Renovation of the flour factory de Sleutels in Leiden



Master Thesis Marloes van Loenhout



Overview of the factory complex Meelfabriek 'de Sleutels' in Leiden Renovation of the flour factory 'de Sleutels' in Leiden

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Preface

This report is a result of the graduation project of the master Building Engineering specialisation Structural Design. After my Bachelor degree in Architecture, I was looking for a more technical challenge. The master Building Engineering educated me as structural engineer and my background of Architecture let me read the language of Architecture.

Looking for an interesting graduation project to prove my design skills as a structural engineer I came to talk with Anne van de Sluis, vanRossum consulting in building engineering, he challenged me to do a renovation project. Immediately I was thinking about the buildings I know for so long, standing empty for a long time. The Flour Factory in Leiden. A design case for my research came to live.

Combining my childhood memories, with my interest in Architecture and proving my structural engineering skills this was a perfect assignment for me. The research of the design cases of the flour factory was an inspiring journey. My detective skills, analytical, design and engineering skills were all put into action. Every bit of the journey I enjoyed and learned a lot.

First I want to thank Anne for his idea to do a renovation project and his (precious) time at vanRossum. Secondly, Sander Pasterkamp, Hielkje Zijlstra and Rob Nijsse for their time and enthusiasm for the project. And I want to thank my family and friends. My parents, who supported me all these years of studying, thank you for your enthusiasm and trust in me. Gerben for coping with my insecurities and grumpiness. And last my friends Amy, Nina and Ilja who helped me with my rapport and for your support.

I hope you enjoy reading this report as much as I enjoyed making it.

Abstract

Currently there are a lot of vacant buildings available. To reuse these buildings, which may or may not have monumental status, the project has to be financially feasible. If a building has good potentials to be reused, the capacity of the structure and the possibilities of adapting the structures needs to be examined to make a project possible This study focuses on how the structural design influence the redesigning for reuse of a monument. As a design case the Flour factory in Leiden has been selected.

The old flour factory 'de Sleutels', located at the corner of the Oosterkerkstraat and the canal the Zijlsingel in Leiden is a complex of nine different buildings with each different characteristics. The architect Peter Zumthor designed a plan on how to reuse the existing buildings and which interventions should be done to realize this.

The problem definition is the following:

How can the interventions, as proposed by Peter Zumthor and partner, be integrated in the current structures of the former flour factory 'meelfabriek de Sleutels' in Leiden, so that sound safe structures, set out in the Dutch Building Regulations and in the Eurocode-regulations, are created and which adjustments and additions should be made to realize this goal?

In the research the following methodology is used:



The methodology generated is applied on this project. First as much as possible data was searched for. This data was, when possible, compared to inspections on the buildings on site to get a realistic overview of the characteristics of the building. Where data was missing assumptions were made (in reality it is recommended to find the missing data by inspections on site) or conclusions were drawn from visible inspections. With this overview it was possible to detect the failures and possibilities of the structures of the buildings. The failures and possibilities resulted in different solutions to realize the proposed architectural interventions in the existing structures. A selection of the best solution was done by testing them on the set preconditions (as set in the architectural analysis, in reality this is done by client, architect, state or municipality and other stakeholders involved). The solution that fits best is selected to develop the final structural design.

To adapt the Boiler House to an workshop building the foundation capacity has to be examined further and the possibility to couple the building in South direction to the cleaning building to provide stability. If it is possible the steel should be examined on its yielding strength and a check has to be done if the masonry is still intact and if the bond between steel skeleton and concrete floors still is present, otherwise anchors could be used to solve this problem.

To adapt the silos built in 1904 to a hotel the foundation should be reinforced, because it has now only a restlife of 25 years. The cracks in the roof should be repaired to prevent (further) carbonation and corroding of the steel. To adapt the Mill to an atelier building, sloping columns are added to transfer the overloading forces to the outer dies, with extra capacity, to make the foundation safe. Braces are added in the outer portals and two inner portals to take care of the displacement. The structure should be cleaned from corrosion and protected; a sprinkler installation should diminish the temperature of the structure to provide fire safety.

To adapt the Flour Warehouse to a fitness building a steel top is realised with steel-plate concrete floors to make a light structure, to create a safe foundation. Outriggers are placed in the top to take care of the displacement. Where reinforcement is visible the concrete should be repaired to prevent (further) carbonation and corroding of the steel.

To adapt the silos built in '37, '38 and '55 to a hotel the concrete has to be repaired where reinforcement is visible to prevent (further) carbonation and corroding of the steel.

To adapt the cleaning building to a design office the foundation capacity has to be examined further and the concrete has to be repaired where reinforcement is visible to prevent (further) carbonation and corroding of the steel.

To adapt the extension of the Mill to apartments the structure should be cleaned from corrosion and protected. The displacement should be diminished by adding braces or a core.

To adapt the Tower of Silos into design and fashion shops the concrete has to be repaired where reinforcement is visible to prevent (further) carbonation and corroding of the steel.

The final conclusion:

The interventions and additions of the structures of The Mill and the Flour Warehouse are sound safe structures verified according to the Dutch Building Regulations and the Eurocode-regulations. The capacity of the existing structures is used at full extend and simple solutions make additions or adaptions possible. The monumental values are kept intact and the preconditions as set according to the vision of the architect and the client wishes are nearly achieved.

Recommendations

When an existing structure is adapted to the needs of a renovation project the following recommendations can be done:

- Use the methodology as generated in this thesis, based on the ABCD method. When data is thoroughly searched and compared with measurements from inspections on the structures it is possible to find failures and possibilities, which give a good base for the redesign.
- When there is a need for adapting the structure search for the extra capacity of a structure and make a solution with this capacity.
- From this thesis it appears that buildings build until at least 1947 were not designed on stability and or horizontal displacement, consider this when making a redesign for a structure of the same period.

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Introduction

At first an introduction is given on the problem described in this thesis, the objective, the limitations, regulations, scope and research methodology. Secondly, background information is given on the flour factory, site, architects and typology of the buildings considered in this thesis.

1 Introduction

Currently there are a lot of vacant buildings available. To reuse these buildings, which may or may not have monumental status, the project has to be financially feasible.

If a building has good potentials to be reused, the capacity of the structure and the possibilities of adapting the structures needs to be examined to make a project possible This study focuses on how the structural design influence the redesigning for reuse of a monument. As a design case the Flour factory in Leiden has been selected.

In this chapter the problem will be introduced. First the context of the design case will be explored by analysing the problem, stating the project description and definition, followed by a definition of the objective and limitations. Second the research methodology will be discussed, i.e. how to make an analysis of an existing building and how to project this on the structure of a building. Moreover, this paragraph describes how insights can be translated into a final design and how this method can be applied to other design cases. Last the report structure will be provided.

1.1 Analysis of the problem

Buildings constructed before 1800 are scarce and therefore highly valued to become a monument. Buildings built after this period are less scarce and need economical, profitable and/or social values to become accepted as a monument. The state does not have the financial means to maintain all the monuments from this period. Adaptive reuse is a solution for a monument, constructed after 1800, to make it financially feasible for a building to live on. The following aspects determine if a project can be selected as a 'listed monument of the state'¹:

- range of possibilities for reusing the building
- the quality and state of the material of the building
- building maintenance over time
- the extent to which the renovation is needed and amount of adaptations
- Is the location attractive for reusing the building?

Problem description

The old flour factory 'de Sleutels', located at the corner of the Oosterkerkstraat and the canal the Zijlsingel in Leiden, was constructed in 1884 by Adriaan Koole and Arie de Koster. In less than one century, flour production increased significantly and the factory grew from one building to nine different buildings. Because the buildings were constructed in different periods, i.e. with different methods, materials and architecture, they each possess a particular set of characteristics. Therefore the factory complex can be seen as a collection of unique buildings.

In 1988 the flour factory closed its doors. Since 1990 project developer, Ab van der Wiel has owned the factory site. In 2000 the municipality decided most of the buildings should become listed as monuments of the state and a plan on how to reuse the buildings was drawn up. The architect Peter Zumthor designed a plan on how to reuse the existing buildings and which interventions should be done to realize this.

The factory, having stood empty for thirty years and without any maintenance being carried out in the meantime, is likely to present failures. The structures of the buildings were designed for the function of a factory and giving the building a new function may introduce other different permanent and imposed loads than which the building was designed for. Moreover, at present, a set of more strict regulations on how to design a safe structure are in place and need to be taken into account. Furthermore the buildings are listed

¹ Peter Nijhof, Ed Schulte. 1994. *Herbestemming industrieel erfgoed in Nederland*. Zutphen. Walburg pers

monuments of the state and therefore there might exist limitations and constraints on making adjustments to the current structures.

Problem definition

How can the interventions, as proposed by Peter Zumthor and partner, be integrated in the current structures of the former flour factory 'meelfabriek de Sleutels' in Leiden, with respect to the monumental values, so that sound safe structures, as set out in the Dutch Building Regulations and in the Eurocode-regulations, are created and which adjustments and additions should be made to realize this goal?

Objective

To develop a sound and feasible structural design to realize the interventions as proposed by Peter Zumthor and Partner for reuse of two flour factory buildings; The Mill and the Flour Warehouse.

Limitations

- This thesis will focus on the buildings that are listed monuments of the state and which will not be demolished. The workshops and office buildings will therefore not be considered in this thesis.
- The final structural design is made of the steel Mill building and the concrete Flour Warehouse.
- At the moment of conducting this thesis only the architectural preliminary design is known. Based on this knowledge an indication is made of the design of the floor plans.
- The façade, partition walls and acoustic isolation are left out of consideration. The selection of these elements is based on consults and reference projects.
- In this research there is no possibility to verify the found data on site and not all the data are known by literature. Therefore some assumptions are made based on the former building regulations, existing calculations or other literature that is found; those assumptions are explained in the appendices.

Regulations

The regulations that are taken into account in this thesis are the Dutch Building Regulations and the Eurocode. The applied verifications of the Eurocode are further explained in chapter 12 till 17. The following regulations are applied on structures of buildings:

- The Dutch Building Regulations constitute restrictions on safety, health, usability, energy consumption and environmental issues regarding buildings.
- The Eurocode constitute the regulations on how to verify the design of a structure.
- The Eurocode in combination with NEN 8700 constitute the regulations on how to verify the design of an existing structure.
- The Eurocode recommends restrictions on displacements; those will be acknowledged as the restrictions for the design.

To verify the design of new structural elements the restrictions of the Eurocode are applied. To verify the existing elements the Eurocode in combination with NEN-8700 are applied.

1.2 Research methodology

Prior to making a redesign for an existing building, the building is analysed. In a building there are three stages, the past, the present and the future time. The analyse starts with gathering as much information as possible; from libraries, literature, newspapers, archives, drawings, pictures and calculations, the building itself, pictures, sketches and interviews. When these documents have been obtained, the information gathered from these documents is structured, analysed, interpreted, combined and reduced. The third stage is about drawing conclusions over the three periods. The context, brief, architect, site, typology, design process, space (interior and exterior), structure, materials, building services are analysed and placed in three different time frames:

the past, the present and the future. This way of examining a building is the ABCD-method, Analysing Buildings from Context to Detail in time, regenerated by Hielkje Zijlstra.²

This method could be useful for a structural engineer, but it takes a lot of time, which means high costs. Therefore a choice should be made on which aspects of the building need to be analysed.³ The ABCD method is used as a reference to analyse the buildings on their structures.

The first step is to find old documents, drawings and calculations of the building, to find out what the former engineer wanted to design.

When these documents are found and studied, old documents differ from drawings and calculations made in current times, the structure and components should be measured on site to check whether these documents are corresponding with the structure that was actually built.

When the measurements of the structure and its components are known an evaluation of strengths and weaknesses is made. The strengths should be used in the design and the weaknesses should be eliminated as much as possible. The structural integrity should be examined as well. ⁴

To analyse the state of the material of the structure, failures and weaknesses, inspections can be made of the building itself. There is a difference between non-destructive and destructive inspections. Destructive research consists for example, of an inspection of the foundation or boring concrete cores to determine the quality. Non-destructive research may consist of measurements made with a Schmidt hammer, ultrasonic measurements, and measurements on the concrete cover of the reinforcement steel, height measurements on site or a visual inspection. The different methods will be discussed briefly in appendix A.

In the architectural analysis the buildings, the monumental values, the architectural redesign and the demands of the architects are examined. With this data a set of requirements for the structural interventions is created. In the structural analysis the failures of the buildings are examined. Based on the results of this analysis two buildings are selected for the first schematic designs. Based on the strengths and weaknesses of the buildings a study is made of structural variants on the redesign. A selection of the variants is made based on the set requirements. When the best solutions for the two buildings are chosen, they will be designed in detail and verified if they are sound structural interventions. This research method is summarised in a scheme (figure 1-1).



Figure 1-1 from seeking information towards a structural design

² Dr. Ir. H. Zijlstra. 2009. Analysing Buildings from Context to Detail in time, ABCD method. Amsterdam. IOS Press.

³ Giebler, G. et al, 2009. *Refurbishment Manual, p22-31*. Basel: Birkhäuser

⁴ Santifaller E. et al, 2008. *Transform, interview with Rainer Hempel, p69-74*. New York: Prestel Publishing L. Hendriks, J.van der Hoeve, 2009, *Guidelines for building archaelogical research,* Den Haag

Scope

Reusing buildings is a topic of current interest, because many buildings are left empty and are not used anymore as originally intended. A feasible design to adapt these buildings to another function will most likely save costs, resources and waste. When considering monumental buildings restrictions are applied and demolishing is no option.

This research focuses on the design case of two buildings of the flour factory in Leiden:

- I. the Mill
- II. the Flour Warehouse

These two buildings are unique. The design results will therefore be unique as well and cannot be translated directly to any other project. However the approach used to obtain these results can be applied to other design cases for reusing buildings. This method is based on finding a series of possibilities and to translate these into variant studies. Next the solution that fits best is selected to develop the final structural design (figure 1-1).

1.3 Report structure

This report consists of three parts, which are preceded by the introduction of the problem and an overview of the flour factory and concluded with an evaluation.

Part I consists of the architectural analysis, i.e. the background of the flour factory, the history and factory production processes, the monumental status, and the new design of Peter Zumthor and Partner. In part II the failures and structural analysis of the building are outlined. Part III will cover the variant studies and the final design. The last part is an evaluation about how the stated requirements are integrated in the design, how the structure influences the architectural and urban design and the final conclusion of this thesis.

On page II a map of the buildings can be found to support all the chapters with a quick reference.

2 The Flour factory

In this chapter an overview is given of the flour factory in Leiden, i.e. location, architects and buildings of the complex. All the buildings are described by typology, structure and material use, in chronological order. This overview of data of the flour factory is the base for the further research. In the chapters following this chapter the data of the buildings of the factory is used to make an architectural and structural analysis and a structural design.

2.1 General background

Flour factory 'de Sleutels' is a former Dutch flour factory located on the street Oosterkerkstraat 18 and next to the canal the Zijlsingel in Leiden (figure 2-1). It used to be an industrial complex to produce flour out of grain. The complex consists of different buildings, from different periods, which all had their own function in the process. At the moment the factory closed its doors it consisted of a boiler house, a cleaning building, one big building with silos for grain, a flour warehouse, a mill, one silo building for the flour, an office with a staff residence, a laboratory, a cycle shed and garage, and a building with workshops.



Figure 2-1 factory complex in Leiden

All the buildings of the factory complex were designed by the office of Architects B.N.A. in Leiden. First the architect W.C. Mulder, 1850-1920, designed the boiler house and the first silos. When Mulder passed away ir. B. Buurman, 1883-1951, designed the Mill and its extension, the new silos, the flour storage, the cleaning building, the office with a residence and he worked together with ir. I.M.P. Schutte, 1914-2007, on the expansion of the silos, the cycle shed and garage and the last expansion of the silos. The last building, the tower with silos Schutte designed together with G. H. Bellaard, 1926-1994. 5

The Dutch company KoninklijkeRotterdamscheBeton- en Aannemingmaatschappij (van Waning & Co) of Rotterdam and the HollandscheBetonMij. N.V. was the building constructors at that time. 6

Since 1988 the factory is closed. From 1990 on it has a new owner, but till present times it is still not in use. The municipality of Leiden could, at the time the factory closed its doors, not decide whether it was a monument or not and if so what the new function should be. In 2000 they made a decision and most of the buildings became

⁵ Rijksdienst voor het cultureel erfgoed, 2011, *monumentenregister Meelfabriek de Sleutels complexnummer 522146*, <u>www.cultureelerfgoed.nl</u>

Permits found in the archive of Leiden

⁶ Drawing of tower of silos 1966 and Drawing of flour warehouse 1937

listed monuments of the state. A plan was made by the municipality for reusing the buildings. The architect Peter Zumthor made a design to give the existing buildings new purposes.

Soil

There are two Cone penetration tests available, one recently made of a location 200 m in the North-east of the factory and one old CPT of the location, made in 1951. The new one is similar to the old one. In those is visible that there is one small sand layer at 0.0 till -0.8 NAP. The second layer is at -12.8 NAP. Which means that the piles should have at least piles with a length of I = 13 m, depending on which NAP level the top edge of the pile is (appendix C).

2.2 The Boiler House, 1896

The boiler house, in Dutch het Ketelhuis, used to be the building where the steam engines were situated. It has seven layers of floors, ground floor included and in total an area of 1900 m² floor space. At the western façade a stair case is added. ⁷

Structure:

The brick façade and an iron skeleton, transport the loads to the foundation. The iron skeleton consists of beams of rolled I profiles and cast-iron columns (figure 2-3). The columns have an U-head, which consists of two bolted pieces and are decorated (figure 2-2). Those columns are standing on a grid of 3500 mm. The arch shape floors are made from concrete. The concrete roof has the shape of a half cylinder and every 3 meters an iron profile resists the tension forces. It has a 15m span and is built according to the Monier system.⁸





figure 2-3 section Boiler house

Figure 2-2 on the inside the steel profiles bear the arch shape floor www.demeelfabriek.nl

H. Budel 1996, De meelfabriek en het milieu, Stielz December 1996, p23

⁷ L. Ummels and J. Gerrits, 2001, Gemeente leiden Dienst bouwen en wonen Uitgangspunten meelfabriek, Leiden: Stadsdrukkerij

⁸ 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie. Code:10386k. ABT bv

Rijksdienst voor het cultureel erfgoed, 2011, monumentenregister Meelfabriek de Sleutels complexnummer 522146, www.cultureelerfgoed.nl

Façade

The boiler house was built against another building. Therefore, the east and south façade have no openings. The north façade has three axes with window openings, later in time the windows of this third axe were filled with masonry (figure 2-5). The west façade consists of an axe of windows with large openings to lift goods (figure 2-4). At the top floor there is a balcony sticking out. ⁹



figure 2-4 Profiles visible in facade

figure 2-5 North facade, beeldbank regionaal archief leiden

2.3 Silos, 1904

The first silos were built in 1904 next to the canal. The grain, which was transported over the water, could immediately be lifted from the ship into the silos. It has seven floor layers and a surface of 1000 m² and is 21 meter high. ¹⁰

Structure:

The structure of the building is a concrete reinforced skeleton. Concrete columns on the ground floor bear the walls of the silo (figure 2-6). In the middle these orthogonal columns of 900 x 900 mm² (250/400/250), are more heavy then the side square concrete columns of 600 x 600 mm². The columns are standing on a grid of 3000 mm in transverse direction and 6000 mm in the other direction.¹¹ The roof has a rectangular top, with on both sides a pent roof supported by piers, with a cover of bitumen.¹²

Foundation:

The foundation consists of a wooden pile foundation with masonry dies, a wooden cross beam and a wooden half-log (figure 2-7). The foundation of the existing building standing next to it is bearing a part of the façade of the silos as well. Those piles have a diameter of 200 mm. The new foundation piles beneath the concrete structure have a diameter of 300 mm. The measurements of the cross beam are $115x350 \text{ mm}^2 / 130 \times 280 \text{ mm}^2$. The top of the cross beam is on NAP -1.19 m³. The number of piles is not known.

⁹ Rijksdienst voor het cultureel erfgoed, 2011, *monumentenregister Meelfabriek de Sleutels complexnummer 522146*, <u>www.cultureelerfgoed.nl</u>

¹⁰ Lara Ummels and Joop Gerrits, 2001, Gemeente leiden Dienst bouwen en wonen Uitgangspunten meelfabriek, Leiden: Stadsdrukkerij

¹¹ 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie. Code:10386k. ABT bv

¹² ing. N.T. Loonen, ir.F.J.J. Hofmans, V.M. Bakker, P van der Hoofd .2009. De meelfabriek te leiden, Onderzoek technische en constructieve kwaliteit. Code: 10386k. ABT bv





figure 2-6 section of the silos, in the back silos of 1937-38 and 55

figure 2-7 Half-log and cross beam, rapport aanvullend onderzoek kwaliteit fundering silogebouw 1904

Façade

The North façade of the silos are built against another building. This building was destroyed by a fire, but parts of the old brick wall are still attached to the concrete wall of the silos.¹³ The wall was coupled to the north façade with cramps for stability. The East façade is plastered in white (figure 2-9).¹⁴ How the other facades looked is not known but it can be assumed that the walls of the silos were the same as the North and East façade and that they were plastered white as well.



figure 2-8 Section, onderzoek ABT haalbaarheid



figure 2-9 East facade

¹³ ing N.T. Loonen. 2009. werkcode 10386 K. ABT bv.

¹⁴ Rijksdienst voor het cultureel erfgoed, 2011, *monumentenregister Meelfabriek de Sleutels complexnummer 522146*, www.cultureelerfgoed.nl

The uata with	ich ale known ale described in ta	IDIE 3.1.		
Concrete	Compressive strength N/mm ²	Cover mm	Carbonation mm	Fire resistance mir
columns	27	40	35	120
floors	21	no	-	-
walls	40	-	-	60
roof	-	22-40	-	90

Quality The data which are known are described in table 3.1. 16

table 2-1 quality of the silos 1904

2.4 Mill, 1931

The mill building, in Dutch Molengebouw, was built to expand the factory with engine rolling mills. It has seven floors and a height of 32 m. The length of the building is 28,5 m and the width 16,5 m. 15

Structure:

The structure is a steel skeleton, connected with rivets.¹⁶ It is a double portal, which repeats itself seven times every 5 meter (figure 2-10).¹⁷ On the ground and first floor extra columns are added. In between the portals extra floor beams are added, to shorten the span of the wooden planks of the floor. The ground floor rests on beams which are connected with the dies of the foundation¹⁸ (appendix D). The portal has very stiff connections (figure 2-12 and 2-13), which can be schematised as rigid. The dimensions of the profiles are taken over from the drawings of BBC management, who measured the elements and the heights of the floors, ceilings and structural elements (appendix D).





Het bouwbedrijf, p27-29, 11/3 1934

¹⁵ Lara Ummels and Joop Gerrits, 2001, Gemeente leiden Dienst bouwen en wonen Uitgangspunten meelfabriek, Leiden: Stadsdrukkerij

¹⁶ Rijksdienst voor het cultureel erfgoed, 2011, monumentenregister Meelfabriek de Sleutels complexnummer 522146, www.cultureelerfgoed.nl

¹⁷ G.F.E. Kiers, 11/3 1934, Staalskeletbouw te Leiden, *Het bouwbedrijf*, p27-29

¹⁸ 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie. Code:10386k. ABT bv



figure 2-12 Connections beams and columns *Het bouwbedrijf, p27-29, 11/3 1934*



figure 2-13 Connection façade to column *Het bouwbedrijf, p27-29, 11/3 1934*

Foundation:

The foundation piles are placed in groups under the columns. The maximum bearing load of a pile is 100 kN. The length of the piles is 14 meter. The columns are placed on a die with reinforcement in the form of a basket. The number of piles is assumed at 25 piles underneath the middle column, 20 piles underneath the façade columns and 4 piles underneath the small columns at the ground and first floor (appendix D).

Façade:

The Brick facade is placed on an iron profile which is connected to the steel columns (figure 2-14). On every floor there are strokes of windows in steel frames.

Quality

The steel profiles are calculated with a maximum yielding strength of 137 N/mm^2 , this also included safety factors in SLS.



figure 2-14 East façade Het bouwbedrijf, p27-29, 11/3 1934



figure 2-15 connection columns www.demeelfabriek.nl



figure 2-16 Interior first floor www.demeelfabriek.nl

2.5 Storage for flour, 1937

The storage for flour, in Dutch Meelmagazijn, was used to store the sacks of flour. It has seven floors and a total floor area of 5250 m². 19

Structure

The structure consists of concrete orthogonal mushroom columns which narrow in size to the top floor levels, on top of those columns are concrete flat slabs. The columns are placed on a grid of 4750 mm x 4750 mm and have sizes of 900 x 900 mm² (200/500/200) on the ground floor. ²⁰



figure 2-17 Facade from waterside



figure 2-18 mushroom columns on ground floor

¹⁹ Lara Ummels and Joop Gerrits, 2001, Gemeente leiden Dienst bouwen en wonen Uitgangspunten meelfabriek, Leiden: Stadsdrukkerij

²⁰ 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie. Code:10386k. ABT bv





figure 2-19 Section

figure 2-20, Foundation, archive Leiden rapport ABT haalbaarheid

Foundation

The columns rest on concrete dies with 5 x 5 wooden piles. The upper part of the wooden pile is at NAP -1.80 m.²¹ Diameter of the round piles is 265 mm. The wooden piles are damaged in the first 10 mm. Because they have the same characteristics as the piles of the mill, the capacity of the piles is considered as 100 kN.

Façade

The façade is a cavity wall with brickwork on the outside and concrete blocks on the inside. Cantilever walls bare the façade. The windows have steel window frames.

Quality

The data which are known are described in the table2.2.²⁵

Concrete	Compressive strength N/mm ²	Cover mm	Carbonation mm	Fire resistance min
Columns	40	34	20	120
Floors	30	15	-	60

table 2-2 quality of the flour warehouse

²¹ ing. N.T. Loonen, ir.F.J.J. Hofmans, V.M. Bakker, P van der Hoofd .2009. *De meelfabriek te leiden, Onderzoek technische en* constructieve kwaliteit. Code: 10386k. ABT bv

2.6 Silos from 1937 and 1938

In 1937 a new building with eight silos was built and in 1938 another one with eight big silos and eight small silos was added. The buildings are designed in the same way. The building from 1937 is 12,6 m width and 25 m long. The building from 1938 is 26,7 m long and 12,65 m width. Both buildings are 41 m high. On top of the buildings there is a big S, from the factory name 'Sleutels'.

Structure:

The structure is a tube structure of reinforced concrete with a closed bottom. The walls of the silos are supported by concrete columns. Every transverse wall is beared by three columns. The middle column is directly underneath the point were the walls cross each other. But the facadewalls are not directly in the grid line of the columns, but cantilever (figure 2-23). In between the ground floor and the silos are flat slab floor plates. The building from 1937 has a grid of columns from 4200 mm x 4500 mm and the columns measure 1300 x 1300 mm² (200/900/200). The façade columns are 220 x 220 mm². The building from 1938 has a grid of columns from 4200 mm x 4460 mm and the columns measure 1200 x 1200 mm² (200/800/200).

The upper floor on top of the silos consists of concrete columns, beams and a concrete roof and has steel window frames. Because the buildings were not built at the same time, there is a dilitation in the middle.

Foundation:

The columns are standing on concrete dies, beared by concrete square piles of 200 mm x 200 mm or wooden piles with a concrete lengthening piece. Per die there are 20, building from 1937, or 18 piles, building from 1938, present. The ground floor is a sandwhich-construction with concrete-sand-concrete (figure 2-24).²³

Façade

The façade are mostly the walls of the silos, made out of concrete. The south façade is covered with profiled steel, with a big sundial attached to it (figure 2-22).





figure 2-22 Facade silos 1938 with sun dial

 ²² 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie.
Code:10386k. ABT bv

²³ ing. N.T. Loonen, ir.F.J.J. Hofmans, V.M. Bakker, P van der Hoofd .2009. *De meelfabriek te leiden, Onderzoek technische en constructieve kwaliteit*. Code: 10386k. ABT bv

Concrete	Compressive strength N/mm ²	Cover mm	Carbonation mm	Fire resistance min
Columns, 1937	36	28,7	-	75
Columns, 1938	37	30	45	120
Floors, 1937	31	24	-	60
Floors, 1938	30	20	-	60-90
Walls, 1937	-	34,4	-	75/105
Walls, 1938	-	28		75/105
roof	-	30	-	-

Quality The data which are known are described in the table 2.3.²⁷

table 2-3 quality of the silos from 1937-38



figure 2-23 Floor plan first floor, drawing foundation silos 1938 – archive municipality Leiden



figure 2-24 Section foundation, drawing foundation silos 1938 – archive municipality Leiden



figure 2-25 Ground floors silo 1938, www.demeelfabriek.nl



figure 2-26 Rooftop silos

2.7 Cleaning building

The cleaning building, in Dutch Schoonmakerij, was used to clean the grain. It consisted of 9 floor layers, including ground floor. It has dimensions of 12,2 m by 32,8 m and a height of 35 m.

Structure

The structure is a concrete skeleton of columns and beams with wooden floors (figure 2-27 and 2-28). The columns have dimensions of 700 x 700 mm² in the façade and on the ground floor middle columns of 700 x 1200 mm² and columns of 350 x 500 mm². The grid of columns is 4600 mm in the length direction and 3200-4200-4800 mm on ground floor and 3200-9000 mm on other floors in transversal direction. In the east part silos are positioned. ²⁴

Façade

The façade is a red and yellow brick wall, with steel frame windows. ²⁵



²⁴ 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie. Code:10386k. ABT bv

²⁵ Rijksdienst voor het cultureel erfgoed, 2011, monumentenregister Meelfabriek de Sleutels complexnummer 522146, www.cultureelerfgoed.nl



figure 2-29 Interior 7th floor level

2.8 Extension of the mill, 1947

In 1947 the mill building was expanded with an extra building of six floors and dimensions of 9,85 m x 25 m and a height of 26,5 m. It is designed almost in the same way as the mill, same materials and elements, only this time it is a single portal and it has smaller dimensions (figure 2-30).

Structure

The structure is a steel skeleton, connected with rivets. The columns and beams are rolled DIN profiles, comparable with HEB profiles. In between the portals there are extra rolled DIL profiles to support the wooden floor. The dimensions of the profiles are taken over from the drawings of BBC management, who measured the elements (appendix E). The columns are positioned on a grid of 5000 x 9850 mm. In between the portals extra beams are added to shorten the span of the wooden planks of the floor. Except for the ground floor, which is a concrete floor, lying lose on the sand bottom.²⁶ The mill building also has very stiff connections.

Foundation

A concrete die on concrete piles bears the load coming from the columns. Every die has 4 piles, which have a capacity of 640 kN. The length of the piles is 17,5 m (appendix E).

Façade

The facade is the same as the mill building from 1931, only in this building it is placed on cantilever steel beams.

Quality

The steel profiles are calculated with a maximum yielding strength of 157 N/mm^2 , this also included safety factors in SLS.

²⁶ 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie. Code:10386k. ABT bv



2.9 Silos 1955

In 1955 another eight pair of silos is added to the buildings with silos from 1937 and 1938. It has almost the same design, except for an extra floor beneath the silos and other dimensions of the elements of the structure. Next to the canal a tower is placed with an staircase and elevator.

Structure

The structure is a tube structure of reinforced concrete with a closed bottom. The walls of the silos are supported by concrete columns (figure 2-21). In between the ground floor and the silos are flat slab floor plates. The columns are standing on a grid of 4250 mm x 4150 mm and the orthagonal columns measure 1100 x 1100 mm² (200/700/200).²⁷ On the first floor there are beams of 250 x 630 mm², and a concrete floor of 100 mm thick. The big silos have walls of 200 mm thick and the small ones of 120 mm thick. On the sides of the façade 60 mm of isolation material is added to the silo walls. The floor above the silos has columns of mm x mm, and concrete beams of 300 mm x 600 mm. The floor consists of 90 mm bimsplates and 80 mm of concrete. The highest floor consists of concrete columns of 250 mm x 350 mm and roofbeams of 250 mm x 450 mm (figure 2-34). The roof consists of hollow core slabs of 100 mm, bimsconcrete of 80 mm and a bitumen roof covering. The façade columns are 220 x 220 mm². The tower is supported by concrete rings, in the corners supported by columns and in the lower part also by the walls of the silos.

Foundation:

The columns are standing on concrete dies, beared by concrete piles of 350 mm x 350 mm, with a maximum bearing capacity of 540 kN or concrete piles with wings of 350 mm x 350 mm, with a maximum bearing capacity of 390 kN (appendix F). The ground floor is a sandwhich-construction with concrete-sand-concrete.

 ²⁷ 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie.
Code:10386k. ABT bv

Façade:

The South façade are the concrete silo walls covered with a white layer of paint (figure 2-32). In the North the walls border on the silos of 1904. The upper floors consist of concrete walls of 120 mm thick with aerocrete plates of 50 mm as insulation.

The façade of the tower is on the outside brickwork and on the inside concrete blocks, with steel frame windows. ²⁸ On the top there is a decoration of 'de sleutels' in concrete (figure 2-35).



figure 2-32 South façade silos 1955



figure 2-33 elevator silos 1955



figure 2-34 on top of the silos, 10th floor



figure 2-35 tower with keys

Quality

The data which are known are described in the table 2-4.³²

	Compressive strength N/mm ²	Cover mm	Carbonation mm	Fire resistance min
Columns	38	39	45	120
Floors	31	18	-	60-90
Walls	40	26	-	30-60-90
roof	-	30	-	-

table 2-4 quality of the silos from 1955

²⁸ ing. N.T. Loonen, ir.F.J.J. Hofmans, V.M. Bakker, P van der Hoofd .2009. *De meelfabriek te leiden, Onderzoek technische en constructieve kwaliteit*. Code: 10386k. ABT bv

2.10 Tower of silos, 1968

The tower of silos was added to the complex in 1968 to store the flour in silos instead of sacks. It has eleven floors and a total floor space area of 4400 m². ²⁹

Structure

The structure is a tube structure of reinforced concrete with a closed bottom, designed in the same way as the other silos (figure 2-39). The columns at ground floor are $1200 \times 1200 \text{ mm}^2$. Standing on a grid of 4400 mm x 4200 mm, on the North side, or 4400 mm x 5400 mm, on the South side. The inside measurements of silos are 1900 mm x 3900 mm or 1900 mm x 5100 mm. On the Easth side, at the side of the water, there is a concrete structure of columns and beams and concrete floor plates.³⁰



figure 2-36 North facade



figure 2-37 section silos

²⁹ ing. N.T. Loonen, ir.F.J.J. Hofmans, V.M. Bakker, P van der Hoofd .2009. *De meelfabriek te leiden, Onderzoek technische en constructieve kwaliteit*. Code: 10386k. ABT bv

³⁰ 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie. Code:10386k. ABT bv



figure 2-38 Floor plan floor 1

Foundation

The foundation consists of a concrete sandwich-structure floor plate of concrete-sand-concrete, to transfer the load to the 306 concrete square piles. The piles have a length of 16m and a diameter of 300 x 300 mm². The piles have a capacity of 785 kN each, as is described in the drawings.



figure 2-39 Foundation – archive municipality Leiden

Façade

In the east façade the beams and columns of the structure and the brickwork in between is visible. When there would be an explosion, the brickwork can pop out easily (figure 2-36). ³¹ The other facades are the walls of the silos and are concrete walls with a layer of plaster.



figure 2-40 Tower of 1955 with flour storage, silos from 1904 and the new silotower

Part I

Analysis of architecture

Preconditions for the structural design are derived from the history of the factory, production process, monumental values, new design and vision of the architect.
3 History of the city of Leiden

The flour factory is located in Leiden. At the time the factory was built it was located on the outskirts of Leiden. However as the town expanded the factory became part of the city centre. In this chapter this development will be described. It will explain why the factory complex lies on a good location in Leiden to redesign.

3.1 11th century

Leiden, a settlement along the Rijn, was formed in the 11th century. A lot of canals were dug for irrigation, because in this area there was a lot of agriculture. A big part of the infrastructure nowadays is influenced by this structure of canals. As at that time the important roads were located next to the big rivers, the Rijn, the Mare and the Vliet. The first buildings were situated near the two dikes of the Rijn.³²



figure 3-1 city of Leiden around 1100

3.2 17th century

In the 17th century the city increased. The fortifications and defence walls at the canal formed the borders of the city (figure 3-2). In the beginning of 17th century the population had increased because of the successful textile industry. A shift of social classes and changing functions of housing was a response to this development. All space left in the city was filled up with small workmen houses. As there was not a real or good urban design to expand the city. The municipality had made a design to dug canals to build bigger and more beautiful and expensive houses next to, but most areas were filled with these small workmen houses, because there was a need for. ³³



figure 3-2 city of Leiden expanding 1300 – 1800, in red location of the flour factory

3.3 18th century

In the 18th century there was not enough space left in the city for housing or industry. However, the municipality of Leiden could not extend outside her borders because then it would have come in conflict with the surrounding municipalities. They had decided to demolish 6 out of 8 gates to the city and the defence walls

³² J. Droge, E. de Regt, P. Vlaardingerbroek, 1996, *Architectuur en monumentengids Leiden*, Leiden

³³ Adviesbureau RBOI Rotterdam/Middelburg, 2007, Leiden, Binnenstad I, Bestemmingsplan

Geschiedenis de meelfabriek, http://www.demeelfabriek.nl/nl/geschiedenis/

to use this space for housing and industry. The area of the former defence walls had turned into an industrial area. A good location for industry because of the possibilities the river offers for transport.³⁴

3.4 19th century

In the 19th century the dwellings in the area around the factory were deteriorating. Therefore, these areas could be used to extend the factory areas even more. All the old defence walls were used to extend the industrial area, except for the old defence walls in the south, where green parks were realized. ³⁵ The flour factory is built on a former defence wall in the east of Leiden (figure 3-3).

3.5 20th century

In the 20th century large parts of the city were deteriorated. A lot of the factories moved to places elsewhere because the factory area became too small or they went bankrupt. These former factories were demolished and green parks are now situated there, except for the Flour factory. The factory site is therefore surrounded with parks nowadays. In 1982 the centre of Leiden was pointed out as a protected city view area, which means that the architectural values of the urban design of the centre have to be remained. It was uncertain if the flour factory belonged to this protected urban design as well.



figure 3-3 city of Leiden expanding 1900 – 2012, in red location of the flour factory

3.6 21th century

Nowadays the factory complex is located in the centre of Leiden (figure 3-3), and surrounded by parks. This makes it a strong location to attract public. Therefore, it offers good opportunities to have a change of function of the factory. Furthermore, only the flour factory and the factory of light are still standing, the other factories are demolished. The flour factory can therefore be seen as a memory to the industrial past of Leiden.

³⁴ 1999, De meelfabriek van leiden, sloop of hergebruik?, Monumenten, Jaargang 20, nr.5 oktober 1999 Negentiende en begin twintigste eeuw:Leiden industriestad,

http://erfgoed.leiden.nl/geschiedenis/stadsontwikkeling/leiden-industriestad/

³⁵ H. de Jonge en S. de Lange, 1997, Benarde veste, Leidse stadsuitbreidingen door de eeuwen heen, Leiden

4 History of the flour factory 'Meelfabriek de Sleutels'

The factory is built on the site of the former defence walls. The complex consists of ten buildings, which are built in different time periods and with different purposes. This chapter explains why and when these buildings were built. Important events in building the factory complex are mentioned here to examine with which purpose the factory is built.



figure 4-1 around 1884, the first factory buildings, Beeldbank regiearchief leiden



figure 4-2 1891 fire



figure 4-3 1896 factory



figure 4-4 around 1900, the second factory building, Beeldbank regiearchief leiden



figure 4-5 1901 fire

In 1855 the excises on the mill in the Netherlands were repealed. At the same time a steamroller to roll the grain was invented, which replaced the old mill stones and made the production of flour faster and easier.

In 1884 the flour factory was established by Adriaan Koole and Arie de Koster on a former defence wall. It was build next to the canal Zijlsingel and the street now known as Oosterkerkstraat (figure 2-1).

Adriaan Koole was the owner of a grain mill in Leiden. From 1879 on he also owned a small factory in Leiden, where the grain was steamrolled mechanically. In 1883 he had bought the area of the factory. Arie de Koster from Gouda was a merchant in grain, seeds and flour. He came in 1870 to Leiden to establish Koster en Compagnie.

Together Koster and Koole had arranged a partnership. On 29 April 1884 they had established the steam flour factory, which could make far larger productions of flour in Leiden in comparison with the old mills without the steam engines. The Flour Factory build in 1884 was constructed in wood, with a silo, cleaning space, a mill and storage (figure 4-1). Another building contained the boilers and steam engines.

In 1886 Koole died. De Koster had bought his share in the company from Kooles family. In 1888 he had decided then to expand the site with extra silos and storages, made of wood. In 1889 extra storage rooms were built. In 1891 a big fire destroys all the buildings, except for the storages built in 1889 (figure 4-2).

The factory was rebuilt after the fire (figure 4-3 and 4-4). Only to be destroyed by another fire in 1901. However this time the boiler house and the silos were still standing. ³⁶ The boiler house was built in 1896, by a design of the architect W. C. Mulder (chapter 2.2).

Probably because of the fires the new buildings were built in concrete, which has a bigger resistance against fire.

In 1904 the first silo building was realised to store the grain (figure 4-6). It was one of the first reinforced concrete buildings in the Netherlands and at this moment it is the last reinforced concrete silo still existing (chapter 2.3).

³⁶ 1999, *De meelfabriek van leiden, sloop of hergebruik?*, Monumenten, Jaargang 20, nr.5 oktober 1999



figure 4-6 around 1910, on the left the first silos from Website Stiel Leiden



figure 4-7 1931 the mill



figure 4-8 1937 cleaning building



figure 4-9 1937 flour warehouse



figure 4-10 1937 silos



figure 4-11 1938 silos

In 1928 the name of the factory was changed in NV Meelfabrieken de Sleutels, v/h de Koster & Co. This time the sons of de Koster were Managers of the factory.

In 1929 the wheat law was introduced in the Netherlands. This law was made to prepare the Netherlands for the threatening war. The company had to increase their production very quickly. Therefore the factory was expanded with a mill (figure 4-2). Because it had to be erected quickly, they chose to build it with a steel structure. It was realised in a steel skeleton in 1931 (figure 4-7 and chapter 2.4).

Another flour factory in Rijswijk, nearby Leiden, was shut down in 1937. The production moved to Leiden, which meant a bigger production at the factory site. ³⁷ In the same year a cleaning building was added to the factory to store the flour (figure 4-8 and chapter 2.7). When the warehouse was realised, a flour warehouse was added (figure 4-9). It was constructed with a concrete structure (chapter 2.5) to cope with the bigger production and as a result of the demand of the government to store more wheat because of the threatening war. Moreover, a silo was added (figure 4-10). The year after, in 1938, the factory was expanded with another silo building (figure 4-11 and chapter 2.6). This silo was also constructed in concrete.

In 1940 the office building/laboratory with a service house was built at the entrance of the area. This building was constructed in brick. After the office was constructed a cycle shed and three garages were added to the complex.

After the Second World War the factory produced 20% of the total Dutch flour production. Besides the flour, it also produced grits (a base for macaroni). Hans de Koster, a grandson of Arie de Koster, was the director of the factory from 1946 till 1967.

In 1947 the mill was expanded with extra space (figure 4-12). A 7 floor high building was built next to it with the same structure (chapter 2.8).

In 1955 another silo building was added, especially for the production of bran (figure 4-13). This silo had a tower with a long ventilation shaft. And in the top of the tower the keys of Leiden were inscribed, as was the name of the factory (chapter 2.9).

³⁷ Eric Jan Weterings, 1996, *Meelfabriek de sleutels een historisch overzicht*, Stielz december 1996, Jaargang 7 nr4,



figure 4-12 1947 extension of the mill



figure 4-13 1955 silos for bran



figure 4-14 1956-1964 fire



figure 4-15 1964 tower of silos



figure 4-16 drawing El Lissitzky

In 1964 the flour company Meneba from Rotterdam took over the company from Hans de Koster. There was still a big production and in 1964 one extra silo next to the canal was added (figure 4-15 and chapter 2-10). These silos were specially made for flour instead of wheat. This way the flour could be transported in trucks.

In the nineties the United States of America offered grain for very low prices to the Middle-East. Meneba could not compete with this and they were contending with overproduction. An Australian owner took the company over. ³⁸ However, Meneba lost a lot of customers and decided to move the total production to Rotterdam. In 1988 the flour factory in Leiden was closed. After closing down the factory, some parts of the building were used for a few years as storage rooms and office rooms. Eventually the building was left unused until now. ³⁹

In 1992 a painting was made on the wall of the tower of silos called 'the two squares' by El Lissitzky (figure 4-16). It measures 17 by 21 meter. It represents a Russian fairy tale of two squares. The red square always wins from the black square. It is an accolade to the 'Stijl', a tendency of artists established in Leiden (appendix H).

At the end of the twentieth century most factories in Leiden were demolished and parks were realised. Next to the flour factory are two parks. One is named Katoenpark (in English Cotton park). As before cotton factory was established here, and on the other side lays the Ankerpark (in English Anchor park). The park owes its name to a forge that used to be situated there.⁴⁰

In 1998 Ab van der Wiel⁴¹ bought the old factory. In 2001 the factory became a listed monument of the state. At that point a new design could be made. The State Architect Jo Coenen, chose Peter Zumthor as the architect to make a renovation design for the factory.⁴² In 2002 the partnership Meelfabriek CV was established. The factory should act as a central point of Leiden, but also of the near villages. Furthermore, it had to offer new urban energy to the surrounding neighbourhood. The goal of the preservation of the valuable parts of the historical monument. Peter Zumthor & Partner, together with the municipality, developed a masterplan for the whole factory complex. In October 2007 the master plan was approved by the municipality.

³⁸ Henk de boer: hart voor de meelfabriek, Michiel Rohlof, Stielz jaargang 14 nummer 4 december 2003, De meelfabriek van leiden, sloop of hergebruik?, Monumenten, Jaargang 20, 1999 nr.5 oktober

³⁹ Het spoor van de industriële revolutie in een Hollandse stad, Primavera Pers & Stiel. Leiden 2002, Henk Budel

⁴⁰ Rijksdienst voor het cultureel erfgoed, 2011, monumentenregister Meelfabriek de Sleutels complexnummer 522146, www.cultureelerfgoed.nl

⁴¹ Ab van der Wiel is a real estate developer, who has a lot of projects in and around Leiden.

⁴² analyse betekenis machines en installaties voor productieproces van meelfabriek de sleutels, Drost en Moerland Projectmanagement 22-04-2009



figure 4-17 1950, in front the mill and the extension, in the middle in white the Silos, on the right the flour warehouse and in front right the office, Beeldbank regiearchief leiden



figure 4-18 around 1950, left to right, Flour warehouse, Silos(1955), Silos(1904), the old factory building, in the back the cleaning building, the boiler house, and more in the back the mill, Website de meelfabriek



figure 4-19 2010, site at the Zijlsingel, left to right, Meelmagazijn, Silo(1955), Silo(1904), Silotower, Website de meelfabriek

5 Process of the production of flour

Around 1900 the factory consisted of one factory building where all the processes of making flour took place. However, as after the Second World War the production was increased to 20% of the Dutch flour production the factory had to expand. In this chapter the production process and the functions of the buildings are explained. This will give an insight with which intend the structures of the buildings are designed.

When the grain and wheat arrived per ship, the wheat was stored in the silos or shifted to the cleaning building (figure 5-1 and 5-2). In the Silos the wheat was transported with elevators to the top floor to store it in a silo.



figure 5-1 old silos with a piston



figure 5-2 tower of silos with a piston

Cleaning of the grain means taking the weeds out of the wheat. In the Cleaning building the process started at the highest floor and at every floor level the process continued a little further. After cleaning, the wheat was transported to the highest floor again to moisturize it. This was done with a big screw with water sprinklers.

Next in the process was the separation of the wheat in the Mill. A grain granule consists of a skin, a germ and an endosperm. These three have to be separated by reducing them with steamrollers followed by sifting the grain.⁴³ To make the factory adaptable to changing situations, there are wooden floors used in the Cleaning building and the Mill. In this way it was easy to make holes for ducts.⁴⁴

When this process was finished the flour had to be stored in jute sacks, which were stored in the flour warehouse. With steel slopes the sacks were transported from higher floors to lower ones (figure 5.4). After 1964 the flour was also stored in silos, because in this way it was easier to transport it with trucks (figure 5-3).⁴⁵



Figure 5-3 truck loading from silo



figure 5-4 Interior flour warehouse, www.demeelfabriek.nl

⁴³ M. Rolof. 2003. Henk de boer: hart voor de meelfabriek. Stielz, December 2003 nr 4, p3-5

⁴⁴ E. J. Weterings. 1996. *Meelfabriek de sleutels een historisch overzicht.* Stielz, december 1996 nr4, p 10-11

⁴⁵ Wibo Burgers. 2000. *Leidse meelsilo van 1955: bijzondere ontwikkeling*. Leiden. Stielz jaargang 11, nr 3/4.

Part of the flour was taken to the laboratory to test all the different kinds of flour on its quality. The humidity and the amount of protein of the flour were measured. After these tests they made bread out of the flour in the test bakery and examined how the flour reacted in production. 46



figure 5-5 process in the factory

This dynamic process will come back in the new design (chapter 8). The different factory buildings will have different functions which are connected by ground floor, with bridges or over water.

⁴⁶ E. J. Weterings. 1996. Sluiting meelfabriek kwam als donderslag bij heldere hemel. Stielz, december 1996 nr4, p 12-14

6 The flour factory, a listed monument of the state

In 2001 the factory became a listed monument of the state. What a listed monument of the state is, what its values are and why the factory is listed as such, is described in this chapter. The monumental values will limit the possibilities in adapting the structure to the architectural redesign.

6.1 Official monument

A listed monument of the state from 1800 or younger should be self financially providing because the state cannot finance all these monuments anymore. A new purpose for a building is a good possibility to make such a monument financially independent. ⁴⁷ Because the buildings of the flour factory are in a good state and the location is in the centre of Leiden these buildings have potential. The area is spacious, it is surrounded by parks and the different buildings can be used for different purposes, which increase possibilities for redevelopment.

The Public Service of Cultural Inheritance is an institute that determines whether or not a building is a state monument, helps the municipality with the maintenance and gives advice about restoration and a new purpose for the building.⁴⁸

The municipality determines if an Environment Permit is submitted. When a monument is restored, demolished, adapted or changed an Environment Permit is needed. The Public Service of Cultural Inheritance gives the municipality advice in these matters (appendix G).⁴⁹

Since 1988 the year the factory was shut down, the municipality debated about the destination of the factory. Ten years later the developer Ab van der Wiel bought the old factory. In the same year, on a city debate, the municipality decided to keep ten of the thirteen buildings from the factory complex to redevelop those and they were assigned as listed monuments of the state. In 2000 the factory buildings became listed monuments of the state. Peter Zumthor, architect, is chosen by Rijksbouwmeester Jo Coenen to design a new plan for the factory.

6.2 Monumental values

According to the Architectural conservation, by Aylin Orbasli, monuments can be valued in different ways. The flour factory is a valuable monument (appendix G). 50

- i. Because it is a rare complex of buildings.
- ii. The flour factory is of architectural importance for the works of Mulder, Buurman and Schutte.
- iii. The factory is of historical value because of the resistance in the second world war;
- iv. The complex is valued as a townscape value as a landmark of the canals of Leiden;
- v. The factory is of public value because an organization was set up to protect the buildings from demolition, who are now organized and concerned with other monumental buildings as well;
- vi. It is of technical value as an example of early reinforced concrete buildings.

⁴⁷ Peter Nijhof, Ed Schulte. 1994. *Herbestemming industrieel erfgoed in Nederland*. Zutphen. Walburg pers

⁴⁸ Mw. Mr. A. Marion, Ing. W. Vos. 1996. *Monumenten op en in de grond. Naar één integraal gemeentelijk monumenten en archeologie beleid*. Den Haag. Vereniging van Nederlandse gemeenten

⁴⁹ <u>http://www.cultureelerfgoed.nl/monumenten</u>

⁵⁰ Aylin Orbasli. 2007. Architectural Conservation. Blackwell Publishing

6.3 Values of the factory, according the register of monuments

The complex of the flour factory consists of ten listed monuments of the state. Every building has its own unique characteristics. Below is discussed how the monumental values of the factory are stated in the register of monuments in 2001.⁵¹

In general

The factory complex is an example of the last memories of the industrial past of Leiden. The Silo buildings from 1955 and 1960 were, at the moment of indicating the status of the monuments in 2001, too young to be a listed monument of the state, as a listed monument of the state has to be at least 50 years old. The building from 1978 with storage rooms and workplaces has no monumental value at all. The other buildings of the factory complex are all listed monuments of the state. The buildings are of importance because of their architectural and cultural-historical value. Every single building is each of them of importance for the unique ensemble of the complex, and the way they are situated opposite each other. Moreover, the location of the former bastion besides the canal makes it a unique location.

The tower of silos and the silos from 1955, not listed as monuments, are important because of the ensemble they make with the other buildings. The tower of silos, the silos of 1904 and 1955 and the flour warehouse are landmarks next to the canal and the office building mark the entrance. The silos from 1937, the cleaning building and mill buildings mark the street of the complex.

Boiler House, 1896

The importance of the Boiler House is that it is an architectural and cultural-historical example of a commercial and industrial building, with an early use of an arched concrete floor combined with an iron structure. The special details of the connections of iron beam and columns are also of importance. The shape of the roof is unusual with this kind of building; normally this is only used within railway buildings. Another aspect is that it is an important building in the works of the architect W. C. Mulder. The staircase in this building is not of importance.

Silos, 1904

The silos are an architectural and cultural-historical example of a silo building. Furthermore, the silos are one of the first reinforced concrete silo structures that still exists The special details of the shape of the silos makes it an extraordinary building as well.

Flour Warehouse, 1937

The Flour Warehouse is an architectural and cultural-historical example of an industrial building with a concrete structure with mushroom columns. The structure exists of a flat surface floor supported by octagonal columns with an octagonal head. This was a common way of building warehouses. However, the structure of the Flour Warehouse is. Firstly, in a building normally a column plate is present which transfers the forces to the column. In this case the floor lies directly on the columns. Moreover, the Flour Warehouse has a massive façade which only have a separating function and not a supporting function.

Cleaning Building

The cleaning building has an architectural and cultural-historical example of an industrial building with characteristics of the architectural style 'Modernism'. This is expressed in the façade which is very massive but does not have a supporting but a separating function. The structure of the Cleaning Building exists of concrete skeleton with wooden floors; this was a unique combination at that time.

⁵¹ complexnummer 522146, of the Rijksdienst voor het cultureel erfgoed.

Mill and the extension of the mill

The Mill is an industrial building with characteristics of the architectural style 'Modernism'. The assembly of the load bearing floors is also characteristic. Another typical feature is that the external walls have only a separating and not a supporting function.

Office and official house and Cycle shed and garage

The office is also an architectural and cultural-historical example of a double building in a proportional way with characteristics of the architectural style 'Modernism'. It is of value of its urban design because of the eye-catching appearance at the entrance of the factory area. It is also an important building in the works of the architect B. Buurman.

The Cleaning building, Mill and its extension, the office building and garage are mentioned for their characteristics of the architectural style modernism. These distinctive features of the modernism (appendix H) are visible in the façades of brickwork, the stereo metrical forms, the designs for their functions and the glass strokes (figure 6-1 and 6-2).



Figure 6-1 Brickwork and glass strokes



Figure 6-2 Brickwork, plaster and glass strokes

Most of the monumental values will be remained in the new design. However a change of values is observed when the municipality determined their demands, described in the next chapter. Moreover, more changes occur in the values of the monuments when the architect Peter Zumthor makes a new plan, described in chapter eight.

Demands for the design for the flour factory by the municipality of Leiden 7

In 2001 the municipality of Leiden developed a list of demands as basis for the design. This list is based on the urban design plan of Leiden, namely Bestemmingsplan I. In the list the municipality expresses the desire for the redevelopment of the area of the flour factory regarding urban design, infrastructure and planting. Furthermore, the monumental values which have to be remained are mentioned, this list differs from the monumental values determined by the Public Service of Cultural Inheritance, as described in chapter 6. This chapter indicates the important preconditions for the architectural design.

7.1 Urban design

Regarding the urban design the old canal Binnenvestgracht will be repaired, the green parks will be connected and the site will be a pedestrian area.

To repair the historical structure in this area, the old canal Binnenvestgracht is restored (figure 7-2) and therefore, the office has to be demolished (figure 7-1). By repairing the canal, the area is subdivided in two areas: one on the east, next to the Singel with the old factory buildings and one on the west with new buildings. The eastern part will be redeveloped for the functions of dwellings, recreation, offices and other amenities. The western part is solely for dwellings. This is determined in the urban cityplan Bestemmingsplan I.







figure 7-1 demolish office

The green areas on the site will connect the two parks (figure 7-3):

- a. The Ankerpark on the north site
- b. The Katoenpark on the south site

The Oosterkerkstraat will be the main road for car traffic and connects the main road with the site and parking garage. In the western part there is one way traffic allowed and the eastern part will become a pedestrian area (figure 7-5). Most of the parking space should be underground or in the building itself. There is a pedestrian area between the two parks, which will also connect the Western part with this area by pedestrian bridges.

The old boiler house in the north and the old office in the south determine the building lines. The new buildings in the west should be between these building lines (figure 7-4).





In the western part there is a maximum of three floors and the maximum height is 12 meters. In the eastern part it should not exceed the height of the existing buildings and should not cause shades in the area.

Programs of functions

The program of functions is described in appendix I.

7.2 Boundary conditions of redesigning the monuments set by the municipality of Leiden

These monumental values should be remained according the list of demands:

- a. *Office and residential living, 1940*: the characteristic elements should be maintained; the steal windows, the entrance and the structure of the floor plan, the staircase, the interior of the board rooms and the interior of the front room on the first floor. However, repairing the historical structure, the old canal, is more important than the maintenance of the office.
- b. *Cycle shed, 1940*: it is built together with the office and should be maintained therefore. The characteristic elements are steel windows and the steel portal.
- c. *Flour warehouse, 1937*: the functional architecture should be remained. Characteristic elements are the concrete structure with mushroom columns and flat floors and the facades with window strips.
- d. *Silos 1937,1938,1955,1960,1904*: the facades can be removed, as long as it it fits with the architecture and it shows the industrial character. The compartments of the buildings, the silo structure, however, should be maintained in a way that the structure is visible.
- e. *Boiler house,1898*: maintain the structure and the concrete round roof. Adjustments can be made but with a sober, functional style of architecture.
- f. *Mill 1937 and extension 1947*: remain the steel skeleton and the windows in the facade.
- g. *Cleaning building, 1937*: remain the marking character of the windows. Adjustments can be made but with a sober, functional style of architecture.
- h. *Workshops building, 1978*: this building does not have a monumental value.
- i. *For all the monuments*: storages should be inside the buildings, sun blinds should not be visible. There should be enough space inside for trafospaces. Entrances should be clustered together.

Other demands to take into account for the new design:

- j. The area should be redesigned by one designer.
- k. The architecture of the dwellings should be referred by existing dwellings in the city.
- I. Materials should be inspired by brick wall architecture, modern built with respect for old traditional buildings.⁵²

In the demands of the municipality there is a change of monumental values of the buildings of the factory visible. The façade of the flour warehouse, registered as a monumental value, is not mentioned to be maintained. Moreover, the office is seen as a landmark of the entrance in the register. However, in the list of demands it can be demolished to restore the old canal.

⁵² Lara Ummels and Joop Gerrits. 2001. *Uitgangspunten meelfabriek, Gemeente Leiden Dienst bouwen en wonen*. Leiden: Stadsdrukkerij

8 New functions for the old factory, a design by Peter Zumthor

Peter Zumthor and Partner are selected to make a redesign for the factory complex. The design is based on the demands of the municipality of Leiden, described in chapter 7. The change of monumental values is described here as well. The design is the basis for the structural analysis and structural design.

Municipality, The Public Service of Cultural Inheritance and owner made an agreement that the architect has this freedom to make a good design that fits the urban plan of the city of Leiden. 53

The architect Peter Zumthor believes there is beauty and strength in the physical structures of the buildings, he emphasises the structures of the factory buildings as the real monumental values. The structure of these monuments is more important than the aesthetics of the building, which makes it possible to allow a certain freedom to design. Therefore the structures will be preserved. The structures have to become visible to give the buildings a strong identity. All the buildings, except for the boiler house will get a new façade. The walls of these facades are non-insulated and have single-pane windows. Therefore, it is not efficient to keep those. The new facades will be transparent in order to highlight these old structures. Any addition or adaptation is done in a different manner to distinguish it from the existing parts.

Peter Zumthor made a design for the factory with the redeveloping demands of the municipality of Leiden as preconditions. However, the Laboratory, Office and Workshops will be demolished (figure 8-1 and 8-2).



figure 8-1 floor plan factory site

figure 8-2 floor plan demolished buildings

The lost canal is reinstated (figure 7-2). A footbridge connects the new square, Aspen place on the West side with the old factory square on the east side. In the western part new buildings are added (figure 8-3). The whole area becomes a pedestrian area and the canal makes the connection with the two squares in east and west. Parking space is provided in a large underground car park.





figure 8-4 functions, website meelfabriek

BUILDING FOR OF DESIGN MEELFABRIEK HOTEL MEELFABRIEK SQUARE GREENHOUSE APARTMENT TOWER

⁵³ Peter Zumthor. Tot op het bot. p 26-29

The street level of the complex is designed as public space and is a pedestrian area. It consists of large open areas with plants and trees and a new harbour. On this level the access to the entrances of the buildings and the underground parking is located.⁵⁴

The complex of the factory consists of 8 different buildings, each with a different function. This concept is repeated in the new design. Therefore, in the new design each building gets its own new function. The new functions and interventions in the buildings will be discussed in the following paragraphs for every building.



figure 8-5 scale-model new design of the factory website meelfabriek



figure 8-6 scale-model new design of the factory website meelfabriek

8.1 The Boiler house

Old function: space for steam engines *New function*: rental spaces for workshops

Interventions:

The six floors of the boiler house have the function of flexible workshop and seminar spaces. Classes, screenings or performances can be held here. On the ground floor there is a shared foyer. Underneath the round roof a small theatre with 100 seats will be located. The floors can be rented by different organizations. There are no changes in the structure other than improvements of the structure. The facades are also remained.⁵⁵



figure 8-7 Boiler House website meelfabriek



figure 8-8 website meelfabriek



figure 8-9 section structure and new functions website meelfabriek

⁵⁴ Masterplan de meelfabriek, <u>http://www.demeelfabriek.nl/nl/masterplan/</u>

⁵⁵ Workshop building, <u>http://www.demeelfabriek.nl/index.php?id=26</u>

8.2 Tower of silos

Old function: flour silos New function: fashion and design stores

Interventions:

The Silotower includes nine layers of silos. It has the function of fashion and design stores. It will accommodate 2000 m2 of stores. Around two tall atriums small stores will be located. Floors with bigger shops are located in between the atriums. On the ground floor a shred lobby and waterfront café will be located. On top of the building an extra floor layer will be placed to accommodate a restaurant. The restaurant fits 150 people. With a special lift the restaurant can be accessed directly.

The walls of the silos are partly removed and extra floors are added. On top of the existing structure one extra layer is added. The facade is removed and a glass facade placed in return. 56







figure 8-11 scale-model and interior silotoren, *website*



figure 8-12 scale-model and interior silotower, *website*

⁵⁶ House of fashion, <u>http://www.demeelfabriek.nl/index.php?id=21</u>

8.3 Cleaning building

Old function: cleaning space New function: house of Design

Interventions:

The cleaning building has seven floors with studios of 250 m² for rent or sale. The top two floors will be combined into one floor with a high ceiling. On the ground floor a lobby will be located.

The concrete structure with wooden floors is preserved if possible. The facade is removed and replaced with a glass facade. ⁵⁷



figure 8-13 section structure and new functions



figure 8-14 Interior cleaning building, website meelfabriek



figure 8-15 Façade cleaning building, website meelfabriek

8.4 Silos

Old function: storage of flour New function: hotel

Interventions:

The Silos are transformed into a hotel, with 7600 m2 of hotel rooms, divided in 67 special rooms of nine different sizes. These rooms are cut out of the silos in the silos of 1937, 1938 and 1955. The rooms are located at the south façade and in the middle, cut into the silos, long bridges to the rooms are placed. Daylight enters in to the north façade. At the top floor of the hotel the restaurant will be located with an entrance that is connected to the tower of silos by bridge. On the ground floor a lobby will be located.

The concrete structure will be remained, floors and bridges are added and doors and windows are cut out of the walls. Glass will be added in the façade.⁵⁸

⁵⁷ House of design, <u>http://www.demeelfabriek.nl/index.php?id=25</u>

⁵⁸ Meelfabriek hotel, <u>http://www.demeelfabriek.nl/index.php?id=20</u>







figure 8-18 interior silos website meelfabriek

figure 8-16 structure silos website meelfabriek

8.5 Flour warehouse

Old function: storage of flour New function: fitness & spa

Interventions:

The flour warehouse accommodates a 4100 m2 fitness and spa. On the ground floor a grand cafe is located and on the first floors a big restaurant of 690 m2. The Fitness& spa will cover seven floors of which two have been specially added to accommodate the swimming pools of 145 m², 25 m² and 45m². In the top the columns will continue on the existing grid.

The concrete structure and concrete floors are preserved. The facade is removed and replaced with a glass facade. On top two floors are added. 59





figure 8-20 structure flour warehouse, website meelfabriek

⁵⁹ Meelfabriek Fitness and Spa, Meelfabriek Café and Restaurant, <u>http://www.demeelfabriek.nl/index.php?id=22</u>



figure 8-21 Interior flour warehouse website meelfabriek

8.6 The Mill

Old function: steamrolling the flour *New function*: loft ateliers

Interventions:

There are seven floors of 450 m² flexible ateliers which are available for rent. The floors can be divided in compartments with furniture or partitions of Peter Zumthor and Partner. At the ground and first floor space is reserved for a supermarket or another store. The other floors will be rented out as lofts, for example to artists, doctors or lawyers.

The existing structure will be remained, except the façade. This will be demolished and replaced by a glass façade. 60



figure 8-23 interior mill website meelfabriek



figure 8-24 interior mill website meelfabriek

⁶⁰ Loft atelier building, <u>http://www.demeelfabriek.nl/index.php?id=24</u>

8.7 Extension of the Mill

Old function: extension of the Mill New function: apartments

Interventions:

The floors are sold as apartments, one or two apartments per floor. The apartments are 150-250 m² with their own loggia on six floors. The apartments can be customised by the architect to the wishes of the client. The existing structure will be used, except for the façade, which will be demolished and replaced by a glass façade. 61







figure 8-26 interior extension mill website meelfabriek



figure 8-27 interior extension mill website meelfabriek

The new design by Peter Zumthor for the flour factory is the base for the structural design. In the next two chapters the vision of the Zumthor and how this is implented in this design is described. His vision together with the new design gives starting point of which interventions can be done in the structures to realize safe sound structures for the architectural design.

⁶¹ Loft apartment building, <u>http://www.demeelfabriek.nl/index.php?id=23</u>

9 The way Peter Zumthor envisions architecture

Peter Zumthor and Partner made the design of the renovation of the flour factory. In this chapter his vision will be described on architecture. To examine what is important in the architectural design and to form preconditions for the structural design.

Aim architect

The aim of an architect is to make a building of good quality. This design process is based on interplay of reasoning and feelings. According to Zumthor do feelings prefer certain forms, therefore these should be controlled by the critical power of reasoning. So the architect has to be patient and come to a design of good quality.⁶²

Zumthor thinks that an architect, who is involved in a project, should be the generalist of the project. He has to take control over the total design of the building, which means: architectural design, materials, structure, installations, and surroundings. He should see the building as a human body and build according to this anatomy, putting all the pieces together. ⁶⁵

Making a design

According to Zumthor:

- a. "In the history of architecture we can find a lot of knowledge and experience, which can lead to solutions for the design assignment. But if it cannot be found there, then history is irrelevant to the design." ⁶³
- b. "in my buildings I try to enhance what seems to be valuable, to correct what is disturbing and to create anew what we feel is missing." 64
- c. "When making a design use the essence of things, do not use artistic additions, because when you stay to the truth of things it will start to withdraw emotions (like art and music do, only less powerful)."
- d. "The landscape changes when a new building is added. Therefore the assignment of designing a building should not only refer to the object itself but also to the surrounding area." ⁶⁵

Atmospheres

When Peter Zumthor thinks about architecture he thinks about the memories he has of buildings and their surroundings. Not the image of the building but the atmosphere is what he remembers. These are the smell, the sound and the experiences in a building. There is a certain interaction between people and objects, these atmospheres are what Peter Zumthor tries to represent by his designs. The following nine points are considered to do so 65 :

a. The body of architecture; see architecture as a body with an anatomy and a skin. Architecture is about collecting different things, materials and objects, and constructs it together. Hence a space comes into being.

Material of compatibility; use materials as ingredients, mix them together and get a unique composition for a building. Materials have a lot of possibilities in them, when you know about these characteristics of the material it is possible to expose the essence of the material. Different materials combined react to each other, they can be close to each other or more separated.

b. The sound of space; spaces are like large instruments. They collect sound, amplify it and transmit it elsewhere. This has to do with the shape and the materials of the objects.

⁶² Aimee de Back, Wiek Röling. 2003. *Het onthaasten van architectuur – Peter Zumthor, Interview.* Haldenstein(Zwitserland).

⁶³ Peter Zumthor. 2006. *Thinking Architecture*. Basel. Birkhauser

⁶⁴ Peter Zumthor. 2006. *Thinking Architecture*. Basel. Birkhauser. p.24

⁶⁵ Peter Zumthor. 2006. Atmospheres. Base. Birkhäuser

- c. The temperature of a space; materials can store warmth and have a different temperatures. For example wood often feels warm and steel does not. Concrete can store a lot of warmth and steel cannot.
- d. Objects; buildings are full of objects, which are owned by people. Their future will be to place these objects, what means the building is in use by people.
- e. Between composure and seduction; the way movement is involved in architecture. There is a difference between directing people to walk in a certain direction or to make them curious and seduce them to stroll around.
- f. Tension between interior and exterior; the awareness of being enclosed. Facades can show you a little from inside but not everything, they can be equal to their surroundings or behave as a diva, standing alone and arrogant.
- g. Levels of intimacy; size, dimensions, scale and building mass in contrast with yourself. For example a big door can make you feel more special than a normal door. There is also a difference in experiencing a building, when you are alone, or in a crowd.
- h. The light; where and how does the light fall. Where are there shadows. Surfaces have their own structure and reflect the light in different ways. Objects, forms and materials also have a difference in strength of radiating light. Design the building as a mass of shadows, and put light in as if you are hollowing out the darkness. Light can makes a difference in scale and dimension, there is a big difference in shadows from the moonlight and a lamp.

Four more things about how he thinks an architect should work:

- i. Architecture as surroundings; architecture or a building becomes part of its surroundings. It becomes part of people's lives. As a human environment, this way, you are not remembered by books about architecture but by people, who have their memories in the buildings.
- j. Coherence; when a building is used by people, it is a compliment. After all architecture is made for use, not as a free art.
- k. The beautiful form; or so-called slow architecture. After designing a shape comes out which can be surprising and exciting
- I. Details; Composite a whole, including the details. A building consists of the construction of single parts, joined together. Hence, the quality of the object as a whole is determined by joints. For example, a sculpture made of one piece has the least possible amount of connections. Therefore, architecture is a challenge of developing an entirely whole out of innumerable details, various functions, forms, materials and dimensions. Do not add small parts that have nothing to do with the whole. Details determine the rhythm, look were surfaces and materials meet each other and design rational forms of connection.⁶⁵

Zumthor thoughts on Architecture

Zumthor stated that a plan or project drawn on paper is not architecture but a representation of it. It is the paper where the music is written on, not the music itself. When images of architecture are too realistic, there is no curiosity anymore and the image is what we expect and not the architectural object in its context. When architecture is executed, then its body comes into being. Then a design is complete and has its final voice/statement in the world. It becomes alive. ⁶³

When Zumthor was developing the project of a thermal bath in the mountains he first did a research to the area, the purpose of the building and the materials. The research resulted in surprising spaces and shapes. Hence, it can be concluded that with a patient process a true design comes alive.⁶²

Monuments

According to Zumthor there is no difference between designing for a monumental building or one without this status. In both cases the designing process is the same and the value of the building is determined by the architect. Changes to buildings should be made by the architect who designed the buildings or another good architect. When designing for an existing building, the architect wants to understand the building. The architect should investigates into the structure and determine whether the building is suitable for reuse and if the new function is suitable for the building. ⁶⁵



figure 9-1 scheme of how the architecture of Peter Zumthor is realised

The vision of the architect Peter Zumthor is used in the next chapter to describe how his vision is implemented in the design for the flour factory.

10 Vision on the new design of the flour factory

The vision of Peter Zumthor, described in chapter 9 is implemented in the design for the flour factory. In this chapter his vision implemented on the design of the flour factory is described.

On different scales his vision is implemented in the design:

a. The masterplan is not only to improve the factory site but also the city of Leiden. The design is contributing to living, recreating, working and shopping in Leiden and therefore gives the small centre a new boost for outside visitors. It creates student accommodations and lofts. There is a lot of space for shopping and space for rent for different kinds of workshops and for offices. The visitors from outside Leiden have the possibility to stay at the hotel. So it has the possibility to attract a variety of people. Besides, the architect connects the complex with the water of Leiden by introducing a harbour and a water-taxi. The buildings improve the surroundings (figure 10-1).





- b. The whole ground floor becomes a public space. In this way even people who have no business there, are welcome. He is creating a big square, which is a pedestrian area, and on this level are all the entrances to the buildings, the cafes and supermarkets. On the second level the buildings divide themselves in different functions. By doing this he is creating the tension between interior and exterior, because at the ground floor this border between function and public space is not totally clear (figure 10-2).
- c. The vague border on ground floor between interior and exterior creates also intimacy between visitors and the buildings. The sight of being under a big building gives an interesting feeling of intimacy, like you are being embraced by these buildings.





- d. Another way that Zumthor plays with levels of intimacy is in the hotel. By adding floors in the silos, the rooms are of natural human size. However, coming out of the room gives a total different dimension, by looking down or up in the high silos. Even so, for the design shops where big atria are cut out of the silos. Next to the normal size shops huge spaces arise.
- e. By removing certain facades, Zumthor is creating again this tension between interior and exterior. Once there were machines doing their work behind closed facades, and now the facades are opened and showing a different sight.
- f. Moreover, it gives the light a bigger playfield. In daytime the structures become visible, which are of important monumental value, and at night the buildings enlighten the surrounding area.



figure 10-3

g. When thinking of a design as a whole entity, including details, it is a good solution to remove the façades. At the Mill and its extension these facades were very massive on a light structure. With this intervention of design, the building is designed as a whole.

These points should be taken into account when making a structural design. Therefore those are used to set out the preconditions for the structural design.

Conclusions part I, architectural analyse of the buildings

In the chapters 3 till 10 the history, monumental factors, new design of the factory and the vision of the architect are described. From these chapters conclusions are drawn about the factory as a monument and the interpretation of the new design. With these conclusions starting points are formulated.

Memory industrial Leiden

As a result of the growth of the textile industry in the 17th century the population increased. In the 18th century Leiden became overpopulated. The old defence walls were used to situate the factories of Leiden. Nowadays only the flour factory and the factory of light are still standing. The flour factory can therefore be seen as a memory to the industrial past of Leiden.

Good location reuse

On the locations where the other factories used to be parks are laid out. Those parks are next to the flour factory. In the 18th century the factory was located on the border of Leiden. However as the city extended the flour factory has become part of the centre of Leiden. The location of the factory complex, in the centre of the city and surrounded by parks, makes it a strong location to attract public.

Monumental value in early structures

The production of the flour factory grew towards 20% of the total Dutch flour production; the factory was therefore an important flour factory in the Netherlands. The growth of this production made it necessary to expand the factory complex. This resulted in different buildings. The designs of these buildings depend on the knowledge and experience of the constructors at that time and the available material. This has an outcome of unique combinations of early use of:

- a. arched concrete floors combined with an iron skeleton
- b. special detailing of an iron structure and an arched shaped concrete roof from 1896
- c. reinforced concrete silos from 1904
- d. concrete mushroom columns from 1937
- e. a concrete skeleton from 1937; and wooden floors combined with an iron skeleton
- f. special detailing of an iron skeleton from 1931 and 1947

The historical values of these structures together with the values of the factory as a memory to the industrial past, the location, the ensemble of the buildings, and the architectural and culture-historical value of the buildings results in a factory complex of buildings listed as monuments of the state.

Dynamic process comes back in the new design

The different buildings all have their own part in the process of making flour. Bridges and lifts to and from the buildings transport the grain or flour to their location. The same dynamic procedure is repeated within the new design. When there are adaptions or additions made in the new design there is a clear distinction between old and new.

Shift of monumental values

The buildings are marked as listed monuments of the state in 2001 because of their architectural and culturalhistorical values.

However in the list of demands for the flour factory, made by the municipality in 2002, there is a change in evaluating the monuments. The façade of the flour warehouse, registered as a monumental value, is not mentioned to be maintained. Moreover the office, in the register seen as a landmark of the entrance, can be demolished to restore an old canal.

Municipality, The Public Service of Cultural Inheritance and the owner made an agreement that the architect has freedom to make a good design that fits in the urban plan of the city of Leiden.

Peter Zumthor and Partner emphasises the structures of the factory buildings as the real monumental values, the client, municipality and the Public Service of Cultural Inheritance agree with this. The result is that the facades, mentioned in the monument register and the list of demands to be remained also because of the modernism characteristics, will be removed in the new design and replaced by transparent facades to highlight the structures. The garage is demolished as well. Some of the buildings are topped with extra floors, while in the list of demands was stated that the heights of the existing buildings should not be exceeded.

The vision of the architect together with making a feasible plan regarding the costs and a practicable plan regarding constructing are set as preconditions for the additions and adaptions to the structures. The preconditions are ranked into importance: the client wishes will be graded highest, secondly the monumental values, thirdly the vision of the architect and then the wish to make an easy solution to construct to prevent mistakes on the building place.

Preconditions for the structural design:

Client wishes:

1. The additional structural design has a high feasibility in terms of costs and quality.

- Monumental value:
 - 2. The structure is seen as the body of the building and as the monumental value. Therefore, it will not be demolished, or as little as possible. Adaptations are made in a way that the structure can be restored to its original state.
 - 3. Make optimal use of the possibilities of the structures.

Vision architect:

- 4. Composite the materials and details as a whole component. The material use of new elements should have a connection with the materials of the original elements.
- 5. However, there should be a distinction between the old structures and the new, added elements or repairs, to show that there is a difference between old and new structures.

Contractor:

6. The additional structural design has a high feasibility regarding constructing

Part II structural analysis

In part II the difficulties to adapt the building to their new functions will be discussed. This is based on a visual inspection, height measurements on site and a structural analysis based on the implemented building rules of the Eurocode and Dutch Building Regulations. Finally conclusions will be drawn and recommendations based on the results of the analysis will be given.

11 Failures in the buildings

By inspecting the buildings, failures or causes of failures can be detected. To draw conclusions on these failures the buildings on the site are visual inspected (see appendix A4 and A5 on background information on inspections). Secondly the data of the height measurements on the site from the report 'De meelfabriek te Leiden, Onderzoek technische en constructieve kwaliteit' by ABT BV are examined. At third, the measurements on the structure of the mill by BBC Bouwmanagement are examined. Together with the structural analysis (chapter 12) this chapter gives information on where the structures are not safe yet, to be adapted to their new function. The failures on the buildings are discussed in chronological order.

11.1 Boiler house

During the visual inspection vertical cracks in the façade were noticed (figure 11-1 and 11-2). This implicates that on the locations where the steel beams rest on the brickwork, high stress occurs. Furthermore, the influence of corrosion can play a part. Vibrations and different expansion coefficients of steel and brick caused the cracks in the facade. 66



Figure 11-1 Visible cracks in North façade



Figure 11-2 Visible cracks in North façade

The height measurements on site indicate that the building sagged more in the southeast than in the northwest (appendix J). This could be explained by the presence of other buildings in the south and east.

11.2 Silos 1904

By visual inspection the cracks that appear in the concrete in the roof were noticed (figure 11-3). This can imply two kinds of failures:

- i. a setting of the foundation of the building
- ii. Too high stresses in the material.

The inspection on the foundation by ABT BV made clear that the wood of the foundation, tested with a hammer, is damaged. SHR Hout Research tested samples of piles and cross beams in a laboratory and concluded that the piles are heavily damaged. The damaged layer of wood has a compressive strength less than 2.5 N/mm². The reason of this damage could be explained by the high age of the wood and the fact that the top of the piles are near the groundwater surface, which makes it an attractive location for bacteria.

⁶⁶ 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie. Code:10386k. ABT bv

Because the lower part of the piles is smaller, the top can be smaller too and the damage will not cause problems yet. The outside layer of wood of the upper part of the piles can be damaged for another 10 a 20 mm. If the piles stay under water they can last another 25 years, according ABT BV.⁶⁷



Figure 11-3 Cracks in the concrete on the roof

The visual inspection by ABT BV made it clear that the cramps that connect the old façade to the new silos on the north-façade are corroded. Furthermore, the plasterwork and brick façade are damaged, vegetation grows on the façade and parts of the pennants and the bitumen layer on the roof are damaged. ⁶⁸

The height measurements on site (appendix J), indicate that there is a difference in sacking between the west and Eastern part of 90 mm. The rooftop sacked in the opposite direction than the ground floor level.

11.3 Mill

The visual inspection by ABT BV made clear that cracks appear in the façade. Vibrations and different expansion coefficients of the iron profile, which supports the façade and the brick façade, caused the cracks in the walls (figure 11-4 and 11-5). ⁶⁹



Figure 11-4 Cracks visible in the south façade



Figure 11-5 Cracks visible in corner of the west and south façade

⁶⁷ ing. N.T. Loonen, ir.F.J.J. Hofmans, V.M. Bakker, P van der Hoofd. 2009. *De meelfabriek te leiden, Onderzoek technische en constructieve kwaliteit*. Code: 10386k. ABT bv

⁶⁸ ing. N.T. Loonen, ir.F.J.J. Hofmans, V.M. Bakker, P van der Hoofd. 2009. *De meelfabriek te leiden, Onderzoek technische en constructieve kwaliteit*. Code: 10386k. ABT bv

⁶⁹ 2002. Haalbaarheidsstudie renovatie terrein meelfabriek Leiden plan P. Zumthor, analyse en beoordeling constructie. Code:10386k. ABT bv

The visual inspection of BBC Bouwmanagement made clear that the steel structure is corroding. Besides the corroding steel, the façade is damaged by fungus. The inside walls need a new layer of plaster. Furthermore, the roof is damaged by fungus as well and the bitumen on the roof needs to be replaced. Moreover, the edges and drains on the roof need to be replaced and the steel staircase needs to be cleaned from corrosion. ⁷⁰ Height measurements on site indicate that the Western part of the building sagged more than the Eastern part, with a maximum of 50 mm (appendix J). This could be explained by heavy machinery causing a different way of loading.

11.4 Silos 37-38

The visual inspection made clear that at the seams of the pouring at the silos of 1937, concrete is spalling and reinforcement is visible (figure 11-7 and 11-8). Moreover, reinforcement is visible at the façade columns on the ground floor (figure 11-6).



Figure 11-6 Reinforcement visible

Figure 11-7 horizontal cracks, showing reinforcement

Figure 11-8 Reinforcement visible

The concrete facades have a lot of locations where the steel is visible. On the east-façade seven big spots are visible where the façade is repaired. Pieces of the repairments came loose again caused by, once again, corroding of the steel. In the upper floors the north façade is damaged. In the south and west façade there is a lot of damage to the concrete because of corroded steel.

At the top columns, walls and roof are heavily damaged. Because of the corroding of the steel a lot of the concrete has cracks or has come off. The cover of the roof has holes in it and damp courses of lead are missing.

In the floors of the stair case a lot of holes are made for ducts going through. By doing so, damages are made to the beams of the upper structure. Furthermore, cracks in the wall are visible.

Height measurements on site (appendix J) indicate that there is not a lot of sacking in the silos of 1937. The eastern part of the silos of 1938 sagged 20 mm more than the western part. The building is enclosed by the silos of 1955 on the east; because those are heavy, this could explain the way of sacking.

⁷⁰ BBC Bouwmanagement. Drawings results inspection Mill and extension. Rijksdienst voor Cultureel Erfgoed, Amersfoort.

11.5 The flour warehouse

The visual inspection shows that a lot of reinforcement at the first floor of the flour warehouse is visible (figure 11-9, 11-10, 11-11 and 11-12).



Figure 11-9 and Figure 11-10 Reinforcement visible in the first floor



Figure 11-11and Figure 11-12 Reinforcement visible in the first floor

ABT BV examined the foundation and concluded that the wood of the foundation, tested with a hammer, is lightly damaged. However with this damage the piles can continue at least 50 years. 71

From their visual inspection it became clear that damages occur in the top, façade and first floor. Firstly, at the top floor in the glass hall, horizontal cracks appear in a column and one of the beams is made smaller. Secondly, the slab on the first floor has a continuous crack with a width of maximum 1 mm. Thirdly, in the corners of the facades vertical cracks appear and damaged brick appears in the façade. The concrete beams that bear the facade are in a bad state as well. The steel windows are corroded at the surface, the concrete cantilever is damaged in several spots and the bitumen covering at the cantilevers is damaged. Furthermore, the roof has traces of leakages and at these spots there is forming of scale. ⁷²

Height measurements on site (appendix J) indicate that the eastern part of the building sagged more than the western part. This could be caused by heavy machinery which resulted in a different way of loading. Where the garages used to be located there are thresholds, in these locations the floors sacked 80 mm. While the rest of the ground floor sacked only 65 mm.

⁷¹ ing. N.T. Loonen, ir.F.J.J. Hofmans, V.M. Bakker, P van der Hoofd. 2009. *De meelfabriek te leiden, Onderzoek technische en constructieve kwaliteit*. Code: 10386k. ABT bv

⁷² ing. N.T. Loonen, ir.F.J.J. Hofmans, V.M. Bakker, P van der Hoofd. 2009. *De meelfabriek te leiden, Onderzoek technische en constructieve kwaliteit*. Code: 10386k. ABT bv
11.6 Cleaning building

The visual inspection made clear that in the east façade iron profiles are visible (figure 11-13). Moreover, there is reinforcement visible in the interior in the concrete floors on the upper floor and the first floor (figure 11-14, 11-15 and 11-16).



Figure 11-13 Steel visible in east façade

Figure 11-14 Steel visible in the upper floors



Figure 11-15 concrete damaged in the upper floors

Figure 11-16 First floor damaged

Height measurements on site (appendix J) indicate that the southern part of the building sagged more than the northern part. This is probably caused by the heavy silos in the south and the less heavy building, the boiler house in the north.

11.7 Extension of the mill

The visual inspection of BBC Bouwmanagement shows that the structure, façade and roof are damaged. Firstly, the steel structure is corroding. Secondly, the façade and roof are damaged by fungus. Thirdly, the inside walls need a new layer of plaster. Furthermore, the bitumen on the roof need to be replaced and the edges and drains on the roof need to be replaced. ⁷³ Moreover, in the north façade (see figure 11-17) lines are visible of the bearing profiles.

The height measurements on site (appendix J) indicate that also the extension of the mill has a difference in sagging; the southern part of the building sagged more than the northern part. This is probably caused by the presence of the Mill in the south.

⁷³ BBC Bouwmanagement. Drawings results inspection Mill and extension. Rijksdienst voor Cultureel Erfgoed, Amersfoort.



Figure 11-17 Lines of the bearing profiles visible

11.8 Silos 1955

The visual inspection made clear that in the south façade vertical cracks are visible (figure 11-19) which implements there is setting of the foundation. Furthermore, there are cracks visible in the façade at ground floor of the tower and in the upper part of the tower there are little damages in the brickwork visible.

The visual inspection by ABT BV made clear that the roof and façade are damaged (figure 11-18 and 11-20). Firstly, the rooftop shows cracks and leakages. Secondly, at the lower part of the stairs there is steel visible in the concrete. Thirdly, in the concrete walls on floor 4 till 8 horizontal concrete cracks are visible of max 1 mm. Furthermore, at the rooftop the concrete blocks on the inside have a bad condition. Moreover, the bitumen on the roof is cracked in several places.⁷⁴



Figure 11-18 Cracks in the roof



Figure 11-19 Vertical cracks in the façade



Figure 11-20 leakages in the roof

The height measurements on site (appendix J) indicate that there is a difference in sacking of 100 mm between the eastern and western part of the building. The building is located next to the water in the east, this might explain that the building sagged more in the east.

⁷⁴ ing. N.T. Loonen, ir. F.J.J. Hofmans, V.M. Bakker, P van der Hoofd. 2009. *De meelfabriek te leiden, Onderzoek technische en constructieve kwaliteit.* Code: 10386k. ABT bv

11.9 Tower of Silos

The visual inspection made clear that in the concrete columns reinforcement steel is visible. Moreover, in the closed part of the façade there are horizontal cracks present on the locations where the floors are positioned.



Figure 11-21 Reinforcement visible



Figure 11-23 Horizontal cracks were floors are situated



Figure 11-22 Reinforcement visible



Figure 11-24 fungus in façade

The height measurements on site (appendix J) indicate that the building sagged everywhere around 10 mm, probably because of the heavy weight on the columns.

11.10 Conclusion

The important failures of the buildings are summarized in table 11-1. In the next chapter the structural analysis is discussed, with these results stated in table 11-1 and the conclusions from the structural analysis, conclusions are drawn on how the buildings should be examined more or where adaptations should take place.

building	failures
Boiler House	Steel profiles resting on the brickwork caused cracks in the façade
Silos 04	Foundation piles are damaged
	Cracks in the roof visible
Mill	The brickwork resting on steel profiles caused cracks in the façade
	Roof and façade are damaged by fungus
	The steel structure is corroding
Silos 37/38	A lot of spalling of concrete and visible reinforcement
Flour Warehouse	Foundation piles are lightly damaged
	Reinforcement visible on the first floor
Cleaning Building	The brickwork resting on steel profiles caused cracks in the façade
	Reinforcement visible on the first and upper floor
Extension Mill	The brickwork resting on steel profiles caused cracks in the façade
	Roof and façade are damaged by fungus
	The steel structure is corroding
Silos 55	Cracks in the rooftop visible
	Rooftop in bad condition
	Bitumen on the roof is damaged
Tower of Silos	Cracks in the facade visible where floors are located
	Reinforcement visible in the ground floor columns

Table 11-1

12 Analysis of the structure of the buildings

A general analysis will be made on the structure of all the buildings. This analysis will clarify where the difficulties in adapting these existing structures to their new functions are. In order to transform the building to its new function and to cope with the Dutch building regulations and Eurocode, adaptations and additions have to be made to the structure. The buildings will be examined on the bearing capacity of the foundation, on stability of the building and on displacement of the building. When there is insufficient data to examine this, estimations are made of the building data and a conclusion will be based on these estimations.

Together with the visual inspection (chapter 11) this analysis gives information on where the structures are not safe to be adapted to their new function yet.

At first a description of the calculation is given. Secondly, it will be explained where the data are based on and how estimations are made on missing data. Thirdly, the buildings are discussed in chronological order on their structural analysis.

12.1 Weight calculation

To verify the bearing capacity of the foundation of a building a weight calculation is made of the design load on the foundation in ultimate limit state. Of all the buildings there are drawings available from BBC Management with the actual dimensions of the structural elements. With this data the self-weight can be calculated. When changes are made on the elements of the building, for example replacements of the floor, estimation are made of the weight of these elements, based on the weights in NEN-EN 1991-1-1. The structure is calculated with safety factors according the NB NEN-EN 1990 and the live load is determined with NEN-EN 1991-1-1 (appendix K). When making a weight calculation the factors 1,2 for dead load and 1,5 for live load are applied as a conservative way of verifying the structures. When the structures do not fulfil the requirements then a combination is used of load combinations of NEN-EN 1990 and NEN 8700. The combinations of imposed loads on the floors of the buildings are verified as stated in the Eurocode, two floors fully loaded and the other floors with partial factors (appendix K).

12.2 Stability check

The building is verified on tension forces on the foundation caused by wind load in ultimate limit state. These tension forces should be dissolved with the vertical dead load from the building (figure 12-1). In this case the factors 0,9 for dead load and 1,5 for wind load are applied on the calculations. The wind load is determined according NEN 6702, chapter 8.3 and table A.1. The buildings are located in Area II, in a built-up area. With the height of the building and table the wind pressure, pw is determined. With the factors for pressure 0,8 and suction 0,4 the wind load is determined.

$$q_w = C_i \times p_w$$
 $C_i = 0,8+0,4$









Windload introduces moment

Figure 12-1 stability of the building

Moment introduces tension forces in foundation

Weight building = pressure forces foundation

No tension forces cause stability

12.3 Horizontal displacement of the building

The maximum horizontal displacement is examined in the serviceability limit state. The maximum displacement is set on 1/500 h. The E-modulus which is applied in the calculations is written down in table 12-1. For concrete the cracked modulus is used. When making a weight calculation the factors 1,0 for dead load and 1,0 for wind load are applied.

E-modulus
210.000 N/mm ²
9.000 N/mm²
15.000 N/mm²

Table 12-1 E-modulus

12.4 Data

The data which is used is written down in table 12.1 and is described in chapter 2. There are no available data of the boiler house, cleaning building and tower of silos. For the Boiler house an assumption is made on the characteristic strength of the brickwork, in this case the lowest possible value is chosen. For the yielding strength of steel a value is chosen which was usually applied on buildings dating from the same period. For the cleaning building the same value is chosen as is for buildings from the same period. For the silo tower, however it is a later period, the same value is chosen as is for the older concrete buildings.

building	values	
Boiler house, assumption	Steel fy = 137 N/mm ²	Brickwork f,rep = 1,0 N/mm ²
Silos 04	Concrete columns C16/20	Concrete floors C12/15
Mill	Steel fy = 137 N/mm ² (SLS)	
Flour warehouse	Concrete C20/25	
Silos 37-38	Concrete C20/25	
Cleaning building, assumption	Concrete C20/25	
Extension mill	fy = 157 N/mm ² (SLS)	
Silos 55	Concrete C20/25	
Silo tower, assumption	Concrete C20/25	

Table 12-2

12.5 Missing data

There is no data about the foundation from the boiler room and the cleaning building. Therefore an estimation is made of the load on the foundation in the past and this is, in order to make an assumption if it is feasible or not, compared with the load on the foundation in the new situation. In reality, the foundation should be inspected in a foundation pit.

The data is based on written calculations and drawings of the following buildings, dating from the same period:

- i. Rijkskantoor voor geld en telefoonbedrijf, Amsterdam, 1923
- ii. Citytheatre, Amsterdam, 1935
- iii. the Mill building at the flour factory complex, Leiden, 1947
- iv. Silos at the flour factory complex, Leiden, 1955

From the written calculations on these four buildings it can be concluded there are no safety factors used in that time in the calculations. From the calculations of the Citytheatre in Amsterdam 1935 it appears that the yielding strength of steel is $fy = 137 \text{ N/mm}^2$ in serviceability limit state. This means that safety factors are already included in the yielding strength.

Stability calculations are not found in these calculations or in the Dutch building regulations on concrete 'Gewapend Betonvoorschriften' from 1918 and 1930; the calculations only consider the weight on the foundation and stresses in the elements.

There is no complete data about the foundation from the silos from 1904 and the mill. Therefore assumptions are made on the found information and an estimation on the feasibility is made.

The data about the foundation of the extension of the mill and the silos from 1968 is coming from old documents and therefore should be checked and inspected in a foundation pit as well.

12.6 Boiler house

The boiler house, the space for the steam engines, will be transformed to a building with a lobby, workshop or seminar spaces and a theatre. The old structure is remained when possible (Chapter 8.1).

Weight calculation on the foundation

There is no data on the foundation of the boiler house. To make an estimation on the bearing capacity of the foundation, a calculation is made on what the possible live load has been on the steel beams in the building. The estimation is based on the fact that the steel beams could not exceed a characteristic yield stress of fy = 137 N/mm² (chapter 12.4). If there is material available to cut out, this should be tested to verify if this assumption is right. The load on the foundation in the old situation, based on a live load of 11 kN/m², is 25557 kN (appendix L).

For the existing structure assumptions are made for the weight of the materials (table 12-3).

load	material	weight
Dead load of the façade	Brickwork	20 kN/m³
Dead load of the floors	Concrete 150-350 mm	6,25 kN/m²
Dead load of the roof	350 mm concrete	8,25 kN/m²
	one layer bitumen	0,10 kN/m²

Table 12-3

The load on the foundation in the new situation is 29076 kN (appendix L). The bearing capacity of the foundation will be insufficient in this case. This calculation is based on a live load of 11 kN/m^2 , there is a possibility the live load used to be less in the former situation. However, even with a calculation made with NEN 8700 the foundation is not sufficient. Therefore, a further examination on the foundation provides more information to examine this.

Stability check

The wind forces on the boiler house are transferred by the stabilising walls (figure 12-2 and 12-3).



Figure 12-2 stability, situation A



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To calculate the reaction forces on the foundation caused by wind load a schematisation of a beam with a bending stifness is made of the brickwork walls (figure 12-4). The dead load is based on the loads in the weight calculation. The windload is:

 $h = 22m \qquad p_W = 0.93 \text{ kN/m}^2 \qquad q_W = 0.93 \text{ x } 1.2 = 1.1 \text{ kN/m}^2$ The reaction forces are no tension forces in situation A. However, in situation B there are tension forces, which will cause instability (appendix L).

Horizontal displacement

Because there is no information on the quality of the brickwork, the smallest E-modulus is taken to calculate the horizontal displacement, $E = 2 \times 10^{-3} \times 10^{-2} \times 10^{-3} \times 10^{-2} \times 10^{-3} \times 10^{-2}$. The maximum possible displacement is u = h/500 = 31000/500 = 62 mm. The displacement in this case is not more than 7,2 mm in serviceability limit state (appendix L). The maximum displacement is not exceeded.

Conclusion

With additional information on the foundation it can be verified if the capacity is sufficient. One of the aspects that should be considered is how to deal with the instability. One solution could be to couple this building on the Cleaning building; however the possibilities to do so should be examined more.

12.7 Silos 1904

The Silos of 1904 will be transformed into a hotel. In order to do so, existing walls are demolished, floors are added and windows and doors are cut out of the walls of the silos (chapter 8.4).

Weight calculation on the foundation

There is no data on the foundation of the silos. To make an estimation on the bearing capacity of the foundation, a calculation is made on what the possible load on the foundation has been. The calculation is based on the calculations of the other silos. The load on the foundation in the old situation is estimated on 3471 kN per portal.

Within the new design only the ground floor as a lobby floor is assumed. The total load on one portal calculated with NEN 8700 is 4170 kN (appendix M).

Based on the estimation, the bearing capacity of the foundation is exceeded. Because it is estimated, the foundation should be examined more on its bearing capacity.

Stability check

The flour silos are schematised (figure 12-5).



Figure 12-5 stability silos

The dead load is based on the loads in the weight calculation. The windload is:

h = 25 m pw = 1,03 kN/m² qw = 1,03 x 1,2 = 1,24 kN/m²

In the ultimate limit state the reaction forces are pressure forces on the foundation (appendix M).

Horizontal displacement

The maximum possible displacement is u = h/500 = 25000/500 = 50 mm. The displacement is 24 mm in serviceability limit state (appendix M). The displacement is not exceeded.

Conclusion

With additional information on the foundation capacity, the sufficiency can be verified.

12.8 Mill building

The former mill will be transformed to a building with atelier spaces. In order to do so, the floors and façades will be removed and replaced with new wooden floors and new glass facades. (chapter 8.6)

Weight calculation on the foundation

The maximum bearing capacity of one pile is 98 kN (chapter 2.4). It is not certain that sacking of the ground and therefore, negative forces on the piles is calculated in the old calculations. The capacity will be reduced with 10%. As a result the piles have a bearing capacity of 88 kN per pile. Per die, the amount of columns differ (table 12-4). The total capacity of the foundation per portal is 6424 kN.

Façade column	4 x 5 piles	1760 kN
Middle column	5 x 5 piles	2200 kN
Extra column floor 0,1	2 x 2 piles	352 kN

Table 12-4 bearing capacity foundation mill

Because the calculation is based on the new design, assumptions are made for the design of the roof, façade and walls and the weight of the materials (table 12-5).

load	material	weight
Dead load of the roof	100 mm concrete	2,5 kN/m²
	70 mm insulation	0,20 kN/m²
	A layer bitumen	0,10 kN/m²
Dead load of the floors of the ateliers	Wooden floor 50 mm	0,30 kN/m²
	Acoustic material	1,00 kN/m²
	Insulation	0,10 kN/m²
Dead load of the façade	Glass 12 mm	0,3 kN/m²
Dead load of the floor of the supermarket	200 mm concrete	5,0 kN/m²
	70 mm insulation	0,20 kN/m²
Dead load of non-bearing walls		0,7 kN/m²

Table 12-5

The load on the ground floor columns are calculated (table 12-6). In total the load is 5703 kN (appendix N). The bearing capacity of the piles underneath the extra columns will be insufficient.

Façade column	1165 kN
Middle column	2185 kN
Extra column floor 0,1	594 kN

Table 12-6 loads on foundation mill

Stability check

The Mill is schematised (figure 12-6) and tested in the program Technosoft Raamwerken as a portal system with a spring foundation. The rotational spring constant of the foundation is calculated (appendix N). The dead load is based on the loads in the weight calculation. The windload is:

h = 31m p_W = 1,04 kN/m² q_W = 1,04 x 1,2 x 5m = 6,24 kN/m The reaction forces are all pressure forces on the foundation (appendix N).



Figure 12-6 scheme mill

Horizontal displacement

The maximum possible displacement is u = h/500 = 31000/500 = 62 mm.

The displacement is 150 mm in serviceability limit state without 2^{nd} order effects (appendix N). The displacement is exceeded already without considering 2^{nd} order effects.

Stresses in columns and beams

The stresses in columns and beams due to the wind load are examined as well (appendix N). It appears that the beams at level 1 exceed the allowable yielding strength of $fy = 137 \text{ N/mm}^2$ in ULS (figure 12-7).



Figure 12-7 beams exceeding strength

Conclusion

A design should be made to deal with the insufficient bearing capacity of the foundation and the horizontal displacement.

12.9 Flour Warehouse

The Flour Warehouse will be transformed to one floor with café, one floor with a restaurant, 5 floors of fitness space, one new floor with fitness space and another new floor with a swimming pool. The façade will be removed and replaced with a glass façade. New columns continue on the existing grid (chapter 8.5).

Weight calculation on the foundation

While the foundation piles have the same dimensions as the piles of the Mill building it will be estimated at the same bearing capacity of 98 kN (chapter 2.4). It is not certain that the sacking of the ground and therefore, the negative forces on the piles are calculated in the old calculations. The piles are also a little damaged. Hence, the capacity will be reduced with 10%. As a result the piles have a bearing capacity of 88 kN per pile. With an average of 25 piles per die this will be a total of 2200 kN per die.

Because the calculation is based on the new design, assumptions are made for the design of the roof, facades and walls (table 12-7). The dead load of the swimming pool and an estimation on the thickness of the walls of the swimming pool are made (appendix O).

load	material	weight
Dead load of the roof	100 mm concrete	2,5 kN/m²
	70 mm insulation	0,20 kN/m²
	A layer bitumen	0,10 kN/m²
Dead load of the façade:	Glass 12 mm	0,3 kN/m²
Dead load of the existing floors:	200 mm concrete	5,0 kN/m²
Dead load of the new floors:	200 mm concrete	5,0 kN/m²
Dead load of non-bearing walls		0,7 kN/m²

Table 12-7

The load on one column is 3194 kN (appendix O). The bearing capacity of the foundation is insufficient.

Stability check

The flour warehouse is schematised (figure 12-8) and tested in a technosoft Raamwerken program as a portal system.



Figure 12-8

The dead load is based on the loads in the weight calculation (appendix O). The windload is:h = 35,4 m $pw = 1,09 \text{ kN/m}^2$ qw = 1,09 x $1,2 = 1,3 \text{ kN/m}^2$ In the ultimate limit state the reaction forces are pressure forces on the foundation (appendix O).

Horizontal displacement

The maximum possible displacement is u = h/500 = 35400/500 = 70,8 mm. The displacement is 145 mm without 2nd order effects and so the displacement is exceeded already without considering 2nd order effects (appendix O). The largest displacement is in the top of the structure. Therefore, extra measurements have to be taken into account in the top.

Conclusion

A design should be made to deal with the insufficient bearing capacity of the foundation and the horizontal displacement.

12.10 Silos 1937-1938

The Silos of 1937-38 will be transformed into a hotel. Existing walls will be demolished, floors will be added and windows and doors will be cut out of the walls of the silos (chapter 8.4).

Weight calculation on the foundation

The foundation piles are the same as the silos of 1955 and therefore, it is assumed they have the same capacity of 540 kN per pile. Per die the load on the die differs (table 12-8 and 12-9). The total bearing capacity of the foundation is 30240 kN.

1 piles	11340 kN
0,5 piles	11070 kN
2	1 piles 0,5 piles

North column	17,5 piles	9450 kN
Middle column	21 piles	11340 kN
South column	17,5 piles	9450 kN
Table 12-9 Bearing capacity silos 1938		

Table 12-8 Bearing capacity silos 1937

Because the calculation is based on the new design, assumptions are made for the design of the floors (table 12-10).

load	material	weight
Dead load of the new floors	200 mm concrete	5 kN/m²
Dead load of the existing floors	100 mm concrete	2,5 kN/m²
	140 mm concrete	3,5 kN/m²
Dead load of the existing walls	200 mm concrete	5 kN/m²
	120 mm concrete	3 kN/m²

Table 12-10

The total load on the foundation is 12142 kN (appendix P). Which means that the bearing capacity of the foundation is sufficient.

Stability check

The flour silos are schematised as an beam (figure 12-9).



Figure 12-9 stability silos

The dead load is based on the loads in the weight calculation. The windload is:

h = 42 m $p_W = 1,14 \text{ kN/m}^2$ $q_W = 1,14 \text{ x} 1,2 = 1,37 \text{ kN/m}^2$ In the ultimate limit state the reaction forces are pressure forces on the foundation (appendix P).

Horizontal displacement

The maximum possible displacement is u = h/500 = 41750/500 = 83,5 mm. The displacement is u = 61 mm in serviceability limit state including 2^{nd} order effects (appendix S). Thus, the maximum displacement is not exceeded.

Conclusion

There is no need for extra additions to make the structure safe.

12.11 Cleaning building

The building will be transformed to a building with design shops. The façade is removed on the west side and replaced with a new glass facade. On the East side only the façade at the ground floor is removed. The new roof will be isolated. The wooden floors are removed and replaced by concrete floors (chapter 8.3).

Weight calculation on the foundation

There is no data on the foundation. Therefore a calculation is made of the early situation, with live load of an industrial building and without safety factors (chapter 12.4). The capacity of the foundation in the old situation, based on a live load of 8 kN/m², is 8446 kN. The capacity of the foundation in the old situation, based on a live load of 5 kN/m², is 7099 kN (appendix Q).

Because the calculation is based on the new design, assumptions are made for the design of the roof, facade, floors, and walls (table 12-11).

load	material	weight
Dead load of the roof	100 mm concrete	2,5 kN/m²
	70 mm insulation	0,20 kN/m²
	A layer bitumen	0,10 kN/m²
Dead load of the floors	Wooden floor 50 mm	0,30 kN/m²
Dead load of non-bearing walls		0,7 kN/m²
Dead load of the façade	Glass 12 mm	0,3 kN/m²
	Brickwork	20 kN/m ³

Table 12-11

The load on the foundation in the new situation is 6633 kN. This would mean the bearing capacity of the building is sufficient. However, the amount of capacity is an assumed number. Therefore, more data on the foundation is needed to make a more detailed calculation of the bearing capacity of the foundation.

Stability check

The cleaning building is schematised (figure 12-10) and tested in the program Technosoft Raamwerken as a portal system.



The dead load is based on the loads in the weight calculation. The windload is:

$$\label{eq:main_state} \begin{split} h &= 42 \ m \qquad p_W = 1,14 \ kN/m^2 \qquad q_W = 1,14 \ x \ 1,2 = 1,37 \ kN/m^2 \end{split}$$
 The reaction forces are no tension forces (appendix Q).

Horizontal displacement

The maximum possible displacement is u = h/500 = 31700/500 = 63,4 mm. The displacement is 63 mm in serviceability limit state including 2nd order effects (appendix Q). The maximum displacement is not exceeded.

Conclusion

The capacity of the foundation should be examined more to verify if the foundation is sufficient.

12.12 Extension of the Mill

The building will be transformed to an appartment building. At the ground floor there will be a supermarket. The floors and facades are removed and replaced with new floors and new glass facades. The new roof will be isolated and acoustic material will be added to the wooden floors (chapter 8.7).

Weight calculation on the foundation

The foundation piles can bear 638 kN (chapter 2.8 or appendix E). Every die has 4 piles, which can bear together 4×638 kN = 2550 kN.

Because the calculation is based on the new design, estimations are made for the design of the roof, facade, floors, and walls (table 12-12).

load	material	weight
Dead load of the façade	Glass 12 mm	0,3 kN/m²
Dead load of the ground floor	300 mm concrete	7,5 kN/m²
	70 mm insulation	0,20 kN/m²
Dead load of the floors of the	Wooden floor 50 mm	0,30 kN/m²
apartments	Acoustic material	1,00 kN/m²
	Insulation	0,10 kN/m²
Dead load of the roof	250 mm concrete	6,25 kN/m²
	70 mm insulation	0,20 kN/m²
	A layer bitumen	0,10 kN/m²
Dead load of non-bearing walls		0,7 kN/m²

Table 12-12

The total load on the foundation is 3577 kN (appendix R). The load per die is 3577 kN/2 = 1789 kN. Which means that the foundation is sufficient to bear the load of the appartments and supermarket.

There is a difference between the design load and capacity of the foundation of 2550 - 1789 = 762 kN. This difference is probably because of the different live loads. This means extra features could be added.

The load of one extra floor layer on top of the building would be 358 kN. The load of a supermarket instead of appartments on the third floor, would be 615 kN (appendix R). Therefore one extra floor layer or an supermarket floor instead of an appartment floor, could be added. Or instead of a supermarket on the third floor, a dance school or fitness space could be made as well.

Stability check

The building is schematised (figure 12-11) and tested in the program Technosoft Raamwerken as a portal system (appendix R). The dead load is based on the loads in the weight calculation. The windload is:

h = 42 m pw = 0,99 kN/m² qw = 0,99 x 1,2 = 1,19 kN/m²

In the ultimate limit state the reaction forces are pressure forces on the foundation 734 kN and 1257 kN. Therefore the building is stabile.



figure 12-11 stability extension mill

Horizontal displacement

The maximum possible displacement is u = h/500 = 26500/500 = 53 mm.

The displacement is 135 mm in serviceability limit state (appendix R). The displacement is exceeded already without considering 2^{nd} order effects. To see if this displacement is as much as the current situation the existing sytem is considered as well. In the old situation there is a big displacement as well.

Conclusion

A design should be made to deal with the horizontal displacement.

12.13 Silos 1955

The building will be together with the other silos transformed into an hotel with a lobby. Existing walls are demolished, floors are added and windows and doors are cut out of the silo walls (chapter 8.4).

Weight calculation on the foundation

The foundation piles have a capacity of 540 kN per pile (chapter 2.9 or appendix E). Per die the amount of columns differs (table 12-13). The total bearing capacity of the foundation is 19036 kN.

	Load in ton kg	Amount of piles	Total bearing capacity
Middle column	6040 kN	11 piles of 540 kN	5940 kN
South column	6088 kN	11 piles of 540 kN	5940 kN
North column	6970 kN	2 piles of 540 kN + 15,5 piles of 392 kN	7156 kN

Table 12-13 The bearing capacity of the foundation

Because the calculation is based on the new design, estimations are made for the design of the floors and walls (table 12-14).

load	material	weight
Dead load of the new floors	200 mm concrete	5 kN/m²
Dead load of the existing floors	100 mm concrete	2,5 kN/m²
	140 mm concrete	3,5 kN/m²
Dead load of the existing walls	200 mm concrete	5 kN/m²
	120 mm concrete	3 kN/m²

Table 12-14

The total load on the total foundation is 11492 kN (appendix S). The total bearing capacity is sufficient.

Stability check

The flour silos are schematised (figure 12-12).



Figure 12-12 stability silos

The dead load is based on the loads in the weight calculation. The windload is:h = 42 m $p_w = 1,14 \text{ kN/m}^2$ $q_w = 1,14 \text{ x}$ $1,2 = 1,37 \text{ kN/m}^2$

In the ultimate limit state the reaction forces are pressure forces on the foundation (appendix S).

Horizontal displacement

The maximum possible displacement is u = h/500 = 41750/500 = 83,5 mm. The displacement is 61 mm in serviceability limit state (appendix S). The maximum displacement is not exceeded.

Conclusion

There is no need for extra additions to the design.

12.14 Tower of silos

The building is transformed to a building with design shops, café and restaurant. Walls are removed to make atrias and floors are added to realize the shops. One extra floor is added on top of the building to realize the restaurant (chapter 8.2).

Weight calculation on the foundation

In total there are 306 piles, which can bear 785 kN each (chapter 2.10). The total bearing capacity of the foundation is $306 \times 785 = 240.210 \text{ kN}$.

Because the calculation is based on the new design, estimations are made for the design of the floors and façade (table 12-15).

load	material	weight
Dead load of the façade	Glass 12 mm	0,3 kN/m²
Dead load of the floor of the added floors of the shops	concrete 200 mm	5 kN/m²

Table 12-15

The total load on the total foundation is 52279 kN (appendix T). So the foundation is sufficient to bear the load of the shops and restaurant.

There is a difference between design load and capacity of 240210 - 52279 = 187931 kN. This difference is probably because of the different live loads and because a part of the area is only used as an atrium and not loaded with floors. This means extra features could be added.

Stability check

The building is schematised (figure 12-13).



Figure 12-13 stability silotower

The dead load is based on the loads in the weight calculation. The windload is:

h = 45 m p_W = 1,17 kN/m² q_W = 1,2 x 1,17 = 1,4 kN/m² The reaction forces are no tension forces (appendix T).

Horizontal displacement

The maximum possible displacement is u = h/500 = 41750/500 = 83,5 mm. The displacement is 38 mm (appendix T). The maximum displacement is not exceeded.

Conclusion

There is no need for extra additions to the design.

12.15 Conclusions

In table 12-16 the failures of the structural analysis are summarised. In the next chapter the results of the visual inspection (chapter 11) and the structural analysis are combined and conclusions are drawn on how the buildings should be examined further or where adaptations should be done.

	Foundation capacity	stability	displacement
Boiler house	X	X	-
Silos 1904	?	-	-
Mill	X	-	X
Flour warehouse	X	-	?
Silos 37-38	-	-	-
Cleaning building	?	-	-
Extension mill	-	-	X
Silos 55	-	-	-
Tower of silos	-	-	-
Table 12-16	•		•

Conclusions and recommendations part II

A redesign is made for the buildings on the factory site. Therefore, the structures should be safe according to the Dutch Building Regulations and the current failures of the structures should be repaired or replaced. In chapter 11 and 12 these failures and difficulties to adapt these structures can be found. In this chapter recommendations are made of each building to adapt those to their new function. The monumental status, the old and new purpose, failures and structural analysis are taken into consideration to make the recommendations.

Boiler house

The façade as well as the iron structure and the connections are monumental values, which are remained in the design.

High forces in the brickwork due to vibrations and different expansion coefficients made the brickwork crack where it is connected to the steel structure. If the floor load on the steel beams compared to the load that used to be on the floor does not increase, it can be concluded the floors are safe structural elements. A check has to be done if the masonry is still intact and if the bond between steel skeleton and the concrete floors is still present. Otherwise anchors could be used to solve this problem.

When making the assumption that the foundation capacity is based on a live load on the floors of 11 kN/m^2 , the bearing capacity is insufficient. Because this is an assumption, further examination of the steel beams and its strength and inspection on the foundation could provide more accurate information. When holes are made in the building a piece of the steel can be cut out to determine the yielding strength. Inspection of the foundation (appendix A) can determine the area and strength of the piles and the amount of piles.

The stability in west-east direction is not a problem, but stability in north-south direction is. A possibility is to support the building with stability by connecting it to the cleaning building.

Silos 1904

The shape and structure of the silos are of monumental value.

The life duration of the foundation piles has a maximum of 25 years, while the buildings should at least have a rest life duration of another 50 years. The foundation should be adapted to this by making a new foundation or add new piles. While this building is 'hanging' on the other silos it is important to make it a sound foundation to avoid dangerous situations in the building itself and big deflections in the other buildings as well.

The cracks in the roof should be repaired to prevent (further) carbonation and corroding of the steel.

Mill

High forces in the brickwork due to vibrations and different expansion coefficients made the brickwork crack where it is connected to the steel structure. The façade and roof are damaged by fungus. However, the façade and roof are replaced and therefore this is not a problem.

The steel of the structure is corroding and has to be cleaned and protected from corroding. Because the material is damaged an examination should be made on the strength of the elements. Where elements are removed or a hole is made, the removed material can be used to examine it on its strength. The material has to be verified if the corrosion did not have an influence on its strength. When its strength has decreased, calculations should be made if the yielding strength is not exceeded. If so, material can be added to the elements or new elements can be added (appendix U).

Same holds for the wooden floors. Those should be tested on their strength as well and holes should be filled.

The capacity of the foundation does not fulfil the requirements and the maximum horizontal displacement is exceeded, solutions to these problems are discussed in part III.

Warehouse of flour

The mushroom column structure and the façade are of monumental value. However the façade will be replaced by a glass façade.

At the ground floor there is spalling of the concrete and steel bars are visible and corroded. A check has to be done on whether reinforcement is necessary to bear the load of the floors. If so, this has to be repaired to prevent (further) carbonation and corroding of the steel (appendix U).

The capacity of the foundation does not fulfil the requirements and the maximum horizontal displacement is exceeded. Solutions to these problems are discussed in part III.

Silos 1937-1938

The shape and structure of the silos are of monumental value.

On the outside of the silos on the façade, there is spalling of the concrete and steel bars visible. This should be repaired to prevent it from more spalling and corroding of the reinforcement steel. After the repairs it should be protected as well.

Cleaning building

The combination of a concrete skeleton with wooden floors is of monumental value in this case.

At the ground and first floor there is spalling of the concrete and steel bars are visible and corroded. A check has to be done, whether this reinforcement is necessary to bear the load of the floors and if so, this has to be repaired to prevent (further) carbonation and corroding of the steel (appendix U).

Further examination on the foundation provides more accurate information on the bearing capacity. Inspection of the foundation (appendix A) can determine the area and strength of the piles and the amount of piles.

Extension of the mill

The façade and roof are damaged by fungus. The façade and roof will be replaced. Therefore this is not a problem. The steel of the structure is corroding, this has to be cleaned and protected from corroding. Because the material is damaged an examination should be done on the strength of the elements. Where elements are removed or a hole is made, the material can be used to examine it on its strength. When its strength decreased, calculations should be made whether the yielding strength is not exceeded. If so, material can be added to the elements or new elements can be added (appendix U).

Same holds for the wooden floors, those should be tested on their strength as well. Holes should be filled. The maximum horizontal displacement is exceeded. This could be solved by adding braces or a core.

Silos 1955

In the south façade and on the rooftop vertical cracks are visible. This could be because of the sacking of the building. To prevent the steel from corroding in those cracks, the cracks should be repaired, to prevent (further) carbonation and corroding of the steel.

The concrete blocks on the rooftop floor are in bad condition. The strength of these blocks should be determined, and a calculation on the maximum strength should be made.

In the floors of level 4 till 8 horizontal cracks of maximum 1mm are visible, those should be filled.

Tower of silos

At the columns on the ground floor there is spalling of the concrete and steel bars visible and corroded. In the façade at the position of the floors there are horizontal cracks visible, due to restraints and movement or expansion of the floors. The cracks should be filled, to prevent (further) carbonation and corroding of the steel.

Because the Flour Warehouse and the Mill have the most structural difficulties to solve, they will be chosen as further case studies for this thesis.

Part III Design on flour warehouse and Mill

In part III different solutions to the problems, described in part II, which occur when the Mill and the Flour Warehouse will be adapted to their new functions. The best solution to these problems is selected according the starting points described in part I. The final designs are based on these selected solutions.

13 Structural variants Mill

In the mill, a steel framework, steamrolling of the grain took place originally (chapter 2.4). The new functions are ateliers on floor 2-5 and a supermarket on the ground and first floor (chapter 8.6).

First the structural problems, which were observed in the structural analysis, are discussed, Then the possibilities to solve these problems in the structure and the variants based on these possibilities. On base of the starting points for the structural design one of the variants is selected. The final design (chapter 16) is based on this selected variant and verified with the Eurocode and NEN 8700 (chapter 15).

13.1 Problems

The bearing capacity of the foundation of the mill is insufficient to bear the load of the new functions. Furthermore, the maximum displacement due to lateral load is exceeded compared with the set requirements of $u_{max} = h/500 = 62 \text{ mm}$ (figure 13-1).



Figure 13-1 insufficient bearing capacity foundation and a large displacement

Foundation

The capacity of the piles beneath the middle columns on the ground and first floor is insufficient to support these columns (figure 13-2).



Figure 13-2 capacity and load on foundation

If these columns would be removed the problem, of insufficient capacity of the foundation, would be transferred to the middle column (figure 13-3).



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To diminish the load on the middle columns, the columns on the first floor could be removed. This will reduce the load to 459 KN (appendix V). However, the design load is still exceeding the foundation capacity.

13.2 Opportunities/Possibilities

The piles beneath the middle column have no capacity left to support the load of these middle columns on the ground and first floor (figure 13-2). However, the outer columns do have this capacity. The piles beneath the middle columns on the ground and first floor have a maximum foundation capacity to bear the ground floor solely (appendix V). A possibility to solve this problem would be to demolish the columns on ground floor and transfer the forces to the outer columns (figure 13-5). Another possibility, to solve the problem of insufficient bearing capacity, would be to add more piles to support the columns and ground floor.



The exceeded displacement, due to the lateral load, could be solved by adding braces or a core.

The following variants are examined and compared with each other:

- A Core + extra piles foundation
- B Core + extra columns
- C Removing columns, adding cross elements and braces
- D Removing columns, adding an extra beam and braces

13.3 Variant A: core & extra piles foundation

Foundation

Extra foundation piles are added next to the dies beneath the middle columns (figure 13-6). To realize this, parts of the ground floor are removed and a beam is placed beneath the die and on the additional piles. The piles which are added to the foundation should be non-vibrating to prevent damage to the existing structures, should prevent relaxation of the stresses in the ground and can be produced in a working height less than 4 meter. Segmented steel tube piles, Tubex piles or piles with injection of the ground fulfil these requirements. A

choice is made for steel tube piles with injection of concrete, those have a little work height and are non-vibrating.



The total load of the die, Fd = 594 kN, is divided on the existing and new piles according the stifness of the piles (appendix V). The forces should be transported to these new piles with a steel profile IPE 450 (figure 13-7). The beam lies between the existing piles and with a jack the forces on the die are transferred to the additional piles. Lateral torsional buckling is prevented by steel plates.

Displacement

Two concrete cores of 4 x 5 m, where elevators and staircases are located, connected to the steel framework, diminish the displacement of the building. The building is schematised as an beam (figure 13-8, 13-9, 13-10 and 13-11). The concrete core is made in B25 concrete and verified on displacement in the serviceability limit state. The core is stabile and the displacement is 60 mm including 2^{nd} order effects (appendix V).



Two steel cores is not possible because these structures are not stabile (appendix V).

Constructing method

To execute the design of the additional dies and the core, at first the ground floor around the die is removed. When this is done the piles should be placed with special equipment. The beam is placed beneath the die and jacked up to transfer the load to the new piles. Around the die the area is filled with sand. The same kinds of piles are used beneath the core. When those are placed the core is casted in situ (figure 13-12).



figure 13-12 execution variant A

13.4 Variant B: core & extra columns

Foundation

A part of the load of the building is transported to new added piles, dies and columns (figure 13-13). The new columns bear the load of floor 0 and 1 (figure 13-14). The new design load on the existing die is F = 367 kN (figure 13-15) and the capacity is exceeded with 4%, which will be allowed. The design load on the new column is F = 93 kN, profiles of HE100A are used as columns (appendix V).



figure 13-13 dies and piles added to foundation



figure 13-14 area beard by existing die



figure 13-15 area beard by existing die with additional dies

The piles which are added to the foundation should be non-vibrating, to prevent damage to the existing structures, should prevent relaxation of the stresses in the ground and can be produced in a working height less than 4 meter. Therefore a choice is made for steel tube piles with injection of concrete, those have a little work height and are non-vibrating.

Displacement

The same solution as Variant A.

Constructing method

Firstly, the ground floor is removed, to execute the design of the new dies and the core. When this is done the piles should be placed. The die is casted in a formwork. Around the die the area is filled with sand and the ground floor is casted in situ. The columns are placed and if necessary placed with a jack underneath the existing beams.

13.5 Variant C: removing columns, adding cross elements and braces

Foundation

The columns on ground floor are replaced by a sloping column (figure 13-17). The sloping columns can be realised with a HE200Aprofile or a double tube profile 200x100x5 (appendix V). While the columns are eccentric loaded the existing beam is verified on Normal Force, Moment and Shear Force (appendix V). A tension cable on level ground floor is added to take care of the horizontal forces due to the force on the sloping column.



Figure 13-16 sloping columns

Displacement

The braces are of steel cables of diameter 60 mm. The different configurations of the braces are set in figure 13-17, 18 and 19. The displacement of the different configurations is calculated in the serviceability limit state including 2^{nd} order effect. The stresses in the steel cables due to lateral load are verified in ultimate limit state (appendix V).



Constructing method

The way of constructing is by add tension cables on both sides of the outside columns. Then add the sloping column next to the existing column. When those are placed the existing column can be removed. While this is done for every portal the extra hinged braces, only loaded in tension, are placed with bolts in two portals (figure 13-22).



Figure 13-20 execution variant C

13.6 Variant D: removing columns, adding an extra beam and braces

Foundation

The middle columns are removed. The load on the removed columns is transferred to two beams on each side of the column. The beams are supported by the outer columns (figure 13-23). The middle column does not support this beam, otherwise it would transfer a too high load to the middle die. The beam can be realised as an HE650B profile (figure 13-24) or a truss of square tube profiles 200x200x16 (figure 13-25). Extra plates added to the beam at the location of the connection transfer the forces to the connection with the column. The beam is verified on stresses in the beam in ULS and on the displacement in SLS. The column is verified on the reaction force of the beam (appendix V).









Displacement

The structure is combined with braces as is examined in variant B.

Constructing method

The way of constructing is by first removing the wooden floor parts from the first floor. The beams are removed on the first floor. A connection is made with the outer columns and the beams are placed. When column is connected with the new beams the middle column is removed. While this is done for every portal the extra hinged braces, only loaded in tension, are placed with bolts in the two outer portals (figure 13-26).



13.7 Selection

The variants are compared on their preconditions. The preconditions are set out from 1 to 6 on their importance. Point 1 is highest valued and point 6 lowest valued. The values given are stated in table 13-1 to indicate the ranking of the variants.

Conclusion from starting points:

 The additional structural design has a high feasibility in terms of costs and quality. Variant A and B are less feasible regarding costs, variant C and D are more simple solutions and cost less therefore. 2. The structure is seen as the body of the building and as the monumental value. Therefore, it will not be demolished, or as little as possible. Adaptations are made in a way that the structure can be restored to its original state.

Nothing on the existing structures of variant A and B is demolished. However, the concrete core is connected to the steel building. Therefore, it will be hard to remove and to restore the structure to its original state. The columns on the ground floor of variant C and D are demolished and the structure can therefore not be restored to its original state. However it can be restored with new added columns.

- 3. Make optimal use of the possibilities of the structures. Variant A does make optimal use of the structure resisting the permanent and imposed loads but not the lateral loads. Variant B does not make optimal use of existing structure, while additional piles and columns are added. Variant C and D make optimal use of the structures.
- 4. Composite the materials and details as a whole component. The material use of the new elements has a connection with the original materials.

While variant A has no connection with the original structure, variant B, C and D do have this connection by making use of the same material. Moreover the core of variant B does not make a connection. The details of variant C have no similarities with the original structure. Variant D comes close to the original structure with its details and continuing of the frame.

- However, there should be a distinction between the old structures and the new, added elements or repairs, to show that there is a difference between old and new structures.
 In variant A it is hard to discover the added elements in the foundation, but the core does make this distinction visible, same holds for variant B. In variant C and D it is made clear there are new elements.
- 6. The additional structural design has a high feasibility regarding constructing Variant C is the most simple solution because of few details and elements and needed equipment, variant D is a little more complicated to make and variant A needs the most equipment and time.

		foundation		displacement			
Starting points		А	В	С	D	A/B	C/D
1	High feasibility regarding costs and quality	-	-	+	+	-	+
2	Structure as little as possible demolished	+	+	-	-	0	+
3	Optimal use of structure	+	-	+	+	-	+
4	Materials and details composed as a whole	-	0	+	+	-	+
5	But distinction and difference between old and new	0	+	+	+	+	+
6	Method of constructing	-	0	++	+	-	+

Table 13-1

On base of the preconditions ranked in importance it can be said that variant C and D are better solutions than variant A. Variant C is selected because of it's more simple solution and execution.

In chapter 16 choices are made for the new elements and the new design is verified.

14 Structural variants Flour Warehouse

The flour warehouse is a concrete mushroom columns structure. Sacks of flour were stored in this building (chapter 2.5). The new functions are a fitness and spa on floor 2-8 and a restaurant and café on ground and first floor. Two extra floors are added on top of the building. The swimming pools are 25 m², 45 m² and 145 m², with a height of 2 m for the small swimming pools and a height of 2,5 m for the big swimming pool (chapter 8.5). First the structural problems, which were observed in the structural analysis, are discussed. Then the possibilities to solve these problems in the structure and the variants based on these possibilities. On base of the starting points for the structural design one of the variants is selected. The final design (chapter 17) is based on this selected variant and verified with the Eurocode and NEN 8700 (chapter 15).

14.1 Problems

The bearing capacity of the foundation of the flour warehouse is insufficient to bear the load of the new functions. Moreover, the maximum displacement due to lateral load compared with set requirements of $u_{max} = h/500 = 71 \text{ mm}$ is exceeded (figure 14-1).



Figure 14-1 too high forces on the foundation and a large displacement of the flour warehouse

14.2 Possibilities/opportunities

Foundation

The numbers of piles is different per each column (figure 14-2). In the structural analysis a capacity of 25 piles per column is assumed. To examine the possibilities of the foundation, the configuration of the different number of piles and therefore different capacity is considered thoroughly (table 14-1). Examination of bearing capacity left on these columns can lead to a solution for an economic configuration of the swimming pools on the floor plan. The amount of piles is determined and multiplied with the capacity of one pile, which is minimised from 100 kN til 88 kN (chapter 12.7).



Figure 14-2 Amount of piles flour warehouse

Number of piles	Capacity
25	2200 kN
34	2992 kN
38	3344 kN
30	2640 kN
40	3520 kN
32	2816 kN
18	1584 kN

column	Load floor 1-6		
Corner column	870 kN		
Façade column	1374 kN		
Middle column	2338 kN		
Façade corner silo column	1342 kN		
Façade silo column	1224 kN		
Middle corner silo column	2452 kN		
Middle silo column	2408 kN		
Table 14 2 Waight floors 1 C			

Table 14-1 number of piles

The existing structure consists of seven floors. These floors have the new functions of restaurant, café and fitness. When only the existing structure on permanent and imposable loads of the floors 1-6 (table 14-2) is considered there is still capacity left on the foundation (figure 14-3). Few capacity is in the middle columns (figure 14-4). Therefore the swimming pools should be located as much as possible on the outside of the building, where the capacity is left.



Figure 14-3 capacity left foundation

Figure 14-4 in middle low capacity

The weight of the swimming pool is the heaviest load of the top. The load of the pool depends on how the pool is configured on the columns, as a corner, half of the pool or total (figure 14-5, 14-6 and 14-7) and on the height of the pool (appendix W).

Table 14-2 Weight floors 1-6







Figure 14-5 total of the weight of swimming pool

Figure 14-6 Half of the weight of swimming pool

Figure 14-7 quarter of the weight of swimming pool

An examination of the load of the top with or without a pool and the left capacity of the foundation after applying the load of floor 0-6, results in different situations. Shifting of the location of the pool the most economic solutions are searched (appendix W).

1. In the first situation the load of the top in concrete without the swimming pools is calculated, from this it can be concluded that without the swimming pool the middle columns (figure 14-4) have not enough capacity.



Figure 14-8 top without swimming pools

2. In the second situation the load of the roof is transferred to the outside columns, the load of the swimming pool is not considered (appendix W). With this configuration no problems with the foundation occur.



Figure 14-9 load of the roof to outer columns without swimming pools

3. In the third situation the load with swimming pools is calculated, with a total, half and quarter load, and different heights. It appears that when the swimming pools would have a height of 1,4 m, the capacity of the foundation is still not sufficient in the middle columns. Solutions should be searched where the numbers of additional piles are most economic.

As the demands of the architect with swimming pools of heights 2,5 m and 2 m the options in figure 14-10 are possibilities, in red the dies where the capacity of the foundation is exceeded.



Figure 14-10 examples of placing the swimming pools, height of 2 m and 2,5 m

4. In the fourth situation the possibility of transferring the load to the outer columns is examined (appendix W). But doing this creates high forces on the outside columns while the capacity of the foundation is not sufficient (figure 14-11). Not all the capacity of the foundation beneath the middle columns is used in this situation, this would mean more additional piles then situation 3 and therefore it is not a good solution.



Figure 14-11 load on outside columns

With an additional concrete top there is a need to add extra piles to the existing dies, or transfer the forces to new dies, but this can be diminished to an economic solution. Instead of making a heavy concrete structure on top a choice can be made to make a light structure in steel on top.

Displacement

To calculate the displacement the building is schematised as a concrete framework, but in reality the foundation has a rotational capacity which will increase the displacement (appendix W). The silos were not taken into account in the framework. Because the silos are stiffer than a framework the displacement of the silos are calculated. The building is divided in two parts, one part with the stiff silos and the other part are the top levels (figure 14-12).



Figure 14-12 displacement with silos


Figure 14-13 displacement with silos

The displacement of the total building is calculated according figure 14-13. The displacement of the silos part is 10,9 mm (appendix W). This structure is stiff enough to take care of the displacement of the first part. Therefore only the top needs to be considered to be stiff enough to diminish the displacement. This can be done with a stiff framework, stabilizing walls, cores or braces in the top.

Variants

The following variants are examined and compared with each other: *A* – *Top of concrete, extra columns and dies added and a stiff framework on top B* – *Top of concrete, roof load on outer columns, extra piles added and a stiff framework on top C*– *Light steel top and outriggers*

14.3 Variant A - Top of concrete, extra columns and dies added and a stiff framework on top

The two top floors in concrete are added (chapter 12.9 and appendix Q). On site casted columns of $300 \times 300 \text{ mm}^2$ and on site casted floors.

Foundation

The options in figure 14-10 give solutions for the configuration of the swimming pools on the top floor. Two aspects have to be examined in this case: the load without the swimming pool exceeding the capacity of the foundation in the middle columns and the load on the walls of the silos.

The capacity on the middle columns is, even without the load from the pool, exceeded with F=769 kN - 654 kN = 115 kN. This means 115 kN/34 piles = 3,4 kN per pile, which is a percentage of 3,4kN/88kN = 3,8%. This can be allowed.

Additional piles have to be added beneath the swimming pools (figure 14-14). To transfer these forces to new foundation piles extra columns will be added at floor 0 till floor 3 (figure 14-15). With a columnplate, forces of the floors 1-4 are transported to the new columns and eventually to the new die and divide the load over more columns (figure 14-16).



The heaviest loaded column is examined. The exceeding load is 453 kN too much, by taking over 4 floors, 670 kN is beard by the columns (appendix W).

The columns have to be designed on punching shear, the additional reinforcement in the floors will be sufficient to transfer the load of the floors to these columns. A column of diameter 300 mm and plate of 200 mm are verified (appendix W).

Furthermore, the load of the swimming pools on the columns on ground floor and the walls of the silos has to be verified. The square/octagonal columns change into thin silowalls at floor 6 and 5, t =160 mm (figure 14-17, 14-18 and 14-19). An effective width of the silos is taken of 1000 mm. The silowalls can bear the load from the top, even with the swimming pool (appendix W).

Figure 14-18 column floor 7,8



Figure 14-17 column with swimming pool





Figure 14-19 column/silowalls floor 2-6







Displacement

The top will be verified on its displacement. There are two possibilities for the framework on top; increase the section of the column or add beams, both are examined on their displacement. With added beams of 300x300 mm² or with columns of 400x300 mm² the displacement is not exceeded (appendix W).

Constructing method

Where the additional columns are placed the floor is removed and segmented steel tube piles with concrete injection and concrete dies are added. The reinforcement of the dies continues and the columns are casted in situ. When the columns are realised, the top structure is added. In the existing columns steel bars are added and the reinforcement of the columns is placed to cast the columns in situ. The floors are made of flat slab floors, which are used as formwork of the floors.

14.4 Variant B - concrete top, roof load on outer columns, extra piles added

The two top floors in concrete are added (chapter 12.9 and appendix Q). On site casted columns of $300 \times 300 \text{ mm}^2$ and on site casted floors.

Foundation

The roof loads are transferred to the outer columns. This will diminish the load on the middle columns and increase the load on the outside columns (appendix W).

Corner column	355 kN	
Façade column	659 kN	
middle column 614 kN		
Table 14-3 forces on columns		



Figure 14-21 span roof beams

A prefab pretensioned concrete beam of 1000 x 350 mm², a steel truss with a h=1250 and tube profiles of 250x150x10 or a steel castellated beam of HEA600 could be applied (figure 14-22). Those are verified on stress and displacement (appendix W).



Figure 14-22 section beams

Where the pools are exceeding the capacity of the foundation, extra piles are added. A choice is made for steel tube piles with injection of concrete, those have a little work height and are non-vibrating. To transfer the load to the new piles beams are laid underneath the existing die. The additional piles bear those beams. The total load is divided on the existing and new piles according the stifness of the piles (appendix W). The heaviest loaded column is examined and bears a load of 3290 kN. The additional piles are designed on taking over load (figure 14-23).



Figure 14-23 added piles to foundation

Displacement

The top will be verified on its displacement. The three beams and the concrete top are tested on their stiffness, hereby are the maximum displacement of the building and per floor not exceeded (appendix W).

Constructing method

Where the additional piles are placed the floor is removed and segmented steel tube piles with concrete injection are added. The beams are casted in situ and the floor is repaired. When this is done the top structure should be made. In the existing columns steel bars are added and the reinforcement of the columns is placed to cast the columns in situ. The floors are made of flat slab floors, which are used as formwork of the floors. When the floors and columns are constructed the roofbeams is connected with the outer columns.

14.5 Variant C - Light steel top and outriggers

The two top floors in steel are examined. The swimming pool consists of 220 mm concrete, a foil, an layer of isolation, and 1,5 mm RVS on the floor and 2,5 mm RVS on the walls (figure 14-24). The floors, span 2,5 m and HE300B and HE360B beams bear the pools. HE300B columns bear the beams.



0 1

Foundation

With a steel structure on top there is no need for additional foundation capacity, whithout a swimming pool. When a floor with pool of a height of 2m are realised, instead of the big swimming pool with a heigt of 2,5 m, it is possible to realise the top structure without additional piles (figure 14-25). When the big swimming pool has a height of 2,5 m the capacity of the foundation will be exceeded (figure 14-26).



Figure 14-25 pools with height 2 m



Figure 14-26 pools with height 2 m and 2,5 m

Displacement

While the steel structure is constructed with hinges extra measurements are needed to make the top stiff. Outriggers are added to the structure on the position of the walls of the swimming pools, at the same height as the pools, in this way they can be made non-visible. In between the outriggers there is space for installations of the pool.



Constructing method

The steel columns are connected with hinges to the existing concrete structure. The steel beams and outriggers are added. When the steel framework is standing the steel floor plates and roof plates are added and when those are placed the concrete to the floor is casted.

14.6 Selection

The variants are compared on their preconditions. The preconditions are set out in importance. So point 1 is highest valued and point 6 lowest valued. The values given are stated in table 14-1 to indicate the ranking of the variants.

Conclusion from starting points:

- The additional structural design has a high feasibility in terms of costs and quality. Variant A and B are far more difficult to execute and need special equipment than variant C. The costs of variant C will be much lower.
- 2. The structure is seen as the body of the building and as the monumental value. Therefore, it will not be demolished, or as little as possible. Adaptations are made in a way that the structure can be restored to its original state.

Nothing on variant A, B and C is demolished. The columns in between the existing structure in variant A and the columns on top in variant A and B are hard to remove and to restore the structure to its original state again.

Make optimal use of the possibilities of the structures.
 Variant C makes the most optimal use of the structure, followed by variant B. Variant A with its added columns not.

- Composite the materials and details as a whole component. The material use of new elements should have a connection with the materials of the original elements.
 Variant C has no connection with the original structure, variant A and B do have this connection.
- However, there should be a distinction between the old structures and the new, added elements or repairs, to show that there is a difference between old and new structures.
 Variant A and B make a distinction in their details and way of constructing, in variant C there is a total distinction between old and new.
- 6. The additional structural design has a high feasibility regarding constructing Variant C is most easy to construct. Variant B is the most complicated to construct.

Sta	arting points	А	В	С
1	High feasibility regarding costs and quality	-	-	+
2	Structure as little as possible demolished	0	0	+
3	Optimal use of structure	-	0	+
4	Materials and details composed as a whole	+	+	-
5	But distinction and difference between old and new	0	0	+
6	Method of constructing	0	-	+
	Total score	-1	-2	4+

Table 14-4

It is clear that variant C is selected as the final solution. In chapter 17 choices are made for the new elements and the new design is verified.

15 Verification of structural design

A final structural design is made based on the selections of the variants for both the mill as the flour warehouse. Because it are both combinations of existing structures with new elements an explanation is made how to verify the structure on strength, stability and stiffness.

15.1 Combination of NEN 8700 and NEN-EN 1990-1999

To verify the existing structure the NEN 8700 in combination with NEN-EN 1990-1999 are applied. With existing structure is meant the strength, stability and stiffness of the existing elements and the foundation.

To verify the new elements of the structure the NEN-EN 1990-1999 are applied. With new elements is meant the added columns, beams and braces.

The ateliers, supermarket, fitness and restaurant are described in class CC2 chapter B.3.1 NEN-EN 1990. In table 15-1 and 15-2 the partial factors for load are stated which belong to the classes. Those have a reference period of 15 year.

The values of Ψ factors according table A1.1, NEN 8700 and NEN-EN 1990 are stated in table 15-3 and 15-4.

Combinations of load	Permanent action		Live load not wind	Wind load
Vgl 6.10a	unfavourable	favourable		
	γGj,sup	γGj,inf	γQ,1	γQ,1
Class 3	1,30	0,90	1,30	1,50
Vgl 6.10b	γGj,sup	γGj,inf	γQ,1	γQ,1
Class 3	1,20	0,90	1,30	1,50

Table 15-1 partial factors NEN 8700

Combinations of load	Permanent action		Live load not wind	Wind load
Vgl 6.10a	unfavourable	favourable		
	γGj,sup	γGj,inf	γQ,1	γQ,1
Class 3	1,35	0,90	1,30	1,50
Vgl 6.10b	γGj,sup	γGj,inf	γQ,1	γQ,1
Class 3	1,20	0,90	1,30	1,50

Table 15-2 partial factors NEN-EN 1990

	NEN 8700		NEN-EN 1990-1999		999	
Sort of load	Ψ0	Ψ_1	Ψ2	Ψ0	ψ_1	Ψ2
Category C	0,4	0,7	0,6	0,25	0,7	0,6
atelier/restaurant/café/fitness/spa						
Category D	1,0	0,9	0,8	0,4	0,7	0,6
stores						
Snow	0	0,2	0	0	0,2	0
Wind	0	0,2	0	0	0,2	0

Table 15-3 factors combinations of load NEN 8700 and NEN-EN 1990-1999

15.2 Loads

Permanent loads

The permanent loads are based on the weights as determined in NEN-EN 1991-1-1. They are already mentioned in chapter 12. Where a definite choice is made the elements are tested and checked again, see chapter 16 and 17.

Live loads

The live loads from NEN-EN 1991-1-1 are stated in table 15-5.

class	qk kN/m²	Qk kN
C1, restaurant	4,0	7,0
C3, ateliers	5,0	7,0
C4, fitness	5,0	7,0
D2, supermarket	4,0	7,0
H, roof	1,0	1,5 (0,1*0,1 m ²)

Table 15-4 live load NEN-EN 1991-1-1

Snow load

The amount of snow load, on both building a flat roof is present, and according the NEN-EN 1991-1-3 is:

$$s=\mu_{\!_1}\! imes\!C_e\! imes\!C_t\! imes\!s_k$$
 = 0,56 kN/m² (appendix X)

Wind load on building in general

The amount of windload according the NEN-EN 1991-1-4 is:

$$W_e = q_p(z_e) \times c_{pe}$$

qp(z) is determined with table NB.4 from NEN-EN 1991-1-4. cpe,10 zone D and E are determined with table 7.1 NEN-EN 1991-1-4/NB



Figure 15-1 windload on buildings, NEN-EN 1991-1-4

For the mill the following wind load is applied:

$$\begin{aligned} \text{side A:} \qquad & w_e = q_p(h) \times c_{pe,10} = 1,04 \times (0,8+0,56) = 1,41 \text{ kN/m}^2 \\ & w_e = q_p(b) \times c_{pe,10} = 0,97 \times (0,8+0,56) = 1,32 \text{ kN/m}^2 \\ & \text{side B:} \qquad & w_e = q_p(h) \times c_{pe,10} = 1,04 \times (0,8+0,52) = 1,37 \text{ kN/m}^2 \\ & w_e = q_p(h) \times c_{pe,10} = 0,82 \times (0,8+0,52) = 1,08 \text{ kN/m}^2 \end{aligned}$$

For the flour warehouse the following wind load is applied:

 $w_e = q_p(h) \times c_{pe,10}$ = 1,09 x (0,8+0,54) = 1,46 kN/m² side A: $w_e = q_p(b) \times c_{pe,10}$ = 1,07 x (0,8+0,54) = 1,44 kN/m² $w_e = q_p(h) \times c_{pe,10}$ = 1,09 x (0,8+0,50) = 1,42 kN/m² side B: $w_e = q_p(b) \times c_{pe,10}$ = 0,88 x (0,8+0,50) = 1,14 kN/m²

Wind, roof



Figure 15-2 windload on roof buildings, NEN-EN 1991-1-4

Cpe,1,F = -2,5 Cpe,1,G = -2,0 Cpe,1,H = -1,2 Cpe,1,I = -0,5

Mill

 $W_e = q_p(h) \times c_{pe,1,F}$ = 1,04 x -2,5 = -2,60 kN/m² $w_e = q_p(h) \times c_{pe,1,H}$ = 1,04 x -1,2 = -1,25 kN/m²

Flour Warehouse

 $w_e = q_p(h) \times c_{pe,1,F} = 1,09 \text{ x} -2,5 = -2,73 \text{ kN/m}^2$ $W_e = q_n(h) \times c_{ne.1,H} = 1,09 \text{ x} - 1,2 = -1,31 \text{ kN/m}^2$ *Wind, façade suction* Cpe,1,A = -1,4 Cpe,1,B = -1,1 Cpe,1,C = -0,5

Aanzicht voor e < d

Aanzicht voor $e \ge d$



Figure 15-3 windload on facade buildings, NEN-EN 1991-1-4

Mill

Maximum windload, suction on façade: $w_e = q_p(h) \times c_{pe,1}$ = 1,04 x -1,4 = -1,46 kN/m² (appendix X)

Flour Warehouse

Maximum windload, suction on façade: $w_e = q_p(h) \times c_{pe,1} = 1,09 \text{ x} -1,4 = -1,53 \text{ kN/m}^2$ (appendix X)

15.3 Combinations

According the NEN-EN 1990 the following combinations for the total building and per element should be verified:

EQU/STR (6.4.1)

(6.10 a)
$$\sum_{j\geq l} \gamma_{G,j} G_{k,j} + \gamma_p P + \gamma_{Q,l} \psi_{0,l} Q_{k,l} + \sum_{i>l} \gamma_{Q,i} \psi_{0,i} Q_{k,i}$$

(6.10 b)
$$\sum_{j\geq l} \xi \gamma_{G,j} G_{k,j} + \gamma_p P + \gamma_{Q,l} Q_{k,l} + \sum_{i>l} \gamma_{Q,i} \psi_{0,i} Q_{k,i}$$

The letters G, P and Q standing for:

G = Permanent load P = Prestressing Force Q = Imposed load

The material properties

The design resistance in ultimate limit state is calculated with partial material factors.

Steel: $\gamma_{M0} = 1,00$ $\gamma_{M1} = 1,00$ $\gamma_{M2} = 1,25$

Concrete: permanent and temporary γ_c = 1,5

Extraordinary situations $\gamma_c = 1,2$

16 Final Structural Design Mill

The Mill has the function of stores on the ground and first floor and of ateliers on floor two till floor seven. To deal with the difficulties to realize the architectural design different variants are studied (chapter 13). The variant with sloping columns to transfer forces to the foundation and braces to take care of the lateral load is selected on the preconditions. To make a final design decisions are made on the material of façade, inside walls, floor and roof type. Furthermore, the floor plan is explained and the building is verified on safety and usability with the Eurocode and NEN 8700. At first, the capacity of the foundation is tested on imposable and wind load. Secondly, the stability and displacement is calculated. Thirdly, the elements are verified on stresses due to normal forces, bending moments and shear forces.

16.1 New design

The building consists of a supermarket or stores on floor 0 and 1 and ateliers on floor 2-7. Cores with vertical traffic are placed inside of the building. The floor plans of the atelier are flexible and can be adapted to the wishes of the client. There is a need for two escape routes. The cores with lifts are focused on the floors 2-6. With a maximum of 50 persons per floor, which results in a workspace of $8m^2$ per person, it counts on 250 persons in total. To use the lift as well for transport of goods a lift of 1000 kg is chosen, with dimensions of 2,4 x 2,3 m². ⁷⁵ The stairs should have a maximum height h =170 mm and depth d=290 mm. Cores are placed inside and if possible are not attached to the structure.



Figure 16-1 floorplan ground floor mill

⁷⁵ Jellema 6c



Figure 16-2 floorplan floor 2-7 mill

16.2 Structural design

The wooden floors in the mill building are preserved. This concerns the floor one till seven. The ground floor is a thin concrete floor and is therefore reinforced with a concrete floor. The floor is casted in situ and the existing floor is used as a formwork. The roof has insufficient bearing capacity. Therefore it is replaced by steel roof plates. To transfer the load from the middle columns to the façade columns, sloping columns from first till ground floor and tension profiles at ground floor transfer these forces (figure 16-3). The lateral load is taken over with braces on the façade portals and two middle portals (figure 16-4). The beams on the first and seventh floor are reinforced with steel plates, beneath the profile to resist the moments (appendix Y).



Figure 16-3 added columns and tension profile on ground floor mill



Figure 16-4 Added braces, in the middle part and the outer part

16.2.1 Floors

The wooden floors on level 1-7 will be reused. Based on the fact that these floors were designed with a live load of 10 kN/m², on level 1 and 2, and a live load of 8 kN/m² on level 2-7 a comparison is made with the design load that is present now. The ground floor is a thin concrete floor and has not enough capacity, therefore it is used as a work floor for a new concrete cast in situ floor.

The existing wooden floors are not sufficient to resist the airborne and contact sound. Measures which can be taken are a layer of multiplex, isolation and gypsum board on top of the wooden planks and beneath the existing floors a cavity filled with isolation and again a gypsum board hanging on the structure with springs. The glass façade and the inside walls have no extra influence on the transfer of sound (figure 16-5).⁷⁶



Figure 16-5 section floor mill



⁷⁶ Jan Persoon, ir. J. Persoon. Junior Projectleider. Cauberg-Huygen Raadgevende Ingenieurs BV

Floor 1 - 2

In the old situation the floors are calculated on a resulting force of F = 25 kN. In the new situation, the weight of the materials of the floor is stated in table 16-3, the design force on the floor is F = 22 kN (appendix Y). The wooden floors of floor 1 and 2 have sufficient bearing capacity.

5.po		1000	0,000
gips	25	1538	0.3845
minerale wol	40	150	0,06
multiplex	10	500	0,05
minerale wol	20	150	0,03
gips	25	1538	0,3845
material	thickness in mm	density	load in kN/m²

Table 16-1 new floor mill

Floor 3 - 7

In the old situation the floors are calculated on a resulting force of F = 20 kN. In the new situation, weight of the materials of the floor is stated in table 16-3, the design force on the floor is F = 15 kN (appendix Y). The wooden floors on floor 3 till 7 have sufficient bearing capacity.

Ground floor

The ground floor consists of a thin floor, 150 mm, with little reinforcement. An easy solution to realize a new floor is to use the existing floor as a formwork for the new floor. Prefabricated floors are mostly in catalogue sizes which mean they should be adapted to the sizes of the building, therefore this would be more expensive to realize and time-consuming than casting on site.⁷⁷ There are 4 types of floors on bearing points with rigid or non-rigid ends sides (figure 16-6).

Concrete B25	f'b = 0,6 x 25 N/mm² = 15 N/mm²
qG = 24 kN/m³ x 0,27 mm = 6,5 kN/m²	Live load $qq = 5 \text{ kN/m}^2$
FEB 500	fs = 435 N/mm²
diam hoofdwapening $\phi_{\!_k}$ = 12 mm	ly / lx = 1,6

Table 16-2 ground floor



⁷⁷ Jellema 9 h5

The height of the floor is chosen as h = 300 mm

$$d = \frac{1}{30}l = 260 \text{ mm} \qquad h = d + c + \phi_k / 2 = 296 \text{ mm}$$

$$qd = \sum_{j \ge 1} \xi \gamma_{G,j} G_{k,j} + \gamma_{Q,1} Q_{k,1} = 1,2 \times 6,5 + 1,5 \times 5,0 = 15,3 \text{ kN/m}^2$$

$$M = coefficient \times 0,001 \times q_d \times l_x^2$$

The moment reinforcement is calculated with moment coefficients, NEN 6720 (appendix Y). To calculate the percentage of reinforcement a strip of width, b = 1m is chosen. From GTB table 11.4 a the reinforcement percentage is chosen and compared with the minimum and maximum percentage of reinforcement, $\omega_{0,\min} < \omega_0 < \omega_{0,\max}$. The results of the applied reinforcement can be found in appendix Y.

16.2.2 Roof

In the old situation the roof was designed with a snow load of $0,74 \text{ kN/m}^2$. In the new situation, the weight of the materials of the roof is stated in table 16-5, the design force on the floor is q = 1,7 kN (appendix Y). The existing roof has not enough capacity and should therefore be replaced.

material	thickness in mm	density	load in kN/m²
bitumen	0	0	0,1
isolation	70	0	0,2
total			0,3

Table 16-3 load on existing roof

To make a light structure on the roof and because of the easy way of constructing, steel plates are added. In this case steel plates of 70-0.70 are selected (appendix Y). 78 The weight of the materials of the roof is stated in table 16-6.



Figure 16-7 Example roof

material	thickness in mm	load in kN/m²
Bitumen	0	0,1
isolation	100	0,2
Wooden plates	18	0,10
Steel roof plate 70-0.70	70	0,08
veerregels	20	0,05
gypsum board	15	0,25
total		0,78

Table 16-4 new materials roof

⁷⁸ Vloerwijzer staalframebouw

The roof is schematised as an beam with b = 1m.

$$\begin{aligned} q_G &= 0,78 \text{ kN/m}^2 * 1\text{m}' = 0,78 \text{ kN/m}' \\ q_{Q,snow} &= 0,56 \text{ kN/m}^2 * 1\text{m}' = 0,56 \text{ kN/m}' \\ q_{Q,roof} &= 1,0 \text{ kN/m}^2 * 1\text{m}' = 1,0 \text{ kN/m}' \\ q_{Q,wind} &= -2,6 \text{ kN/m}^2 * 1\text{m}' = -2,6 \text{ kN/m}' \end{aligned}$$

Windload gives a maximum loading upwards. The verifications of the roof in ULS on Moment Resistance and in SLS on displacement are calculated in appendix Y.

16.2.3 Beam first floor

The middle beams on the first and seventh floor do not have enough moment resistance capacity in the middle of the beam. Therefore extra material is added to the beam. Strips of t = 26 mm are welded on the beams (figure 16-8) This changes the moment of Inertia (table 16-5). Therefore the beams can resist the moment.



Figure 16-8 material added to beam

	1	W
Beam 1	150374156	1222554
Beam 2	150374156	1222554
Beam 3	185296314	1422075
Beam 4	532995784	2821576

Table 16-5 new characteristics beams





Figure 16-9 beams reinforced on floor 1 and 7

16.2.4 New structural elements

The sloping columns are HE160M profiles (figure 16-3). The added tension profile is a round steel profile of diameter 50 mm. The braces are profiles of diameter 60 mm (figure 16-4).

16.2.5 Choice of façade

As already mentioned in the structural analysis a glass façade is chosen by the architect, the properties are stated in table 16-5.

Glass H++	
d	12 mm
ρ	25kN/m³
W	0,3 kN/m²

Table 16-6 façade of glass

16.2.6 Inside walls

The inside walls can be moved or removed easily because the floor plan can be adapted to the client wishes. The inside walls have acoustic measurements as well. For the design a choice is made for a Sepawand (figure 16-10).

Gypsum board	
d	100 mm
W	240 N/m²
	depends on floor height

Table 16-7 inside walls



Figure 16-10 sepawand

16.3 Fire-safety:

The steel structure has no cover protection against fire. According the Dutch building regulations it needs a fire protection of 120 minutes. To realize this in a steel structure without covering of the profiles a sprinkler installation can lower the temperature of the structure which gives it more time before the structure fails.

16.4 Verification of whole building

16.4.1 Foundation

The verification of the load on the foundation in ultimate limit state is a combination of NEN 8700 and NEN-EN 1990-1999. Two critical cases are examined:

- i. wind-load fully loaded and the imposable load with an instantaneous factor
- ii. two floors fully loaded and 6 floors loaded with an instantaneous factor

The case with only self-weight is not critical and therefore not considered.

	Imposed load, $\mathit{Q}_{k,i}$	ψ_0	Amount of floors
1 Atelier	5,0 kN/m²	0,4	6
2 supermarket	4,0 kN/m²	1,0	2
3 roof	0,4 kN/m²	0,0	1
4 snow	0,56 kN/m²	0,0	1
5 wind	-	0,0	7

Table 16-8 load on mill

6,1 m

25 m

The design load per floor is calculated based on chapter 15.2 and 16.2 (table 16-8 and 16-10). The total design load on the foundation is calculated in appendix Y and compared with the bearing capacity of the foundation (table 16-9 and 16-11). In both cases the bearing capacity is not exceeded by the design load.

i. wind-load fully loaded and the imposable load with an instantaneous factor



Figure 16-11 windload on mill transverse direction

floor 0	Gk,2 = 0,15*24+0,3*25 = 11,1 kN/m ²
	Qk,2 x Ψ0,2 = 4,0 kN/m ² x 1,0 = 4,0 kN/m ²
floor 1	Gk,2 = 0,9 + 0,3 kN/m ² = 1,2 kN/m ²
	Qk,2 x Ψ0,2 = 4,0 kN/m ² x 1,0 = 4,0 kN/m ²
floor 2-7	Gk,1 = 0,9 + 0,3 kN/m ² = 1,2 kN/m ²
	$Q_{k,1} \times \Psi_{0,1} = 5,0 \text{ kN/m}^2 \times 0,4 = 2,0 \text{ kN/m}^2$
roof	Gk,4 = 0,8 kN/m ²
	Qk,4 x Ψ0,4 = 0,56 kN/m ² x 0,0 = 0,0 kN/m ²

Table 16-9 floor design loads on mill

	Dead+imposed	wind	total
Façade die	1301 kN	943 kN	2244 kN
Middle die	1820 kN	-669 kN	1151 kN

Table 16-10 design load on foundation mill

ii. two floors fully loaded and 6 floors loaded with an instantaneous factor

$\sum 1,20 \times G_{k,j}$ +	$1,30\times Q_{k,1}\times 0,4\times 6$	$+1,30 \times Q_{k,2} \times 1,0 \times 2 +$	$-1,50\times 1,0\times Q_{k,5}$
j≥1	atelier,6 floors	sup <i>ermarket</i> ,2 <i>floors</i>	wind

floor 0	Gk,2 = 0,15*24+0,3*25 = 11,1 kN/m ²	
	Qk,2 x Ψ0,2 = 4,0 kN/m ² x 1,0 = 4,0 kN/m ²	
floor 1	Gk,2 = 0,9 + 0,3 kN/m ² = 1,2 kN/m ²	
	Qk,2 x Ψ0,2 = 4,0 kN/m ² x 1,0 = 4,0 kN/m ²	
floor 2-3	Gk,1 = 0,9 + 0,3 kN/m ² = 1,2 kN/m ²	
	Qk,1 x 1,0 = 5,0 kN/m ² x 1,0 = 5,0 kN/m ²	
floor 4-7	Gk,1 = 0,9 + 0,3 kN/m ² = 1,2 kN/m ²	
	Qk,1 x Ψ0,1= 5,0 kN/m ² x 0,4 = 2,0 kN/m ²	
roof	Gk,4 = 0,8 kN/m ²	
	Qk,4 x Ψ0,4 = 0,56 kN/m ² x 0,0 = 0,0 kN/m ²	

Table 16-11 floor design loads on mill

	W	Capacity foundation
Façade die	1539 kN	1760 kN
Middle die	1973 kN	2200 kN
Small die	365 kN	352 kN

Table 16-12 design load on foundation mill

The capacity of the foundation is not exceeded.

16.4.2 Lateral load

The lateral load caused by the wind introduces a moment on the building. A verification is done if there are no tension forces due to the moment in ULS on the building. The wind load in transverse and longitudinal direction is examined, including 2nd order effects and initial sway. To check whether tension forces are present in ULS the following load combination is verified:

$$\sum_{j\geq 1} 0,9 \times G_{k,j} + 1,50 \times Q_{k,1}$$

The displacement is calculated in SLS. The maximum displacement of the building is $u_{max} = 31100 \text{ mm}/500 = 62 \text{ mm}$. To verify the displacement the following equation is used:

$$\sum_{j\geq 1} 1, 0 \times G_{k,j} + 1, 0 \times Q_{k,j}$$

transverse direction

At the outer portals and on two inner portals braces are placed (figure 16-12). The wind load is:

$$w_e = q_p(h) \times c_{pe,10} = 1,41 \text{ kN/m}^2$$
$$w_e = q_p(b) \times c_{pe,10} = 1,32 \text{ kN/m}^2$$







Figure 16-12 windload divided over building

Figure 16-13 braces on the outer portals

Figure 16-14 braces on the inside portals

1-braces on the outer portals (figure 16-13) The total lateral design load is: H = 5,3 kN/m *6,1m + 5 kN/m *25 m = 157,3kNThe total vertical design load is: V = 3058 kN

The 2nd order effects do not have to be taken into account when $\alpha_{cr} = F_{cr}/F_{Ed} \ge 10$. To calculate the stiffness of the building the area of the smallest column A = 4172 mm² is taken over the braced part (figure 16-13). The critical force is Fcr = 884895 kN (appendix Y). $\alpha_{cr} = F_{cr}/F_{Ed} = 884895 \text{ kN}/3058 \text{ kN} = 289$ $\alpha_{cr} \ge 10$ There is no need to take second order effects into account.

Initial Sway does not have to be taken into account when per floor $HEd \ge 0,15$ VEd.

 $HEd = 157 \ kN \qquad VEd = 3058 \ kN \qquad 0,15 \ VEd = 459 \ kN \\ Initial sway has to be calculated.$

$$\boldsymbol{\phi} = \boldsymbol{\phi}_0 \times \boldsymbol{\alpha}_h \times \boldsymbol{\alpha}_m$$

$$\phi_0 = \frac{1}{200}$$
 $\alpha_h = \frac{2}{\sqrt{h}}$ $\frac{2}{3} \le \alpha_h \le 1,0$ $\alpha_m = \sqrt{0,5\left(1 + \frac{1}{m}\right)}$

h is height of the building m is number of columns in a row

$$\phi = \phi_0 \times \alpha_h \times \alpha_m$$
 = 0,0027

There are no tension forces on the foundation caused by the lateral load in ULS. (appendix Y). The displacement is u = 8 mm in SLS and the maximum displacement is not exceeded. (appendix Y).

2-braces on inside (figure 16-14) The total lateral design load is: H = 14,1 kN/m * 6,1 m + 13,2 kN/m * 25 m = 416 kNThe total vertical design load is: V = 5921 kN

To calculate the stiffness of the building the area of the smallest column A = 4172 mm² is taken over the braced part (figure 16-14). The critical force is Fcr = 70433 kN (appendix Y). $\alpha_{cr} = F_{cr}/F_{Ed} = 70433 \text{ kN}/5921 \text{ kN} = 12$ $\alpha_{cr} \ge 10$ There is no need to take second order effects into account

There is no need to take second order effects into account.

Initial Sway $\Phi = 0,0029$ (appendix Y)

There are no tension forces on the foundation caused by the lateral load in ULS (appendix Y). The displacement is u = 58 mm in SLS and the maximum displacement is not exceeded (appendix Y).

Longitudinal direction

In the longitudinal direction the building is coupled to its extension. The windload is divided over the middle part and the sides.

The wind load is:

$$w_{e} = q_{p}(h) \times c_{pe,10} = 1,37 \text{ kN/m}^{2}$$
$$w_{e} = q_{p}(b) \times c_{pe,10} = 1,08 \text{ kN/m}^{2}$$

1-Middle part:

The total lateral design load is:H = 10,8 kN/m *15,3m + 8,5 kN/m *15,8 m = 300 kNThe total vertical design load is:V = 3220 kN

To calculate the stiffness of the building the area of the smallest column I = $10,75*10^{6}$ mm⁴ is taken over 12 columns. The critical force is Fcr = 220 kN (appendix Y). $\alpha_{cr} = F_{cr}/F_{Ed} = 220 \text{ kN}/2320 \text{ kN} = 0,09$ $\alpha_{cr} < 10$ The 2nd order effects have to be taken into account. The design effects have to be multiplied with $\alpha_{cr} = 1,09$

Initial Sway $\Phi = 0,0029$ (appendix Y)

There are no tension forces on the foundation caused by the lateral load in ULS (appendix Y). The displacement is u = 28 mm in SLS and the maximum displacement is not exceeded (appendix Y).

2-side parts

The total lateral design load is:H = 5,4 kN/m * 15,3 m + 4,3 kN/m * 15,8 m = 150 kNThe total vertical design load is:V = 2320 kN

To calculate the stiffness of the building the area of the smallest column I = $10,75*10^{6}$ mm⁴ is taken over 12columns. The critical force is Fcr = 220 kN (appendix Y). $\alpha_{cr} = F_{cr}/F_{Ed} = 220$ kN/2320 kN = 0,09 $\alpha_{cr} < 10$ The 2nd order effects have to be taken into account. The design effects have to be multiplied with $\alpha_{cr} = 1,09$

Initial Sway $\Phi = 0,0025$ (appendix Y)

There are no tension forces on the foundation caused by the lateral load in ULS (appendix Y). The displacement is u = 56 mm in SLS and the maximum displacement is not exceeded (appendix Y).

16.5 Verification of existing elements

16.5.1 Verification of Beams

The elements are verified in ultimate limit state on normal Force, Moment and shear force.

Normal force:

$$\frac{N_{Ed}}{N_{el,Rd}} \le 1 \qquad N_{el,Rd} = \frac{A \times f_y}{\gamma_{M0}}$$

Moment:

$$\frac{M_{y,Ed}}{M_{el,y,Rd}} \leq 1 \qquad M_{el,y,Rd} = \frac{W_{_{el,y,\min}} \times f_y}{\gamma_{M0}}$$

Interaction between Normal force and moment:

$$\frac{N_{\scriptscriptstyle Ed}}{N_{\scriptscriptstyle el,Rd}} + \frac{M_{\scriptscriptstyle y,Ed}}{M_{\scriptscriptstyle el,y,Rd}} \leq 1$$

Shear force:

$$\frac{\tau_{Ed}}{\tau_{y,d}} \le 1 \qquad \tau_{Ed} = \frac{V_{z,Ed} \times S}{I_y \times t} \qquad \tau_{y,d} = \frac{f_y}{\sqrt{3} \times \gamma_{M0}}$$

Interaction between shear force and moment:

$$\left(\frac{\sigma_{x,Ed}}{f_y / \gamma_{M0}}\right)^2 + 3\left(\frac{\tau_{Ed}}{f_y / \gamma_{M0}}\right)^2$$

Lateral-torsional buckling of the beams:

The reduction factor for buckling $\, arnothing \,$ is determined with $\, \lambda_{\it rel} :$

$$\lambda_{rel} = \xi \sqrt{\frac{lh}{bt_f} \frac{f_y}{E}} \qquad \xi = 1,23$$
$$\frac{M_{y,Ed}}{\omega \times M_{el,y,Rd}} \le 1$$

The maximum yielding strength in service limit state is $fy = 137 \text{ N/mm}^2$, the elements are tested first in ultimate limit state, but when the elements do not have sufficient resistance then a new check will be done in service limit state, because safety factors are implemented in the yielding strength.

Lateral load in transverse direction

The elements in the inside portal are the heaviest loaded elements due to the permanent and wind load:

$$\sum_{j\geq 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,wind}$$

The elements are verified on resistance of normal force, moment, interaction between normal force and moment, shear force and interaction between shear force and moment and lateral torsional buckling of the beams (appendix Y).

While the columns and beams have stiff connections the effective length of the beams is $l_{eff} = \frac{l_{sys}}{2}$.

For the beams floor 3-7: $l_{eff} = \frac{l_{sys}}{2} = 7,88 \text{ m}/2 = 3,94 \text{ m}$ For the beams floor 1-2: $l_{eff} = \frac{l_{sys}}{2} = 3,94 \text{ m}/2 = 1,97 \text{ m}$

Lateral load in longitudinal direction

The elements in the middle part are the heaviest loaded elements due to the permanent and wind load:

$$\sum_{j\geq 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,wind}$$

The internal forces and moments are multiplied with $\alpha_{cr} = 1,09$, due to the 2nd order effects. The elements are verified on resistance of normal force, moment, interaction between normal force and moment, shear force and interaction between shear force and moment (appendix Y). Lateral torsional buckling of the beams does not have to be taken into account because the 2nd order effects are taken into account.

Imposed load

The elements of the roof, floor 7 and floor 1 are the heaviest loaded elements due to permanent and imposed load:

Floor 0 is a new floor and designed on the imposed load, floor2-7 are loaded in the same way and because floor 7 has the smallest elements those will be tested. Floor 1 has a different way of loading and is tested as well.

$$\begin{array}{l} \operatorname{Roof:} & \left\{ \begin{array}{l} \displaystyle \sum_{j\geq 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,wind} \\ \displaystyle \sum_{j\geq 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,roof} \\ \displaystyle \sum_{j\geq 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,snow} \end{array} \right. \end{array}$$

Floor 2-7:
$$\sum_{j\geq l} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,atelier}$$

Floor 0-1:
$$\sum_{j\geq l} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,store}$$

The elements are verified on resistance of normal force, moment, interaction between normal force and moment, shear force and interaction between shear force and moment and lateral torsional buckling of the beams (appendix Y).

Roof:

roofbeam1: $l_{eff} = \frac{l_{sys}}{2} = 5,0 \text{ m}/2 = 2,5 \text{ m}$ roofbeam2: $l_{eff} = l_{sys}$ = 7,88 m = 7,88 m

Floor 7:

Beam3,4: $l_{eff} = \frac{l_{sys}}{2} = 2,5 \text{ m}$ beam 2: $l_{eff} = l_{sys}$ = 7,88 m Beam r1: $l_{eff} = \frac{l_{sys}}{2} = 1,97 \text{ m}$ For the beams floor 3-7: $l_{eff} = \frac{l_{sys}}{2} = 7,88 \text{ m}/2 = 3,94 \text{ m}$ Floor 1:

Beam 6,7: $l_{eff} = \frac{l_{sys}}{2} = 2,5 \text{ m}$ beam 8: $l_{e\!f\!f} = l_{sys}$ = 7,88 m Beam r3: $l_{eff} = \frac{l_{sys}}{2} = 1,97 \text{ m}$

16.5.2 Verification of Columns

The elements are verified on normal Force, Moment and shear force in the same way as the beams. The reduction factor for buckling ω_{Euler} is determined with λ_{rel} :

$$\lambda_{rel} = \frac{\lambda}{\lambda_e}$$
 $\lambda_e = 93, 9\varepsilon$ $\varepsilon = \sqrt{\frac{235}{f_y}}$
 $\lambda = \frac{l_{eff}}{i}$ $i = \sqrt{\frac{I}{A}}$

The effective length of the columns is determined with the nomogram of NEN 6700 chapter 12. The columns are verified on:

$$\frac{N_{Ed}}{\omega \times N_{el,Rd}} \le 1$$

The maximum yielding strength in service limit state is $fy = 137 \text{ N/mm}^2$, the elements are tested first in ultimate limit state, but when the elements do not have sufficient resistance then a new check will be done in service limit state.

Lateral load

The facade columns are heaviest loaded in transverse direction and the middle columns in longitudinal direction due to the permanent and wind load:

$$\sum_{j\geq 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k, \textit{wind}}$$

The columns are verified on resistance of normal force, moment, interaction between normal force and moment, shear force, interaction between shear force and moment and buckling of the columns (appendix Y).

Lateral load in transverse direction

The façade columns are heaviest loaded in transverse direction (appendix Y).

The columns are verified on buckling in their weakest axe. The effective length is determined with nomograms, therefore the parameters of connection have to be determined:

$$C = \frac{\sum \frac{I_{c\ln}}{l_{c\ln}}}{\sum \mu \frac{I_{beam}}{l_{beam}}} \qquad \mu = 2$$

Lateral load in longitudinal direction

The middle columns are heaviest loaded in longitudinal direction (appendix Y). Buckling of the columns does not have to be taken into account because the 2nd order effects are taken into account.

Imposed loads

The columns are verified on the imposed loads with two fully loaded floors and the rest instantaneous. The columns are verified on buckling in their weakest axe. The effective length is determined with nomograms, therefore the parameters of connection have to be determined:

$$C = \frac{\sum \frac{I_{c\ln}}{l_{c\ln}}}{\sum \mu \frac{I_{beam}}{l_{beam}}} \qquad \mu = 2$$

Three façade columns and three middle columns are verified.

16.6 Verification of added elements

16.6.1 Verification of sloping columns

The sloping columns are verified on normal Force, due to lateral and imposed load (appendix Y).

The reduction factor for buckling $\, arnothing \, \, \omega_{\!\scriptscriptstyle Euler} \,$ is determined with $\, \lambda_{\!\scriptscriptstyle rel} \, : \,$

$$\begin{split} \lambda_{rel} &= \frac{\lambda}{\lambda_e} \qquad \lambda_e = 93, 9\varepsilon \qquad \varepsilon = \sqrt{\frac{235}{f_y}} \\ \lambda &= \frac{l_{eff}}{i} \qquad i = \sqrt{\frac{I}{A}} \,. \end{split}$$

The columns are verified on:

$$\frac{N_{Ed}}{N_{el,Rd}} \le 1 \qquad N_{el,Rd} = \frac{A \times f_y}{\gamma_{M0}}$$
$$\frac{N_{Ed}}{\omega \times N_{el,Rd}} \le 1$$

16.6.2 Verification of Braces

In the braces only tension stresses from the lateral wind load occur, these should be verified on the resistance of normal tension forces .

Round 60 chosen Verified on normal tension force

17 Final structural design Flour Warehouse

The Flour Warehouse has the function of a café and restaurant on the ground and first floor, fitness areas on floor two till seven and swimming pools on floor eight. To deal with the difficulties to realize the architectural design different variants are studied (chapter 14). The variant with a light steel top and outriggers to take care of the lateral load is selected on the preconditions. To make a final design decisions are made on the material of façade, profiles of columns and beams, floor and roof type. Furthermore, the floor plan is explained and the building is verified on safety and usability with the Eurocode and NEN 8700. At first, the capacity of the foundation is tested on imposable and wind load. Secondly, the stability and displacement is calculated. Thirdly, the elements are verified on stresses due to normal forces, bending moments and shear forces.

17.1 New design

The building consists of a café and restaurant on the ground and first floor, fitness areas on floor two till seven, pools on floor eight and a floor in between for the installations, floor 7,5. The existing concrete floors one till six bear the light steel top with fitness and pools. The top continues on the grid of the existing structure. The spa in the flour warehouse has three swimming pools; 140, 45, 25 m2 (2-2,5m high). The situation of the swimming pools is seen in figure 17-2.

Vertical traffic on the stairs takes place on the original stairs and added stairs where the sloping shafts used to be. The existing elevator-shaft will be used. Furthermore a few extra cores with elevators will be added. There is a need for two escape routes.



Figure 17-1 section functions Flour Warehouse





Floor 1





Floor 2-5 Figure 17-2 floor plans functions Flour Warehouse

17.2 structural design

The existing structure, concrete columns and floors are preserved. This concerns the floor one till seven. The columns and beams on floor seven and eight are steel profiles. The outriggers take care of lateral load. Four frames are placed in transverse direction and one in the middle in longitudinal direction, steel profiles as well. The floors are steel plate floors with casted in situ concrete. The roof is a steel plate roof (appendix Z).











17.2.1 Floors

The concrete floors on floor 1-7 will be reused. The design load on which they are calculated is compared with the design load of the new functions. On top a new floor on the swimming pool level, level 8, and between this level and floor 7 the installations floor which bear the pools are located, level 7,5.

Floor 0-1:

In the old situation the original floors bear a design load in SLS of 16,5 $\rm kN/m^2$

In the new situation the floors have the function of a restaurant and are loaded with a design load in ULS of:

Qd =
$$\sum_{j \ge 1} \xi \gamma_{G,j} G_{k,j} + \gamma_{Q,1} Q_{k,1}$$
 = 1,2 * 0,2 m * 25 kN/m³ + 1,5 * 4,0 kN/m² = 12 kN/m²

The floors have sufficient bearing capacity.

Floor 2-7:

In the old situation the original floors bear a design load in SLS of 16,5 kN/m^2 In the new situation the floors have the function of a fitness and are loaded with a design load in ULS of:

$$Qd = \sum_{j \ge 1} \xi \gamma_{G,j} G_{k,j} + \gamma_{Q,1} Q_{k,1} = 1,2 * 0,2 \text{ m} * 25 \text{ kN/m}^3 + 1,5 * 5,0 \text{ kN/m}^2 = 13,5 \text{ kN/m}^2$$

The floors have sufficient bearing capacity.

Floor 7,5:

The floor on level 7,5 bear the installations and the pool. To make the floor as light as possible a ComFloor with steel plates and a concrete layer are selected. To prevent mistakes during the constructing period the same elements are used over the total area of the floorlevel. A ComFloor 210 will be applied, where the pools are located an extra concrete layer of h=200 mm is applied. The floors span 2,375 m, material and weight are stated in table 17-2.



material	thickness in mm	load in kN/m²
Concrete layer	200	4,8
foil	-	-
Comfloor 210	280	2,78
veerregels	20	0,05
gips	25	0,25
total		7,88

Table 17-1 floor mill

The floor is schematised as an beam with b= 600 mm. q_G = (7,88 kN/m² + 20 kN/m²) * 0,6 m = 16,7 kN/m $q_{Q,fitnessfloor}$ = 5,0 kN/m² * 0,6 = 3,0 kN/m'

The verifications of the floor on Moment Resistance in ULS and displacement in SLS are calculated in appendix Z.

Floor 8:

The floor had the function of fitness floor. A ComFloor 100 is selected. The floors span 2,375 m, material and weight are stated in table 17-3.



material	thickness in mm	load in kN/m²
dekvloer	35	0,70
Wooden plates	18	0,10
Comfloor 51	150	2,15
veerregels	20	0,05
gips	25	0,25
total		3,25

Table 17-2 floor mill

The roof is schematised as an beam.

Loads:

 q_G = 3,25kN/m² * 0,61 m = 1,98 kN/m

 $q_{Q,fitnessfloor}$ = 5,0 kN/m² * 0,61 m = 3,05 kN/m

The verifications of the floor on Moment Resistance in ULS and displacement in SLS are calculated in appendix Z.

17.2.2 Roof

The new roof is designed as light as possible; a steelplate roof 120-1.0 is selected. The floors span 4,75 m, material and weight are stated in table 17-3.



Figure 17-5 Example roof



material	thickness in mm	load in kN/m²
Bitumen	0	0,1
isolation	100	0,2
Wooden plates	18	0,10
Steel roof platte 120-1.0	120	0,15
veerregels	20	0,05
gypsum board	15	0,25
total		0,85

Table 17-3

The roof is schematised as an beam with b=1000 mm. Loads:

 $\begin{aligned} q_G &= 0,85 \text{ kN/m}^2 * 1\text{m}' = 0,85 \text{ kN/m}' \\ q_{Q,snow} &= 0,56 \text{ kN/m}^2 * 1\text{m}' = 0,56 \text{ kN/m}' \\ q_{Q,roof} &= 1,0 \text{ kN/m}^2 * 1\text{m}' = 1,0 \text{ kN/m}' \\ q_{Q,wind} &= -2,7 \text{ kN/m}^2 * 1\text{m}' = -2,7 \text{ kN/m}' \end{aligned}$

The windload gives a maximum loading upwards. The verifications of the floor on Moment Resistance in ULS and displacement in SLS are calculated in appendix Z.

17.2.3 New structural elements

The roofplates are supported by beams HE160B which span 4,75 m. Where columns are missing the roofbeams make a span of 9,5 m, here roofbeams HE260B are applied. The fitness floor on level 8 is supported by beams HE200B, which are supported again by beams HE300B. The floors on level 7.5 which bear the pools are supported by beams HE400B, the installations are supported by beams HE320B. The columns are HE360B profiles. The structural elements which are applied in the top are stated in table 17-6. In appendix Z the floor plans are scaled 1:100.



Figure 17-6 structural floor plan 7,5



Figure 17-7 Structural floorplan 8



Figure 17-8 Structural floorplan roof

New structural elements:

Structural elements	profile	fy in N/mm²	G in kN/m	A in mm²	I in 10⁴ mm⁴	W in 10 ³ mm ³
Floorbeam 8	HE300B	235	1,15	14900	8563	1678
Floorbeam 8	HE200B	235	0,60	7810	5696	570
Floorbeam 7.5	HE400B	235	1,52	19800	57680	2884
Floorbeam 7.5	HE320B	235	1,24	16100	30820	1926
roofbeam	HE260B	235	0,91	11800	14920	1148
roofbeam	HE160B	235	0,42	5430	2492	312
Truss	HEB400	235	1,52	19800	57680	2884
Column	HE360B	235	1,38	18100	43190	2400

Table 17-4 new structural elements

17.2.4 Choice of façade

As already mentioned in the structural analysis a glass façade is chosen by the architect, the properties are stated in table 17-5.

Glass H++	
d	12 mm
ρ	25 kN/m³
W	0,3 kN/m²

Table 17-5 façade of glass

17.2.5 Inside Walls

The walls of (dance/aerobics) halls on the fitness floors should have extra acoustic measurements (figure 17-9).



Figure 17-9 inside walls

17.3 Fire-safety:

Measurements have to be taken to take care of fire safety. The structure should not fail in 120 minutes. The floors have a fire resistance of 60 min and the columns of 120 min in the existing structure. The floors are not sufficient and need covers. The additional steel top has to be protected from fire by protecting the steel with additional material.

17.4 Verification of whole building

17.4.1 Foundation

The verification of the load on the foundation in ultimate limit state is a combination of NEN 8700 and NEN-EN 1990-1999. Two critical cases are examined:

i. wind-load fully loaded and the imposable load with an instantaneous factor

ii. two floors fully loaded and 7 floors loaded with an instantaneous factor

The case with only self-weight is not critical and therefore not considered.

Imposable load	Imposed load, $\mathit{Q}_{k,i}$	Ψ_0	Amount of floors
1 Fitness	5,0 kN/m²	0,4	7
2 Restaurant	4,0 kN/m²	0,4	2
3 roof	1,0 kN/m²	0,0	1
4 snow	0,56 kN/m²	0,0	1
5 wind	-	0,0	9

Table 17-6 load on mill

The design load per floor is calculated based on chapter 15.2 and 17.2 (table 17-9 and 17-11). The total design load on the foundation is calculated in appendix Z and compared with the bearing capacity of the foundation (table 17-10 and 17-12). In case i) two different columns are examined and in case ii) four different columns are examined, two with the least bearing capacity and two locations with silowalls. In both cases the bearing capacity is not exceeded by the design load.

J≥1	fitness,7 floors	retaurant,2 floors	wind
floor 0-1(restaurant)	Gk,2 = 0,2m * 24 kN	l/m ³ = 4,8 kN/m ²	
	Qk,2 x Ψ0,2 = 4,0 kN	/m² x 0,4= 1,6 kN/m²	
floor 2-7 (fitness)	Gk,1 = 0,2 * 24 kN/m ³ = 4,8 kN/m ²		
	Qk,1 x Ψ0,1= 5,0 kN/m ² x 0,4 = 2,0 kN/m ²		
floor 7,5 no pool	Gk,1 = 7,88-4,8 kN/1	m² = 3,1 kN/m²	
	Qk,1 x Ψ0,1= 5,0 kN,	/m² x 0,4 = 2,0 kN/m²	
floor 7,5 pool	Gk,1 = 7,88 kN/m ²	+ 20 kN/m² = 27,9 kN/m²	
	Qk,1 x Ψ0,1= 5,0 kN	/m² x 0,4 = 2,0 kN/m²	
floor 8	Gk,1 = 3,25 kN/m ²		
	Qk,1 x Ψ0,1= 5,0 kN,	/m² x 0,4 = 2,0 kN/m²	
roof	Gk,4 = 0,85 kN/m ²		
	Qk,3 x Ψ0,4 = 1,0 kN	/m² x 0,0 = 0,0 kN/m²	

i. wind-load fully loaded and the imposable load with an instantaneous factor

Table 17-7 floor design loads on flour warehouse

	Dead+imposed	Wind, top	Wind, silos	total
Column 5	2224 kN	11 kN	-1346 kN	889 kN
Column 6	1219 kN	77 kN	1346 kN	2642 kN

Table 17-8 resulting forces on foundation mill

ii. two floors fully loaded and 7 floors loaded with an instantaneous factor

$$\sum_{j \ge 1} 1, 20 \times G_{k,j} + \underbrace{1, 30 \times Q_{k,1} \times 2}_{\textit{fitness}, \textit{2 floors}} + \underbrace{1, 30 \times Q_{k,1} \times 0, 4 \times 5}_{\textit{fitness}, \textit{5 floors}} + \underbrace{1, 30 \times Q_{k,2} \times 0, 4 \times 2}_{\textit{retaurant}, \textit{2 floors}} + \underbrace{1, 30 \times 0, 0 \times Q_{k,3}}_{\textit{roof} / \textit{snow}}$$

floor 0-1(restaurant)	Gk,2 = 0,2 * 24 kN/m ³ = 4,8 kN/m ²	
	Qk,2 x Ψ0,2 = 4,0 kN/m ² x 0,4= 1,6 kN/m ²	
floor 2-3 (fitness)	Gk,1 = 0,2 * 24 kN/m ³ = 4,8 kN/m ²	
	Qk,1 x 1,0 = 5,0 kN/m ² x 1,0 = 5,0 kN/m ²	
floor 4-7 (fitness)	Gk,1 = 0,2 * 24 kN/m ³ = 4,8 kN/m ²	
	$Q_{k,1} x \Psi_{0,1} = 5,0 \text{ kN/m}^2 x 0,4 = 2,0 \text{ kN/m}^2$	
floor 7,5 no pool	Gk,1 = 7,88-4,8 kN/m ² = 3,1 kN/m ²	
	Qk,1 x Ψ0,1= 5,0 kN/m ² x 0,4 = 2,0 kN/m ²	
floor 7,5 pool	Gk,1 = 7,88 kN/m ² + 20 kN/m ² = 27,9 kN/m ²	
	Qk,1 x Ψ0,1= 5,0 kN/m ² x 0,4 = 2,0 kN/m ²	
floor 8	Gk,1 = 3,25 kN/m ²	
	Qk,1 x Ψ0,1= 5,0 kN/m ² x 0,4 = 2,0 kN/m ²	
roof	Gk,4 = 0,85 kN/m ²	
	$Q_{k,3} \times \Psi_{0,4} = 1,0 \text{ kN/m}^2 \times 0,0 = 0,0 \text{ kN/m}^2$	

Table 17-9 floor design loads on flour warehouse

	W	Wmax
Column 1	2293 kN	2992 kN
Column 2	2625 kN	2992 kN
Column 3	2706 kN	2640 kN
Column 4	1505 kN	2200kN

Table 17-10 forces on foundation mill

The bearing capacity of the foundation is maximum R=2640 kN. At column 3 the foundation piles are exceeded with 2,5 %, this is allowed. The other columns the capacity is not exceeded.

17.4.2 Lateral Load

The lateral load caused by the wind introduces a moment on the building. Verification is done if there are no tension forces due to the moment in ULS on the building. The wind load in transverse and longitudinal direction is examined, including 2nd order effects and initial sway. The heaviest lateral loaded top in steel is chosen in combination with the concrete silos. The reactions of the top are included in the silos model and the resulting forces are examined on tension forces. To check whether tension forces are present in ULS the following load combination is verified:

$$\sum_{j\geq 1} 0,9 \times G_{k,j} + 1,50 \times Q_{k,j}$$

The displacement is calculated in SLS. The maximum displacement of the building is $u_{max} = 35400 \text{ mm}/500 = 71 \text{ mm}$. To verify the displacement the following equation is used:

$$\sum_{j\geq 1} 1, 0 \times G_{k,j} + 1, 0 \times Q_{k,1}$$

Transverse direction steel top:

First the steel top is examined. The outriggers are applied on four places in transversal direction The wind load is:

$$w_e = q_p(h) \times c_{pe,10}$$
 = 1,09 x (0,8+0,54) = 1,46 kN/m²

$$w_e = q_p(b) \times c_{pe,10} = 1,07 \text{ x} (0,8+0,54) = 1,44 \text{ kN/m}^2$$





Figure 17-10 windload transverse direction

The maximum windload is on the 4th portal The total lateral design load is: H = 14 kN/m * 12m = 168 kNThe total vertical design load is: V = 2134 kN

The 2nd order effects do not have to be taken into account when $\alpha_{cr} = F_{cr}/F_{Ed} \ge 10$.

To calculate the stiffness of the building the moment of Inertia of the columns is taken into account. The critical force F = 24778 kN (appendix Z).

 $\alpha cr = Fcr/FEd = 24778 \text{ kN}/2134 \text{ kN} = 12$ $\alpha cr \ge 10$

There is no need to take second order effects into account.

Initial Sway does not have to be taken into account when per floor $HEd \ge 0,15 VEd$ 0,15 VEd = 320 kN

Initial sway has to be calculated:

$$\phi = \phi_0 \times \alpha_h \times \alpha_m$$

$$\phi_0 = \frac{1}{200} \qquad \alpha_h = \frac{2}{\sqrt{h}} = 0.58 \qquad \frac{2}{3} \le \alpha_h \le 1,0 \qquad \alpha_m = \sqrt{0.5\left(1 + \frac{1}{m}\right)} = 0.77$$

$$\phi = \phi_0 \times \alpha_h \times \alpha_m = 0.0026$$

There are no tension forces from the steel top that have to be taken into account on the calculation of the stability of the silos. The displacement is u = 15 mm this had to be added to the displacement of the silos (appendix Z).

Transverse direction concrete silos:

The total lateral design load is: $H = 1,44 \text{ kN/m}^2 * 4,75 \text{ m} * 20,2 \text{ m} = 138 \text{ kN}$ The total vertical design load is: V = 1903 kN

The stiffness of the silos is calculated I = 7,03* x 10^{12} mm⁴, the critical force is Fcr = 399595 kN α cr = Fcr/FEd = 399595 kN/1903kN = 210 α cr ≥ 10 There is no need to take second order effects into account.



Figure 17-11 part of stiff silos

Initial sway ϕ = 0,0033

No tension forces, the displacement of silos is u = 12 mm. ϕ = 12 mm/20200 mm = 5,9 * 10⁻⁴ rad ϕ x l = 5,9 * 10⁻⁴ rad x 15200 mm = 9 mm Added up with the displacement of u = 15 mm utotal = 12+9+15 = 36 mm The maximum displacement is not exceeded.

Longitudinal direction steel top: The wind load is:

$$\begin{split} & w_e = q_p(h) \times c_{pe,10} = \text{1,42 kN/m}^2 \\ & w_e = q_p(b) \times c_{pe,10} = \text{1,14 kN/m}^2 \end{split}$$


Figure 17-12 windload longitudinal direction

The total lateral design load is: $H = 1,42 \text{ kN/m}^2 * 19 \text{ m}^* 12\text{m} = 324 \text{ kN}$ The total vertical design load is: V = 3740 kN

To calculate the stiffness of the building the moment of Inertia of the columns is taken into account. The critical force F = 39645 kN (appendix Z). $\alpha_{cr} = F_{cr}/F_{Ed} = 39645 \text{ kN}/3740 \text{ kN} = 11$ $\alpha_{cr} \ge 10$

There is no need to take second order effects into account.

Initial sway ϕ = 0,0025

There are no tension forces from the steel top that have to be taken into account on the calculation of the stability of the silos. The displacement is u = 18 mm this had to be added to the displacement of the silos (appendix Z).

Longitudinal direction concrete silos:

The total lateral design load is:H = 1,14 kN/m² * 19 m * 19 m + 1,42 kN/m² * 19 m * 1,2 m = 444 kNThe total vertical design load is:V = 13321 kN

The stiffness of the silos is calculated I = 558 * x 10^{12} mm⁴, the critical force is Fcr = kN α cr = Fcr/FEd = 31717509 kN/13321kN = 2381 α cr \geq 10 There is no need to take second order effects into account.



Figure 17-13 stiff silos

Initial sway ϕ = 0,0033

No tension forces, the displacement of silos is u = 2 mm. Φ = 2 mm/20200 mm = 0,99 * 10 ⁻⁴ rad ϕ x I = 0,99 * 10⁻⁴ rad x 15200 mm = 1,5 mm Added up with the displacement of u = 18 mm utotal = 2 + 1,5 + 18 = 21,5 mm The maximum displacement is not exceeded.

17.5 Verification of structural new elements

17.5.1 Verification of Beams

The elements are verified in ultimate limit state on normal Force, Moment and shear force (chapter 16.5.1).

$$\frac{N_{Ed}}{N_{el,Rd}} \le 1 \qquad \qquad \frac{M_{y,Ed}}{M_{el,y,Rd}} \le 1 \qquad \qquad \frac{\tau_{Ed}}{\tau_{y,d}} \le 1$$
$$\frac{N_{Ed}}{N_{el,Rd}} + \frac{M_{y,Ed}}{M_{el,y,Rd}} \le 1 \qquad \qquad \left(\frac{\sigma_{x,Ed}}{f_y / \gamma_{M0}}\right)^2 + 3\left(\frac{\tau_{Ed}}{f_y / \gamma_{M0}}\right)^2$$

Lateral-torsional buckling of the beams:

The reduction factor for buckling ω_{Euler} is determined with λ_{rel} :

$$\lambda_{rel} = \xi \sqrt{\frac{lh}{bt_f} \frac{f_y}{E}} \qquad \xi = 1,23$$
$$\frac{M_{y,Ed}}{\omega \times M_{el,y,Rd}} \le 1$$

While the columns and beams have hinged connections and the same span the effective length of the beams is $l_{eff} = l_{sys}$ = 4,75 m

The material properties:

$$\gamma_{M0} = 1,00$$
 $\gamma_{M1} = 1,00$ $\gamma_{M2} = 1,25$

Lateral load in transverse direction

The elements on the 4th portal are the heaviest loaded elements due to the permanent and wind load:

$$\sum_{j\geq 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,wind}$$

The elements are verified on resistance of normal force, moment, interaction between normal force and moment, shear force and interaction between shear force and moment and lateral torsional buckling of the beams (appendix Z).

While the columns and beams have hinged connections the effective length of the beams is

$$l_{eff} = l_{sys}$$
 = 4,75 m

Lateral load in longitudinal direction

The elements in the middle part are the heaviest loaded elements due to the permanent and wind load:

$$\sum_{j\geq 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,wind}$$

The elements are verified on resistance of normal force, moment, interaction between normal force and moment, shear force and interaction between shear force and moment and lateral torsional buckling of the beams (appendix Z).

While the columns and beams have hinged connections the effective length of the beams is

$$l_{eff} = l_{sys}$$
 = 4,75 m

Imposed load

The elements of the roof, floor 7-8 are verified on resistance of normal force, moment, interaction between normal force and moment, shear force and interaction between shear force and moment and lateral torsional buckling of the beams (appendix Z).

$$\operatorname{Roof:} \begin{cases} \sum_{j \ge 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,wind} \\ \sum_{j \ge 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,roof} \\ \sum_{j \ge 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,snow} \end{cases}$$
$$l_{eff} = l_{sys} = 4,75 \text{ m}$$
$$\operatorname{Floor 8:} \sum_{j \ge 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,atelier} \\ l_{eff} = l_{sys} = 4,75 \text{ m}$$
$$\operatorname{Floor 7:} \sum_{j \ge 1} 1, 2 \times G_{k,j} + 1,50 \times Q_{k,store} \end{cases}$$

 $l_{eff} = l_{sys}$ = 4,75 m With pool

Floor 7:
$$\sum_{j \ge 1} 1, 2 \times G_{k,j} + 1,50 \times Q_{k,store}$$
$$l_{eff} = l_{sys} = 4,75 \text{ m}$$
Without pool

17.5.2 Verification of Columns

The elements are verified on normal Force, Moment and shear force in the same way as the beams. The reduction factor for buckling ω_{Euler} is determined with λ_{rel} :

$$\lambda_{rel} = \frac{\lambda}{\lambda_e}$$
 $\lambda_e = 93, 9\varepsilon$ $\varepsilon = \sqrt{\frac{235}{f_y}}$
 $\lambda = \frac{l_{eff}}{i}$ $i = \sqrt{\frac{I}{A}}$

The effective length of the columns is determined with the nomogram of NEN 6700 chapter 12. The columns are verified on:

$$\frac{N_{Ed}}{\omega \times N_{el,Rd}} \le 1$$

Lateral load

The façade columns are heaviest loaded in longitudinal direction due to the permanent and wind load:

$$\sum_{j\geq 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_{k,wind}$$

The columns are verified on resistance of normal force, moment, interaction between normal force and moment, shear force, interaction between shear force and moment and buckling of the columns (appendix Z). Column are verified (appendix Z). The columns are verified on buckling in their weakest axe. While the columns and beams have hinged connections the effective length of the beams is

$$l_{eff} = l_{sys} = 4,75 \text{ m}$$

Column floor 7: $l_{eff} = l_{sys}$ = 4,0 m

Column floor 7,5: $l_{eff} = l_{sys}$ = 2,5 m

Column floor 8: $l_{eff} = l_{sys}$ = 5,5 m

Imposed loads

The columns are verified on the imposed loads with two fully loaded floors and the other floors instantaneous:

$$\sum_{j\geq 1} 1, 2 \times G_{k,j} + 1, 50 \times Q_k$$

The columns all have the same profiles to provide stability. The heaviest loaded column are the columns beneath the pool, these are verified on resistance against normal force. The columns are verified on buckling in their weakest axe.

17.6 Existing elements

The floors will succeed see chapter 17.2

17.6.1 Verification of Columns

If the Silos take care of the wind forces Only Normal forces in columns Columns are heaviest loaded underneath the swimming pool. See 17.3



Figure 17-14 verified columns

The heaviest loaded column is 2376 kN The amount of reinforcement is unknown A calculation is done without reinforcement

$$N_d = A_b \times f_b' + A_s \times f_s$$

Ab = 658057 mm²

As = ? fcd = α cc*fck/ γ c = 1,0*12 N/mm² /1,5 = 8 N/mm² Nd = 658057 mm² * 8 = 5264 kN

General and temporary: γ_c =1,5 extraordinary: γ_c =1,2

17.6.2 Verification of silos





Aeff = 800*330-235²+800*140+310*140 = 364175 mm²

 $N_{d} = A_{b} \times f_{b} + A_{s} \times f_{s}$

fcd = α cc*fck/ γ c = 1,0*12 N/mm² /1,5 = 8 N/mm² Nd = 364175 mm² * 8 = 2913 kN





Aeff = 780*140+460*140 = 173600 mm²

$$N_d = A_b \times f_b' + A_s \times f_s$$

fcd = α cc*fck/ γ c = 1,0*12 N/mm² /1,5 = 8 N/mm² Nd = 173600 mm² * 8 = 1388 kN

Conclusion and recommendations Part III

After detecting the failures in part II it was concluded that both the Mill as the Flour Warehouse had problems with the foundation capacity and the exceeded displacement. In chapter 13 and 14, the possible solutions are discussed and chapter 16 and 17 provide the final solutions to verify a safe structure. In this chapter, conclusions of what the possibilities of the structures are and how to deal with these are given. First, the Mill will be discussed on possibilities and solutions and secondly the Flour Warehouse.

The Mill

The problems that occur in the structure of the Mill are that the foundation capacity in the middle columns is too little and that the maximum displacement is exceeded.

Around the existing dies there is enough space left for extra foundation piles. The piles that are added to the foundation should be non-vibrating to prevent damage to the existing structures. Furthermore, they should prevent relaxation of the stresses in the ground and they can be produced in a working height less than 4 meters. Added foundation piles will sack more than the existing piles. Therefore the stiffness of the existing and new piles is examined to determine the load they bear. To prevent a too large displacement of the new piles these can be jacked to have an equal displacement with the existing piles.

Another solution would be to add new columns to take over a part of the load. The load on the new columns will be transferred to new foundation piles.

The façade dies of the Mill have capacity left. Therefore, load can be transferred to the façade dies with sloping columns or large beams. The sloping columns transfer the load from the first floor middle column to the façade dies. A tension bar on the ground floor puts the forces in equilibrium. The columns are easy to construct with hinged connections. The other solution is to transfer the load from the first floor middle column to the façade columns with large beams. The façade columns have enough capacity to deal with the transferred load. The large beams have some more difficult detailing and need a large profile height to resist bending moments and to prevent large displacements.

A solution to diminish the displacement of the structure could be provided with braces. The braces could be added in two portals in different ways, which could be done according to the demands of the architect or client. Another solution is to add cores. A concrete core can provide enough stability. However, a steel core cannot provide enough stability because it will introduce tension forces on the foundation.

To select one of the variants to make a final design the variants are compared with each other on the set preconditions (part I). Variant C, sloping columns and braces, appears to meet the most requirements.

The final structural design of the Mill is verified with the Eurocode and NEN 8700. The foundation and the existing beams and columns are verified with the Eurocode in combination with NEN8700. Verification of stability, sloping columns and braces is done with the Eurocode.

In the final structural design it appears that the wooden floors can be used as atelier floors. The thin ground floor is used as a formwork for a reinforced cast in-situ floor. A light steel roof replaces the roof. The beams on the first and seventh floor are reinforced with a strip beneath the profile to resist the bending moments. The lateral load is divided over 4 braced parts in transverse direction and in longitudinal direction it is coupled to the extension of the mill. With these additions a safe structure is realised.

The Flour Warehouse

The problems that occur in the structure of the Flour Warehouse are the foundation capacity at the location of the swimming pools and that the maximum displacement is exceeded.

Without the pools the capacity of the foundation would not be a problem. The façade dies and the southern dies have extra capacity left in the foundation. The pools can be located where this capacity is left in the foundation to make the fewest interventions in the structure. A solution is to add more piles to existing dies, because there is enough space left for extra foundation piles around the existing dies. The piles that are added to the foundation should be non-vibrating to prevent damage to the existing structures. Moreover, the piles

should prevent relaxation of the stresses in the ground and should have the possibility to be produced in a working height less than 4 meters.

Added piles to a die will sack more than the existing piles. Therefore the stiffness of the existing and new piles is examined to determine the load they bear.

Another solution is to take over part of the load by new columns. Those columns are placed between the columns that are exceeding the foundation capacity. The load on the new columns will be transferred to new foundation piles.

Furthermore, a solution is to diminish the load on the foundation by making a light top of steel instead of a concrete top. The pools should be designed with a concrete floor. However, walls and columns can be made of steel.

To diminish the displacement the building is divided into two parts, the existing structure and the top. The silos of the existing structure can provide stability in transverse and longitudinal direction. A concrete framework on top is stiff enough to take care of the displacement in both directions. A steel top with outriggers creates a stiff structure to take care of the lateral load. Moreover, the outriggers create space for an extra floor of installations.

To select one of the variants to make a final design the variants are compared with each other on the set preconditions (part I). Variant C, the steel top with outriggers, appears to be the best solution.

The final structural design of the Flour Warehouse is verified with the Eurocode and NEN 8700. The foundation and the concrete elements are verified with the Eurocode in combination with NEN8700. Verification of stability and the steel top is done with the Eurocode.

In the final structural design it appears that the concrete floors are safe to reuse. The floors in the top are steel plate concrete floors to diminish the weight and make a fast constructing time possible. The roof is designed with a steel plate. The profiles of the columns are dimensioned to diminish the displacement. The profiles of the beams of the floors and roof are dimensioned to take care of the bending moments due to imposed load.

The silos in the existing structure take care of the lateral load in transverse and longitudinal direction. The lateral load on top is divided in 4 outriggers in transverse direction and one outrigger in longitudinal direction. The existing columns and silo walls have enough capacity to take care of the lateral and imposed loads of the

new functions.

Evaluation

In the evaluation the results of this research are discussed. First the final structural design is evaluated on the requirements set out in part I and the influence of the structural interventions on the architectural and urban design. A final conclusion is given on the research question and recommendations on structural redesign. Furthermore, concepts are given for future research based on this thesis.

18 Evaluation

Both of the structural designs of the Mill and Flour Warehouse are discussed on the list of preconditions set in part I. Furthermore the influence of the solutions on the architectural design and on urban design is discussed.

18.1 List of preconditions

The following requirements are formulated on the basis of the vision of the architect together with making a feasible plan regarding the costs and a practicable plan regarding constructing for the additions and adaptations to the structures:

- 1. The additional structural design has a high feasibility in terms of costs and quality.
- 2. The structure is seen as the body of the building and as the monumental value. Therefore, it will not be demolished, or as little as possible. Adaptations are made in a way that the structure can be restored to its original state.
- 3. Make optimal use of the possibilities of the structures.
- 4. Composite the materials and details as a whole component. The material use of new elements should have a connection with the materials of the original elements.
- 5. However, there should be a distinction between the old structures and the new, added elements or repairs, to show that there is a difference between old and new structures.
- 6. The additional structural design has a high feasibility regarding constructing

Both the buildings are evaluated on these points.

Mill

- 1. The simple solutions and details make the execution financially feasible.
- The structure is as little demolished as possible, the small columns on the ground floor are removed. When removing the braces and the sloping columns, the structure almost returns to its original state.
- 3. By transferring the load to the façade dies the foundation of the structure is used optimally.
- 4. The sloping columns, which have a bearing function, have the same form of the profile and material use as the original bearing structure. The braces, which have a support function against lateral load, differ from this type of profile, however the material used is the same.
- 5. The distinction of the interventions in the structure compared with the original structure is made in the different profile type of the braces and the sloping angle of the added columns.
- 6. The simple solutions above ground make constructing far more easily than beneath the floor. Because the solutions are simple the constructing method has a high feasibility.

Except for precondition 2, all the other preconditions are met by the additional structural design.

Flour Warehouse

- 1. The costs of the additional structure are minimised by fast execution of the steel hinged elements and low crane capacity because of the light weight of the steel structure.
- 2. The structure is not demolished and when the additions are removed it can return to its original state.
- 3. By placing the pools in the right location economic use is made of the capacity of the foundation. In this way there is no need for additional piles in the foundation.
- 4. The existing structure is a concrete structure and the new top is designed in steel. The material use of the new elements has therefore no connection with the original structure.
- 5. The distinction between the existing structure and new top lies in the use of material and the slender profiles of the top compared with the original robust columns of the existing structure.
- 6. The structure has simple solutions which makes the execution simple and fast.

Except for precondition 4, all the other preconditions are met by the additional structural design.

18.2 Interaction between architectural design and structural design

The structural design makes the change of functions possible. Furthermore it can influence the architecture by its interventions as well. The structural interventions of both buildings are briefly discussed in terms of their influence on architecture.

The Mill

The small columns on ground floor are replaced by sloping columns to transfer load to the façade dies. This changes the space at the ground floor from divided into 'four parts' to 'two parts' and decreases the height. It creates more flexible space in the floorplan but at the same time does not diminish the height in a 3d-view (figure 18-1).





Figure 18-1 influence sloping columns on ground floor space

Braces are added in four parts of the building, two on the outer portals and two half portals on the inside. The two outer portals do not influence the space in the building. The two inner portals do influence the space, as their presence divides the flexible plan in sections (figure 18-2).





Figure 18-2 influence braces on space

Furthermore, the braces influence the aesthetics of the building. They make a clearly visible pattern in the façade.

The Flour Warehouse

The outriggers in the top diminish the displacement. By placing the outriggers in the middle of the top a small floor height in-between the fitness and spa floor is created. This floor can be used to place the installations. In this way a solution is provided for the problem of the big installations. The outriggers also influence the aesthetics of the building. They make a clear distinction in the façade between the functions fitness or spa and installations (figure 18-3).



Figure 18-3 light top with closed façade at the installation floor

There is a clear distinction between the light slender steel structure and the large concrete columns on the existing floors. Furthermore, there is a difference in the floor heights of the existing structure and the new top, as the new top layers are higher than the existing floors. The difference in height, material and profiles creates a light open top on a less open heavy structure.

18.3 Interaction between urban design and structural design

The structural design makes the change of functions possible; these functions will influence the surrounding area of the factory. Furthermore it will influence the image of the factory site. The structural interventions of both buildings are briefly discussed on their influence on the urban plan.

The Mill

While there are no large interventions in the structures of the buildings, the interventions are clearly visible in the façade. This will change the image of the factory and could be eye-catching. It makes clear that changes were needed to improve the structure to their new function.

The Flour Warehouse

The steel structure on top of the building shows a clear distinction between existing monument and new structure. It might enhance the existing monumental structure as well. Because of the increasing height it becomes a landmark of the area.

19 Conclusion

The different parts that play a role in the problem definition are discussed and result in a final conclusion on the research question. Furthermore recommendations on structural redesign and concepts for future research are given.

19.1 Problem definition

The problem definition of this thesis was stated as the following:

How can the interventions, as proposed by Peter Zumthor and partner, be integrated in the current structures of the former flour factory 'meelfabriek de Sleutels' in Leiden, with respect to the monumental values, so that sound safe structures, as set out in the Dutch Building Regulations and in the Eurocode-regulations, are created and which adjustments and additions should be made to realize this goal?

To determine the answer the problem definition is divided into parts that will be discussed separately. How can <u>the interventions</u>, as proposed by Peter Zumthor and partner (I), be integrated in <u>the current structures</u> of the former flour factory 'meelfabriek de Sleutels' in Leiden (II), with respect to <u>the monumental values</u> (III), so that <u>sound safe structures</u>, as set out in the Dutch Building Regulations and in the Eurocode-regulations (IV), are created and which <u>adjustments and additions</u> (V) should be made to realize this goal?

I. <u>The interventions, as proposed by Peter Zumthor and partner</u>

The architectural design includes the following functions: rental workshops, fashion and design stores, hotel, ateliers and apartments and a fitness&spa. To translate these functions of the architectural design into the structural design the following starting points, based on the wishes of the architect, client and municipality for the structural design are regenerated:

- 1. The additional structural design has a high feasibility in terms of costs and quality.
- 2. The structure is seen as the body of the building and as the monumental value. Therefore, it will not be demolished, or as little as possible. Adaptations are made in a way that the structure can be restored to its original state.
- 3. Make optimal use of the possibilities of the structures.
- 4. Composite the materials and details as a whole component. The material use of new elements should have a connection with the materials of the original elements.
- 5. However, there should be a distinction between the old structures and the new, added elements or repairs, to show that there is a difference between old and new structures.
- 6. The additional structural design has a high feasibility regarding constructing

Except for precondition 2 all the preconditions are met in the final structural design of the Mill. Except for precondition 4 all the preconditions are met in the final structural design of the Flour Warehouse.

II. <u>The current structures of the former flour factory</u>

The buildings that will be reused are:

- The Boiler House, an iron skeleton with masonry walls and concrete arched floors
- The concrete silos
- The Mill, an double iron portal frame skeleton with wooden floors
- The Storage for flour, concrete mushroom columns and flat slab floors
- the Cleaning building, a concrete skeleton
- The extension of the Mill, a single iron portal frame skeleton with wooden floors
- The concrete tower of silos.

The concrete silos and the tower of Silos are the only buildings that do not need extra measurements when adapting the new functions in the buildings regarding safe structures. The other buildings need to be examined in more detail (? in table 20-1) or need structural interventions to realize safe structures (X in table 20-1).

	Foundation capacity	stability	displacement
Boiler house	X	X	-
Silos 1904	?	-	-
Mill	X	-	X
Flour warehouse	X	-	?
Silos 37-38	-	-	-
Cleaning building	?	-	-
Extension mill	-	-	X
Silos 55	-	-	-
Tower of silos	-	-	-

Table 19-1

III. <u>The monumental values</u>

The buildings were marked as listed monuments of the state in 2001 because of their architectural and cultural-historic values. Based on these monumental values the municipality made a list of demands for the flour factory. In the urban design plan for the area, made by the municipality, a shift of monumental values is visible. It is allowed to demolish the Office building and the façades are not mentioned anymore as monumental.

When Peter Zumthor and Partner were chosen as the designing architects the municipality, Public Service of Cultural Inheritance and the owner made an agreement that the architect has the freedom to make a good design that fits in the urban plan of the city of Leiden.

Peter Zumthor and Partner emphasise the structures of the factory buildings as the real monumental values. This means facades can be replaced and cavities will be made.

IV. Sound safe structures, set out in the Dutch Building Regulations and in the Eurocode-regulations

The Dutch Building Regulations constitute restrictions on safety of the structure, which can be divided into strength of the structure in general and fire safety. To verify the strength of the existing structures, foundation and structural elements, the restrictions of the Eurocode in combination with NEN8700 is applied. To verify the strength of new structural elements the restrictions of the Eurocode are applied. In the final structural design of the Mill this resulted in verification of the foundation and the existing beams and columns by the Eurocode in combination with NEN8700. Verification of stability, sloping columns and braces is done with the Eurocode. In the final structural design of the Flour Warehouse this resulted in verification of stability and the steel top is done with the Eurocode. It can be concluded that the structures are safe and sound according to the Eurocode and NEN8700 regulations.

V. Adjustments and additions

To adapt the Boiler House to a workshop building the foundation capacity has to be examined further and the possibility to couple the building in the south direction to the cleaning building to provide stability. If it is possible the steel should be examined on its yielding strength and a check has to be done if the masonry is still intact and if the bond between steel skeleton and concrete floors still is present, otherwise anchors could be used to solve this problem.

To adapt the silos built in 1904 to a hotel the foundation should be reinforced, because it now only has a restlife of 25 years. The cracks in the roof should be repaired to prevent (further) carbonation and corroding of the steel.

To adapt the Mill to an atelier building, sloping columns are added to transfer the overloading forces to the outer dies, with extra capacity, to make the foundation safe. Braces are added in the outer portals and two inner portals to take care of the displacement. The structure should be cleaned from corrosion and protected against it; a sprinkler installation should be installed to enable lowering of the temperature of the structure to provide fire safety.

To adapt the Flour Warehouse to a fitness building a steel top is realised with steel-plate concrete floors to make a light structure, to create a safe foundation. Outriggers are placed in the top to take care of the displacement. Where reinforcement is visible the concrete should be repaired to prevent (further) carbonation and corroding of the steel.

To adapt the silos built in '37, '38 and '55 to a hotel the concrete has to be repaired where reinforcement is visible to prevent (further) carbonation and corroding of the steel.

To adapt the cleaning building to a design office the foundation capacity has to be examined further and the concrete has to be repaired where reinforcement is visible to prevent (further) carbonation and corroding of the steel.

To adapt the extension of the Mill to apartments the structure should be cleaned from corrosion and protected. The displacement should be diminished by adding braces or a core.

To adapt the Tower of Silos into design and fashion shops the concrete has to be repaired where reinforcement is visible to prevent (further) carbonation and corroding of the steel.

VI. <u>Methodology used in the thesis</u>

Next to the different parts of the problem definition the methodology which is generated and used in this thesis is discussed.



Figure 19-1 from seeking information towards a structural design

The generated methodology (figure 19-1) is applied on this project. First as much data as possible was searched for. This data was, when possible, compared to inspections on the buildings on site to get a realistic overview of the characteristics of the building. Where data was missing assumptions were made (in reality it is recommended to find the missing data by inspections on site) or conclusions were drawn from visual

inspections. With this overview it was possible to detect the failures and possibilities of the structures of the buildings. The failures and possibilities resulted in different solutions to realize the proposed architectural interventions in the existing structures. The best solution was selected by testing the different solutions on the set preconditions (as set out in the architectural analysis, in reality this is done by client, architect, state or municipality and other stakeholders involved). The solution that fits best was selected to develop the final structural design.

By following this methodology a sound safe structures is designed according to the client and architect's wishes. In addition a thorough examination of the data on the buildings prevents the design of structures with overcapacity or with dangerous situations within the structures. This methodology can therefore be applied to other design cases as well.

19.2 Final conclusion

This thesis gives a clear solution to the problem definition:

The interventions and additions of the structures of The Mill and the Flour Warehouse are sound safe structures verified according to the Dutch Building Regulations and the Eurocode-regulations. The capacity of the existing structures is used to their full extent and simple solutions make additions or adaptations possible. The monumental values are kept intact and the preconditions as set according to the vision of the architect and the client's wishes are nearly achieved.

19.3 Recommendations

When an existing structure is adapted to the needs of a renovation project the following recommendations can be made:

- Use the methodology as generated in this thesis, based on the ABCD method. A thorough search for data and a comparison with measurements from inspections on the structures makes it possible to find failures and possibilities, which provide a good basis for the redesign.
- When there is a need for adapting the structure search for the extra capacity of a structure and create a solution based on this capacity.
- From this thesis it appears that buildings build until at least 1947 were not designed on stability and or horizontal displacement, so this should be considered when making a redesign for a structure of the same period.

19.4 Future research

Future research based on this thesis could be done on

- I. How existing concrete reacts with repairs of concrete.
- II. Interaction between the Mill and its extension
- III. The foundation of the silos of 04
- IV. Coupling of the cleaning building on the Boiler house
- V. How existing structures deal with instability

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