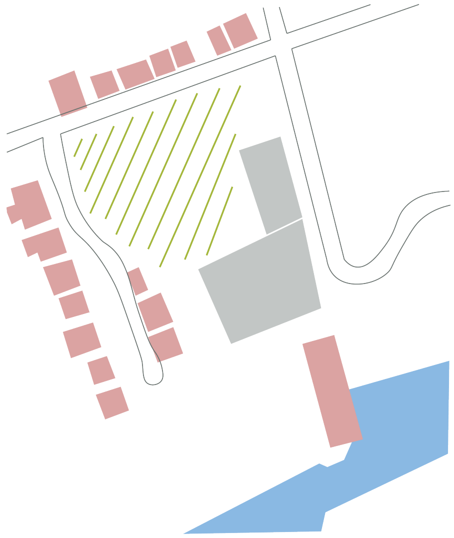

Figure 9: Site plan of "Vindmøllebakken - The green hatch area displays the housing area

Union Canning is an old herring factory, which dates back to 1912[11]. Union Canning's long history and existence on the site has resulted in the building being labeled "worth preserving"[3], however it is not a listed building. Helen & Hard's vision for the Union Canning is to use it as their new office, while still retaining the historical association in the building[17]. Union Canning's placement on the site is seen in figure 11.

Figure 10: Union Canning

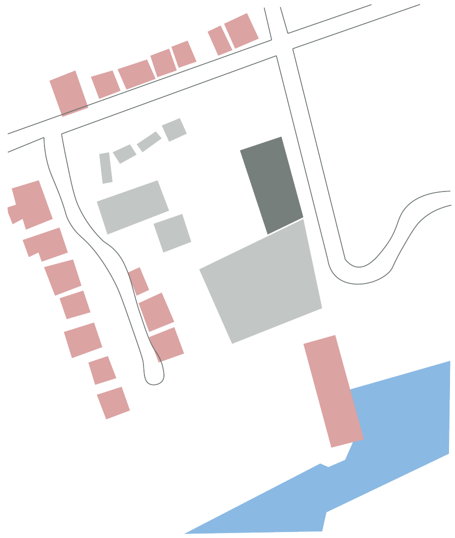

Figure 11: Sitepicture with the Union Canning building highlighted

The building highlighted in the figure 12 is the warehouse. The warehouse was built in the 80's and has in the recent years not been functioning as it was intended. Helen & Hard wishes the building to fulfill the requirement for parking spaces following their new housing area[17].

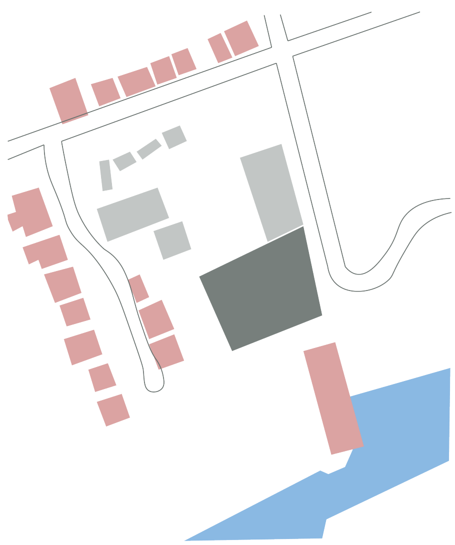

Figure 12: Site picture with the warehouse highlighted

Methodology

This section describes and explains the chosen methods in order to illustrate why and how the methods are used to elucidate the research topic. The overall methodological approach is first described, followed by the focus of the project, the delimitations and boundaries.

Practical Approach

The methodological approach consists of three main sections: "Quantification of materials", "Union Canning" and "Warehouse". Each section is a detailed description of what has been done in the project to assess it's focus area.

Focus of the Project

In this project there will be focused on environmental sustainability following different design strategies. There will be used two methods in evaluating the environmental sustainability of the design proposals. One is through discussion of consequences and benefits, and the other is through thorough LCA calculations using LCAbyg.

Spatial delimitation

This project is focused on the Union Canning and the warehouse described in "The Site - "Vindmøllebakken"" under the "Case-study Background" section. The Union Canning building has an interesting history and Helen & Hard's visions for the building gives the opportunity to establish an alternative design proposal where the environmental impacts and benefits can be assessed through the life cycle method. The warehouse poses some interesting possibilities for discussion. The project will assess possible environmental benefits and impacts through the discussion of recycling potential for the warehouse.

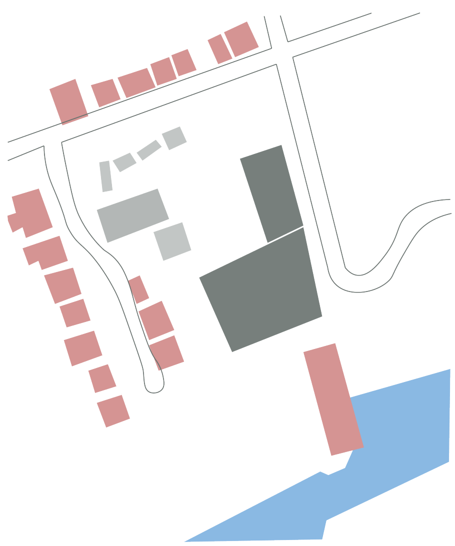

Figure 13: The project focuses on the two buildings, Union Canning and the warehouse

System boundary

The system boundary for the Union Canning assessment is set according to the standard DS/EN 15978, introduced in the section "Theoretical background". Life cycle stages A-C are included for all the building parts to be installed in the new Union Canning, while only the life cycle stage C is included for the building parts uninstalled.

Methodological Approach of Quantification of Materials

Method

objective of the trip was to meet our contact person, Håkon M. Solheim, and to quantify the specific given area, where the project's topic is centralised about. We spent 3 days in Stavanger. During these three days we quantified the whole area. This was done by observing and recording materials of the buildings including measurements of the components length, width etc. and furthermore gathering samples from the Union Canning building. The purpose of the process was to gather information and determine the size and extent of the different materials on the site. These measures and samples are to be used for the analysis of the area and future progress of the project. While quantifying the area several photos was taken. These photos were helpful for the further work in Denmark. At the end of the visit we had a meeting with Håkon M. Solheim, to summarize our observations and the projects direction and share notes taken during the quantification.

Delimitation

Some quantities of the site were estimated from original building drawings of the warehouse and building drawings of the Union Caning made by DTU students working with Union Canning in an earlier project. In some cases we did not get an exact value of various component of the site. In such cases we have performed estimations from both photos, our notes and given notes were combined to get the most reliable registration.

Several other estimations were taken while quantifying the site. In the warehouse there was a steel staircase and a steel machine, these will not be included in our calculations. When Union Canning stopped being a herring factory, the building was used by people for events, an art studio and has once been used by a motorcycle club. There is in that case a lot of left behind furniture in the building, which is assumed to be sold or thrown away, and therefore are not included in calculations. A big steel machine, which has been used for grain production, placed on the top floors of the Union Canning, has also been excluded from the calculation. It was not feasible to get information about elements such as water pipes, heaters, bathroom equipment etc., why this was also not included in the registration process. On the outside area, there is placed a lot of concrete walls. There has been given some plan drawings of the area, but these does not included enough information to quantify the concrete walls, so measurements of these concrete walls has been estimated not only from the given plan drawings, but also from own registrations.

Pictures

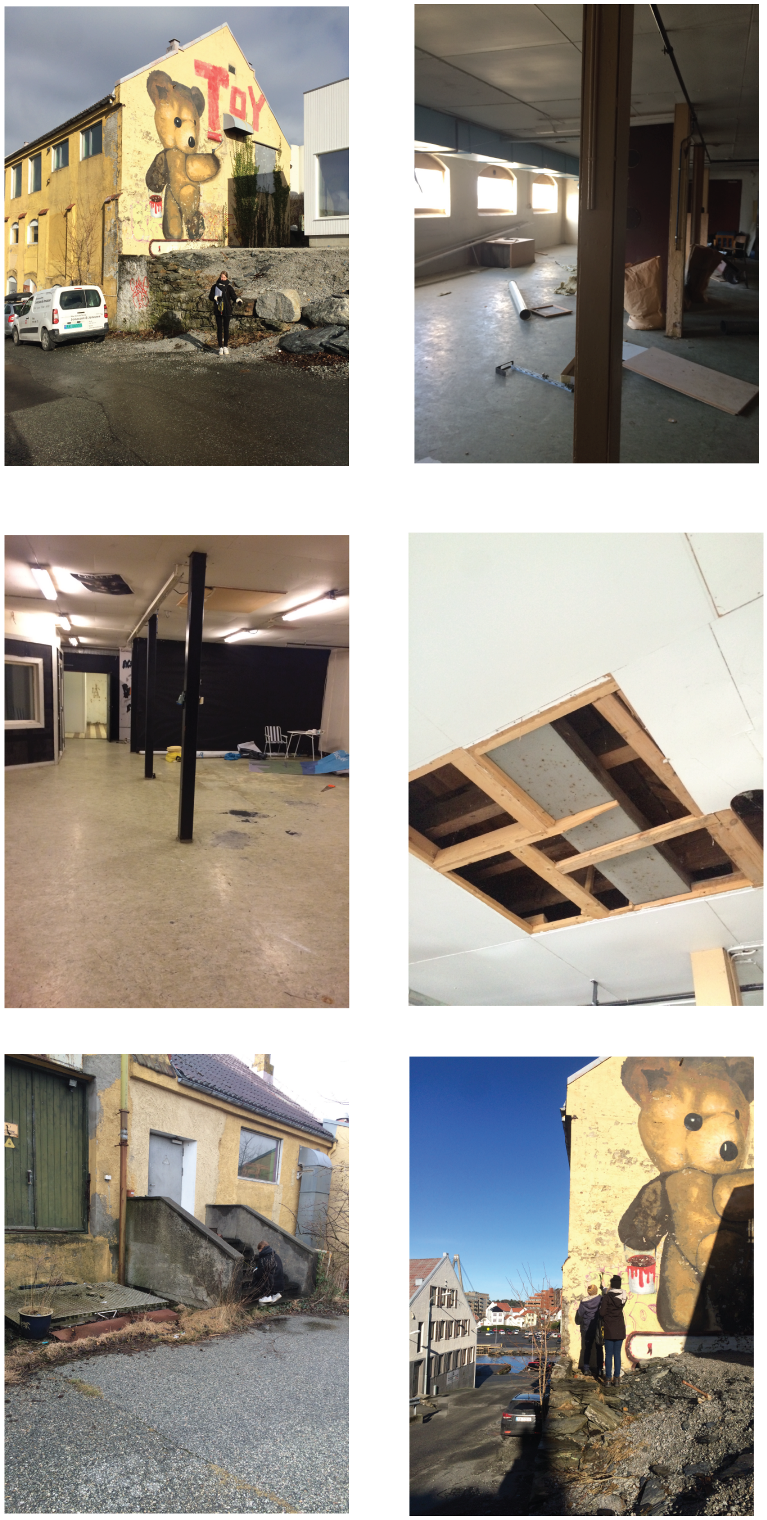

Figure 14: Site pictures of the Union Canning

Figure 15: Site pictures of the warehouse

Presentation of Results

A long process of noting the quantified data from the site and enter them into an excel sheet, resulted in tables containing the final values of the total materials. There has been made tables for each area on the site, which are Union Canning, the warehouse and the outside area. Furthermore, a table showing the total amount of materials from all the sites added together. Each table will be commented on, describing the necessary information.

Methodological Approach of the Union Canning

In this section the reader will be guided through the design process and the environmental assessment of the Union Canning.

Design

Sustainable Design Approach

"*To create sustainable solutions we must explore potential in mutual exchange between mankind, surroundings and material resources.*" [3]

We design towards preserving parts from the existing building. The motivation behind this decision is both of sustainable and historical reasons. Not only do we wish to minimize the environmental footprint of the project but we also thrive to preserve the building's historical spirit. Herring factories in Stavanger represent the pre-oil era. This was the time when the fishing and trade of herring provided work and income for the largest part of the community. The hardworking men and woman working in factories like the Union Canning, lay the foundation for the city of Stavanger that we know today and to show our respect to this generation and time period we thrive towards retaining the buildings character.

Keeping the existing foundation and parts of the bearing structure we are preserving the backbone of the building. In addition to preserving some of the building, we wish to give it an uplift and new life by combining the old parts with a new extension. Together the two building structures shall give the building a new architectural value and prolong the lifetime of the original building.

Concept of construction

The composition of the buildings outer shell is that the structure shall be visible from the inside and the building envelope is attached onto the bearing structure. This design decision is based on the following arguments.

- By having a visual structure, the recycled materials are clearly tangible for the individuals using the building. The essence of the old building is something to be enhanced, not concealed behind walls. As the recycled materials will be combined with the new it will be easy to perceive which building parts are from the former building and which are brought in as new.
- As the bearing structure is primarily of steel this could lead to challenges with thermal bridge if they where to be a part of the building envelope. By closing the envelope around the steel this challenge is avoided.
- Another beneficial by not combining the building envelope and the bearing structure, is that we achieve more floor area and volume to the rooms. Some places the combined wall thickness will be thicker, but the general wall thickness is thinner by having the separated.

In making this design proposal it is important to make it as realistic as possible, as the analysis made following will be based on the decisions made in this phase. There will be many sources of errors as our background knowledge can be limited in some fields of theory. Therefor it is of outmost importance that the design choices are based on well contemplated engineerical assumptions. Such assumptions have been made in estimating the composition of the structural system in the new building. Most of the assumptions have been made by observing the structural system in the current building, for example, by reusing the steel girders in the current flooring structure, we know that it is safe to assume that they will be sufficient in the new flooring structure as long as the span length is equal to each other. The implemented truss system to stabilize the building is an assumption made from inspiration from structure systems in other buildings.

Figure 16: Joint steel girder and wooden beam - Structural inspiration

Dimensions of steel wires

When dimensioning steel wires a specific method is proceed. The approach of this procedure has been proceed with knowledge and help from the book *Teknisk Ståbi*, section 4.7 and 4.8.3[10].
The most critical scenario is considered, in regardless to the most roughly burdened element.
First, is calculated the area of the affected facade, where the wind force is pressing.

$$A_{facade} = 25.55 + 76.76 + 5.03 + 5.35 = 112.691m^2 \quad (1)$$

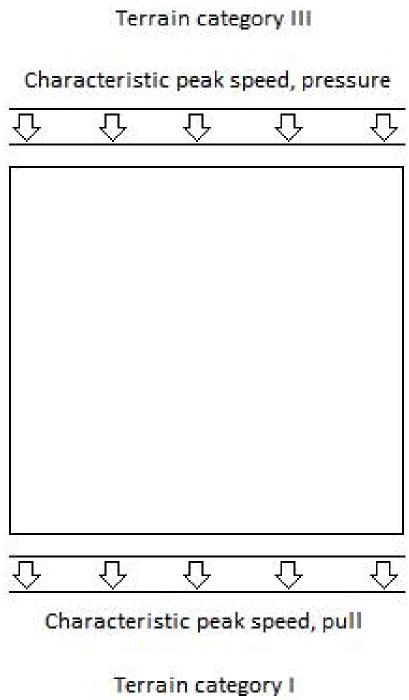

Figure 17: Image illustrating the surrounding terrain categories

Now, it is wanted to calculate the terrain factor, to get a value describing the terrain surrounding the building. the coastal area is calculated as terrain category I, onshore wind, giving us the us the roughness length z_0. The facade south and east of the house is assessed to be terrain category III. This gives us a roughness length $z_{0,II}$. The values of the roughness length are as following:

$$z_0 = 0.01m$$
$$z_{0,II} = 0.3m$$

The terrain factor can be determined by the following equation.

$$k_r = 0.19 \cdot (\frac{z_0}{z_{0,II}})^{0.07} \tag{2}$$

From equation (2) the terrain is calculated, as follows.

$$k_r = 0.19 \cdot (\frac{0.01m}{0.3m})^{0.07} = 0.1497 \tag{3}$$

Now it is wanted to find the the characteristic peak speed, q_p, as function of the function of the height, z, for a basis wind speed of v_b. This can be done with following equation:

$$q_p(z) = (1 + \frac{7}{ln(\frac{z}{z_0})}) \cdot \frac{1}{2} \cdot \rho \cdot (v_b \cdot k_r \cdot ln(\frac{z}{z_0}))^2 \tag{4}$$

Values are as follows

$$
\begin{aligned}
v_b &= 27m/s \\
z &= 10m \\
z_0 &= 0.3m \\
\rho &= 1.25kg/m^3 \\
k_r &= 0.1497
\end{aligned}
$$

Where as choice of v_b is based on a conservative choice for coastal areas and rim zones, such as Vesterhavet[23], ρ is the density of air and z_0 is the roughness length of the terrain, where the wind load is directed from.
So from equation (4), can the characteristic peak speed be calculate.

$$
q_p = (1 + \frac{7}{\ln(\frac{10m}{0.3m})}) \cdot \frac{1}{2} \cdot 1.25kg/m^3 \cdot (27m/s \cdot 0.1497 \cdot \ln(\frac{10m}{0.3m}))^2 = 376.408N/m^2
$$

Now it is wished to find the Form Factor, c_p, for pressure and pull. First, is calculated the zone value, which is done by the values of the height, z, and the depth, d.

$$
Zone = \frac{z}{d} \tag{5}
$$

From equation (5), we can calculate the zone value, with associated values of the height and depth:

$$
\begin{aligned}
z &= 10m \\
d &= 9m
\end{aligned}
$$

$$
Zone = \frac{10m}{9m}
$$

With the given value from above, we get a correlation factor of 0,85, from table 4.10, in *Teknisk Ståbi*[10]. With reference to figure 4.3, ground plan, and values from table 4.10, *Tekniske Ståbi*, it is now possible to find the wanted Form Factors for pressure, $c_{p,pressure}$, and pull, $c_{p,pull}$.

$$
\begin{aligned}
c_{p,pressure} &= ZoneD - 1 : 0.8 \\
c_{p,pull} &= ZoneE - 1 : 0.5
\end{aligned}
$$

With the form factor values, characteristic peak speed and the burdened façade area, it is now possible to find the wind loads in the sense of pressure and pull, done by the following equations:

$$
Pressure = q_p(z) \cdot A_{facade} \cdot c_{p,pressure} \tag{6}
$$

$$
Pull = q_p(z) \cdot A_{facade} \cdot c_{p,pull} \tag{7}
$$

$$
\tag{8}
$$

Furthermore from equation (6) and (7), it is now possible to find the total wind load on the steel wire, as following:

$$
v_total = Pressure + Pull \tag{9}
$$

So from equations (6), (7) and (9), the total wind load can now be calculated.

$$
v_total = (376.408N/m^2 \cdot 112.69m^2 \cdot 0.8) + (376.408N/m^2 \cdot 112.69m^2 \cdot 0.5) = 55142.69N
$$

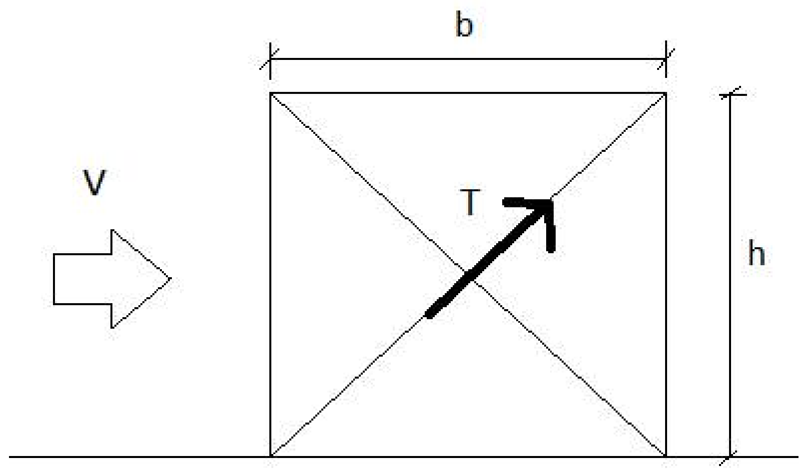

Figure 18: On the figure is seen total normal tension force T which the steel wire is able to cope

From the total wind load, v_{total}, it is now possible to find the total normal tension force, T, the steel wire is able to cope, in purpose to the value of the height, h, and the thickness, b, as shown in figure 18.The total normal tension, T, can be calculated with the following equation:

$$\frac{T}{\sqrt{h^2+b^2}} = \frac{\frac{v_{total}}{2}}{b} \Rightarrow T = \frac{\frac{v_{total}}{2}}{b} \cdot \sqrt{h^2+b^2} \tag{10}$$

And the new values From equation (10), we get the following total normal tension force:

$$T = \frac{\frac{55142.69N}{2}}{7m} \cdot \sqrt{4.75m^2+7m^2} = 33319,82N$$

From table 6.1 and 6.2 in *Teknisk Ståbi*[24], it is possible to find the characteristic yield stress value, f_{yk} and the partial coefficient γ_s. The values chosen are based on that these are classic sizes on steel strengths.

$$f_{yk} = 400 \cdot 10^6 Pa$$
$$\gamma_s = 1.10$$

From these values, it is possible to find the value of the design yield stress, f_{yd}, with following equation:

$$f_{yd} = \frac{f_{yk}}{\gamma_s} \tag{11}$$

Which gives us

$$f_{yd} = \frac{400 \cdot 10^6 Pa}{1.10} = 3.636 \cdot 10^8 Pa$$

It is now possible to dimension the area of the steel wire, $A_{Steelwire}$. With the values from the total normal tension force, T, and the design yield stress, f_{yd}, gives the following equation for the steel wire area:

$$f_{yd} = \frac{T}{A_{Steelwire}} \Rightarrow A_{Steelwire} = \frac{T}{f_{yd}} \tag{12}$$

From equation (12), we get the following:

$$A_{Steelwire} = \frac{33319.82N}{3.636 \cdot 10^8 Pa} = 0.0000916m^2$$

From the area of the steel wire, the diameter of the steel wire can be found.

$$A_{Steelwire} = \pi \cdot r^2 \Rightarrow r = \sqrt{\frac{A_{Steelwire}}{\pi}} d = 2 \cdot r \tag{13}$$

From the above the diameter of the steel wire can be calculated

$$r = \sqrt{\frac{0.0000916m^2}{\pi}} = 0.005md = 2 \cdot 0.005m = 0.01m$$

Resulting with a diameter of 1 cm for the steel wire.
Evaluating the result of the steel wires diameter, with a point of view from an engineer's perspective, the resulting thickness is assessed to be reasonable, to be fitted for the new design proposal of Union Canning. Furthermore, as mentioned in the beginning, *the most critical scenario is considered, regarding to the most roughly burdened element*, which indicates that this dimension can safely be used on all steel wires.

Formation of the design

Figure 19: Historical photography of the Union Canning building from unknown date. The building is situated on the raw mountain.

Today the solid rock shown on the historical photo is leveled out and covered by asphalt. The only imprint of the existing nature is an inclination of the infrastructure. In our design proposal we wish to draw a line to the indigenous landscape by working with differences in the levels of our building.

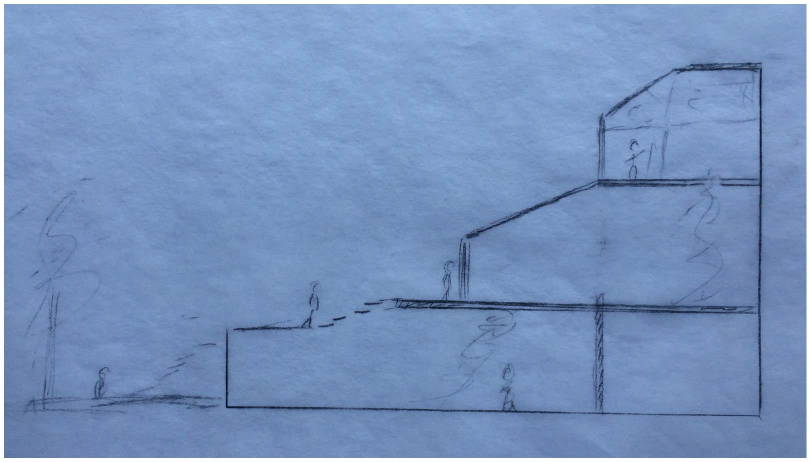

Figure 20: A sketch from the design phase giving an idea of the levels in the building

We are enhancing the hills impact on the perception by choosing the same inclination direction as the hill. A more common and discrete design approach could be to form itself according to the hill. This could be done by leveling out with the hill. But as a contrast to this proposal we wished to work with the contradicting angle and amplify the inclination. The feature of the terrain is emphasized through design proposal as a tribute to the area.

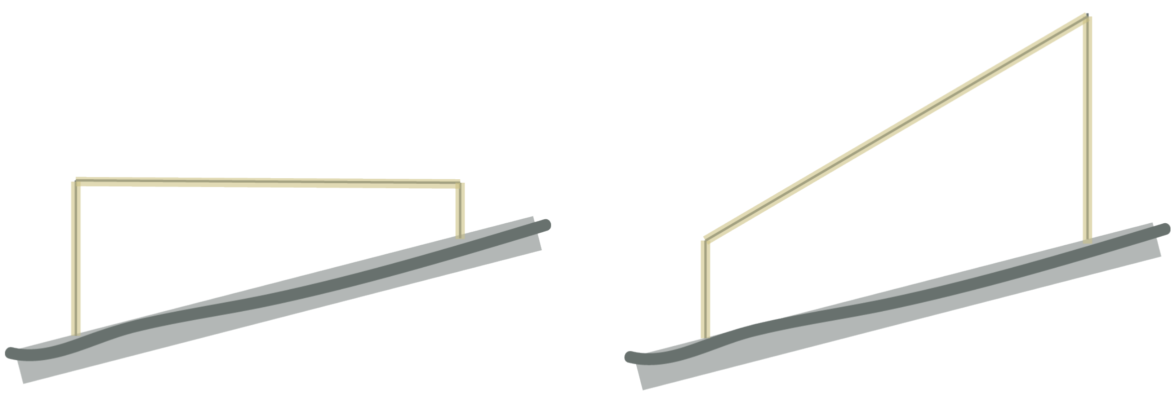

Figure 21: Two approaches on the inclination of the building

Pictures of Inspiration

Figure 22: The pictures represent some of the inspiration which has contributed to the design process

Presentation of Results
Under the section "Results and Analysis" a conceptual drawing of the Union Canning refurbishment proposal will be presented. This is to give the reader an understanding of the composition of the building and material use. The dimensions of the steelwires will also be described and a detailed overview of the materials necessary to realize the proposal will be presented.

Recycling potential of materials

When quantifying the site some samples were gathered, as mentioned in "Methodological Approach of Quantification of Materials" section "Method". These samples of the Union Canning's exterior wall was; a brick, mortar and painting from the inside of the walls, and the façade with and without graffiti. The aim of these samples was to test for content of toxic substances as one aspect of the recycling potential.

Through a meeting with Ebba Schnell, laboratory coordinator from the department of civil engineering at DTU, we decided which of the materials was to be tested and for which toxic substances. We decided to test the painting from the facades and inner walls for any content of lead. Ebba Schnell herself tested the samples. For a detailed description of the approach, see appendix 4.

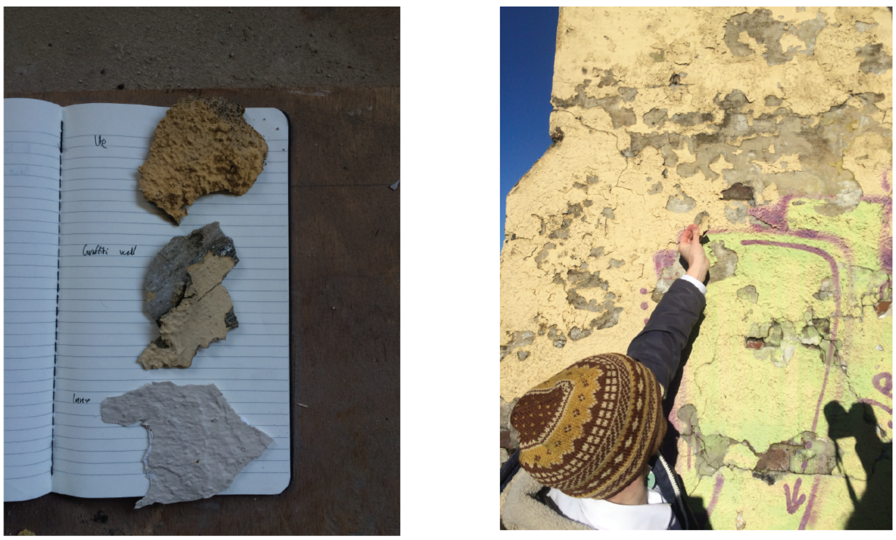

Figure 23: Paint samples taken at the site

Life Cycle Assessment of Union Canning

The section describing the environmental assessment of the Union Canning starts with describing the material flows and which life cycle phases are included in the assessment. Following there will be a description of the four main analysis made, consisting of:

- LCA of the Union Canning refurbishment using LCAbyg
- Lifespan of a refurbished building
- New development VS refurbishment
- Comparison with the Union Canning - No re-use

Flow of materials
The materials in this project can be categorized in three groups:

- Materials in the existing building which are to be re-used in the new design proposal for the renovation project
- Materials brought in to fulfill the design proposal. Representing the material flow in.
- Materials to be uninstalled and disposed of. Representing the material flow out.

From the "Results from the final design of the Union Canning" the amount of materials in the outgoing and inwards-going flow is assessed.
The existing building parts that will be directly reused in the renovation will not be included in the life cycle assessment. After a life span of over 100 years the materials embodied energy has been reduced to zero, as mentioned in section "Theoretical Background".

Presentation of Results
Under the section "Results and Analysis" the material flow in the renovation project will be illustrated. The exact amount of materials going in and out of the building will also be described. These amounts represent the material quantities applied in the life cycle assessment.

Life cycle phases included in the assessment of Union Canning

A significant feature with the LCA calculation in this project is that it is chosen to only account for a selection of phases in a buildings life cycle. The delimitations of the LCA in this project is based on the life cycle phases included in LCAbyg. These are also the delimitations generally used in both the DGNB International Scheme and in other similar scientific studies[25].

Table 1: Life cycle phases and processes in a building's LCA defined after the CEN/TC 350-standards. Processes included in this project is highlighted in bold text.

Life Cycle Stages	
Product stage	**A1 Raw material supply**
	A2 Transport to manufacturing
	A3 Manufacturing of material
Construction Process	A4 Transport to construction site
	A5 Installation
Use stage	B1 Use
	B2 Maintenance
	B3 Repair
	B4 Replacement
	B5 Refurbishment
	B6 Energy consumption in operation phase*
	B7 Water Consumption
End of Life	C1 Deconstruction demolition
	C2 Transport to waste processing
	C3 Waste processing
	C4 Disposal
Next product system	D Reuse, recovery, recycling

*Energy consumption will not be accounted for in LCAbyg but rather as a separate chapter of discussion

The delimitation of the project corresponds as a simplified version of a complete LCA of a building. A large proportion of the phases not taken in account in the LCA where not included as they are based on scenarios concerning high uncertainty, for example the reparation phase. This phase is based on a lot of different factors depending on user behavior, weather conditions at the building location, how one repairs, etc. In addition to the uncertainty entailing some of the scenarios connected to the phase, some of the phases are omitted due to the fact that they have a minor imprint on the overall environmental impact from a building assessed through an LCA, i.e. only by a few percentage. This applies especially to the transport processes, installation and construction of the building as well as the deconstruction demolition phase.

Environmental impact categories and indicators

As mentioned in the section "Theoretical Background", the DGNB system includes eight categories for environmental impacts and consumption of resources. As a delimitation and simplification of this LCA profile only three categories will be included;Primary energy consumption; global warming potential and degrading of the ozon layer. This decision is based on the report "LCA-profile of building parts - A catalog for use in early design process" made by SBI. In the report describes that there is a significant statistical ratio between most of the environmental impacts and recourse consumption. Therefor they conclude that a simplified LCA profile consisting of only three categories; Primary energy consumption; global warming potential and degrading of the ozon layer, is enough to represent the building parts total environmental impacts on a scientific justifiable level [19]. In this report the term GWP will be used for Global Warming Potential, ODP for Ozon Depletion Potential and PEtot for Primary energy consumption.

Table 2: Environmental impact categories and indicators

Category	**GWP**, Global Warming Potential
Unit	kg CO^2 equivalent
Problem	When the amount of green house gasses in the atmosphere rises, the temperature of the air layers close to the earth increases causing climate changes.
Category	**ODP**, Ozone Depletion Potential
Unit	R11 equivalent
Problem	Breakdown of the stratospheric ozone layer which protects flora and fauna from the dangerous UV-A and UV-B radiation from the sun.
Category	**PEtot**, Total Primary Energy Consumption
Unit	MJ og kWh
Problem	A large consumption of primary energy resources from renewable and non-renewable sources can contribute to scarcity of resources.

1. LCA of the Union Canning Refurbishment using LCAbyg

The software LCAbyg is used for assessing the environmental impacts caused by the refurbishment proposal throughout it's lifetime.
The existing building parts in LCAbyg has contributed in choosing the compositions of the building parts to be installed in the refurbishment proposal. This is to avoid the need to modify the existing building parts. It is assumed that the available building parts in LCAbyg meets the requirements expected of the different components. This implies i.a. U-value for building envelope including the windows, roofing and exterior wall. Some building parts have been modified to fit the composition of the building parts to be installed.

- The terrace implemented is made up of a combination of the roofing and flooring structure
- A steel girder was not included in the database. However a steel girder was found in an exterior wall. This exterior wall was therefore modified by removing all other building components other than the steel girder.
- The same tactic has been used for the steel wires which are to be installed. They have been stated in kg to correspond with the steel girder.
- The re-insulation was made of a modified interior wall to fit the composition of how a re-insulating wall is built up.

As the extent of LCAbyg's database of building components does not include the composition of the building parts which is existing in the Union Canning building, the components in LCAbyg has been modified to fit the required composition. Modifications made to fit the Union Canning's building parts is hereby listed:

- The share of glass in the three layered window is modified to correspond with the existing two layered windows to be uninstalled.
- The exterior brick wall is modified to correspond the solid brick wall in the Union Canning.
- The roofing structure has been modified to fit the existing roof in the Union Canning

The results provided in LCAbyg is exported to excel for further assessment of the results.
Presentation of results
All LCA results for the Union Canning refurbishment project under the section "Results and Analysis" will be presented graphically. This gives the reader an illustrative understanding of the impacts under the three impact categories; GWP, ODP and PEtot. The impacts will be shown sorted by life cycle phases, materials and building parts.

2. Lifespan of a refurbished building

When making a LCA calculation for a building it is very important that the buildings lifetime expectancy is realistic. If there is a habit of tearing down buildings before they have outlived their estimated lifetime, the LCA studies will have not illustrate a realistic picture of the actual environmental impacts they have had.

After a renovation of an existing building, it is recommended to use a building life expectancy of 50 years.[25]. This number is due to an assumption of that a building will undergo a larger renovation halfway through its estimated life span of 100 years. For our design proposal it can be discussed whether it could be realistic to predict a longer life time of 100 years as this is not just a renovation to improve the energy consumption but also an attempt in giving the building a new architectural expression. Therefore it could be discussed if one could consider the building to have an expected life time equal to a completely new building.

In the LCA calculation of the refurbished Union Canning there has been analyzed for two lifetime scenarios, 50 and 100 years. The alteration of this parameter may give two very different results. It is not only interesting to see if this alteration will give us a better result that building a new building but it will also give us an indication of how sensitive a LCA calculation of a building is to the assumed life time.

Presentation of results
The LCA results for the two lifetime scenarios for the Union Canning refurbishment project under the section "Results and Analysis" is presented graphically in three diagrams. The graphs will show the total impact from the different life cycle phases for each impact category. This presentation form is chosen to able an evaluation of which phases are influenced by the prolonged lifetime expectancy.

3. New developments VS Refurbishment

To assess the sustainability of the Union Canning refurbishment the LCA calculation is compared with a LCA calculation of an existing DGNB certified building. The new development is chosen as the building has approximately the same size as the Union Canning refurbishment proposal. To able the comparison the amount is given in environmental impact per m^2 per year. Both lifetime scenarios are stated for the Union Canning and the lifetime of the new development is set to 100 years. As the LCA for the new development categorized it's phases in production, replacement and end of life, the LCA results from the waste processing phase and the disposal phase has been joined for the Union Canning project.

Presentation of results
The LCA results for the three calculations; "Union Canning 50 years", "Union Canning 100 years" and the "DGNB certified development" will be presented under the section "Results and Analysis. The three diagrams represent the three different impact categories per m^2 per year, describing the total impact in the different phases.

4. Comparison With the Union Canning - No Re-use

To supply with a new dimension of the assessment, another comparison scenario is made. This scenario is based on the Union Canning refurbishment proposal but without re-using any materials. The materials that where not included in the original assessment (as they did not pose any embodied energy) have now been included. Understood that the re-used materials are uninstalled and demolished, and replaced by new materials. The existing steel girders and the foundation is replaced by the same material, while the brick wall is replaced by the wooden exterior wall which the new design proposal consists of. This decision is based on what is assessed to be the most realistic scenario.

This assessment is made to able the comparison of two different building strategies but assuring that the comparison has the same underlying assumptions.

Presentation of results
The LCA results gives an understanding of the impacts under the three impact categories; GWP, ODP and PEtot. Firstly the impacts are sorted by life cycle phases and materials. This gives the opportunity to compare with the results found under the section "LCA of the Union Canning Refurbishment - using LCAbyg". A diagram illustrating the impacts from the different metals is shown, for further assessment of the comparison. Three diagrams directly comparing the total impacts from the three impact categories for the two buildings will be illustrated.

The operative stage

An assessment of the Union Canning refurbishment proposal's operative stage has been performed by comparing the total allowed energy consumption in Denmark and in Norway. Furthermore, the electricity grid performance has been analyzed, by comparing the grid in Denmark with the grid in Norway. In the program, Quantis Suite, it is possible to find the indicators performance degree of the electricity resources for a load per 1 kWh, set in perspective with the individual country. In Quantis Suite is shown five indicators, which are; Human health, Ecosystem quality, Climate change, Resource and water withdrawal. However, we are only taking Climate Change (GWP) and Reources (PEtot) into consideration, because these are the indicators we have been working with through this thesis. In addition to this there will be made a comparison between Union Canning (Norway) and a new development (Denmark).

Methodological Approach of the Warehouse

Method

As mentioned in section "Case-study Background", Helen & Hard has the idea to turning the warehouse into a car park for the site "Vindmøllebakken". The car park is to be used by the inhabitants of the communes established on the site. Consequently, there has been set up a description of how the renovation process of the warehouse could be handled.

If the the warehouse will not turn into a car park, other opportunities a parking area on the site have to be investigated. Therefore, alternative solutions parking solutions have been provided.

However, if the preferred parking solution as indicated by H&H in the sense of reusing the warehouse seem suitable, it is presumed that this solution will accomplishes some environmental benefits. With the perspective of the life cycle of the warehouse, there has been made an assessment of the environmental benefits in reusing, by reflecting on each stage of the life cycle process.

Lastly there will be a discussion of the method used in assessing the sustainability of the scenarios for the warehouse.

Delimitation

There will not be made a thorough LCA calculation, with LCAbyg as a tool, of the design proposal of the warehouse. This decision is based on the lack of a realistic frame of reference to compare with. In order to make a realistic comparison of two LCA calculations, the building which we compare our design proposal with needs to be a realistic estimation of how a multi story parking lot will look like. This is difficult to predict, however it is certain to presume that a new car park will not be built using the same methods and materials as the existing warehouse to be converted into a parking house.

Presentation of results

Because of the delimitations presumed, there will not be made any LCA calculation, and therefore not be any results for the warehouse. Instead, a discussion of the potential environmental benefits, as mentioned earlier, will frame the beneficial of reuse.

Results and Analysis

Quantification of Materials

Below is shown tables containing the results of the measurement of materials the different areas contains, and furthermore a table with the totals for the whole site.

Union Canning

As seen in table 3 below, bricks are the material that represent the biggest part of volume in the building and the material that weighs the most. Concrete is the material with the second largest volume and wood with the third largest volume. The volume of wood and concrete are not far from being the same. However, concretes weight is around four times larger. This is because of concretes density, which is 2400 kg/m^3, whereas woods density is 650 kg/m^3.

Table 3: Measurement results of materials - Union Canning

Material	Volume [m^3]	Weight[kg]
Steel	2	14.887
Wood	55	35.567
Wooden Fibre	15	12.258
Roof tile		9.645
Concrete	60	144.467
Reinforcement steel	1	9.645
Brick	217	389.910
Mortar	51	106704

Warehouse

It is seen in table 4 that concrete is the material, which represents the biggest amount of the volume. However, the weight of reinforcement steel is just as big as the weight of concrete, even though the volume is around 3 times smaller. The density of steel is 7.850kg/m^3, while the density of concrete is 2.400 kg/m^3, which is the reason for the weight evening up.

Table 4: Measurement results of materials - Warehouse

Material	Volume [m^3]	Weight [kg]
Concrete	575	1.380.945
Reinforcement steel	174	1.369.245
Light Concrete	43	34.404
Steel	2	16.756
Mineral Wool	142	22.849
Wood Fiber	4	2.709
Asphalted felt	3	3.311

Total

Below in table 5 it is seen the results from the quantification of both Union Canning and the warehouse/whole site. Concrete amounts the biggest part of the total results, both in volume and in weight. This is because of the significant amount of concrete in the warehouse and the outside areas walls.

Table 5: The total result of measurement of materials

Material	Volume [m^3]	Weight [kg]
Concrete	636	1.525.413
Reinforcement steel	176	1.378.890
Light concrete	43	24.405
Wood	55	35.567
Brick	217	389.910
Mortar	51	106.704
Steel	4	31.643
Asphalted felt	3	3.311
Wood fibre	19	14.967
Roof tile		9645
Mineral wool	143	22.850

Union Canning

Final design

The design proposal is a result of different ambitions and restrictions following these ambitions. As we thrived towards reusing and preserving as much of the existing structure, there were many restrictions in our design development. Our flooring area is a result of the existing structural beams carrying the floor in the factories, while simultaneously trying to achieve the desired architectural expression of the mountain coming out of the concrete.

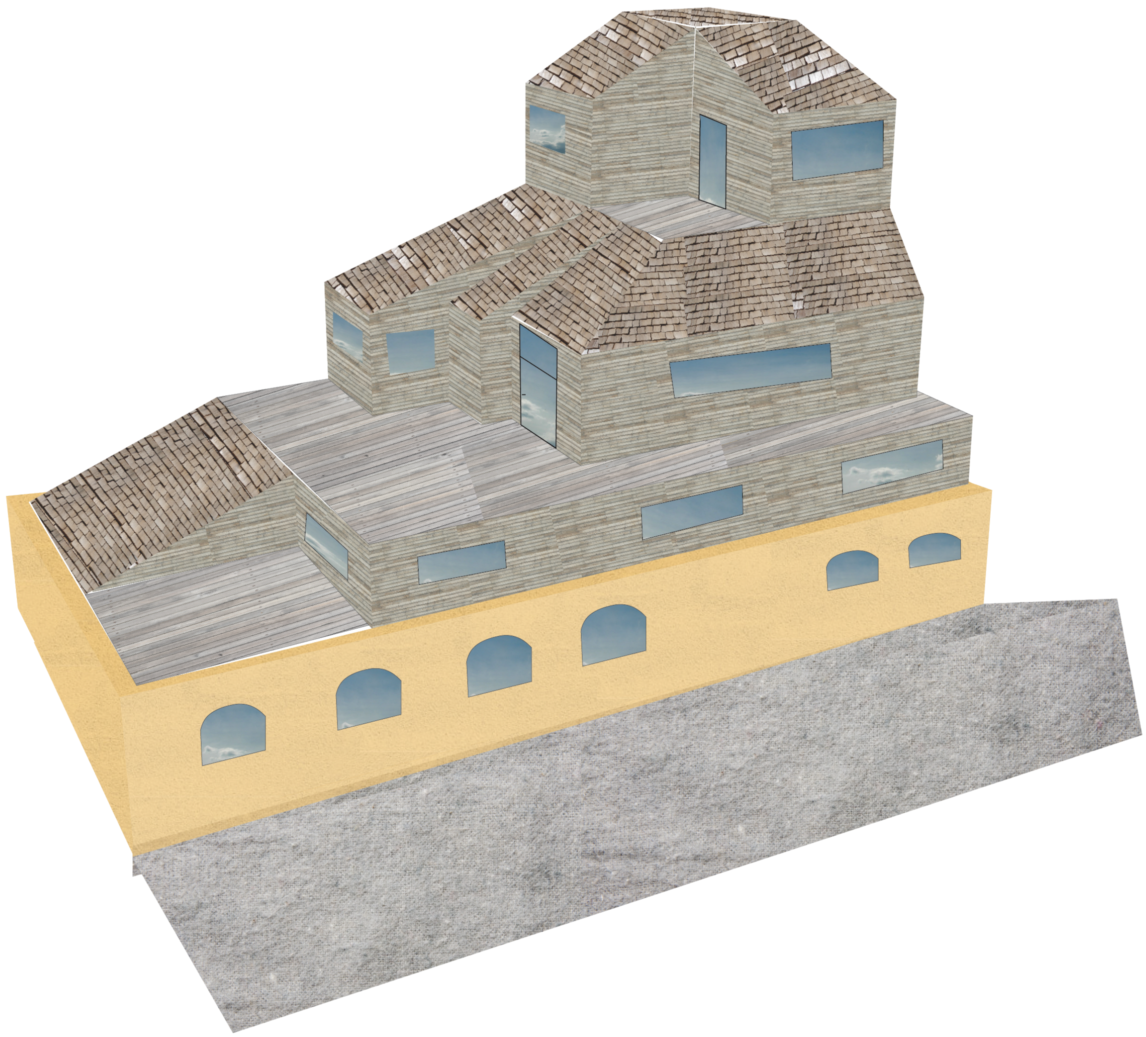

Figure 24: Conceptual illustration of the Union Canning refurbishment proposal

For design proposal to be fulfilled the following amounts of building parts is needed:

Table 6: Amount of building parts resulting in the design proposal

Building Element	Amount	Unit
Re-insulation	213	m^2
Exterior Wall	332	m^2
Flooring Structure	135	m^2
Roof	123	m^2
Roof Terrace	115	m^2
Windows	37	m^2
Doors	6	m^2
Steel Girders	9.331	kg
Steel Wires	251	kg

Recycling potential of materials

As mentioned in the section method for testing of materials, the tests include the painting from the inner walls and facades with and without graffiti. In table 7 is seen three tests made on every sample. This is done to insure the correctness in the results. The results shows that the painting on the graffiti painting contained the most lead, which was around 70 mg/kg, whereas the other two samples contained around 15 mg/kg lead.

Painting is characterized as dangerous, if the lead content is over 2500 mg/kg[16]. From this we can conclude that the samples from Union Canning are fare from dangerous.

Table 7: Measurement of lead painting

Tests	mg/kg Pb
Painting from facade with graffiti a	75
Painting from facade with graffiti b	71
Painting from facade with graffiti c	64
Painting from inner walls a	16
Painting from inner walls b	20
Painting from inner walls c	16
Painting from facade without graffiti a	16
Painting from facade without graffiti b	14
Painting from facade without graffiti c	15

Flow of Materials

The material flows seen in figure 25 represent the primary materials going in and out of the renovation project. Materials going in are the new building parts to be installed in the new design proposal, whilst materials going out are the existing buildings parts that are not to be used in the project.

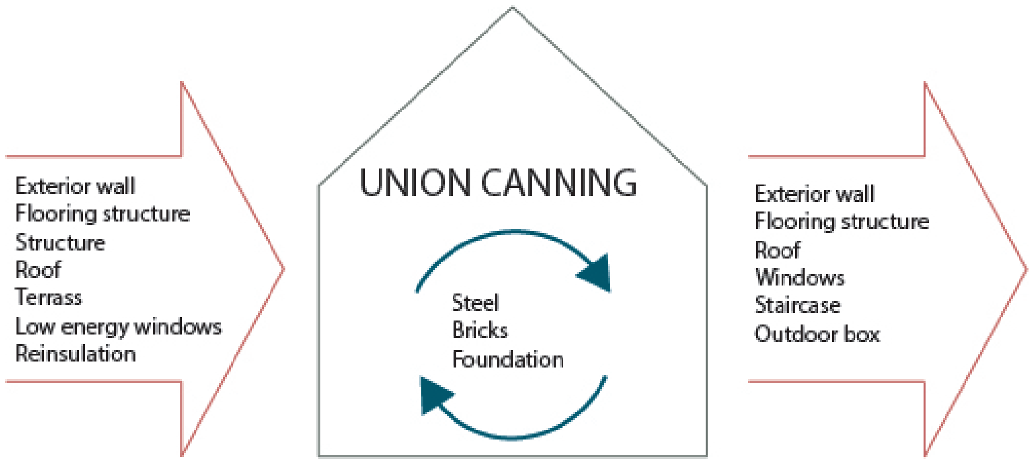

Figure 25: Screening of primary material flow in and out of the renovation project

Figures 26 and 27 gives an indication of how much materials are going in and out of the Union Canning renovation project. The quantity of materials uninstalled and disposed corresponds to approximately 376 kg pr m^2 floor area whilst produced and installed materials corresponds to approximately 128 kg pr m^2. This discrepancy is due to the uninstalled building parts where a part of a heavy construction, whilst the new design imposes a more light weight construction.

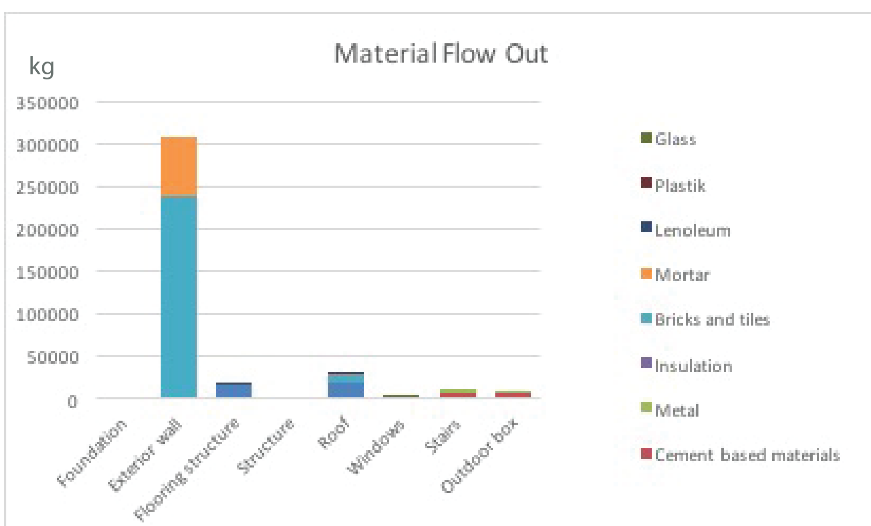

Figure 26: Material flow of the Union Canning refurbishment devided in building parts

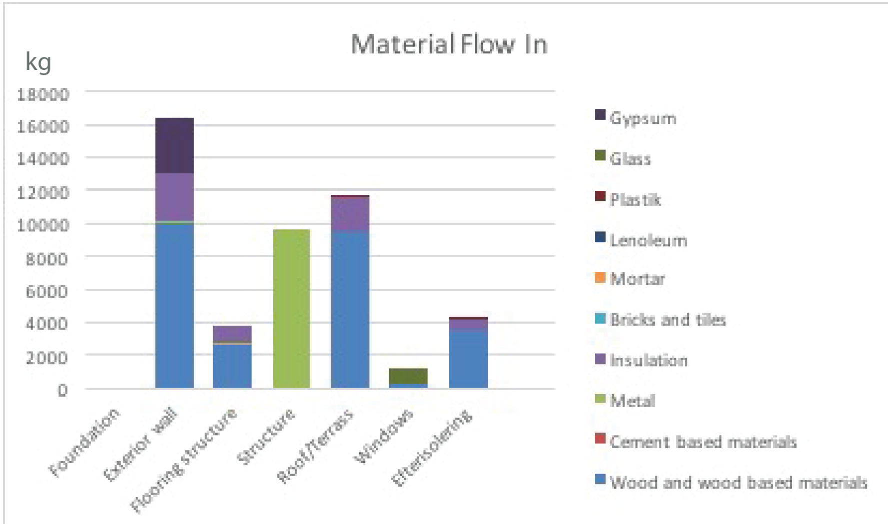

Figure 27: Material flow of the Union Canning refurbishment devided in building parts

Figure 26 shows that the amount of exterior wall to be disposed of, accounts for a large quantity of the total amount of uninstalled materials. In figure 27 it is seen that also it is the exterior wall that accounts for the largest proportion, however the leap down to the other categories is not as drastic. Again this is a result of the exterior wall uninstalled where components in a heavy weight construction.

1. LCA of the Union Canning refurbishment

Figure 28 shows the distribution of impacts from the different life cycle stages in the three impact categories. It is calculated over a period of 50 years, representing the amount of years the renovation will prolong the lifespan of the building. From the figure it is evident that the GWP differentiates itself from the other two impact categories. In GWP it is the life cycle phase; Waste processing, which defines the largest proportion. Whilst in the categories ODP and PEtot the division of impacts from the phases are almost identical. The production phase significantly represents the largest share in impact, replacement comes after, contributing approximately 1/5 of the total impact.

In figure 28 it is seen that the production phase has a minimal impact on the GWP category. The production phase in this LCA implies only the "Flow in" materials, as the production phase for the materials that are uninstalled does not belong in this LCA system but to the old Union Canning. Wood and wooden based materials represent a significant amount of the materials going in the renovation. This is probably an explanation to why the production phase under GWP is so minor. Due to the absorption of CO^2 during the photosynthesis and CO^2 storage in the wooden masses, wood has a positive effect on the environment. This environmental benefit from wood affects the results in the GWP category in a negative way, reducing the total amount of CO^2 emissions contributed by the production phase[18]. These results are consequences of the underlying deliminations found in the Ökobau 2013 database. It is difficult to make a profound evaluating of the extent of these delimitations as the Ökobau system is very "black boxed", the information is not accessible for the users. It can be concluded that wood has a large affect on production phase. There is much discussion to whether this contribution is justifiable. Being a material that absorbs CO^2 during it's production phase is very "impressive" from a LCA point of view, however when the material is cut down and used, this positive contribution to the environment ceases to exist and potential absorption of CO^2 is lost.

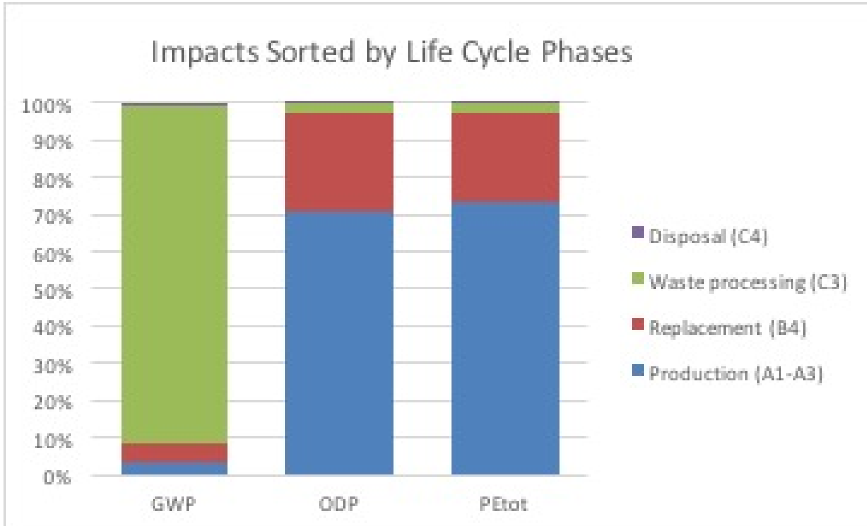

Figure 28: LCA results of Union Canning renovation. Contribution to the total result divided by the various life cycle phases.

Figure 29 shows the division of the impacts from the different material groups in the three impact categories. Again, the impacts are calculated over a period of 50 years. From the figure it is evident that wood and wooden based materials and metals represent the two material groups contributing the most in all categories. Wood and wooden based materials contribute a minimum of 60% in both GWP and PEtot and over 40% of the total ODP. The material group metals contribute upto 25% in both GWP and PEtot and almost 45% of total contribution to ODP.

That the material group wood can contribute with a large amount of the total GWP in spite of woods negative affect on the production phase, indicates that the impacts from wood caused by the remaining phases are relatively large. As waste processing accounts for large section of the total GWP (as seen in figure 29), it points to that waste processing of wood has a great impact on the GWP. This is caused by the the CO^2 emissions emerging in connection with incineration of wood.

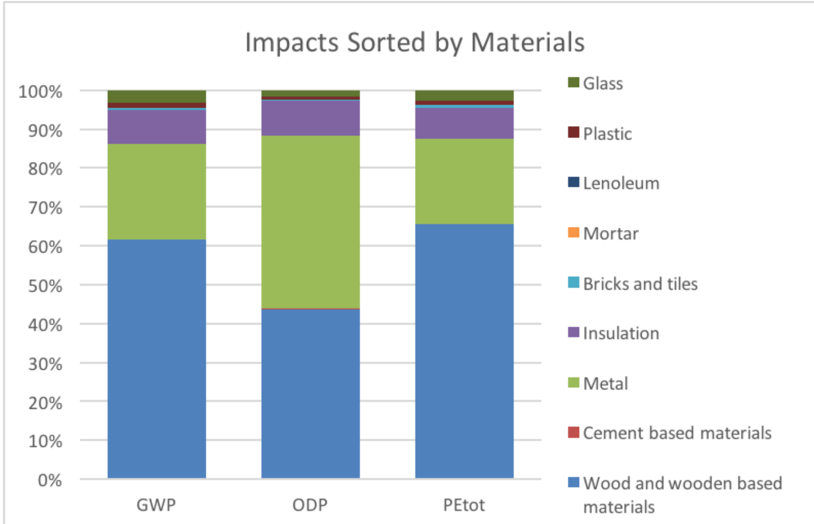

Figure 29: LCA results of the Union Canning renovation. Contribution to the total result devided by the materials.

Figure 30 describes the distribution of impact emerging from the different building parts in the three different impact categories over a period of 50 years. It is seen that there is a consistency in the contribution for the structure throughout the three categories. Contributing almost 35% in GWP, over 40% to ODP and almost 30% to PEtot. The flooring structure contributes approximately with 40% of the GWP.

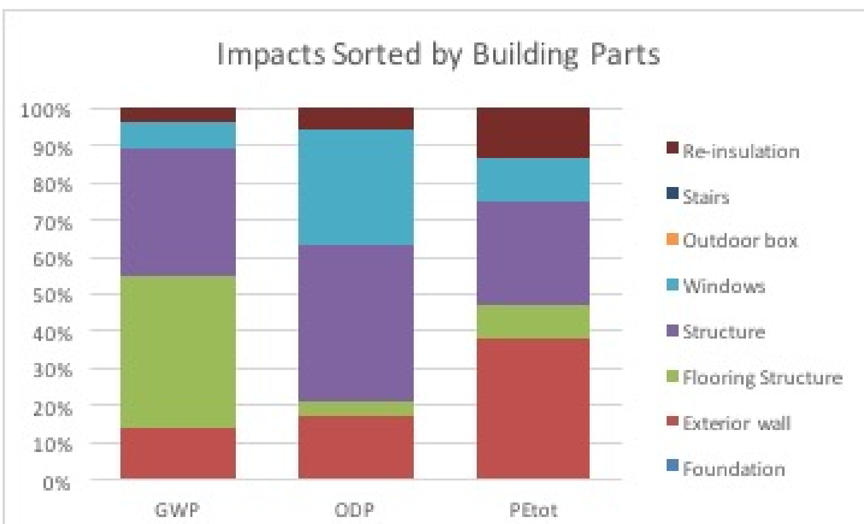

Figure 30: LCA results of Union Canning renovation. Contribution to the total result devided by the various buildingparts.

2. Lifespan of a refurbished building

The three following figures, figures 31, 32 and 33 each describe the impacts from the life cycle phases for the two lifetime scenarios, under the three different impact categories.This helps to get an impression of how the parameter of life expectancy can manipulate the results. The results show that in all impact categories the production phase, waste processing phase and the disposal phase is reduced by half. This is coherent with that the results are in impact per year, and by doubling the life expectancy, the results are reduced by half. However the life cycle phase: replacement does not represent similar results. For all impact categories the impact from this phase increases for a longer life expectancy. This is due to that when a buildings life time is prolonged the building parts and materials demand more replacement, therefor a larger impact per year.

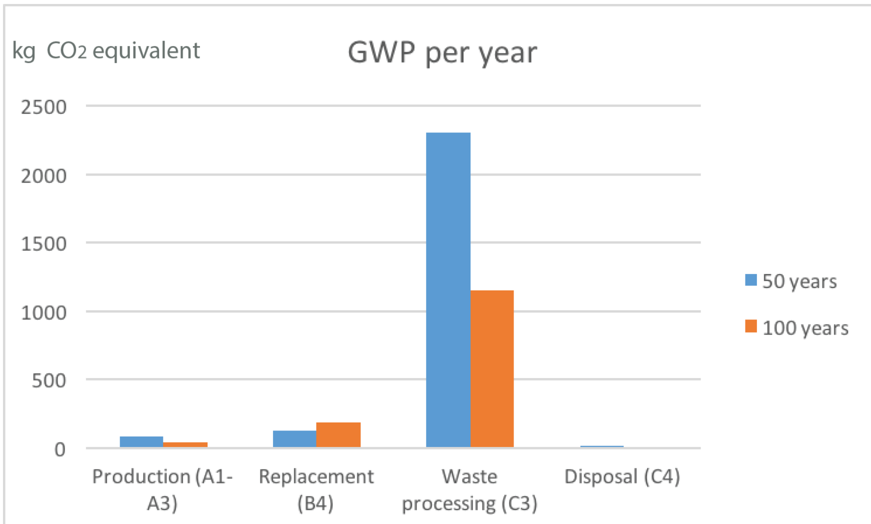

Figure 31: Lifespan of 50 vs 100 years GWP

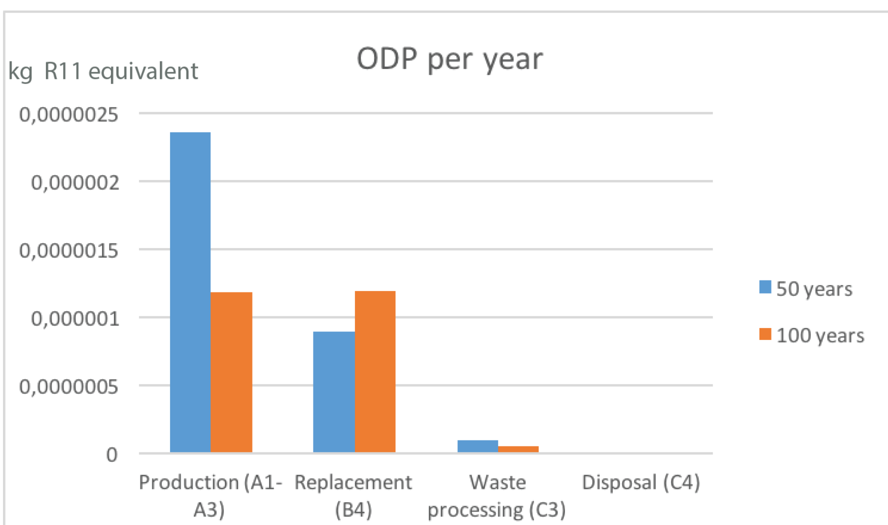

Figure 32: Lifespan of 50 vs 100 years OPD

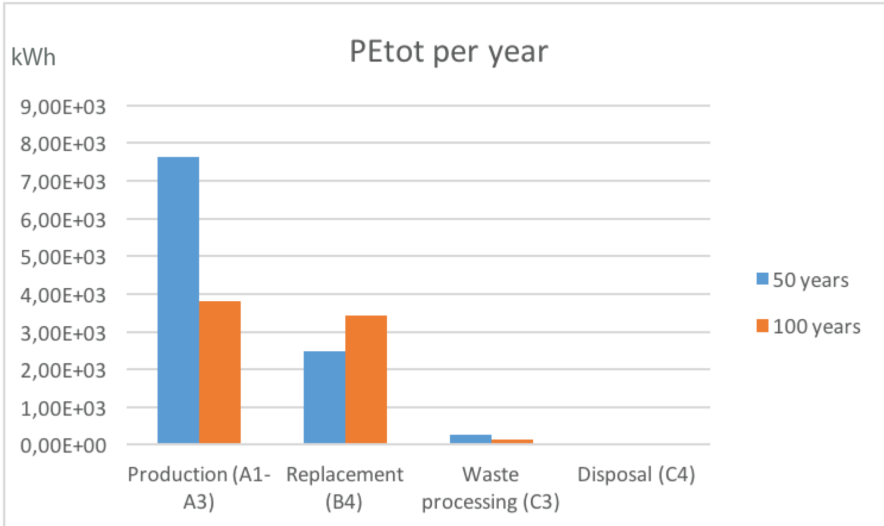

Figure 33: Lifespan of 50 vs 100 years PEtot

3. New Development VS Refurbishment

Figures 34, 35 and 36 shows the the impact category per m^2 per year for the three buildings, now sorted by three life cycle phases. The comparison shows that the production and replacement phase for the Union Canning refurbishment have a lower environmental impact than for the new development in all impact categories. Especially for the impact category GWP there is a distinguished difference in the production phase.

Consistent through the three environmental impact categories, it is seen that the results for the EOL phase for the new development is negative. This indicates that the LCA for the new development has some different underlying assumptions and scenarios in the EOL phase than for the LCA made for the Union Canning building. If the energy arising during incineration of waste is exploited, this can lead to a positive contribution for the environmental impacts, explaining the negative values in the EOL phase. The energy arising during the waste processing is this case weighed up against the amount of environmental impact which would be caused by producing the same amount of energy through on renewable energy.

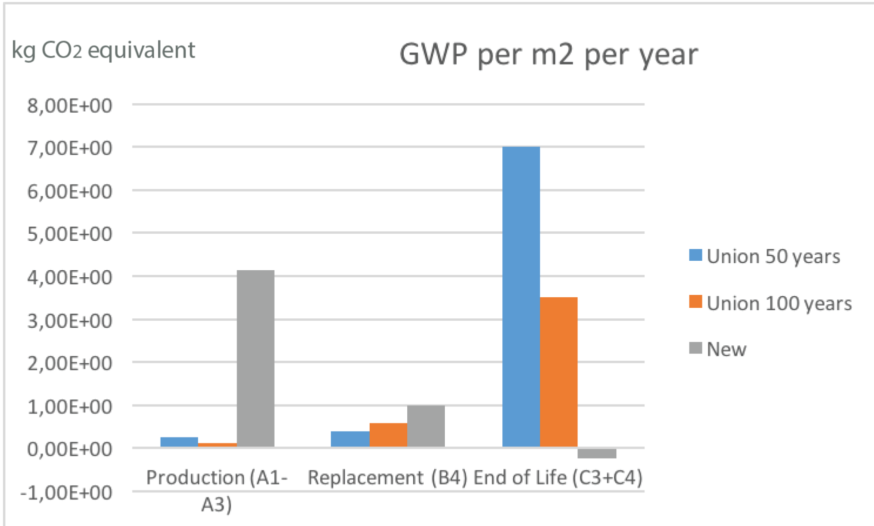

Figure 34: LCA of refurbished Union Canning with life expectancy of 50 and 100 years and LCA of a new DGNB certified development

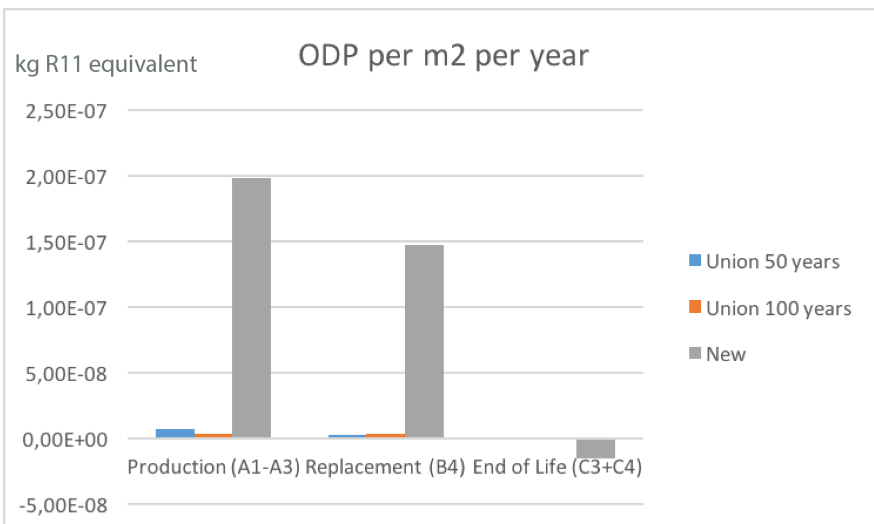

Figure 35: LCA of refurbished Union Canning with life expectancy of 50 and 100 years and LCA of a new DGNB certified development

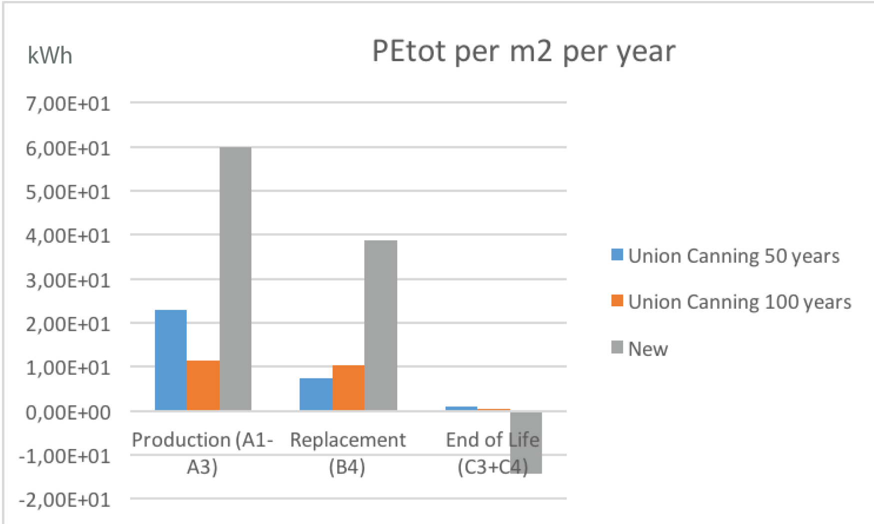

Figure 36: LCA of refurbished Union Canning with life expectancy of 50 and 100 years and LCA of a new DGNB certified development

4. Comparison with the Union Canning - no re-use

Figure 37 shows the distribution of impacts from the different life cycle stages in the three impact categories, calculated over a period of 100 years. It is noticed that compared with the results in figure 28 under section "LCA of the Union Canning refurbishment", the production phase under GWP accounts for a larger section of the total impact. This is not due to a reduction of the waste processing phase, as this has also risen, due to an increase of materials to be uninstalled and to be disposed of.

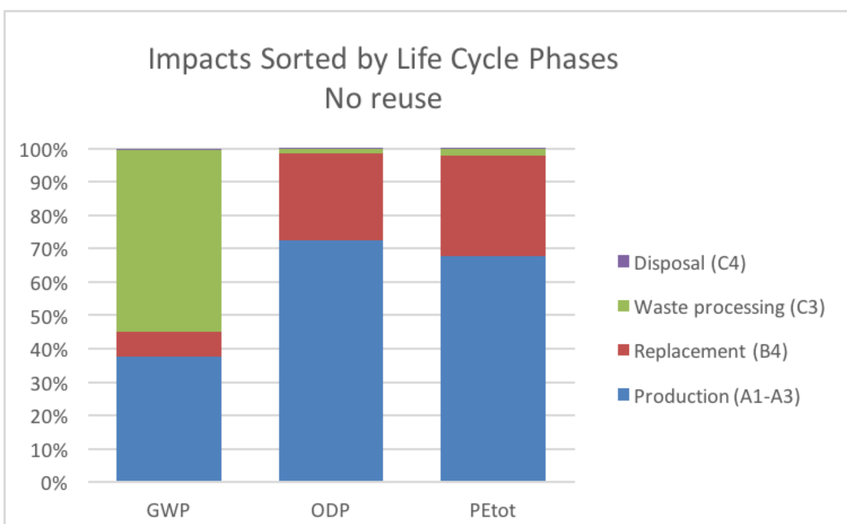

Figure 37: Environmental impacts divided by phases for the Union Canning with no reuse

Figure 38 shows the division of the impacts from the different material groups in the three impact categories. Compared to figure 29 it is seen that now metal accounts for the largest section of impact, while in the refurbishment proposal it was wood and wooden based material.

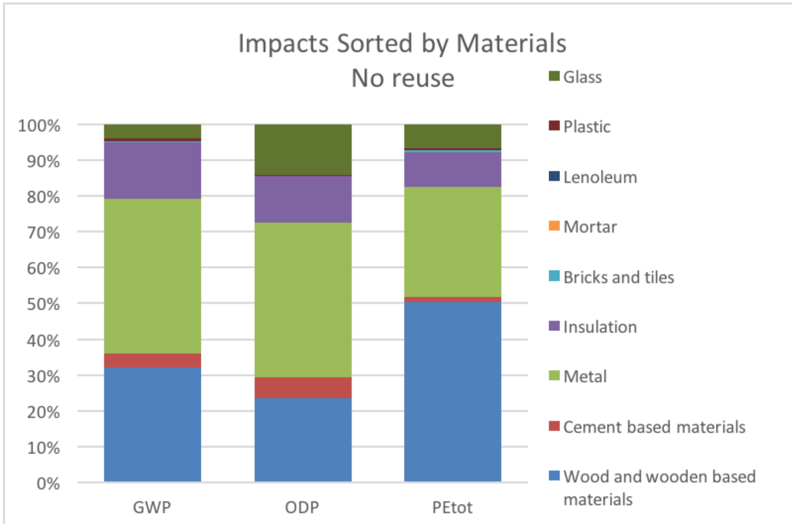

Figure 38: Environmental impacts divided by materials for the Union Canning with no re-use

As an interesting follow-up from the previous figure, figure 39 illustrates which metal group is responsible for the total impact contributed by metals. It is seen that in all impact categories the structural steel accounts for the majority of the total impact from the metal materials.

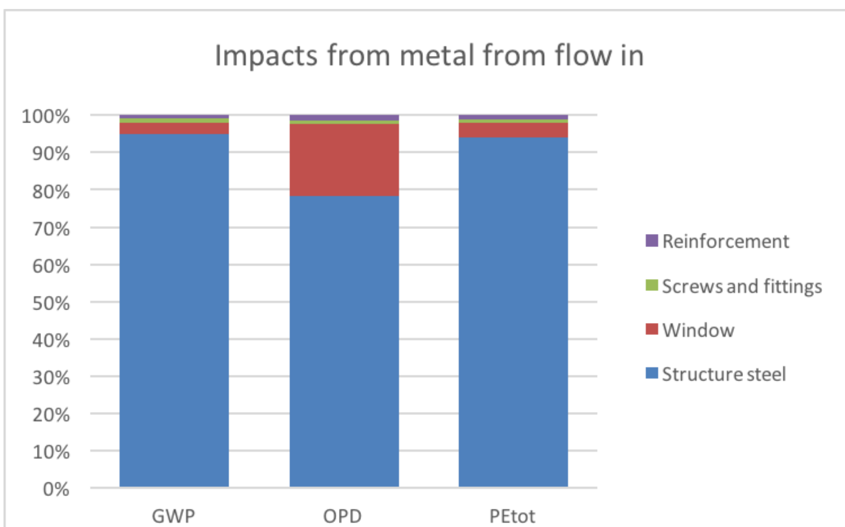

Figure 39: Impacts from different metals

The following the diagrams represent a direct comparison of the two buildings. The refurbished Union Canning is set to have an expected lifespan of 50 years, while the Union Canning No Re-use is expected to have a lifespan of 100 years. The diagrams clearly indicate the effect of re-using the existing materials. The risen production phase under GWP seen in figure 37 contributes to doubling the total GWP impact seen in figure 40. In the three diagrams it is seen that the total impacts resulting the no re-use strategy doubles the total impacts. This is a result of increased amount of waste to be processed and disposed and increased amount of materials to be produced.

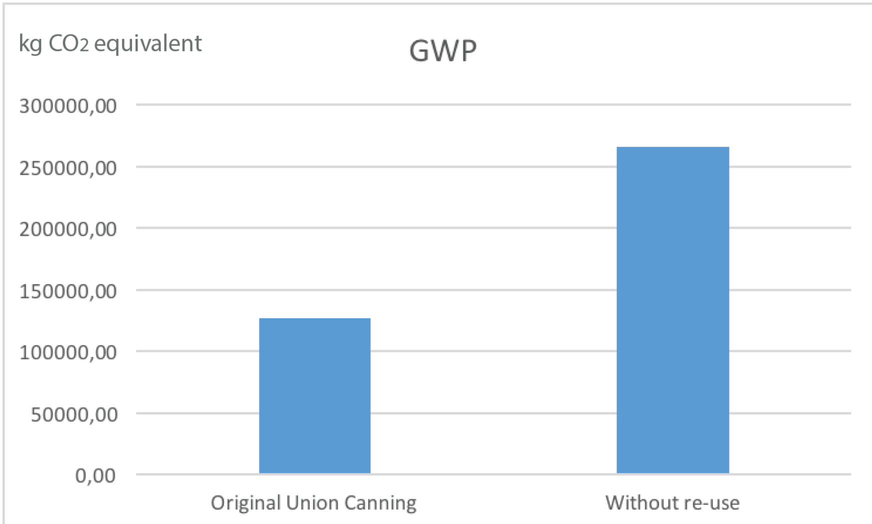

Figure 40: GWP for the refurbished Union Canning and Union Canning No Re-use

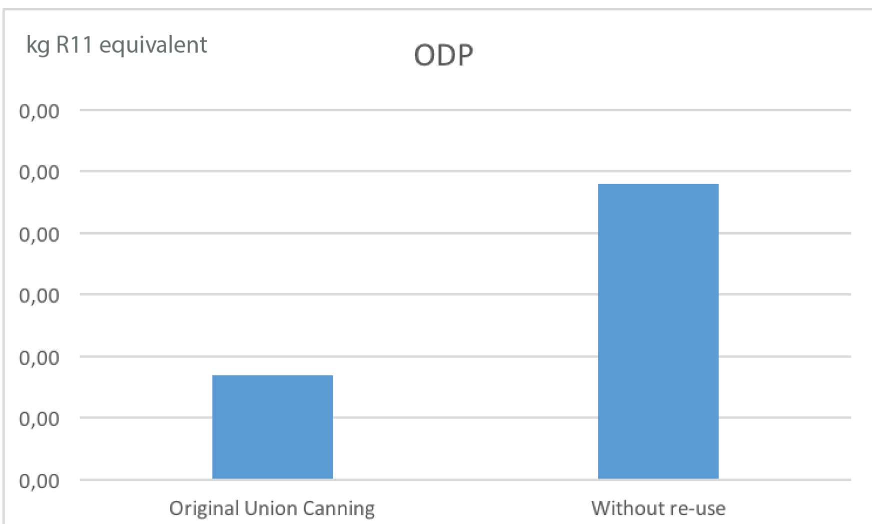

Figure 41: ODP for the refurbished Union Canning and Union Canning No Re-use

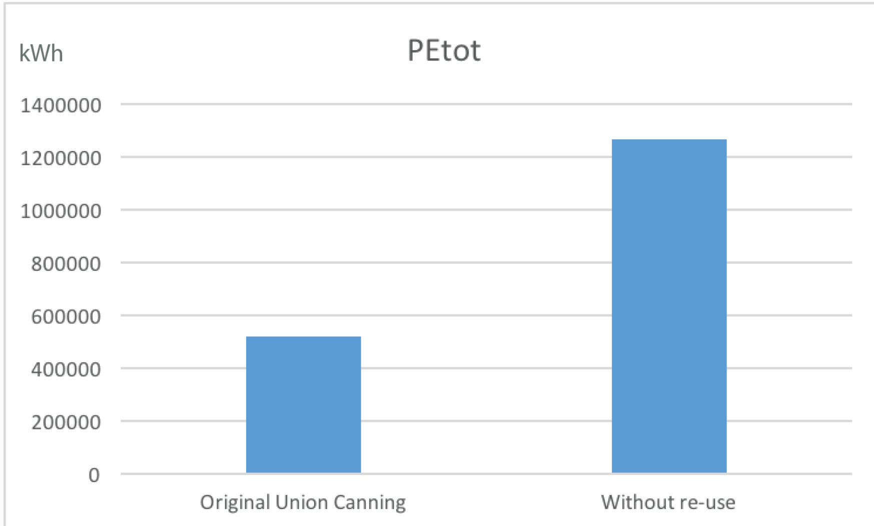

Figure 42: PEtot for the refurbished Union Canning and Union Canning No Re-use

The operative stage

The buildings total energy demand may not exceed 115 kWh/m^2 in Norway and 41kWh/m^2 + 1000/A, where A is the heated floor area, in Denmark. This means that the Union Canning's energy performance may not surpass 41.975 kWh/y. under the Norwegian conditions, and 15.950 kWh/y. under the Danish conditions. This signifies that the Union Canning refurbishment proposal is allowed to have a 2.5 times larger energy consumption in Norway than in Denmark.

Table 8: Environmental impact per 1 kWh

	GWP [kg CO_2]	**PEtot [MJ]**
Norway	0,0325	0,972
Denmark	0,562	7,95

It appears from table 8, that the GWP and PEtot values for Norway are remarkably lower than the values for Denmark. This is because of the electricity grid in Norway is significantly greener than the electricity grid in Denmark. In Norway, hydropower accounts for 95,3% of the country's total power production, while in Denmark the electricity is primarily produced through coal power. The high production of hydropower is achievable due to the given natural landscape in Norway containing the right conditions for exploiting hydropower.

Table 9: Environmental impact per m^2

	GWP [kg CO_2 eq./m^2]	PEtot[MJ/m^2]
Union Canning refurbishment (Norway)	1,33	111,78
New development (Denmark)	7,56	120,24

In table 9 is seen the indicator for the performances of Union Canning refurbishment (Norway) and the new development (Denmark). As expected, the values of the Union Canning refurbishment is remarkably lower than the new development. The reasons are as above based on Norway's sustainable power production.

Discussion

Quantification of Materials

The registration of the site was performed in the very early stage of the bachelor project. At that point the thesis had not taken it's fully shape, and the subject was still under consideration. There was still questions to be answered and topics to be discussed, before being able to set the correct direction and to provide the most interesting portions of the project.

If another trip to the site in Stavanger had been made other and more usable registration would probably have been made. Not because the existing registrations was not usable, but knowing the specific purpose of the project, and after having gained more knowledge, the registration phase would have been set up with more specific desires. However, from already knowing the site inside and out from the first visit, a second visit would have been much more manageable and a new quantification would have been proceeded quicker and more efficiently. If another visit was possible more measurements and gathering of more samples would have been made. However, a lack of a second visit has not blocked the progress of the project and we considered that the project could still fulfill its objective. In cases when we realized that we have missed important data from the site our Helen & Hard contact person, Håkon M. Solheim, was very helpful by gathering the missing measures.

As mentioned in the section "Methodological Approach of Quantification of Materials the approach for gathering measurements has been manual noting and measuring on the site and from given plan drawings of the site.

The given plan drawings of the warehouse, were the original from the building's construction in the 80's, made by educated engineers, whereas the given plan drawings of the Union Canning building were drawn and estimated by students working with Union Canning in an project some years ago. The big gab between the construction of Union Canning and these drawings and because of less sophisticated technology used by students the drawings are subject to uncertainties. Examples of such uncertainties could include materials in the constructions and measurements of the building elements. Consequently, the drawings of the warehouse is found more reliable than the drawings of the Union Canning. The plan drawings for the two buildings are attached in appendix 3.

Just as stated above the drawings made by earlier DTU students may be slightly less reliable the same apply to our measurements. However, because the purpose of the quantification was to get an outline of materials and not the exact values, these estimations are considered acceptable.

Union Canning

Design

During the design process it was necessary to seek advisement and counseling several times. It was particularly needed for assessing the structural composition of the design proposal. As mentioned earlier it is very important in creating a realistic proposal as this may have great effect on the results given through the environmental assessment.

Recycling potential of materials

In order to conclude whether the materials are suitable for recycle the samples should have been tested for other toxic substances, however, for this thesis we have limited the test to lead due to time and access to technical facilities. Before drawing the final conclusion other test have to be performed as well.

Furthermore, an assessment of the uncertainty related to the test has to be performed. This include an assessment of whether the samples have been picked from representative spots and whether the number of samples are sufficient, as it is important that a wrong conclusion is not made, i.e. materials that disqualify are approved for recycling or materials that qualify are not approved for recycling.

Flow of materials

When quantifying the amount of outgoing elements there is a consistent source of error, as it is difficult to know in advanced exactly what the composition of the building parts consist of, both materials and proportion. However, these sources of errors will presumably not inflict the overall assessment of the building, as they do not represent large section of the quantification.

Life cycle phases included in the assessment of the Union Canning

In the LCA of the Union Canning all phases where not included. Only including certain life cycle phases in the assessment may result in getting an impact calculation that does not represent the actual impact from the building. The deselection of certain phases was due to either uncertainty regarding the scenarios or that the phase simply did not contribute any significant impacts or benefits to the overall assessment.

Environmental impact categories and indicators

The decision to only include the three chosen environmental impact categories of the eight included in the DGNB system, was based on the argumentations given in SBI's report "LCA-profile of building parts - A catalog for use in the early design process"[19]. The report arguments that including the three impact categories ensures a simplified understanding of the total environmental impacts for the object assessed. However, as the DGNB system has chosen eight impact categories which they consider to be relevant for an assessment, it can be questioned which consequences the delimitation to three categories have. There may be some categories which are not represented in the chosen impact categories. If there is a case where one category drastically fluctuates compared to the others, there is no possibilities to precept this fluctuation.

However the decision to only include three impact categories enables the possibility make a simplified assessment that is easy to comprehend. This is a huge advantage seeing that the results from the assessment is to help designers and architects in making sustainable design choices.

1. LCA of the Union Canning refurbishment using LCAbyg

When entering the building parts into LCAbyg many modifications was made to the existing building components available in the database. It is difficult to assess whether the software can handle these modifications. As an example, there was made a manipulation of an exterior wall which originally is stated in m^2, to fit the needs of a steel girder, which then was stated in kg per m. It is entrusted that LCAbyg can handle these manipulations as there is no indication stating otherwise, however it is not possible to be sure of this, as there is no information about the software programs limitations in use.

2. Lifespan of a refurbished building

Buildings are often refurbished to become more energy efficient. When a building undergoes this process it is accounted that the remaining life expectancy is 50 years. If the reason for refurbishment of a building is not only for energy optimization, but also as an attempt on giving the building an architectural renovation, it can be discussed whether the building's remaining life expectancy can be increased. If an architectural renovation is successful and causes the building to prolong its lifespan, the total environmental impact per year is reduced considerably. However, it is difficult to assess if it is in fact necessary to conduct the architectural renovation. If an architectural renovated building has a longer life span than the 50 years expected of a typical renovation, it is not necessarily because of the architectural renovation. Maybe a typical renovation would also have lead to a longer lifespan than 50 years.

3. New developments VS refurbishment

In the comparison of the two LCA calculations for the two buildings, it was noticed that in the impact category GWP, there was a distinguished difference in the production phase. This indicates that the Union Canning building has a lower environmental impact in its production phase. This may be a result of Union Canning producing less materials due to the re-used elements, but is most likely a result of different building methods. If the exterior wall used in the new development does not have a production phase that approximately correspond to the wall installed in the Union Canning, it is difficult to assess to what extent the material efficiency strategy of re-use is contributing to the Union Canning.

Unfortunately the LCA provided of the DGNB certified building did not provide the results divided by materials. This would give the opportunity to get an indication of the building type.

It is safe to assume that there are some different scenarios underlying in the different life cycle phases. This is clearly seen as the new development only has negative values for the EOL phase. However, it is difficult to draw a clear picture of the other possible distinctions between the two assessments.

An interesting aspect of the sustainable discussion in the comparison of the new development and the refurbished building lies in the system boundary. Meaning which life cycle phases is included in the life cycle assessment. In the assessment of the Union Canning the life cycle phase C1, "Deconstruction demolition" is not included due to limitations in LCAbyg. If this is not included as it is based on scenarios entailing high uncertainty or because it accounts for a minimal percentage of the total environmental impact is uncertain due to lack of information about LCAbyg's assumptions. However, as this stage is not included it is not possible to specify the demolition method used.

If a new development was to be built on the ground of which the Union Canning stands on today, it would be necessary to demolish and remove the existing building, leading to waste processing and disposal of the building parts. This process does not form a part of the new development's LCA calculation, as it does not belong within the system boundary. However, for the refurbishment proposal, the building parts which are uninstalled and does not form a part in the new design, their EOL processes are included in the LCA. This can be seen as an unfair comparison, as the uprising of the new development, would require waste processing and disposal of more materials than for the refurbishment proposal. The demolition process of the building parts in the Union Canning for the refurbishment and for the new development will probably be conducted with different methods. But as mentioned, the demolition stage is not included in the LCA, so this indifference can not be accounted for.

4. Comparison with the Union Canning - No re-use

As an attempt to assess some of the unfair comparison conditions in the system boundary of a renovation project and a new development, a LCA of the Union Canning design proposal was made with no re-use of the existing materials. This assessment gives an indication of what effect our design strategy of re-using the materials had on the environmental impacts.

It is chosen to illustrate the results of the assessment in three diagrams which each include all impact categories. This was done to able the comparison between the two Union Canning assessments, with and without re-use. This comparison strategy helps to give indication to what the different phases contribute in the different impact categories.

A direct comparison of the the two Union Canning building give a clear indication of how well the Union Canning refurbishment proposal distinguishes it self from the alternative with no re-use. However as the life cycle phase C1 is not included in the assessment, the comparison poses an unfair condition. This is the life cycle phase that does not correspond in the two assessments. A deconstruction demolition of the Union Canning refurbishment proposal demands a more careful demolition process where only parts of the building are to be dismantled. While the demolition of the No Re-use alternative does not demand this process.

The operative stage

It can be concluded that electricity grid in Norway is far more greener based on the results and analysis. This allows a larger energy use compared to the permitted energy consumption in Denmark. This makes it clear how great influence a green energy grid can have on the operative stage, and further how remarkable a difference there can be on producing 1 kWh depending on the country.

Warehouse

Re-use

As mentioned, in section “The Site”, the warehouse was built in the 80’s, which makes the building around 30-40 years old. This means that the building has not lived its fully potentials yet. It is normally said that a building has a service life of around 100 years, which sums up that the warehouse still has a potential of 60-70 years of further use. So instead of demolishing the whole warehouse and building something new, has there been worked on ideas of how to reuse at least parts of the building, so the materials will not be wasted taken in consideration its potential of further service life.

Reusing opportunities for the warehouse is to use it for a car park. When turning the warehouse into a car park the requirements for the indoor environment is less compared other use for other purposes such as office or . The warehouse is not insulated, and this a good reason to use it for parking. However it is not Helen & Hards intention to keep the whole warehouse. It is the plan to demolish the upper floor and maintaining the ground floor. The building is very huge, so it will not be necessary for using it all for parking. Furthermore, it is doubtful whether the floor structure is strong enough so it can bear as many cars as a parking facility would require. Another reason for demolishing the upper floor is that the warehouse is massive and would be too dominant on the space of “Vindmøllebakken” in respect of design and architecture. Furthermore, by demolishing the upper floor the nice view over the coast would be improved from certain part of the area.

Alternatives

If it turns out that the whole warehouse has to be demolished other parking possibilities on the site have to be investigated. These alternatives could be the following:

- A Basement Car Park; the underground is to be exploded, which provides the ability to create an underground car park. Because the underground consist of rock this solution is probably not feasible.

- Usage of potential living space for parking at the each house; instead of creating a shared car park, the parking space would be a part of the plot for each house, leaving less space for the living area.
- Demolishing the warehouse and building up a complete new multi-story car park; In this case a complete new multi-story car park is to be built on the current site. This car park would have all the abilities and equipment as a normal modern car park that from a sustainable point of view probably would be less preferable.

Environmental Benefits

There are environmental benefits by reusing the warehouse. This is seen in almost all stages of the warehouses life cycle, comparing reuse with demolishing and building something new.

Raw Materials Extraction
When reusing the warehouse a big saving is made on use of new recourses, such as water and cement. Material Processing/Manufacture The manufacturing process has a huge CO2 emission impact, especially in case of the warehouse, because of the main materials contained in the building. These materials are steel and concrete. Manufacturing of these materials have a very big CO2 emission impact.

Transport
Another benefit is the less need of transportation. Transport is included in-between all the stages of the life cycle. This leads to a big saving on cost based on the need for fuel and use of fuel.

Usage
An environmental benefit of the warehouse in the use stage is that steel and concrete has a very long service life, without need of any replacements or treatments. Concrete and steel has an estimated service life of up to 100 years, and in some cases even more.

Generally, results show that at the operating phase energy use is a significant contributor to a buildings life cycle demand of nature resources and pollution. In new developments, the operative phase has been highly optimized due to new technology and advancement in this sector. Therefore, from a LCA-perspective, the environmental benefits resulting in the operative phase may justify the environmental impacts from the production phase. Nevertheless, as the building is to be used as a car park, a non-heated building, the operative phase will not have the same impact and not weigh in as much in the warehouses life cycle. However, if the building is going for a different purpose this may not be the case.

End of life
When demolishing a building at its “End of life”-stage, machines are used to tear down construction. When reusing this whole phase in the life cycle is postponed, which results in a big saving of the machines usage of fuel. In the warehouse case, it is not the whole building that is to be reused, but only the ground floor. This could lead to a more complicated demolishing process. Only demolishing parts of the building could need more machines with each a specific facility, compared to tearing down the whole building at once. Which of these two scenarios are the most demanding in respect of nature sources, has not been calculated. However, it can be concluded that the amounts of environmental benefits that are in the other stages compensates for the demolishing process.

Knowing that the Car Park still has 60-70 years of further life service and that there are so many environmental benefits of reuse makes it more convincing engaging a future usage of the building.

By changing the function of the warehouse to a carpark, the opportunity of prolonging its lifespan arises.

Discussion of Method

When analyzing a building with no reliance on given or calculated data, implies methods with another perspective of how to evaluate buildings. The method is based on assessments gain through knowledge and assumptions. This develops a more critical view on the sources found and estimations made. Nevertheless, this method is more realistic to be conducted on the warehouse, because the purpose of the building is a car park, a non-heated building. The criterions are limited, and it is therefore possible to make more assumption, thus still with a foundation based on a solid arguments.

Working with LCAbyg

Working with LCAbyg has had its pros and cons. The program has only existed since 2015, which means it is still under development. This means that there are still errors to be corrected and improvements to be made.

The interface of the program is very user-friendly. It is easy understanding how the program functions and where the buttons are placed and how the division of the program's stages is managed. There is attached a user guide, which is very helpful in the beginning of the process and with situation that are taken for granted. However, when more critical situations occurs, the users guide is less helpful. It would be further helpful, if the user guide includes a section explaining the consequences of the actions made during the input of data, such as when modifying the existing building components. As mentioned in section "Mothodological Approach of the Union Canning" under the subsection "LCA of the Union Canning Refurbishment using LCAbyg", the wall structure was modified to provide the steel girder. The existing wall was set in kg/m2, while we changed the units to suit the steel girder, kg/m. There is an uncertainty about this method, as the consequences of this approach is unknown. This leads us to the limited content of building elements consisted in the database. There is not a big spectrum of options, which leads to some alternative solutions when fabricating the building elements needed.

When entering building elements in the program, it is possible to set the element for demolition. This is simply done by ticking off a box. There are no further options of way of handling the demolition process. The assumptions behind the demolition process in LCAbyg are uncertain that makes system less clear.

When input of data has been completed, it is possible to export the results to an excel file. The excel file gives a better overview of the results, than the figures presented by the program. In the excel sheets it is possible to see exact numbers, and from that the causes for the specific result.

We support the idea of LCAbyg and the need for such a program, however some improvement is required. Many assumptions are made in the program which does not appear from the program and therefore it is difficult to understand the results.

Conclusion

This project has assessed the environmental impacts for an alternative renovation proposal. The calculations have been compared with two different new development scenarios to evaluate the environmental benefits and impacts of the design approach. The LCA method has been discussed whether if it motivates building developers to take sustainable choices.

The project opens up for a new design approach when renovating, and has revealed the need for a multidisciplinary design approach. In order for an environment assessment of a renovation scenario is realistic, it is important that the design proposal is realizable. This demands that certain fields of knowledge are obtainable. An overall understanding of the life cycle meaning and method is needed. The structural concepts lay the foundation for the dimensions of materials which figures an important section in the LCA. Knowledge about recycling potential is also an important part of the process.

The project has also attempted two different approaches to discussing sustainability of a renovation proposal. For the Union Canning a thorough LCA was made, documenting the results under different impact categories. While for the warehouse the sustainability was assessed through methods of discussion.

The LCA results and analysis shows that a buildings service life has great affect on the total environmental impact contributed by the building. This is a good motivation for ensuring a long lifespan for a building. When developing new buildings this can be done by ensuring the possibilities for shift of building function, and for existing buildings it is seeing the possibilities for the function shift.

The delimitiations in the LCA calculation has showed it to be difficult to achieve a precise basis for comparison. The comparison between the Union Canning and the DGNB certified development indicated distinctions in the underlying premises for the LCA. This complicates and prevents the possibility to conclude that one building is more sustainable than the other. However the analysis gives us an understanding and indication of the environmental benefits achieved when thriving for re-use in the renovation proposal.

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Appendix

Appendix 1

Appendix 1.1

The three tables below the total environmental impacts from the Union Canning refurbishment proposal with a life span of 50 years. The three tables show impacts divided by: Life cycle phases, Materials and Building Parts. These results are achieved through use of LCAbyg.

Union Canning Refurbishment Proposal 50 years - Phases					
	Production (A1-A3)	**Replacement (B4)**	**Waste processing (C3)**	**Disposal (C4)**	**Total**
GWP	4,29E+03	6,36E+03	1,15E+05	6,31E+02	126673,63
ODP	1,18E-04	4,46E-05	4,91E-06	1,47E-07	
PEtot	3,82E+05	1,24E+05	1,36E+04	6,99E+02	5,20E+05

Union Canning Refurbishment Proposal 50 years - Materials									
	Wood and wooden based materials	**Cement based materials**	**Metal**	**Insulation**	**Bricks and tiles**	**Mortar**	**Lenoleum**	**Plastic**	**Glass**
GWP	7,70E+04	3,20E+01	3,06E+04	1,09E+04	6,75E+02	1,88E+02	1,09E+01	1,74E+03	3,93E+03
ODP	6,98E-05	2,48E-08	7,09E-05	1,42E-05	5,22E-07	1,45E-07	1,20E-10	1,15E-06	2,72E-06
PEtot	3,34E+05	1,82E+02	1,12E+05	3,97E+04	3,84E+03	1,07E+03	9,90E-01	4,95E+03	1,38E+04

Union Canning Refurbishment Proposal 50 years - Building Parts								
	Foundation	**Exterior wall**	**Flooring Structure**	**Structure**	**Windows**	**Outdoor box**	**Stairs**	**Re-insulation**
GWP	0	1,13E+04	3,39E+04	2,82E+04	5,66E+03	1,41E+01	1,79E+01	3,19E+03
ODP	0	1,97E-05	4,57E-06	4,81E-05	3,63E-05	1,09E-08	1,38E-08	6,16E-06
PEtot	0	1,42E+05	3,54E+04	1,02E+05	4,38E+04	8,05E+01	1,02E+02	5,10E+04

Appendix 1.2

The three tables below the total environmental impacts from the Union Canning refurbishment proposal with a life span of 100 years. The three tables show impacts divided by: Life cycle phases, Materials and Building Parts. These results are achieved through use of LCAbyg.

Union Canning Refurbishment Proposal 100 years - Phases				
	Production (A1-A3)	**Replacement (B4)**	**Waste processing (C3)**	**Disposal (C4)**
GWP	4,29E+03	1,90E+04	1,15E+05	6,31E+02
ODP	1,18E-04	1,19E-04	4,91E-06	1,47E-07
PEtot	3,82E+05	3,44E+05	1,36E+04	6,99E+02

Union Canning Refurbishment Proposal 100 years - Materials									
	Wood and wooden based materials	**Cement based materials**	**Metal**	**Insulation**	**Bricks and tiles**	**Mortar**	**Lenoleum**	**Plastic**	**Glass**
GWP	8,25E+04	3,20E+01	3,24E+04	1,09E+04	6,75E+02	1,88E+02	1,09E+01	1,74E+03	7,85E+03
ODP	1,11E-04	2,48E-08	9,26E-05	1,42E-05	5,22E-07	1,45E-07	1,20E-10	1,15E-06	5,44E-06
PEtot	5,22E+05	1,82E+02	1,20E+05	3,97E+04	3,84E+03	1,07E+03	9,90E-01	4,95E+03	2,76E+04

Union Canning Refurbishment Proposal 100 years – Building parts								
	Foundation	**Exterior wall**	**Flooring Structure**	**Structure**	**Windows**	**Outdoor box**	**Stairs**	**Re-insulation**
GWP	0	1,46E+04	3,39E+04	2,82E+04	1,05E+04	1,41E+01	1,79E+01	4,50E+03
ODP	0	2,84E-05	4,57E-06	4,81E-05	7,25E-05	1,09E-08	1,38E-08	9,68E-06
PEtot	0	2,12E+05	3,54E+04	1,02E+05	8,74E+04	8,05E+01	1,02E+02	9,15E+04

Appendix 1.3

The table below describes the total environmental impacts from the DGNB certified building. The table describes its impacts divided by phases. These results are taken from the LCA of the DGNB certified building, see Appendix 2.

DGNB certified New Development			
	Production (A1-A3)	**Replacement (B4)**	**End of Life**
GWP	3,30E+05	7,96E+04	-1,89E+04
ODP	1,58E-02	1,17E-02	-1,27E-03
PEtot	4,76E+06	3,09E+06	-1,14E+06

Appendix 1.4

The three tables below the total environmental impacts from the Union Canning No Re-Use Development. The three tables show impacts divided by: Life cycle phases, Materials and Metal. These results are achieved through use of LCAbyg.

Union Canning No Re-use 100 years - Phases				
	Ptoduction (A1-A3)	Replacement (B4)	Waste processing (C3)	Disposal (C4)
GWP	9,38E+04	2,19E+04	1,49E+05	8,84E+02
ODP	3,46E-04	1,27E-04	7,12E-06	1,99E-07
PEtot	8,25E+05	4,14E+05	2,53E+04	9,43E+02

Union Canning No Re-use 100 years – Materials								
	Wood and wooden based materials	Cement based material s	Metal	Insulatio n	Bricks and tiles	Mortar	Lenoleu m	Plasti c
GWP	7,99E+04	9,85E+03	1,07E +05	3,92E+04	1,03E+03	2,90E+ 02	1,09E+01	1,98E +03
ODP	1,21E-04	3,05E-05	2,22E- 04	6,58E-05	7,96E-07	2,24E- 07	1,20E-10	1,36E- 06
Petot	6,46E+05	1,53E+04	3,93E +05	1,23E+05	5,86E+03	1,65E+ 03	9,90E-01	5,86E +03

Union Canning No Re-use - Metal				
	Structure steel	Window	Screws and fittings	Reinforcement
GWP	1,02E+05	3,50E+03	1,09E+03	9,22E+02
OPD	1,74E-04	4,35E-05	1,75E-06	3,06E-06
PEtot	3,69E+05	1,55E+04	3,99E+03	4,16E+03

Appendix 2

The following table is the LCA results from a DGNB certified building. The table is divided into two sections.

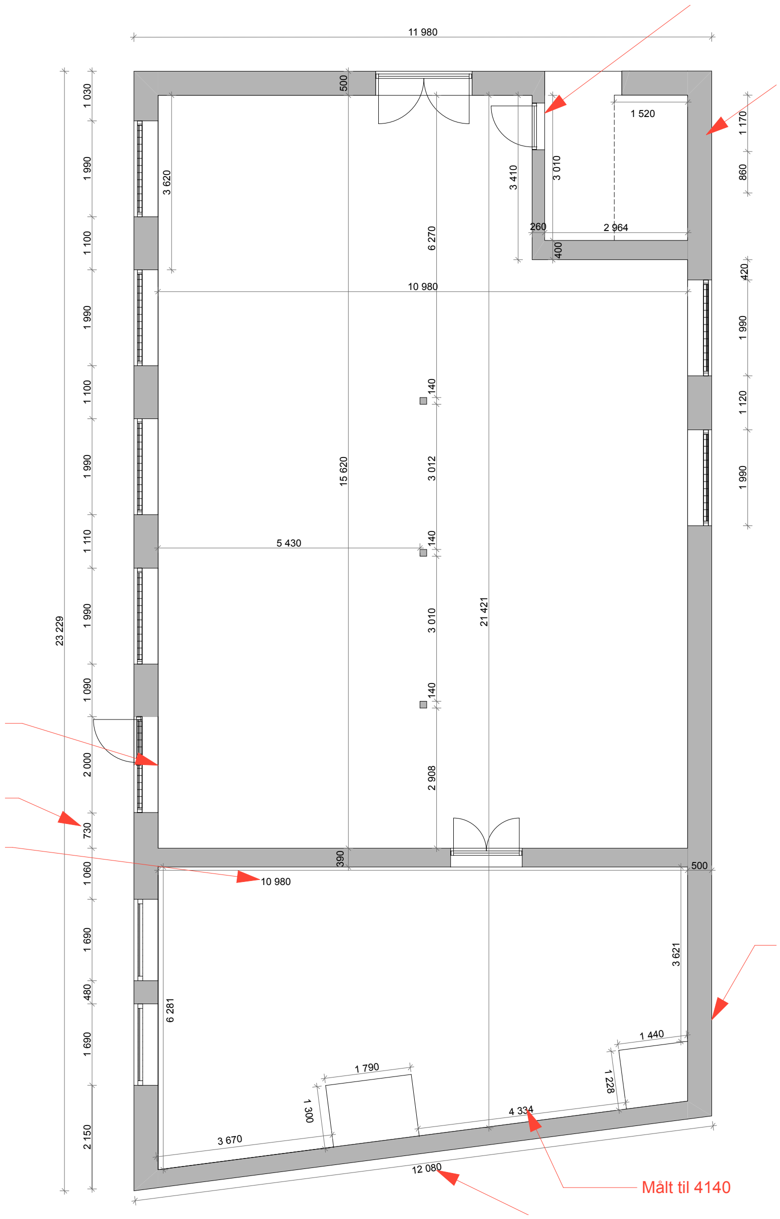
Total	GWP	ODP	POCP	AP
	[kg CO2-Equiv.]	[kg R11-Equiv.]	[kg Ethene-Equiv.]	[kg SO2-Equiv.]
Opførelse af bygning, total	**3,50E+05**	**1,89E-02**	**1,24E+02**	**1,28E+03**
Fundamenter (12)	7,64E+04	2,59E-03	1,84E+01	1,91E+02
Terrændæk (13)	5,07E+04	1,57E-03	1,27E+01	1,58E+02
Ydervægge (21)	7,74E+04	3,86E-03	3,27E+01	3,36E+02
Indervægge (22)	2,38E+04	1,07E-03	7,28E+00	8,13E+01
Dæk (23)	2,66E+04	8,60E-04	7,30E+00	7,19E+01
Trapper og ramper (24)	5,98E+03	2,53E-04	2,19E+00	1,66E+01
Altaner (26)	-1,22E+03	6,38E-05	1,03E+00	4,03E+00
Tage (27)	3,53E+04	1,91E-03	1,57E+01	1,71E+02
Ydervægge, komplettering (31)	1,57E+04	1,61E-03	5,98E+00	8,99E+01
Indervægge, komplettering (32)	5,53E+03	7,56E-04	3,33E+00	2,38E+01
Dæk, komplettering (33)	1,04E+03	2,72E-05	2,49E-01	2,30E+00
Trapper og ramper, komplettering (34)	5,17E+02	4,17E-05	3,84E-01	2,70E+00
Lofter, komplettering (35)	6,02E+02	2,73E-05	1,56E-01	2,75E+00
Altaner, komplettering (36)	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Tage, komplettering (37)	1,12E+04	1,13E-03	5,60E+00	6,66E+01
Udvendige vægoverflader (41)	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Indvendige vægoverflader (42)	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Dæk og gulve, overflader (43)	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Trapper og ramper , overflader (44)	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Lofter, overflader (45)	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Altaner, overflader (46)	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Tage, overflader (47)	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Køling (55)	2,17E+02	5,92E-04	6,83E-02	6,89E-01
Varme (56)	1,93E+04	2,47E-03	1,09E+01	6,15E+01
Ventilation (57)	1,10E+03	3,64E-05	3,28E-01	2,77E+00
Varmebehov	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Kølebehov	0,00E+00	0,00E+00	0,00E+00	0,00E+00
El til bygningsdrift	0,00E+00	0,00E+00	0,00E+00	0,00E+00
El til belysning	1,11E+05	5,25E-03	2,20E+01	2,57E+02
Udskiftning af bygningsdele	7,96E+04	1,17E-02	4,38E+01	3,31E+02
End of Life	-1,89E+04	-1,27E-03	-7,06E-01	-1,83E+01
Bygningsbasis	1,27E+05	4,16E-03	3,11E+01	3,49E+02
Ydervægge	9,31E+04	5,47E-03	3,87E+01	4,26E+02
Indervægge	2,93E+04	1,83E-03	1,06E+01	1,05E+02
Dæk, trapper, ramper, altaner, lofter	3,35E+04	1,27E-03	1,13E+01	1,00E+02
Tage	4,66E+04	3,04E-03	2,13E+01	2,37E+02
VVS	2,06E+04	3,10E-03	1,13E+01	6,50E+01

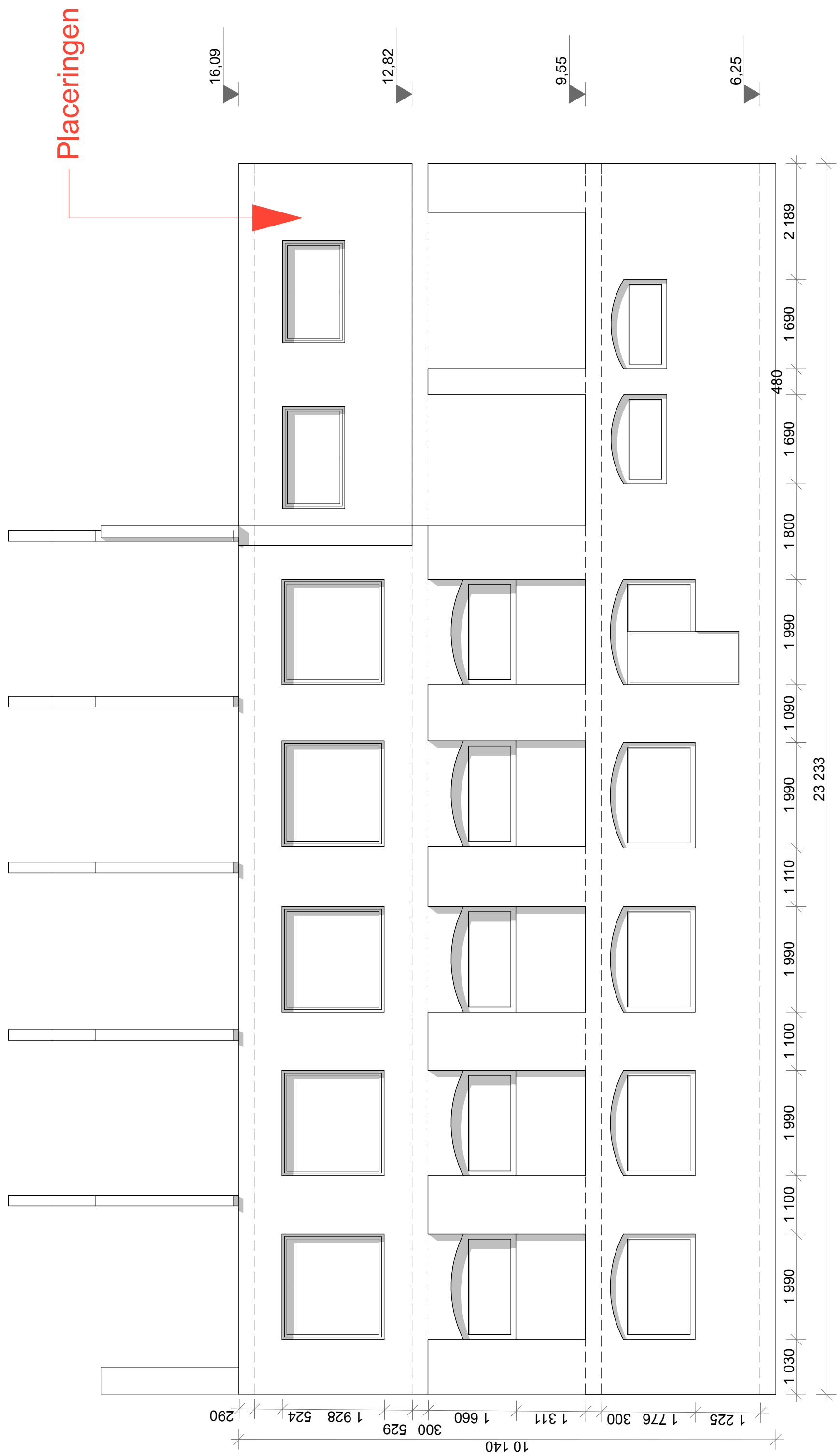
EP [kg Phosphate-Equiv.]	ADP [kg Sb-Equiv.]	PE, NR non-renewable [MJ]	PE, R renewable [MJ]	Sekundære brændsler [MJ]	9,000E+00 Sekundære brændsler [MJ]
1,37E+02	**2,00E+03**	**4,78E+06**	**8,38E+05**	**1,08E+05**	**1,078E+05**
2,20E+01	2,48E+02	6,13E+05	2,56E+04	3,13E+04	**7,637E+04**
2,02E+01	1,88E+02	4,44E+05	1,27E+04	1,88E+04	**5,066E+04**
3,52E+01	4,46E+02	1,07E+06	3,14E+05	2,36E+04	**7,745E+04**
9,02E+00	1,05E+02	2,55E+05	6,28E+04	1,05E+04	**2,378E+04**
8,41E+00	9,01E+01	2,20E+05	8,24E+03	9,68E+03	**2,661E+04**
1,61E+00	2,69E+01	6,58E+04	4,80E+03	1,00E+03	**5,978E+03**
8,93E-01	6,33E+00	1,55E+04	2,46E+04	4,12E-01	**-1,219E+03**
1,82E+01	2,80E+02	6,56E+05	1,77E+05	1,05E+04	**3,534E+04**
6,41E+00	9,06E+01	2,48E+05	7,15E+04	9,83E+00	**1,568E+04**
1,92E+00	4,35E+01	1,19E+05	4,08E+04	5,69E+00	**5,528E+03**
3,59E-01	6,34E+00	1,46E+04	3,26E+02	8,18E+01	**1,038E+03**
2,22E-01	4,73E+00	1,15E+04	4,26E+03	7,29E-02	**5,169E+02**
3,53E-01	5,85E+00	8,46E+03	2,50E+02	3,26E+01	**6,024E+02**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
5,28E+00	8,01E+01	1,94E+05	7,82E+04	2,29E+03	**1,123E+04**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
6,90E-02	1,28E+00	3,02E+03	1,49E+02	1,27E-01	**2,173E+02**
6,50E+00	3,66E+02	8,25E+05	1,19E+04	3,44E+01	**1,930E+04**
2,09E-01	6,96E+00	1,58E+04	1,17E+03	3,31E+00	**1,102E+03**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,000E+00**
2,46E+01	0,00E+00	1,60E+06	3,44E+05	0,00E+00	**1,107E+05**
2,82E+01	1,25E+03	2,88E+06	2,13E+05	2,40E+03	**7,965E+04**
1,75E+00	-4,45E+02	-9,63E+05	-1,76E+05	1,24E+03	**-1,886E+04**
4,22E+01	4,36E+02	1,06E+06	3,83E+04	5,01E+04	**1,27E+05**
4,16E+01	5,36E+02	1,32E+06	3,86E+05	2,36E+04	**9,31E+04**
1,09E+01	1,48E+02	3,74E+05	1,04E+05	1,06E+04	**2,93E+04**
1,18E+01	1,40E+02	3,36E+05	4,25E+04	1,08E+04	**3,35E+04**
2,35E+01	3,60E+02	8,50E+05	2,55E+05	1,28E+04	**4,66E+04**
6,77E+00	3,74E+02	8,43E+05	1,33E+04	3,78E+01	**2,06E+04**

Appendix 3

Appendix 3.1

The following three plan drawings are plan drawing of the original Union Canning building. These drawings were used when quantifying the materials.




Placeringen
16,09
12,82
9,55
6,25
2 189
1 690
480
1 690
1 800
1 990
1 090
1 990
1 110
1 990
1 100
1 990
1 100
1 990
1 030
23 233
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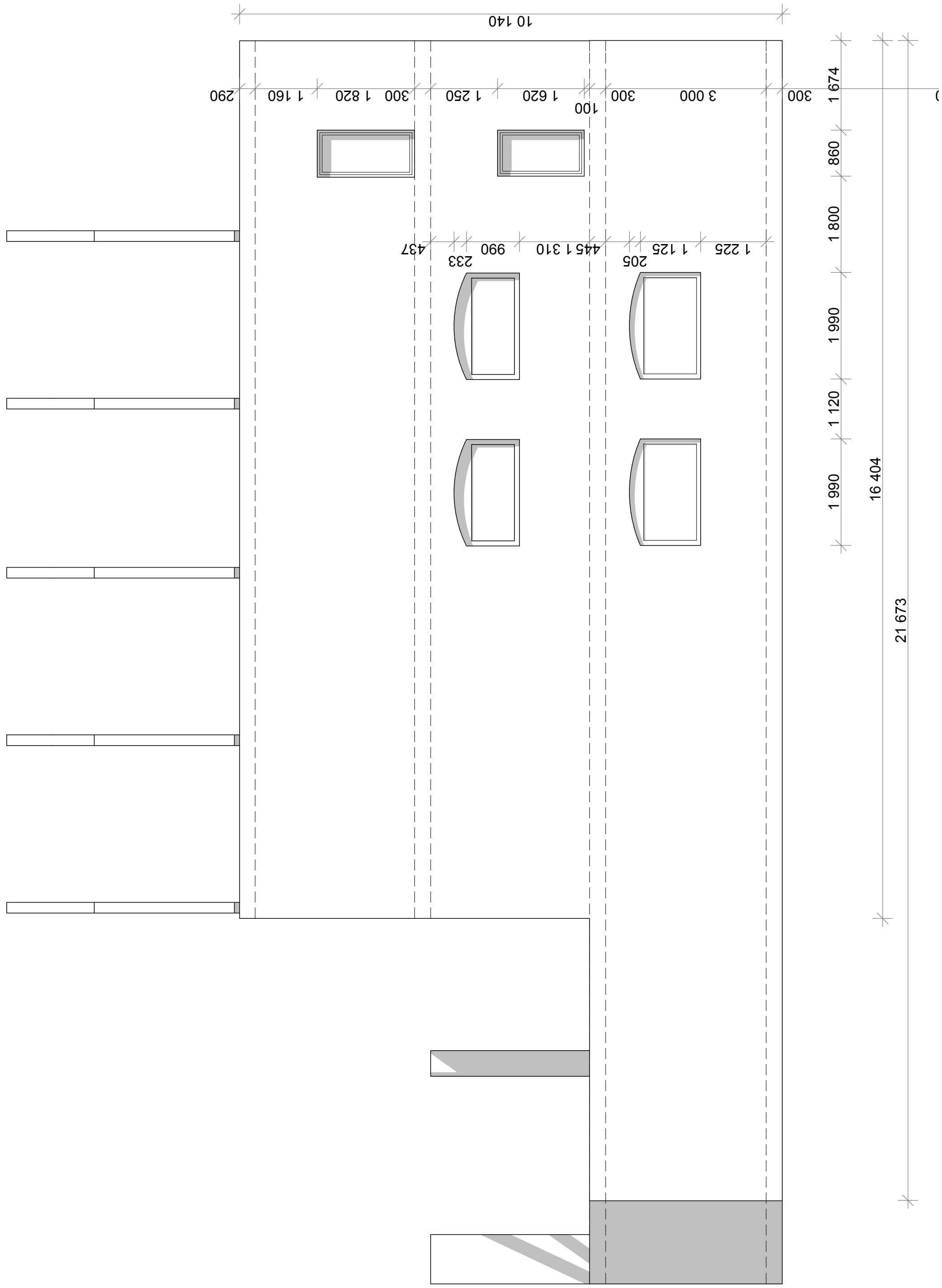
524
1 928
529
300
1 660
1 311
300
1 776
1 225
10 140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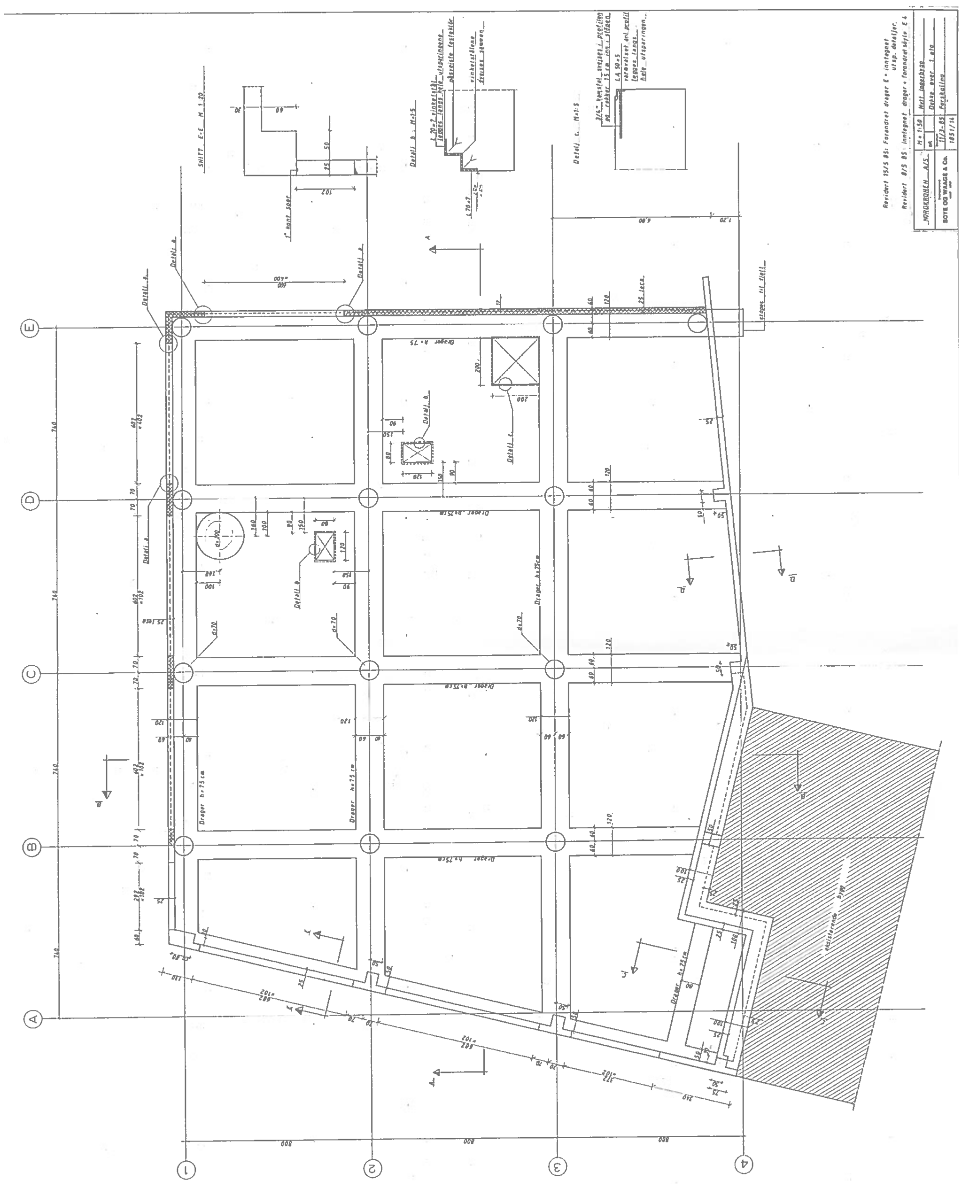
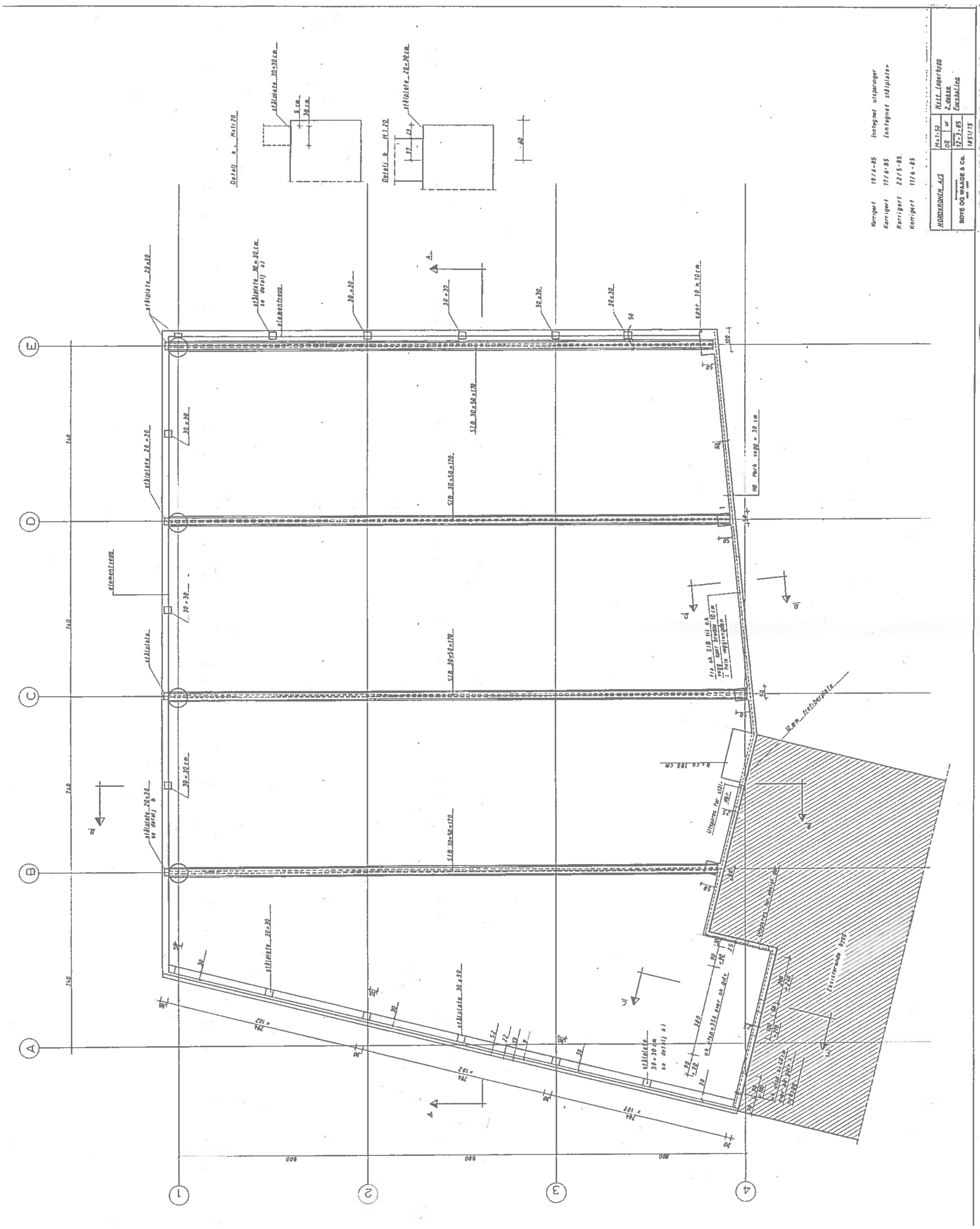
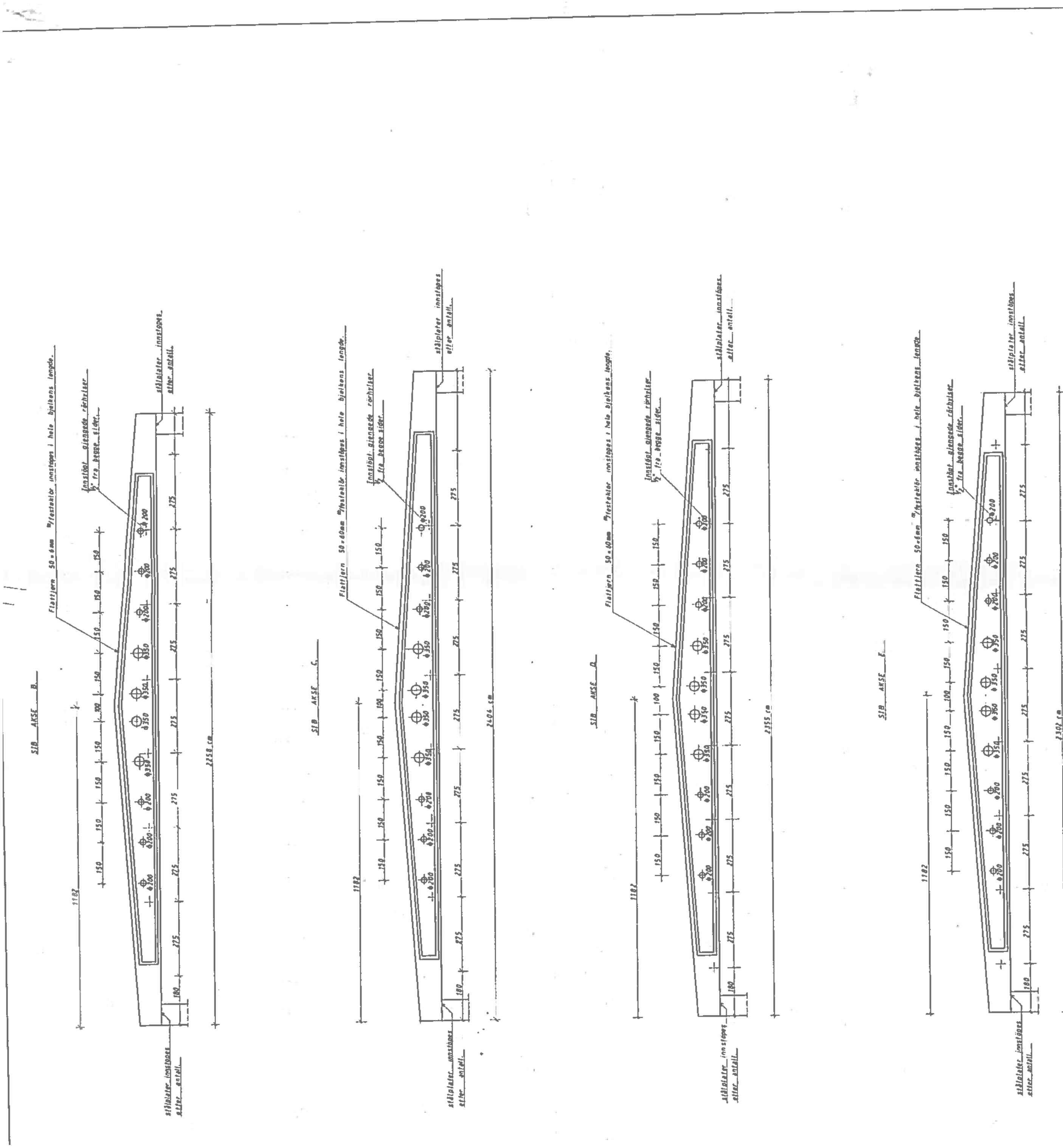
1 160
1 820
300
1 250
1 620
100
300
3 000
300
437
233
990
1 310
445
205
1 125
1 225
1 674
860
1 800
1 990
1 120
1 990
16 404
21 673

Appendix 3.2

The following three plan drawings are plan drawing of the original Warehouse building. These drawings were used when quantifying the materials.







Appendix 4

The information in this appendix describes the process of assessing the amount of lead in paint.

Oplukning af jord- og askeprøve efter DS 259

A **Princip**

Denne oplukningsmetode er en Dansk Standard (DS 259) til bestemmelse af syreopløselige metaller i jorden. Metalkoncentrationen fundet ved denne metode svarer til en "total-koncentration" af det pågældende metal i jorden. Ved en fuldstændig destruktion af jorden, vil man dog have mulighed for at finde en højere værdi af de forskellige metaller, så DS 259 giver derfor snarere et fastlagt niveau for en metalkoncentration, end en fuldstændig bestemmelse af metalkoncentrationen i jorden.

B **Specielt apparatur**

Til målingen benyttes ICP
Autoklave

C **Kemikalie sikkerhed**

Salpetersyre - Brandnærende; Ætsende; Brandfarlig ved kontakt med brandbare stoffer. Alvorlig ætsningfare. Undgå indånding af dampe. Brug syrehandsker, plastikforklæder, sikkerhedsbriller og stinkskab ved afmåling.

Salpetersyre halv konc. (1:1) - Lokalirriterende; Irriterer øjnene og huden. Brug engangshandsker, sikkerhedsbriller og stinkskab ved afmåling.

Læs kemikaliebrugsanvisningen før arbejdet begynder.

D **Reagenser**

1) **Salpetersyre halvkonc, (1:1) HNO_3:**
500 mL koncentreret HNO_3 overføres med måleglas til en 1000,00 mL målekolbe som er ½ fyldt med destilleret vand. Der blandes godt og tilsættes vand til mærket. Efter blanding overføres opløsningen til en plastikflaske og mærkes.

E Analysens udførelse

1,00 g tør, knust jord afvejes på teknisk vægt i et pyrex-glas med skruelåg (autoklaveglas) og der tilsættes 20,00 mL halvkoncentreret HNO_3 med fuldpipette (skal foregå i stinkskab).

Autoklavflaskerne lukkes helt, da HNO_3 ellers ville fordampe. Flaskerne stilles i autoklaven.

Der hældes 1,5L destilleret vand i autoklaven og låget lukket helt og den orange låseknap lukkes. Den sorte ventil midt på låget åbnes helt og drejes derefter en ½ omgang tilbage. Autoklaven tændes og der går ca. 10-15 min indtil den er varmet op. Efter 3 min med damp ud at ventilen lukkes denne og trykket begynder at sige. Når trykket er kommet op i det blå felt på manometeret tages der tid på autoklaveringen (30min). Derefter slukkes autoklaven.

Flaskerne afkøles derefter til stuetemperatur.

Prøverne filtreres med sug gennem et 0,45 µm filter i stinkskab. **Brug engangshandsker**. Autoklaveflasken skylles med 3 gange destilleret vand. Filtreret skal suge tør mellem hvert skyl.

Filtratet hældes i en 100,00 mL målekolbe og der tilsættes destilleret vand til mærket og blandes. Væsken hældes på en 20 mL plast-vials og gemmes til ICP.

F Bestemmelse af metaller

Ekstraktens indhold af metaller måles på ICP under benyttelse af de standarder som hører til de enkelte metaller.

G Beregning af resultat

På baggrund af standardkurverne beregnes jordens indhold af metaller angivet i mg/kg.

$$mg/kg = \frac{A \cdot 0{,}100 L \cdot C}{B \cdot 10^{-3}\, kg/g\ jord}$$

hvor

A	=	ekstraktens metal koncentration, mg/L = ppm
B	=	g jord afvejet
C	=	fortyndingsfaktor

H **Affaldshåndtering**

Ekstrakerne hældes i affaldsdunk mærket X 4.41 (tungmetaller).

Filterpapiret bortkastes i skraldespanden i stinkskabet.

Jorden og asken skal opsamles i beholder til jordaffald.