SUSTAINABLE DESIGN GRADUATION REPORT

WINCH BALCONY

JOEP NIZET
4411838
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PREFACE

This paper will end my journey as a student of the master track Building Technology.

These last couple of years at the Delft University of Technology, have been interesting, inspiring and fun with some hard times. It has been a great adventure.
The gained knowledge will help me for the rest of my life.

I would like to thank my two mentors Marcel Bilow (main mentor) and Ate Snijder (second mentor) for all their helpful advice, assistance, critical remarks and support.
Always there when needed.
Thank you both for supporting me in accomplishing this result.

Many thanks to all the people at Scheldebouw for giving me the opportunity, and warm welcome when I started my internship at Scheldebouw.
Special thanks to Jean-Paul Erkens (my mentor at Scheldebouw) for helping me with all the knowledge, support, assistance and criticism in designing this balcony.

This thesis could not have been made possible without their help and knowledge.

CONTENTS

1 BACKGROUND

The residential market in London has exploded (Scheldebouw & McPhillips & Gleeson, 2018). There is a high demand for high end residential towers. These towers consist out of many apartments. Apartments with an outdoor space like a balcony add additional space and create additional value for the inhabitants. An outdoor space gives the inhabitants a way to stay in contact with the environment, and enjoy the fresh air and direct sunlight. This balcony can be recessed, cantilevered or a combination of the two.

A recessed balcony (figure 1) is integrated within the building façade, but reduces the total amount of usable indoor floor space. The balcony is an outside space, which means that adjacent next to a room the wall and floor between the spaces needs to be insulated (red lines figure 1).

A cantilevered balcony is an extension of the building. It literally cantilevers outside of the building. This balcony adds space instead of using the existing building floor area. With a cantilever balcony the building sequence of the façade is interrupted. The balcony creates holes in the façade. This requires specialized panels that connect the balcony to the façade. Specialized start and finish details to solve the wind, water and cold bridges. And a complex technical logistic workload, to ensure that the quality and installations meet the standard.

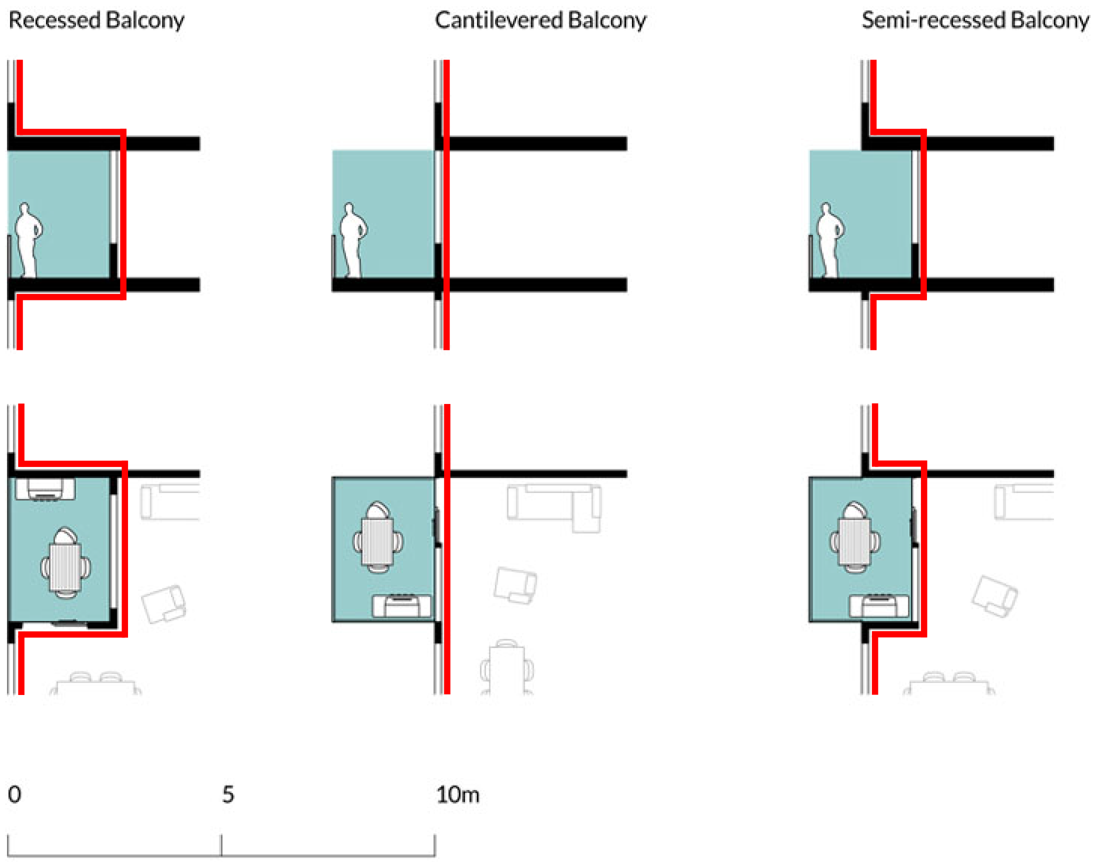


Figure 1 Balconies types (Aucklanddesignmanual, 2019)

2 PROBLEM STATEMENT

What if there was a product that could combine the positive elements of the recessed and cantilevered balconies. That not reduces the floor area of the indoor living area, and not interrupt the flat façade look and function. For instance a temporary balcony that is present when the residents use it. But disappears when it is not needed. Creating a dynamic façade, which is influenced by the weather. Just like the picture of the square in Delft (normally it is empty but when there is a market it is filled with market stands. When the market is finished the stands disappear. The same concept could apply for a transformable balcony which is intergraded into the unitized façade.

Figure 2.1 Marketplace Delft empty (Leiden Delft, 2019)

Figure 2.2 Marketplace Delft full (Markt delft, 2019)

This is an example (figure 2.3) that shows clearly the difference in façade view between no balconies, transformable balconies and permanen balconies.
The transformable balconies create a dynamic façade.

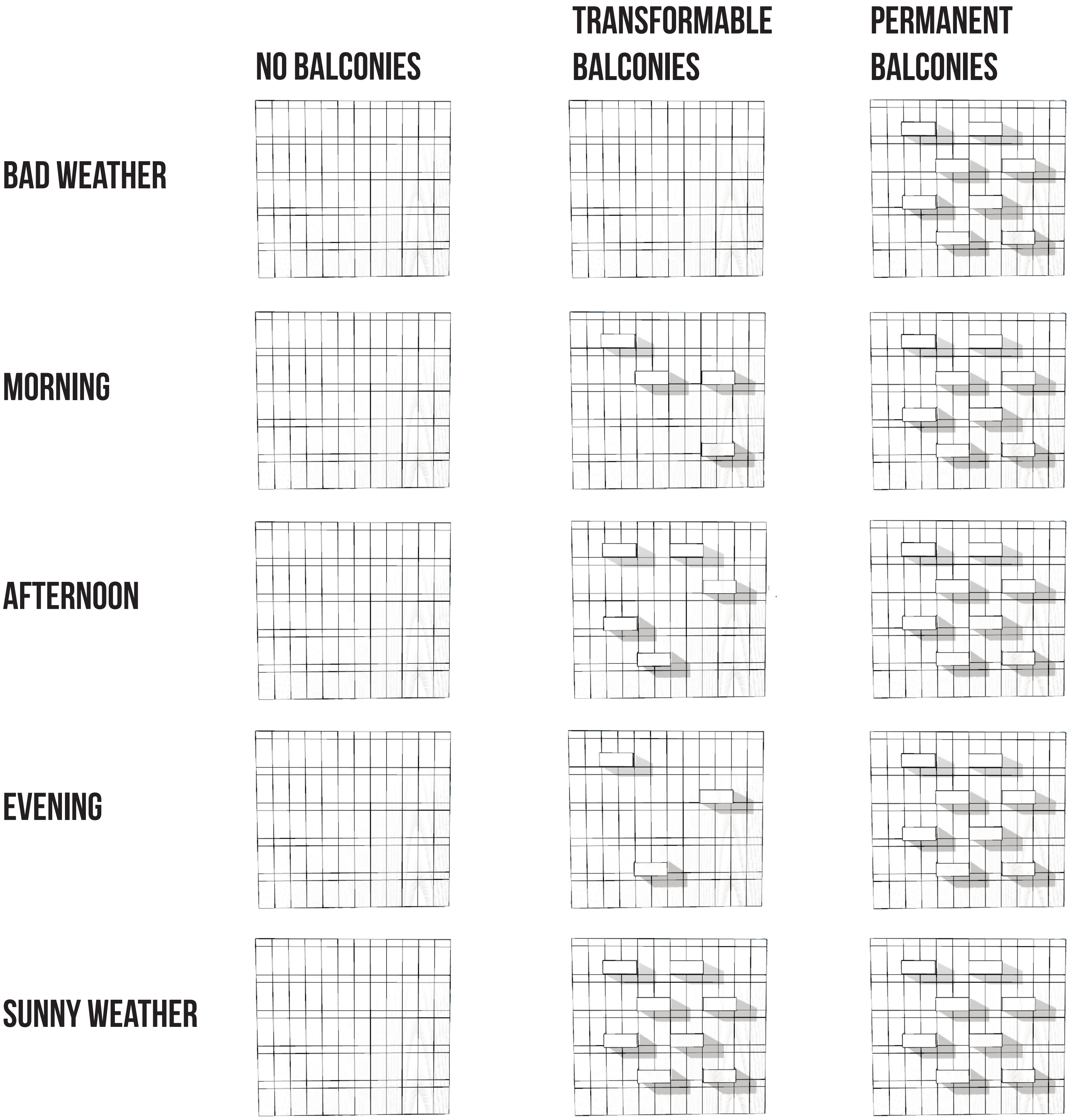


Figure 2.3 facade example (own figure)

3 OBJECTIVE

The main goal of this graduation project is to create a feasibility study. The objective is to design, calculate and test different ways of how a unitized façade element can transform, rotate or convert for creating a temporary outdoor space. This façade element is connected with the same façade brackets used in the unitized façade system. The focus point in this study will be, façade fittings, profiles, construction (dimensions, movement, strength etc.), dimensions compared with the current unitized façade elements, practicality of the design and how much the design would cost to produce.

The final product is a working scale model of a transformable unitized façade element (figure 3.1). This can lead to multiple concepts that have different aesthetics for different kind of façades. Is the supporting construction integrated into the mullions or transoms of the façade? Is it an element that is mounted to the ceiling that pushes a part of the façade outwards? Are the glass and other parts of the unitized façade element used for the balcony? Is there a double façade? These are all hypothesis of how this product could work, leading to potentially different working concepts and different product look.

The product is bound by the condition that it can be delivered to the building site as a prefabricated unitized panel. This means that this product could be placed in any unitized façade. Taking into consideration that the façade brackets (brackets that connect the facade to the building) may need to be reinforced to support this element. No additional constructive element can be used to support this element.

It needs to be one package, one transformable unitized façade element. With no additional construction at the building site.

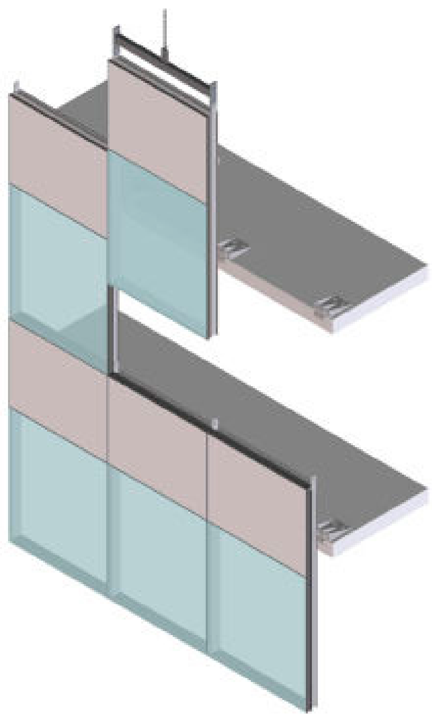


Figure 3.1 unitized facade (eldenbrach, 2019)

4 RESEARCH QUESTIONS

To achieve all these objectives a lot of research and research by design is necessary.
The main research question is: How can a unitized vertical façade element be transformed in a temporary horizontal outdoor living space?

Several sub-questions are needed to answer to the main question. The sub-question are:

4.1 What is the additional value of a temporally balcony?
4.2 What are the alternatives on the market?
4.3 In what way can the façade transform?
4.4 Is the balcony intergrade in the façade?
4.5 What is the best glass composition?
4.6 In what way can the construction function?
4.7 What is the total cost of the transformable façade, and is it feasible?
4.8 Can the transformable façade be scaled in width?

5 APPROACH AND METHODOLOGY

The main research question was divided into research parts. Each part consisted out of a research question and additional topics that provide important information for this research.

5.1 Research existing products.
5.2 Research balcony use and impact on the living area.
5.3 Research unitized façade element.
5.4 Research current façade brackets.
5.5 Calculate glass strength, thickness and weight when used as balcony floor.
5.6 Dimension of the glass element, considering the weight of reinforced glass.
5.7 Location
5.8 Design requirements
5.9 Design process

These research parts are part of an organisation scheme (Figure 5.0.1). This scheme gives a clear view of the research flow. It is based on Research by design. Design a concept. Calculate, test evaluate and rewind the process to a new improved design, which will be tested again. Ideally one design could be made into a working prototype (scale). But this all depends on how much time is available after the design process. If there is a need for new aluminium profile, than there will be time enough to test it on 1:1 scale during this graduation process. There is also the possibility to make a scale model. Or make a 1:1 part of the concept, for instance an important hinge.

Software will be mainly Rhino + Grasshopper; the structural software will be determined later on. There is a possibility that the software which Scheldebouw uses, also will be used for this graduation project. Scheldebouw uses Mepla and Autocad.

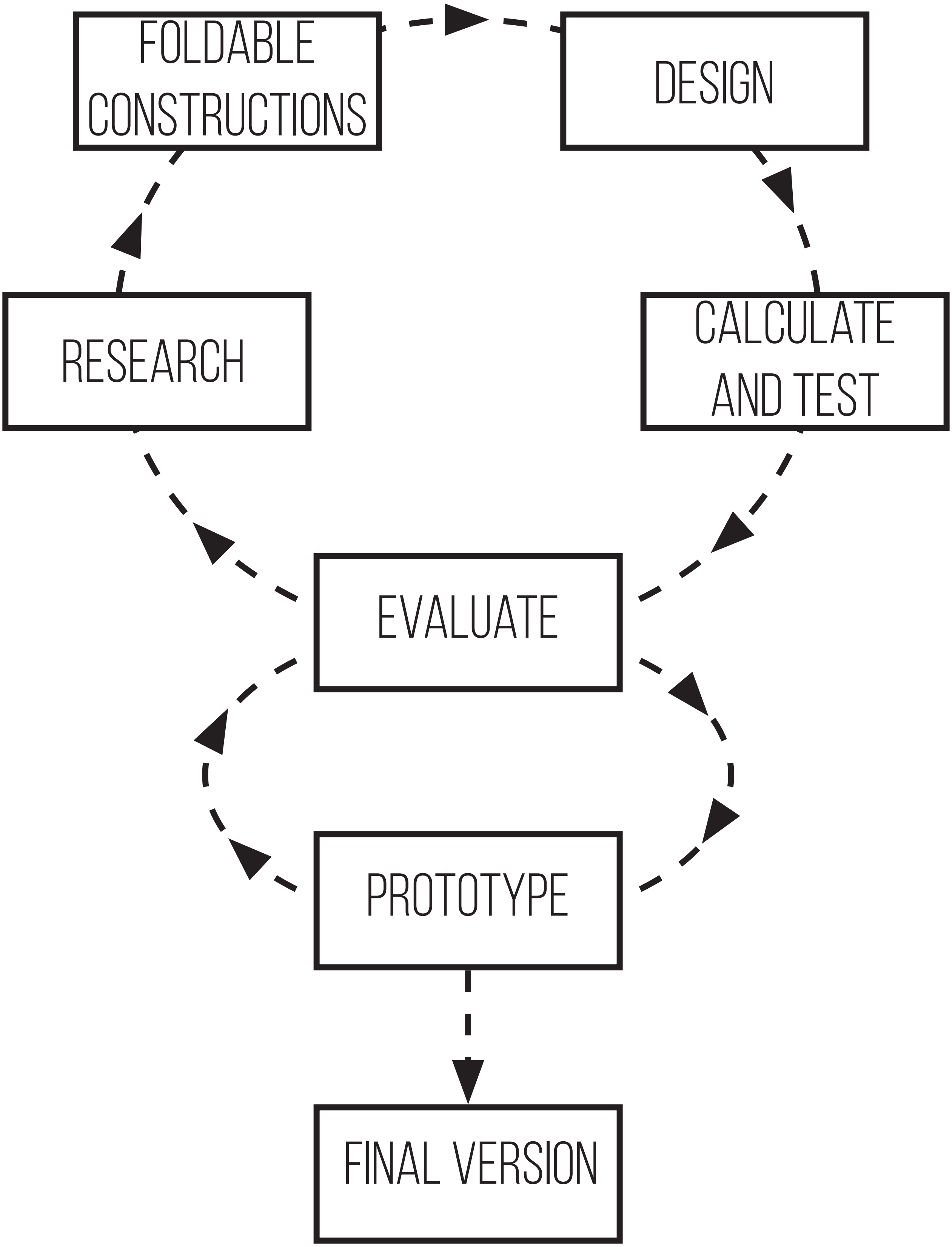


Figure 5.0.1 organisation scheme (own figure)

5.1 RESEARCH EXISTING PRODUCTS

TEMPORALLY

There are a couple of transformable windows on the market. There is the Bloomframe, the Moresky and the Velux cabrio balcon. All these create a space where people can stand, sit or lean to enjoy a view of the surroundings.

Bloomframe:
The Bloomframe (figure 5.1.01) is a product that transforms a flat façade into a balcony. It uses the glass from the window as floor and railing of the balcony. The benefits of this product is that it creates outdoor space, is temporally, and gives a great unobstructed view of the surroundings. The downsides is that it requires a permanent additional construction. Also when the product is in the extended balcony status it is essentially one big window. When the outside temperature is low and the Bloomframe is open, the whole living space will cool down. The same applies when it is raining.

The Bloomframe comes in 3 different sizes. A standard height of 2360mm with a width of 1752/2352/3052mm. This creates a balcony area of 1,9/2,5/3,3 m2. The depth of the balcony is 1100mm according to Bloomframe. The bloomframe depth is fixed.
The smallest Bloomframe cost without taxes €10,000. And the cost per m2 is €5260. This is very expensive.

Figure 5.1.01 Bloomframe (Bloomframe, 2019)

Glazing	Type	Min. thickness	Max. thickness
Lower panel	Double	56,28 mm	56,28 mm
Upper panel	Double	33,8 mm	47,5 mm

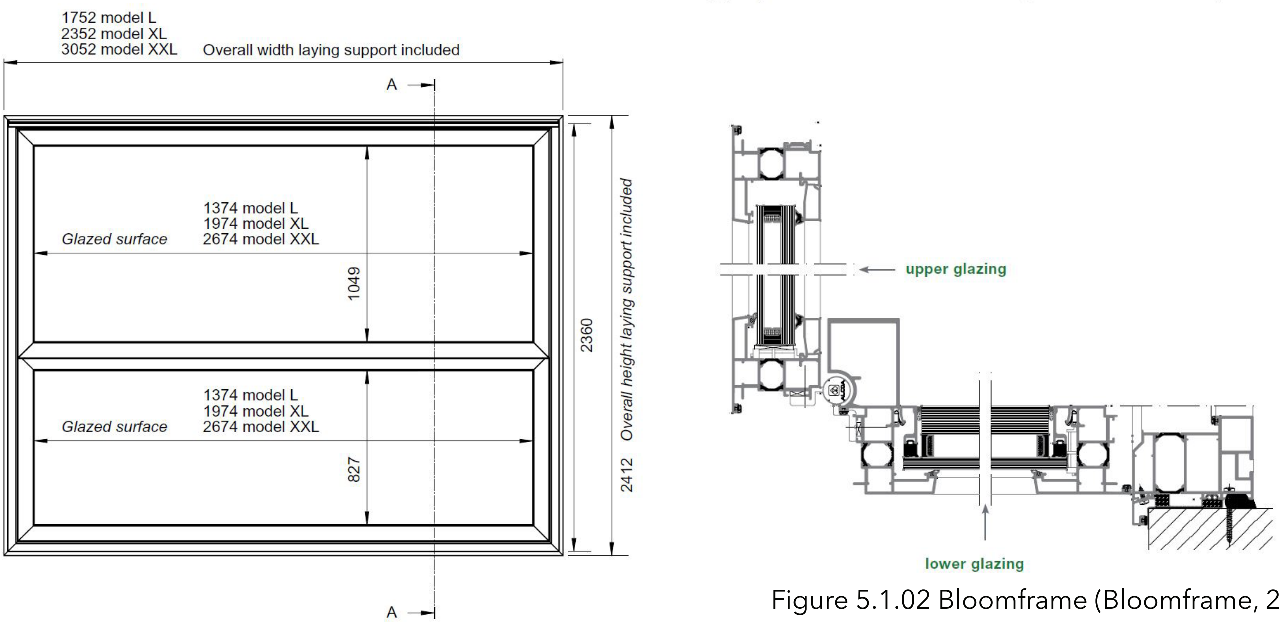


Figure 5.1.02 Bloomframe (Bloomframe, 2019)

Figure 5.1.03 Bloomframe (Bloomframe, 2019)

The Moresky:
The Moresky (Figure 5.1.2) are three different designed windows, each transforms in a small area where people can enhance the view they experience from that window. One person can sit or lean in this window frame to enjoy the view. The benefits of this product is that is temporally, can be adjusted manually and gives a better view of the surroundings. The downside is that is does not create an outdoor space. The window frame obstructs the added view and it only works for small windows.

HOPPER WINDOW

"MoreSky"
Aldana Ferrer Garcia

CASEMENT WINDOW

"MoreSky"
Aldana Ferrer Garcia

AWNING WINDOW

"MoreSky"
Aldana Ferrer Garcia

Figure 5.1.04 Moresky (Archdaily, 2019)

Figure 5.1.05 Moresky (arch20, 2019)

Velux Cabrio balkon:
The Velux cabrio balkon (figure 5.1.3) consist out of a skylight. This skylight transforms in a balcony. This balcony has a railing an gives one person direct contact with the outdoor air. The benefits of this product are that it is temporally, gives an unobstructed view of the surroundings and it does create an outdoor space. The downside is that it requires a permanent fixed construction, only works with skylights that are installed in sloped rooftops and is only suitable on small narrow windows.

“The only real product contester on the market is the Bloomframe with the downside that it can only be installed as an permanent construction element and thus not suited for a unitized façade system. Also it requires additional construction when used for renovation.

This gives the development of a new transformable façade element a lot of potential uses.

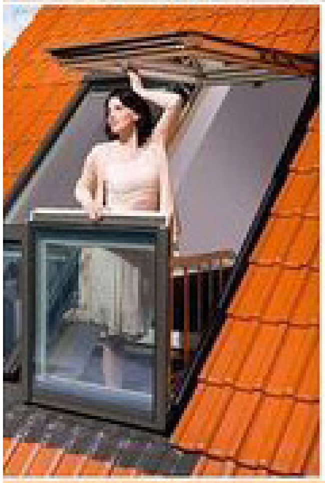


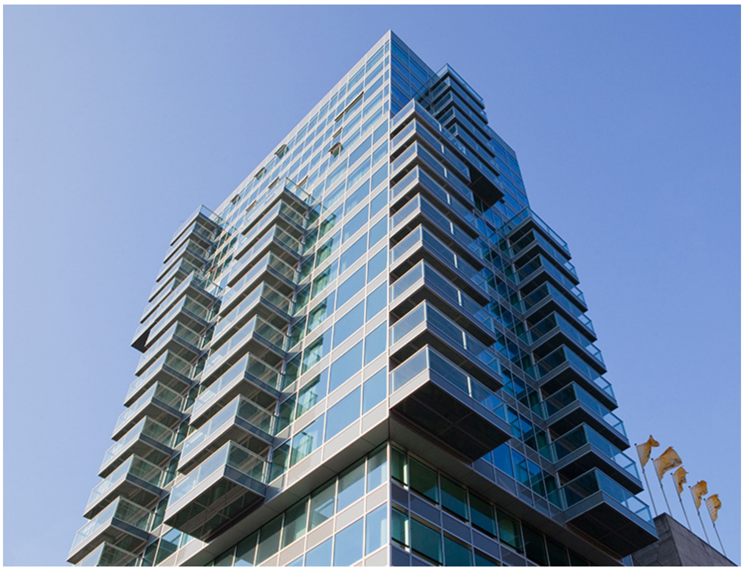
Figure 5.1.06 (Velux Cabrio balcon, 2019)

PERMANENT

Curtain wall balconies made by Scheldebouw

There are different curtain wall balcony systems. Scheldebouw has three different systems. Each system consists out of prefab elements. These have to be assembled on the building site in a predetermined sequence. The building sequence of the three systems are all different. Each system has its pros and cons. It is difficult to compare the systems because there is a different budget for the façade. System one is a low budget façade and located in the Netherlands. Where system two and three are made for a higher end building. Different budget result in different balconies, different finishing, different materials etc.

TYPE 1
B-TOWER ROTTERDAM



TYPE 2
GREENWICH LONDON

TYPE 3
GREENWICH LONDON

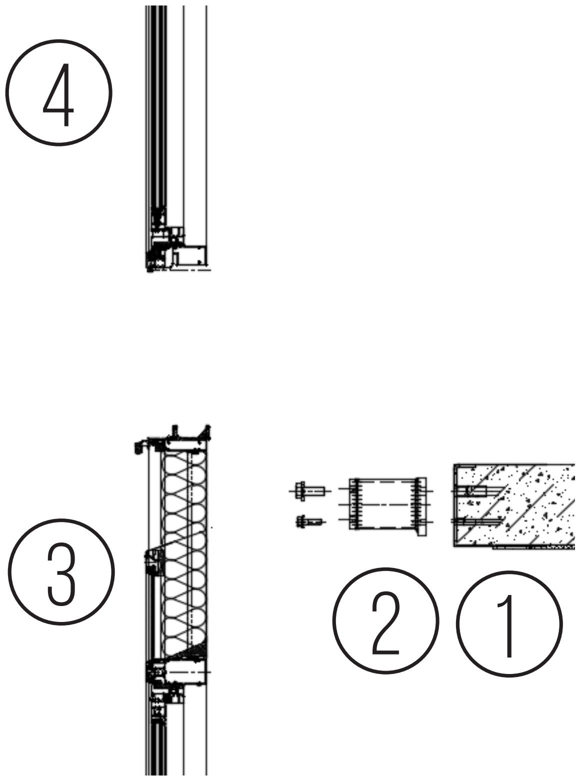
Figure 5.1.07 Curtain walls (Scheldebouw, 2019)

Type 1 Bijenkorf tower rotterdam

This curtain wall type consists out of six different elements.

1 Concreate slab with insert for balcony fixation
2 Façade brackets
3 CW panel with cut-outs for bracket (5 element)
4 CW next level panel
5 Extending bracket
6 Prefab balcony

The six elements are sorted on building sequence. The size of the balcony is 4950x2300mm.



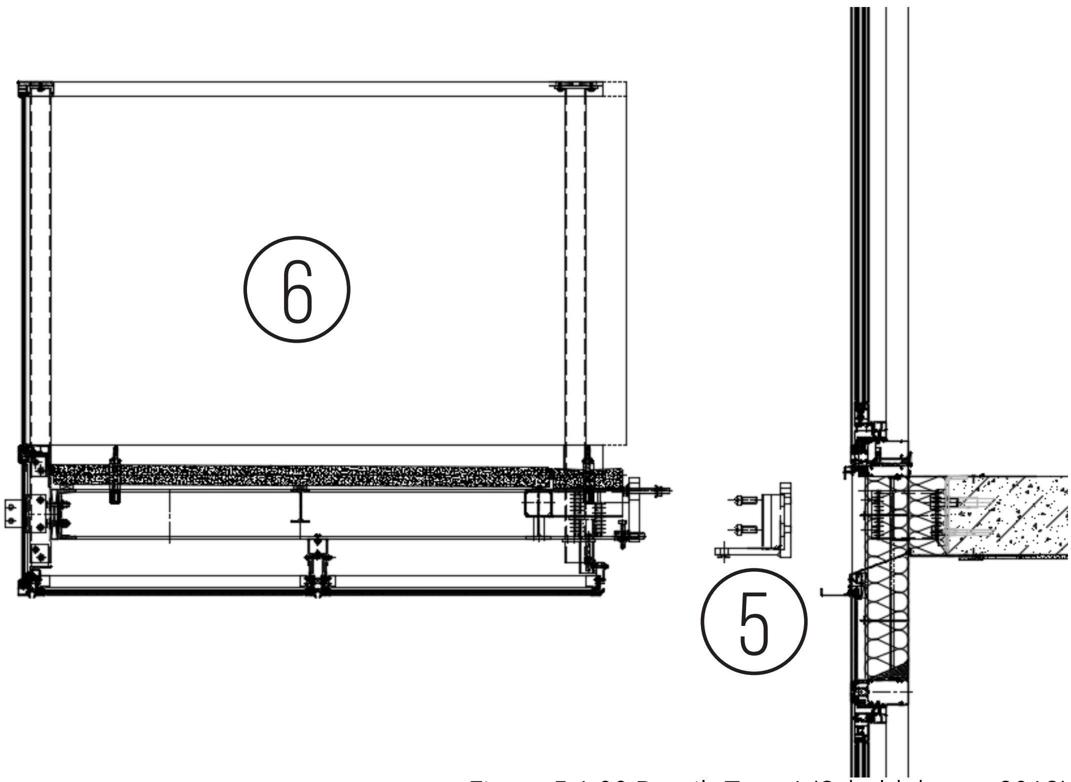


Figure 5.1.08 Details Type 1 (Scheldebouw, 2019)

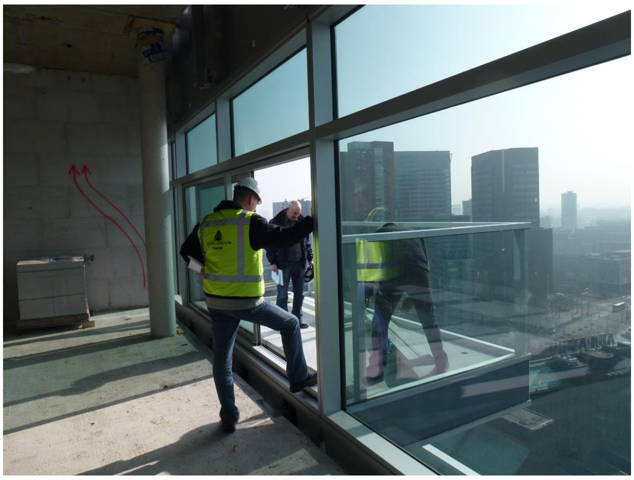


Figure 5.1.09 Building foto's (Scheldebouw, 2019)

Pros and cons

- \+ Façade can be wind & water tight without balcony
- \+ Balconies not directly needed in sequence of installation
- \- Sealing around transit brackets is difficult and has to be done after panel installation
- \- Fixing of balcony to bracket has to be done while sitting on the balcony
- \- For fixing of balcony a part of the floor decking next to the façade needs to be installed afterwards
- \- All balcony transit brackets need to be x-ray checked for welding failures
- \- Structural frame of balcony is out of steel while some claddings are in aluminium; so tolerances to fit are critical
- \- This type of balcony with long cantilever is susceptible for own frequence resonancy while in use

Figure 5.1.09 Building foto's (Scheldebouw, 2019)

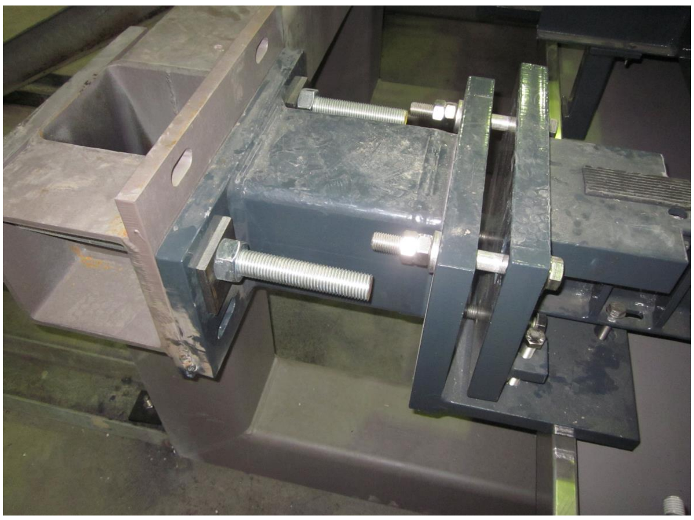


Figure 5.1.10 structural connection (Scheldebouw, 2019)

Type 2 Greenwich London
The size of the balcony is 3900x1850mm.

This curtain wall type consists out of five different elements, again the elements are sorted on the building sequence.

1 Concrete slab with insert for balcony fixation
2 CW-panel with cut-outs for balcony beams
3 CW-panel underneath
4 Prefab balcony
5 Next level CW-panel

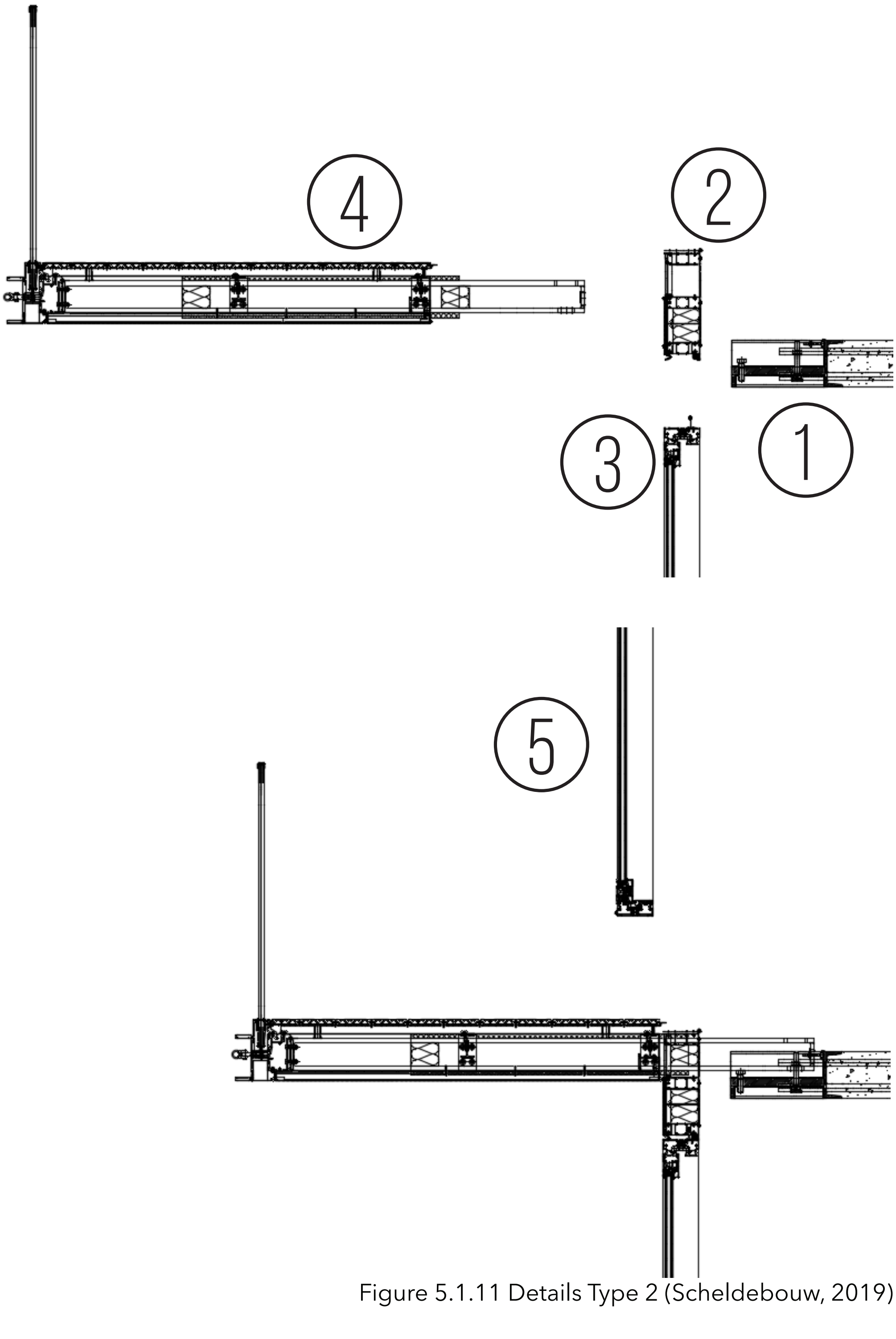


Figure 5.1.11 Details Type 2 (Scheldebouw, 2019)

Figure 5.1.12 Building foto's (Scheldebouw, 2019)

Pros and cons

- \+ Fixing of balcony beams to floor can be done from floor
- \- Balconies needed in sequence of installation
- \- Sealing around balcony beams is difficult
- \- For lifting of balcony a part of the floor decking needs to be installed afterwards
- \- Structural frame of balcony is out of steel while some claddings are in aluminium so tolerances to fit are critical

Figure 5.1.13 Building foto’s (Scheldebouw, 2019)

Type 3 Greenwich London
The size of the balcony is 4500x1200mm.

This curtain wall type consist out of four different elements, again the elements are sorted on the building sequence.

1 Concrete slab with insert for balcony fixation
2 CW-panel underneath
3 Prefab balcony with spandrel panel
4 Next level CW-panel

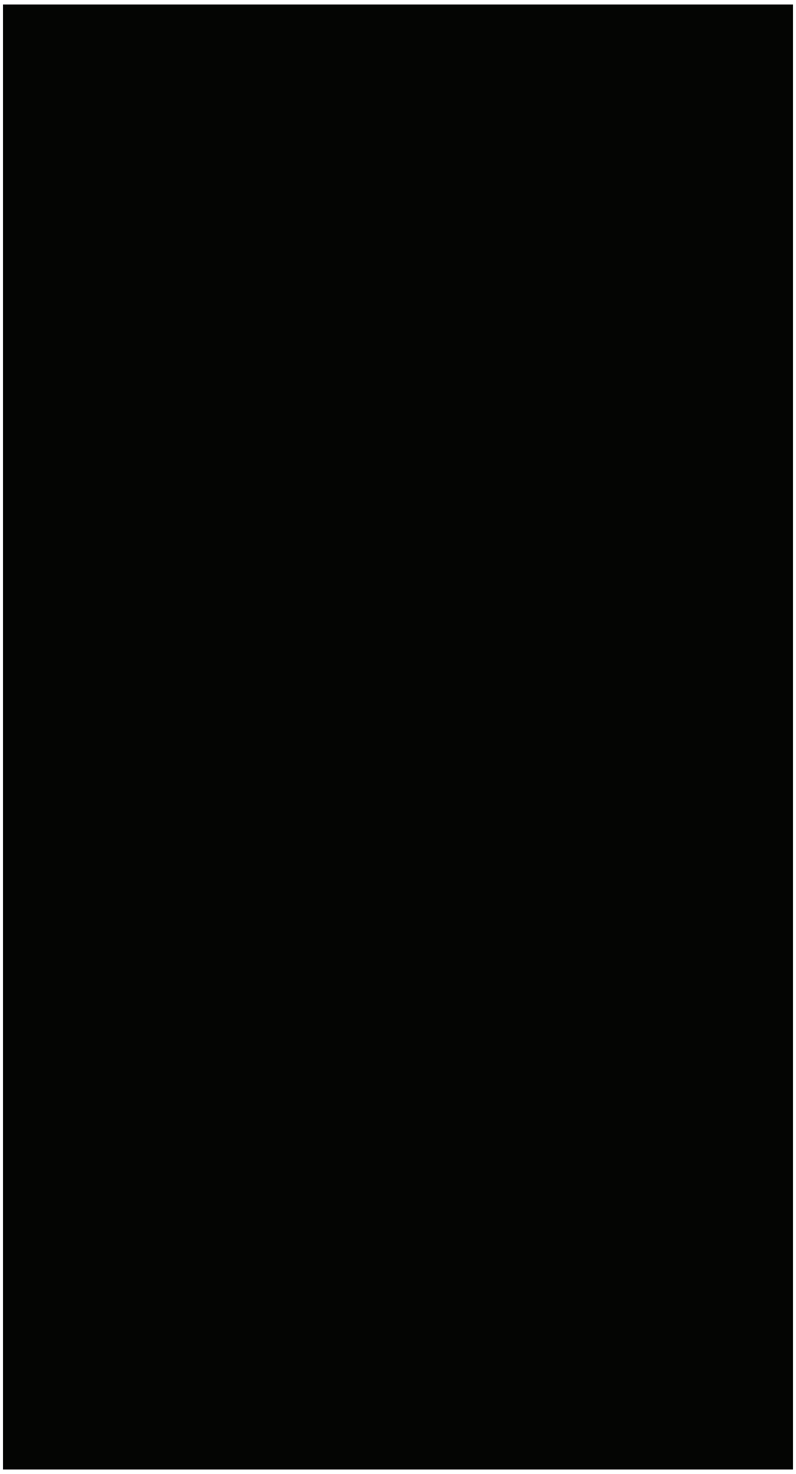


Figure 5.1.14 Details Type 3 (Scheldebouw, 2019)

Pros and cons

+ Fixing of balcony
+ truss panel to floor can be done from floor
+ Sealing of truss panel is identical to all CW-panels
+ Structural frame of balcony and all claddings are in aluminium so tolerances are much tighter
- Balconies needed in sequence of installation

System three is the most integrated system, and uses the least amount of different elements. It uses the façade brackets to be attached to the building. It is fully made out of aluminum which allows for smaller tolerances. The balcony is needed for the sequence of installation. This results into an integrated installation process. As the façade can be completed in one go, there is no need to come back later to install an additional panel or element.

Figure 5.1.15 Building foto's (Scheldebouw, 2019)

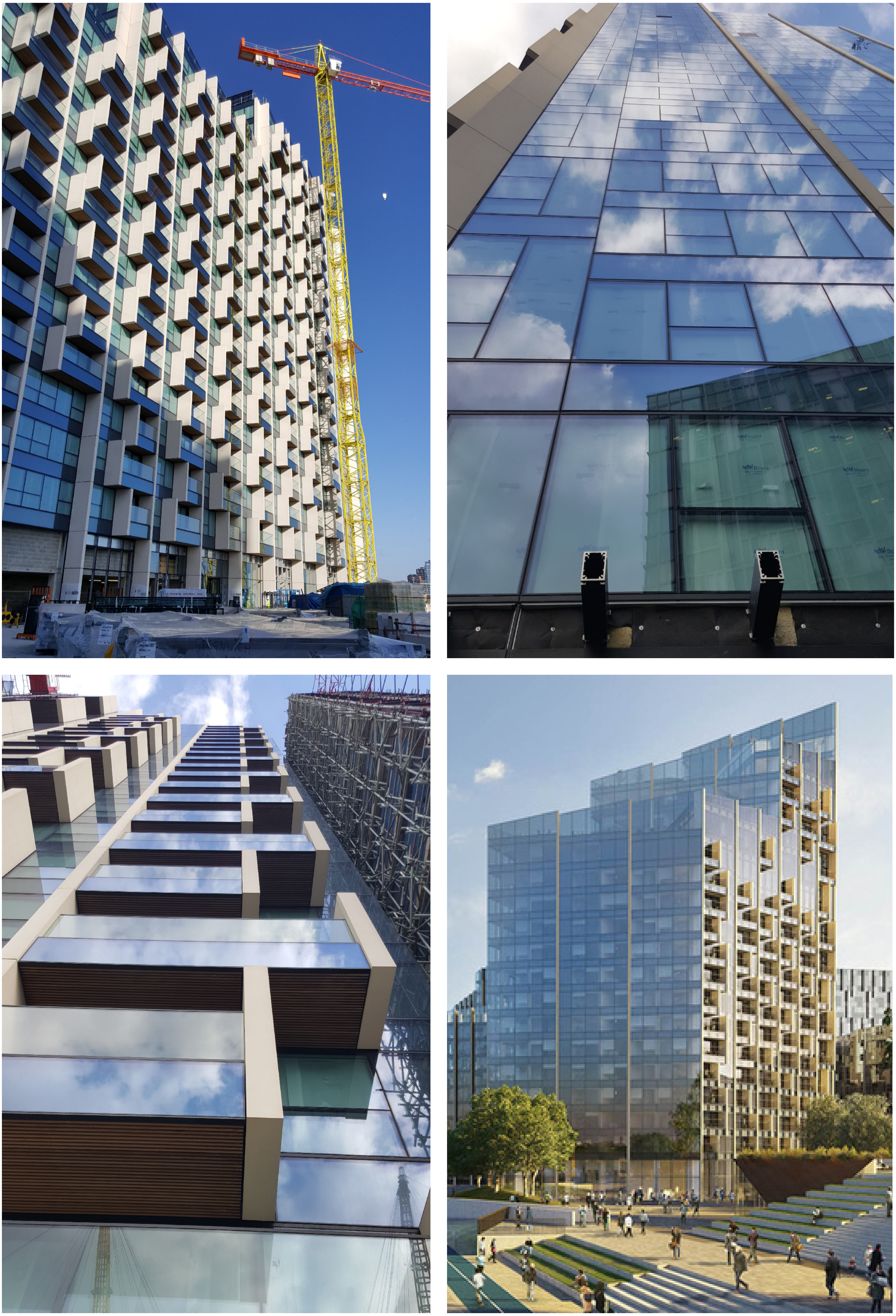


Figure 5.1.16 Building foto's (Scheldebouw, 2019)

COMPARISON

It is very difficult to compare the balconies. Each balcony type is different, used in different buildings with different budgets, and not made with the intension to be a competitor of the other types. The Bloomframe is a balcony and façade integrated into one element, designed to be placed in many different buildings. The B-tower balcony and the Greenwich balcony are permanent balconies specifically designed and made for one building. The level of finish is directly related to the budget of the façade. Just the façade of Greenwich is almost twice as expensive as the B-tower façade. This means that the budget of a project influences the cost of a balcony.

A other problem is that there is no easy way to compare the size and cost of the three different facades. A permanent balcony consists out of two different elements. The first element is the façade and the second one is the balcony. The Bloomframe is one element with two functions, façade or balcony. The smallest Bloomframe has a cost of €10.000. Consist out of 4,6m2 vertical façade but also 1,9m2 of horizontal balcony.
While the permanent balcony type 1 (B-tower) consist out of a balcony of 11,4m2 with the cost estimated between €7.000 and €10.000. Permanent balcony type 3 (Greenwich Tower) has a balcony that is 5,4m2 and cost between €9000 -
€12000. The prices for the permanent (Scheldebouw) balconies are estimations of the cost for a single balcony. These are estimations because the balcony is calculated as part of the façade, and not as a separate element. Three different price tags for three different balconies. This makes it difficult to compare the balconies. Each balcony was built for a different situation, build for different countries, different demands, and different budgets.
When designing a new transformable balcony, the cost price of the product will have a huge influence on the marketability. Ideally it would be financially comparable with the permanent type 3 (Greenwich tower) balcony and the Bloomframe. These balconies have been build and there is a market for them.

BLOOMFRAME

Figure 5.1.17 Bloomframe (Bloomframe, 2019)

Dimensions
↕ 1100
↔ 1752 / 2352 / 3052
m² 1,9 / 2,5 / 3,3

Cost
1pcs € 10.000 +

B-TOWER ROTTERDAM TYPE 1

Figure 5.1.18 Type 1 (Scheldebouw, 2019)

Dimensions
↕ 2300
↔ 4950
m² 11,4

Cost
1pcs € 7.000 - 10.000
Facade € 750 m²

GREENWICH LONDON TYPE 3

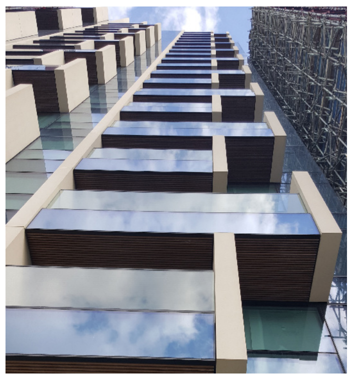


Figure 5.1.19 Type 3 (Scheldebouw, 2019)

Dimensions
↕ 1200
↔ 4500
m² 5,4

Cost
1pcs € 9.000 - 12.000
Facade € 1.250 m²

5.2 RESEARCH BALCONY USES AND IMPACT ON THE LIVING AREA

A lot of different factors influents the possible activities and uses of a balcony. The different factors are climate, location, size and orientation of the balcony, and the user of the balcony.

Climate
On average people spend 87% of their time indoors, 6% is spend in a public transport- or closed vehicle (Klepeis, et al., 2001); 7% is spent outside. 7% is about 100 minutes each day. Kleipeis also concludes that people who live in an area with cold winters and mild summers spent an equal amount of time outside as people living in an area with mild winters and hot summers. The temperature is not a reason for people spending more or less time outside. Off course the weather will have an influence. People tent to stay more inside when it is raining.

Situation
The situation of the balcony influences the usage. For instance a balcony situated in a smog filled city will likely be used less. The main reason is obvious, it is unhealthy to stay outdoor in a smog filled environment (Laumbach, Meng, & Kipen, 2015). Another reason is that smog reduces the view and blocks the sun. Or the balcony is above a busy street which lots of noise. When a balcony provides a great view, like on a nearby green environment, it can have an influence on stress relief (Morita, et al., 2007). This gives the balcony a potential to be used more often. These are just a couple of locations that can increase of decrease the usage of a balcony

Size of the balcony
The size of the balcony has an impact on the possible usage of the balcony. If it is a French balcony, there is hardly any space to do anything other than stand on the balcony; maybe smoke a cigarette if you can close the door behind you. This makes the main purpose of the balcony to refresh the air in the room; the same effect a window has.
Is the balcony just a couple of square meters? Then there is place for some seats and a small table, or a lounge chair and some plants. This gives the balcony more usage options, for instance a place to read the paper, or eat dinner, relaxing in the sun or enjoying the view. Or a balcony to grow some plants, herbs, vegetable and fruits. It can also be just a place to store some stuff and smoke a cigarette.
If the balcony is bigger than the possible options grow. It can be a place for a BBQ and an outdoor small party place. A place for a large lounge set. Or maybe a Jacuzzi or hot top if the construction allows the weight.
To conclude: a small balcony has less possible usage options; a a large balcony more and can allow more people on it

Orientation
The orientation of the balcony can play a major role in what time the balcony will be used. The four main orientations are the north, east, south and west direction. The east direction will get the morning sun, with the right temperature this could make a great breakfast location. The south will have the hottest temperature and will get the most direct sunlight. Depending on the temperature this could be ideal and used a lot. Or way to hot and avoided in the hot summer sun. The west will get the last sun of the day, again with the right temperature an ideal place for dinner. The north orientation will get no direct sunlight. In a hot climate this will be in the shadow and will make an relative cool outdoor space. Like any orientation the climate will be the factor when a balcony is used. In a hot climate the sun will be avoided, and the balcony will be used when there is shadow. In a cold climate the period of sunshine will define the usage.

Permanent balcony
A mentioned before the size of the balcony will influence the usage options of the balcony. A permanent balcony can be used for a large range of activities. From storage to seating, cooking, eating, growing plants etc. The only impact on the indoor living space is that the door to the balcony needs to be . accessible.

Temporally balcony
A temporally balcony has different usage options.. Every time you want to use it , you first have to make the balcony appear. After the transformation to balcony the user will have to place every piece of furniture on it and all other objects intended to be used. When the user has finished his activity on the balcony, he or she first has to remove all the objects off the balcony, and, when it is empty, it can finally be transformed back into the façade. The usage of a temporally balcony requires more steps and more time compared to an permanent balcony.
The impact on the indoor living space all depends on the final design of the temporally balcony. If the balcony folds down an uses the existing façade as part of the balcony (floor & railing), then the space in front of the balcony needs to be empty when the balcony is in place. The place in front of the balcony/façade can be used for furniture and other things intended for the balcony.

User
The user of the balcony influences the way the balcony is used. If the user is a smoker and only smokes outside, the balcony has a potential to be a place for him or her to smoke. The same applies for users that do BBQ a lot. Users with children may use the balcony as a playground for them.. If the user has a full time job then there is a possibility that the balcony will only be used in the weekends. These are just a few examples on how the user influences the way and time the balcony will be used.

5.3 RESEARCH UNITIZED FAÇADE ELEMENT.

There are different width for unitized façade panels. When looking at the Netherlands the common width is 1,8 meters or a plural of 1,8 for one façade panel. The United Kingdom uses a width of 1,5 meters of a plural of 1,5. There is no standardized height for one panel. The height will depend on the floor height, design of the building, the present of a permanent balcony etc.

The Rotterdam building in Rotterdam is used as a research object.
The main principle of the construction system is the cantilever setup. The concrete floor are connected to the concrete pillars. These pillars are the primary construction to dispense the forces to the foundations. A part of the facade brackets (cast in channel) is connected to the rebar before the floors gets poured. The facade brackets is connected to this channel, on which the facade panels are hanged from. This face brackets is the secondary structure. These brackets dispense the dead load of the facade panels to the concrete floors, which dispense the forces to the concrete pillars. The brackets also make sure that the additional forces, like wind get disperse to the primary construction.

Aluminum and stainless steel are the main two materials used in the facade panels. These two materials are strong and very stiff, which makes them highly suitable for use in a facade. The aluminum is a lot lighter than (stainless) steel, and needs almost no maintenance. The Aluminum is used for the mullions and transoms of the facade panels. The mullions are designed to be extra deep. This stiffens the profile and ensure that they can handle the wind force. These mullions are the main backbone of the facade panels. The mullions ensure that the forces (dead load, wind forces etc.) gets directed to the facade brackets.

Figure 5.3.01 Rotterdam vieuw (Rotterdam, 2019)

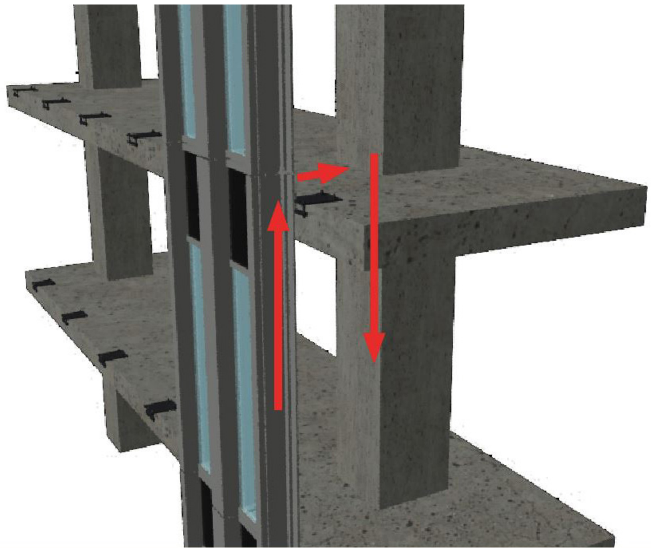


Figure 5.3.02 building sequence (own figure)

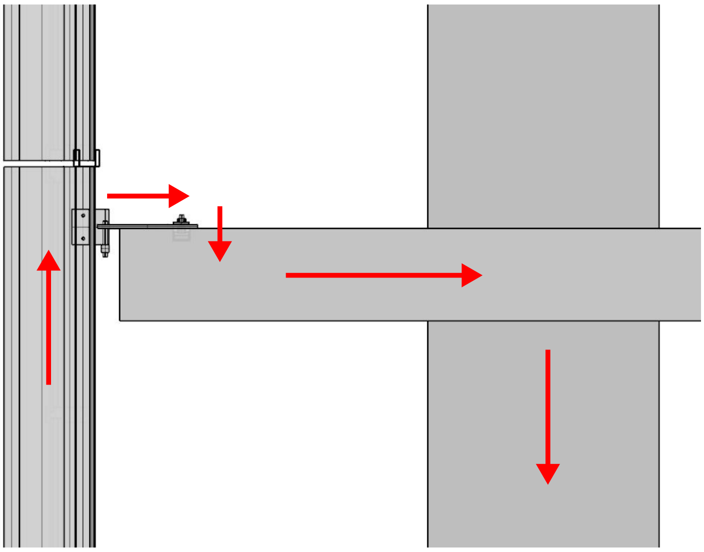


Figure 5.3.03 structural forces transfer (own figure)

The mullions on the outside of the facade panels are designed to interlock with the next panel. This joint is design to allow for movement between the facade panels. In this connection there are four different barriers to prevent the wind and water to reach the inside structure. For the horizontal joint between the panels a special aluminum profile is designed that is screwed onto the top of one facade panel. This profile slides around the bottom transom of the profile above it. This ensures a water and air tide connection between the horizontal panels.
Inside the panels round every different material, think about the glass, extra room is accounted for. This room is designed for tolerances with the production plus thermal movement between the different materials. The glass is held into place by gaskets. These rubbers also can be compressed if needed for thermal expansion.

Figure 5.3.04 Rotterdam (Wiconafinder, 2019)

Facade Fragment

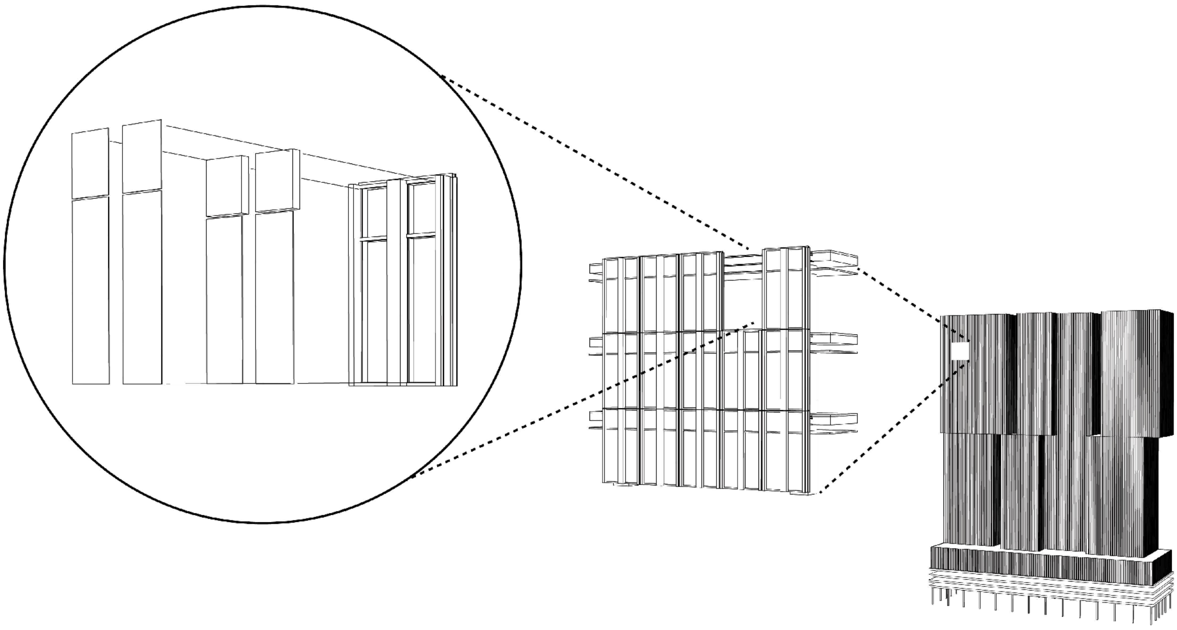


Figure 5.3.05 facade fragment (own figure)

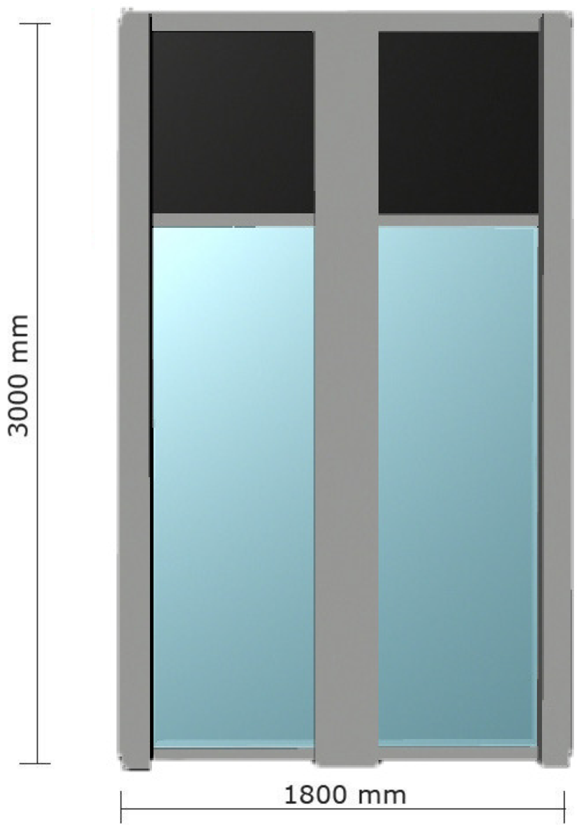


Figure 5.3.06 facade fragment (own figure)

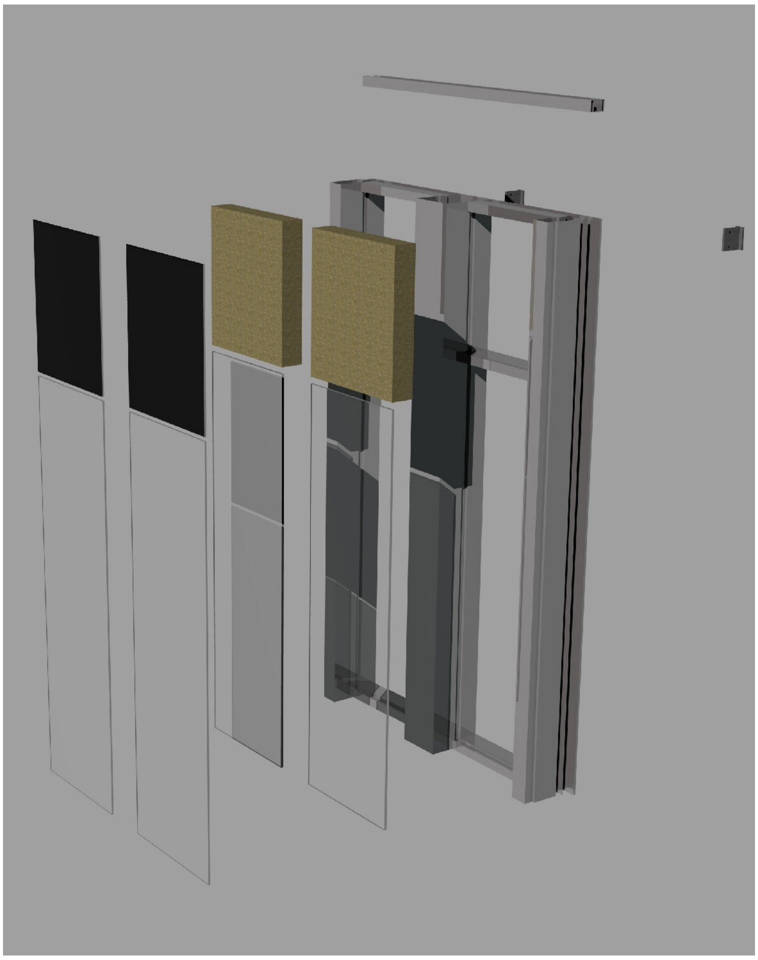


Figure 5.3.06 facade Element (own figure)

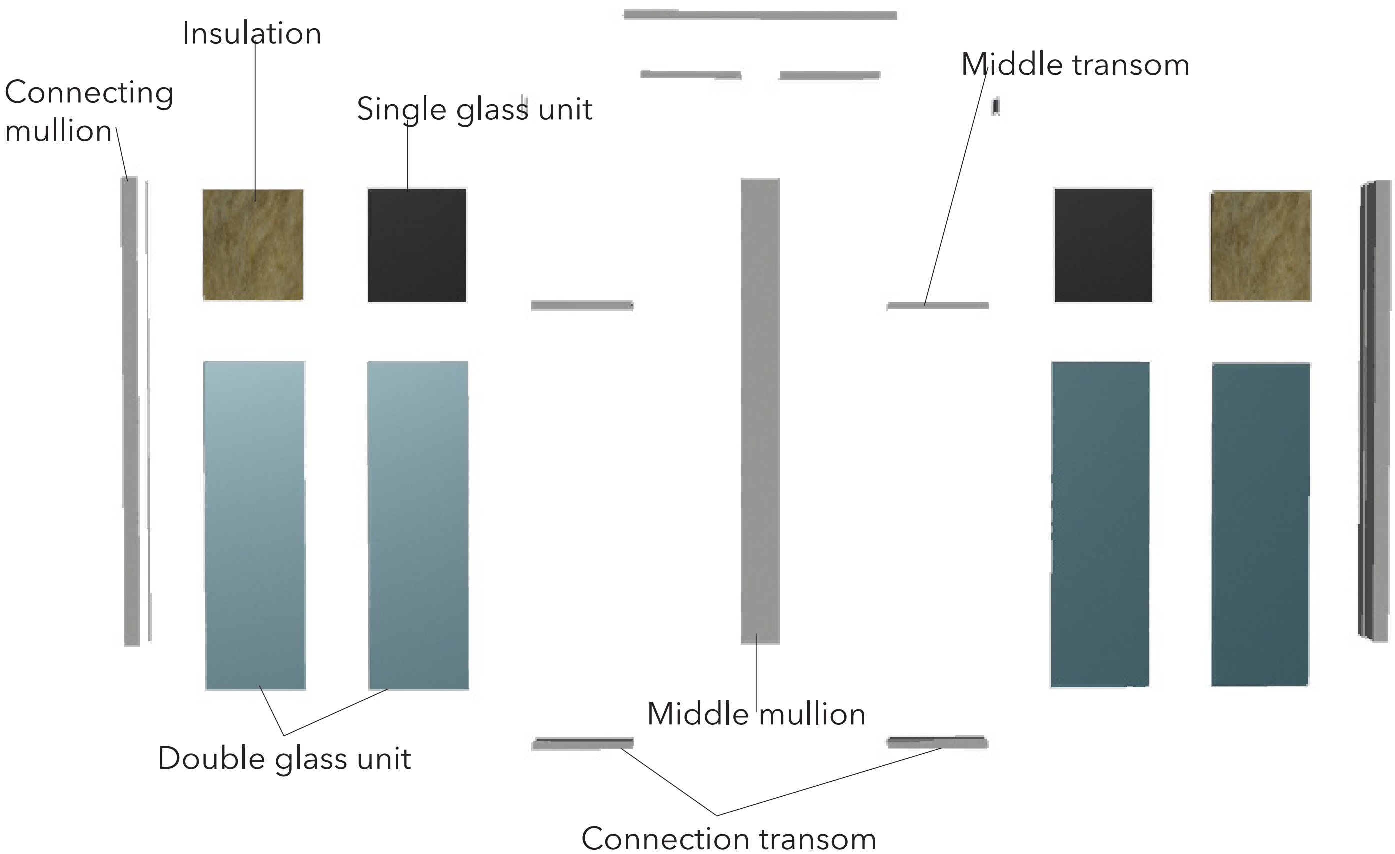


Figure 5.3.07 facade Element (own figure)

Aluminum

A custom profile is made for the aluminum frames. These profiles are made of extruded aluminum. There are six different profiles, three mullions and three transoms. The mullion in the middle is connecting the glass panels together and makes the panel stiff. The mullion on the sides are connecting the panels together. The middle transom is connecting the glass and spandrel together. The transom on the sides connects the panels together. The specific type of aluminum is AlMgSi 0.5 EN-AW 6060 T66. The material is medium strength alloy with a heat treatment. It has very good corrosion resistance, can be used for complex sections and responses very good to anodizing. The 'T66' indicates the temper designation. This means that the aluminum is heated up and rapidly cooled down to harden the material. This makes the aluminum harder but also more brittle. This requires a precise control in the hardening process. The frames are fire resistant for 30 minutes. The aluminum is anodized to prevent corrosion. To prevent thermal bridges, there are plastic spacers used in the profile.
At the location where two profiles are connecting, there are some additional rubbers to ensure water tightness and movement. The two different colors in the detail show the connection between two elements.

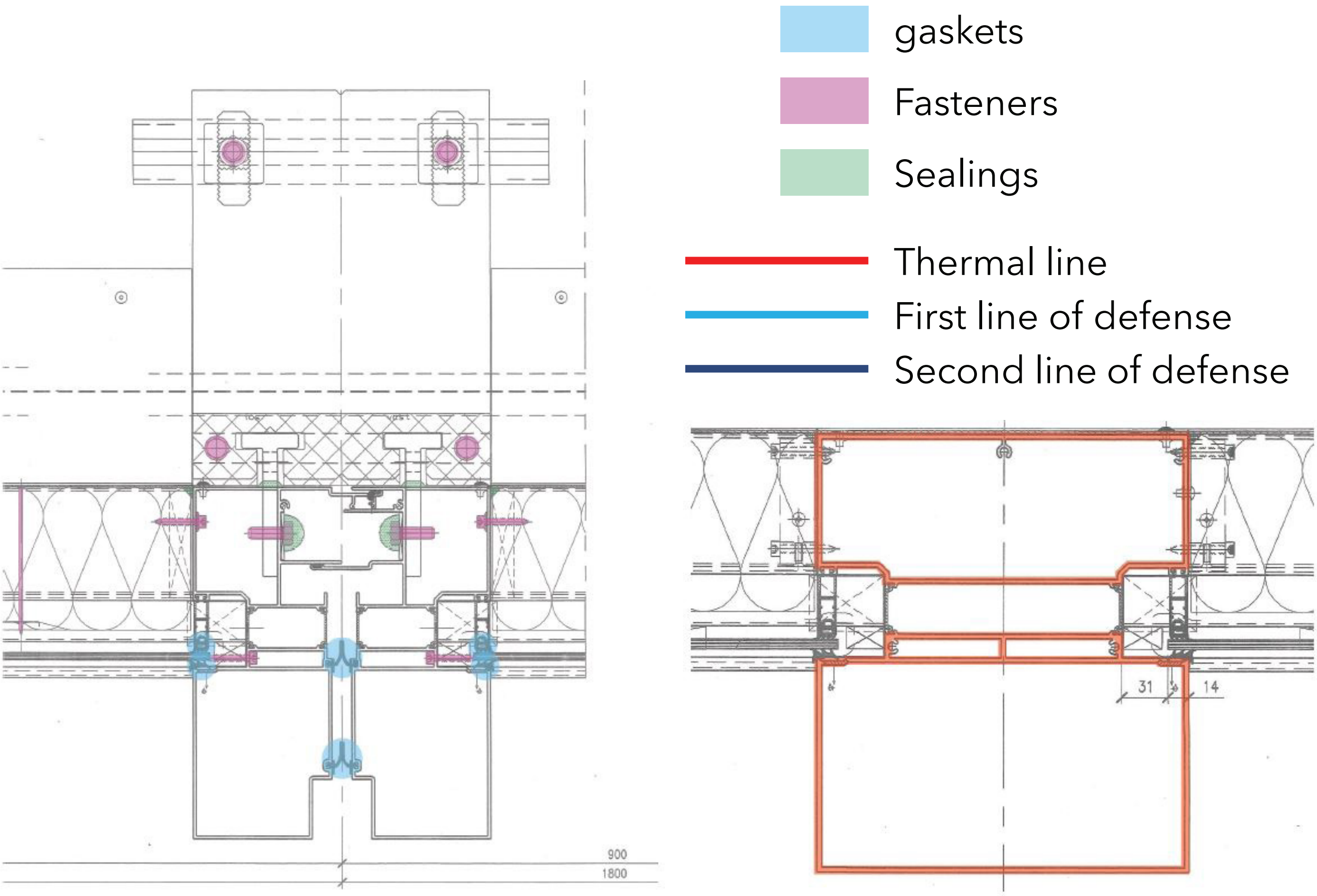


Figure 5.3.08 Details (scheldebouw 2019)

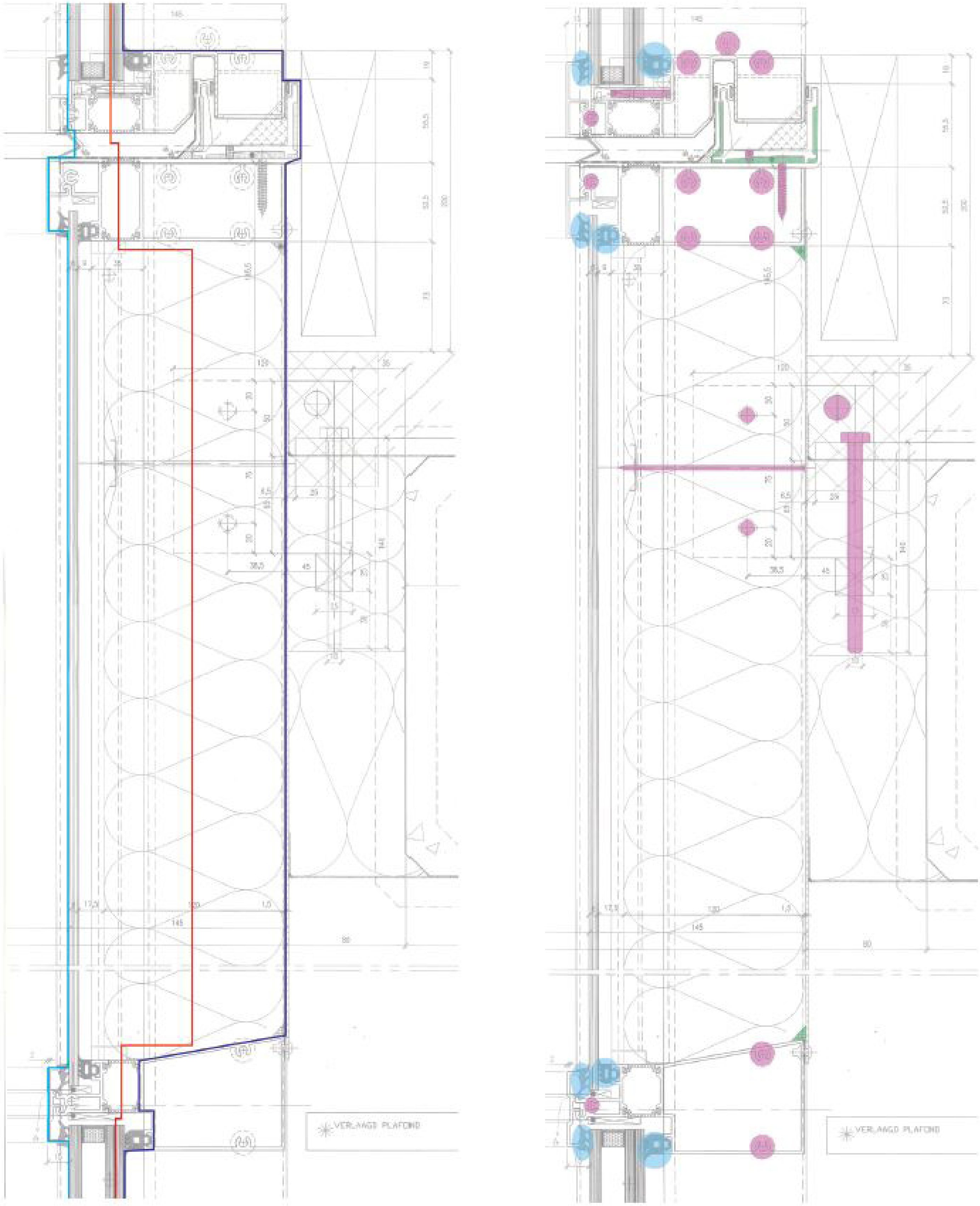
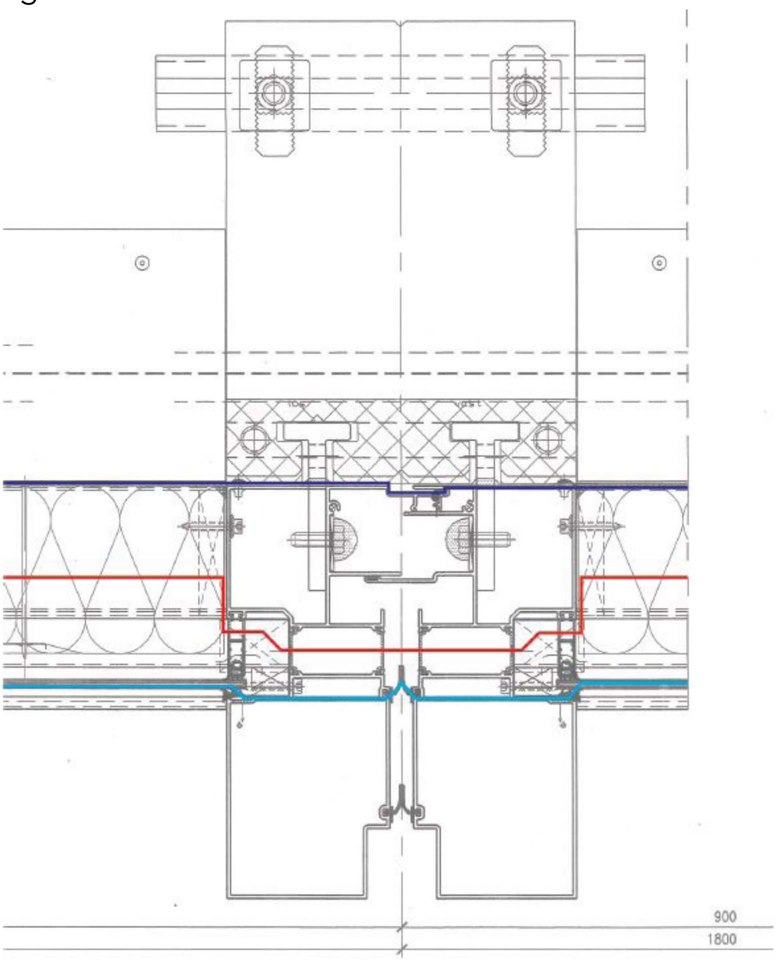


Figure 5.3.09 Details (scheldebouw 2019)

Gaskets, fasteners and sealing

In the details several things are emphasized. The blue parts are gaskets, which keep the glass in place and are a water barrier. The gasket is EPDM-rubber. The rubber allows for some movement of the panels.
The pink parts are fasteners, for the frame and structure. These bolts are from steel.
The green parts are seals that ensure water tightness.
Thermal line and wind & water tightness

The light blue line is the first line of defense. The glass, aluminum frame and rubbers have the biggest role to keep the water out. The second line of defense (dark blue) is partly due to a steel plate that is on the inside of the facade. This line of defense ensures that there is no air of water that leaks in from the outside.
The thermal line (red) goes through the insulation, the plastic spacers in the aluminum frame and the glass.



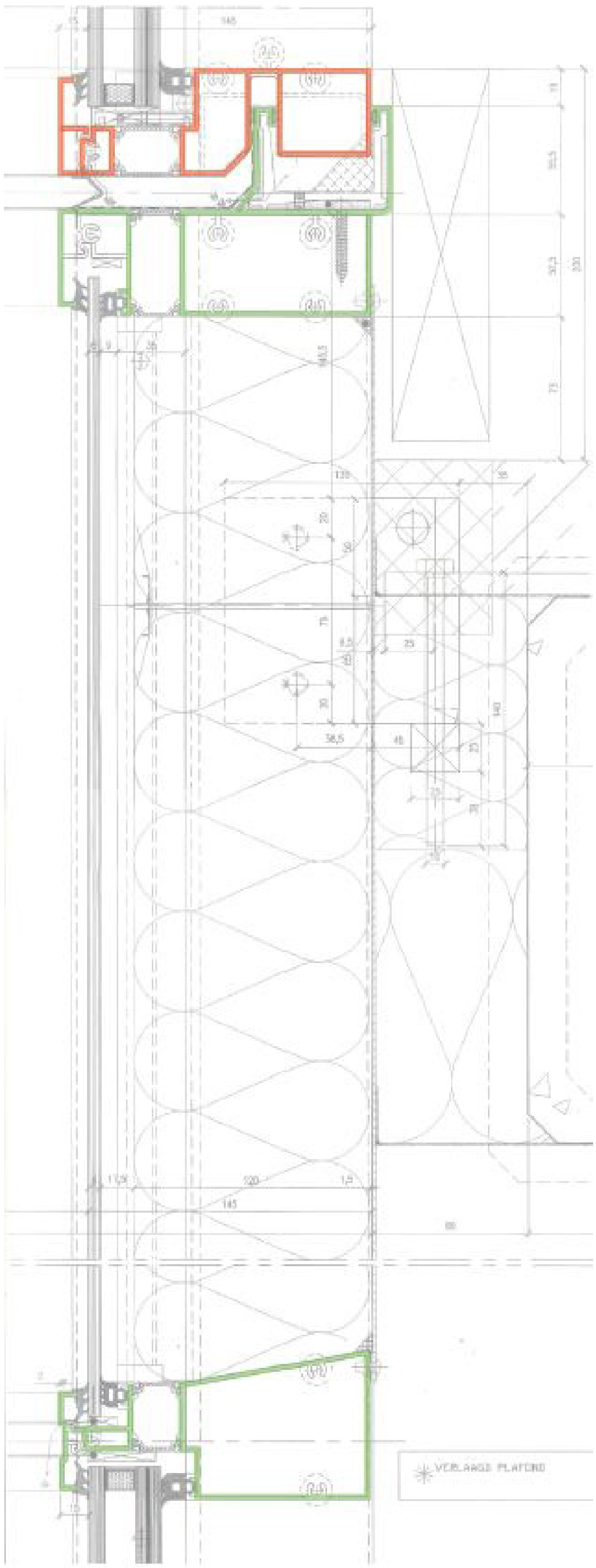


Figure 5.3.10 Details (scheldebouw 2019)

5.4 RESEARCH CURRENT FAÇADE BRACKETS.

A façade bracket is an adjustable bracket that transfer the weight and forces of the façade onto the main construction system. The brackets consist out of different parts that can be adjusted. The adjustment is needed to reduce the building tolerances and ensure that the gaps around each element are consistent. This way the water and air tightness can be guaranteed. The same applies for the fire resistance, to reduce the change for flashover.

Almost every façade brackets consist out of the following elements

1 cast in channel
2 bold, nut and washer
3 Floor bracket with anchor channels
4 Dead load block (can be integrated into the floor bracket)
5 T bracket (bolded to the façade panel)

The dimensions of the steel plate are influenced by the weight and forces the brackets needs to handle. The weight of the façade panel infects the thickness (T) of the plate. The Wind forces on the façade panels affect the distance (D).
More weight means thicker plates, and more wind forces means a larger distance. The steel plate becomes larger and thicker the more forces it needs to handle.
A lightweight façade panel weights around 300-350 kg, supported by two brackets. A heavy weight façade panel can weigh as much as 800kg and is also supported by two brackets. Brackets can handle a lot of weight. And can be made bigger as long as there is room in the floor composition.

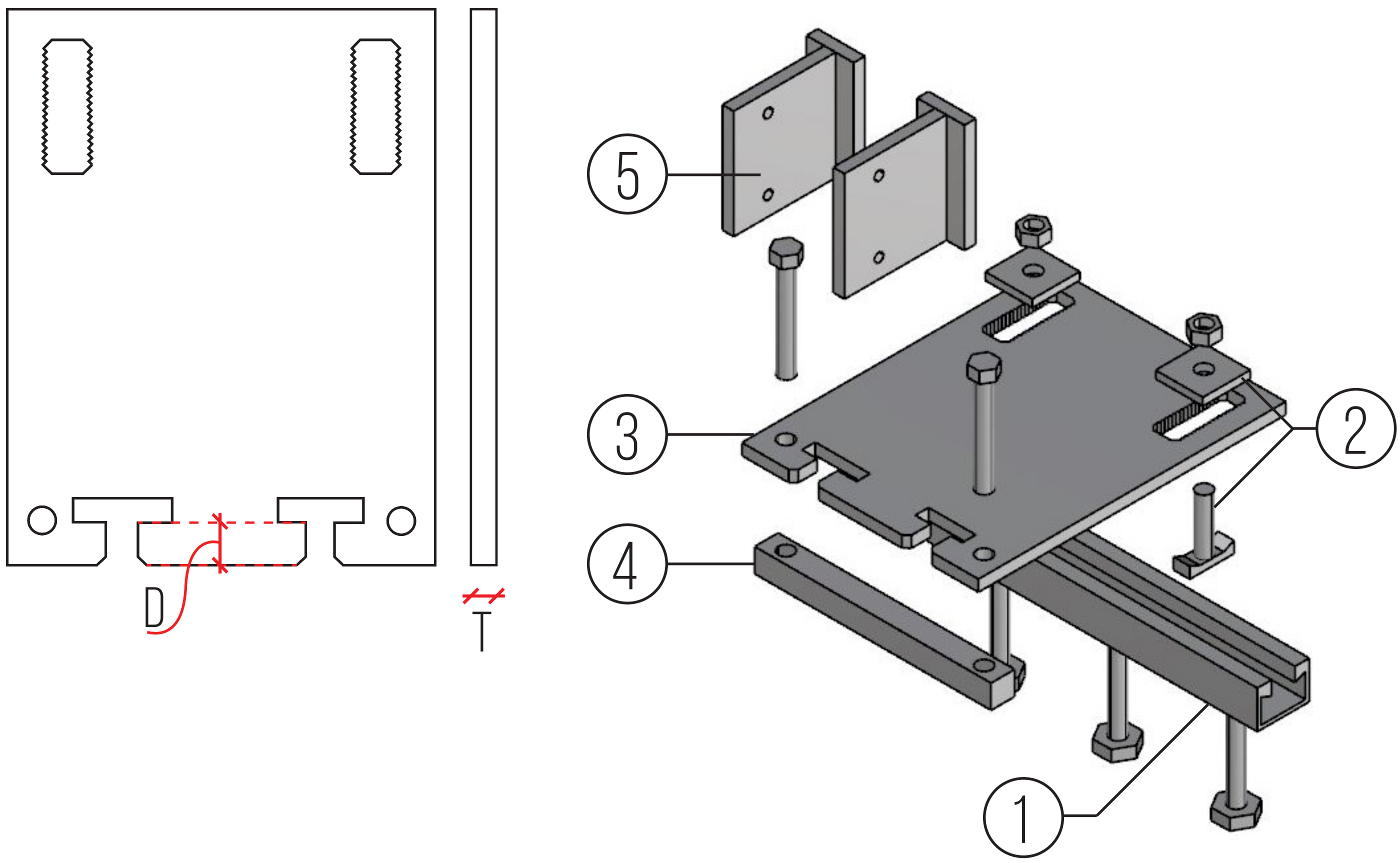
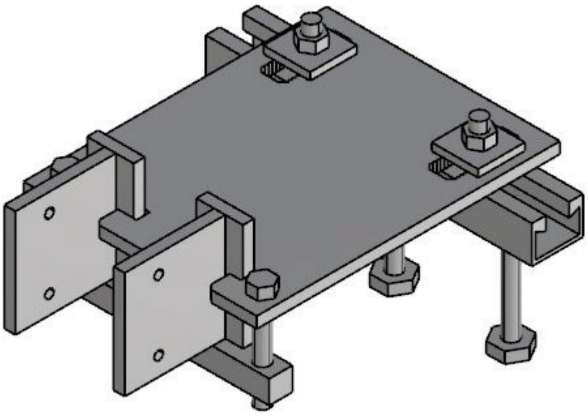


Figure 5.4.1 Facade bracket (own figure)



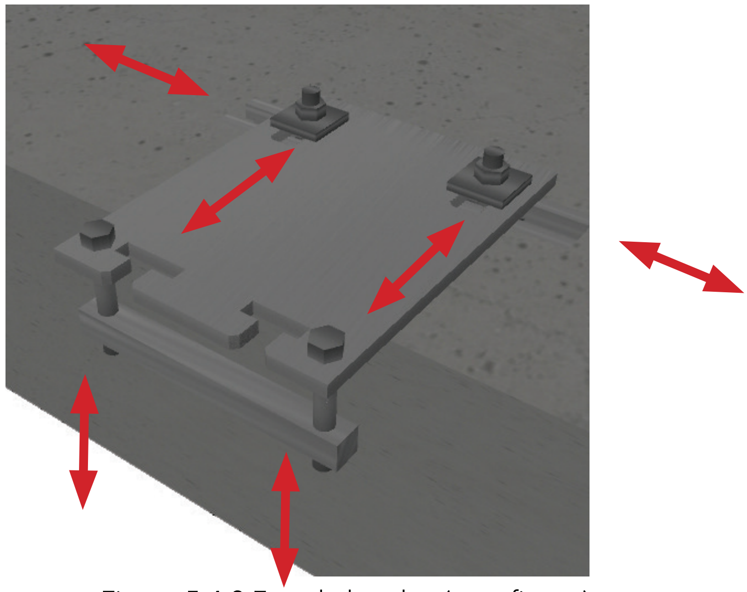


Figure 5.4.2 Facade bracket (own figure)

The wind force is almost always the biggest load the façade brackets need to handle. Especially the negative (suction) force. The shape, position, orientation, height and environment are all aspect that influence the wind force. Wind forces start from -1kPa and go as high as -6kPa. -6kPa almost never happens. For a whole building it is inefficient and expensive to build each façade panel to handle the maximum wind force. The panels are divided into stronger normal and weaker panels. Normally the thickness of the extruded aluminium profiles are what gives a panel extra strength.

There are many engineering companies that are specialized in façades. Almost every company has their own façade bracket. The floor bracket, and dead load block can have a different shape, and the way the tolerance are adjusted can be different. But the basic principle in how they work are the same.

Image shows a double façade bracket. It consist out of a double cast in channel. The top channel still transfer the weight and forces of the façade onto the main construction system. The double façade bracket is designed to support a balcony. But because of the extra weight there is a change the balcony will not be levelled. The bottom channel is to adjust to balcony and make sure it is levelled.

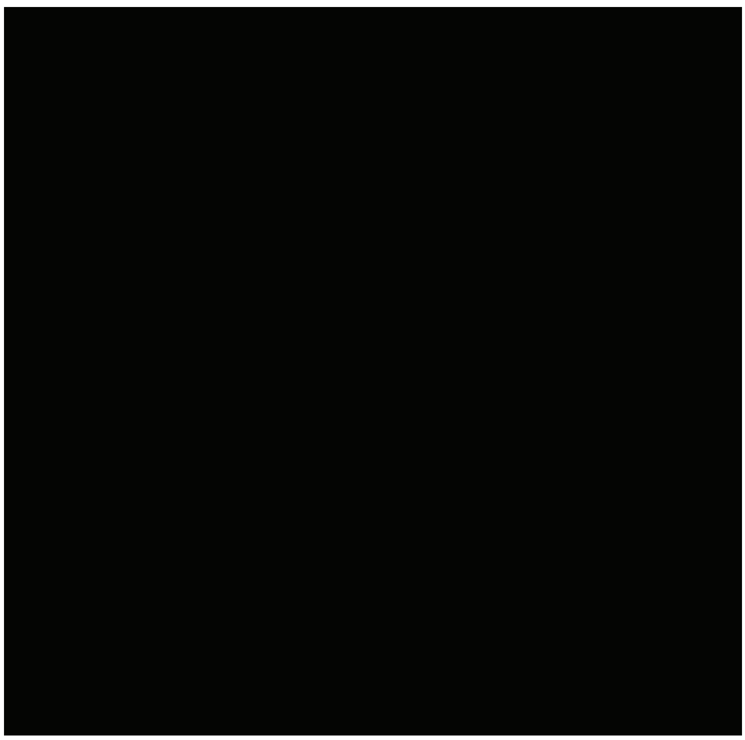


Figure 5.4.3 Facade bracket (Scheldebouw, 2019)

5.5 RESEARCH GLASS STRENGTH, THICKNESS AND WEIGHT

Two walkable glass floors where researched to give an answer to this research part.
The rooftop squire garden located in London, on the rooftop of the UCH Cancer Centre. And the Bloomframe window.

The squire rooftop garden has a walkable glass floor. The glass floor consists out insulated laminated glass units. The dimensions of each unit are 900 x 3600mm. One unit consist out of 5 pieces of glass sheets, with an air cavity. The outer line (top surface) consist out of 3 pieces of 10mm toughened laminated glass sheets.

The inner line consist out of heat strengthened 6(0,76 translucent pvb)6mm heat strengthened glass of 6 mm. The air cavity between the outer and inner line is 16mm thick. This makes the total thickness of the unit 61,8mm. Only the glass weighs approximately 105kg/m2. The aluminum frame is engineered, to support planters.

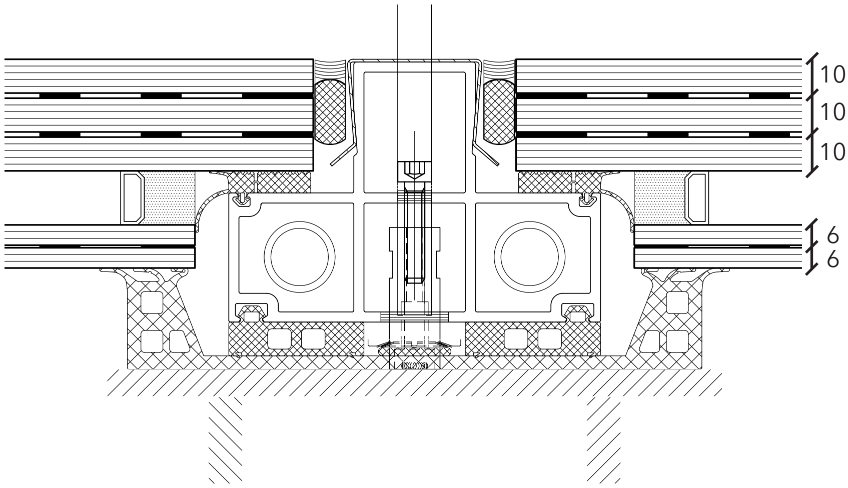


Figure 5.5.1 detail glassfloor (Scheldebouw, 2019)

Figure 5.5.2 UCH Macmillan Cancer Centre (Arub, 2019)

The Bloomframe has two double glazing units. The bottom piece is the glass that is walkable. This glass unit has the dimensions of 827x 1374/1974/2674, depending on which of the 3 width is chosen. The outer line (outside surface) consist out of heat strengthened 6mm glass sheets. The inner line consist out of 2 pieces of 12mm toughened laminated glass sheets. The air cavity between the outer and inner line is 18mm thick. This makes the total thickness of the unit 56mm. Only the glass weighs approximately 90kg/m2. The glass unit is designed to support 350kg/m2.

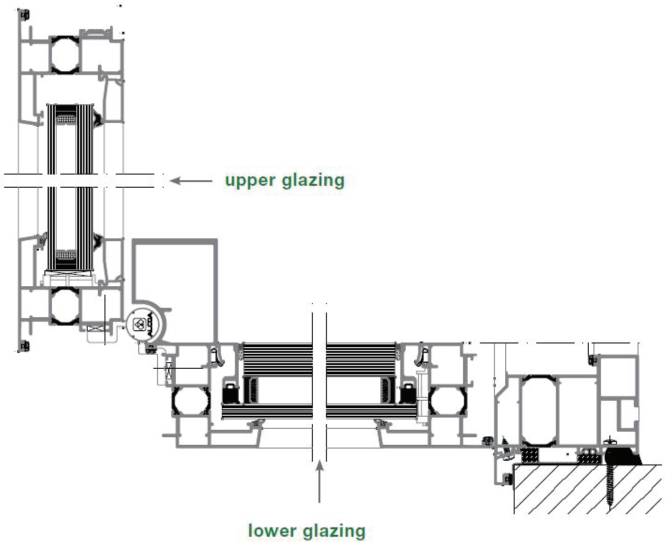


Figure 5.5.3 detail glassfloor (Bloomframe, 2019)

5.6 DIMENSIONS GLASS ELEMENT

Walkable glass can be made into a lot of different sizes. The key is the span direction and distance. A span of one meter or more is possible but the whole glass unit gets increasingly thicker and heavier.

The size of glass unit has to be in agreement with the facade elements. If the façade is build up out of 1,5m width elements, the transformable façade unit will be 1,5m or plural of 1,5m. The depth of the glass has to be calculated, the weight, strength and forces on the glass will be the constraints.

There are production limitation to the size of float glass sheet sizes. The standard production dimensions of float glass are 6 x 3,21m.
Additional glass calculation will be made together with a concept. This way the glass thickness can be calculated for each concept.

MEPLA
Software for Structural Glass Design

Figure 5.6.1 Logo (mepla logo, 2019)

5.7 LOCATION

The first location for the placement of the design will be London. London is a city where many high end residence skyscrapers are being build. The transformable balcony will be a luxury product. This will likely result in a more expensive product than a permanent balcony. The second reason is that Scheldebouw build a lot of skyscrapers in London. Keeping these two reasons in mind makes London the ideal location where the product can be used. Off course there are many potential locations for this product. But the first focus will be London.

Figure 5.7.1 London (own image)

5.8 DESIGN REQUIREMENTS

For a functional design and well performing design multiple design requirements are necessary. This way the quality and user satisfaction can be guaranteed. The design requirements will get updates during the design process. This way any new information, view, or feedback can be integrated to possibly enhance the final product.
The design requirements are:

- High product end finished look of the product
- Operational for with more than 20000 open/close operations
- Fully transformable flat façade to balcony
- Wind, thermal and water thigh
- Structural Safe, support people with eternal forces like wind.
- Intergraded railing in the design
- Railing height of at least 1200mm
- Strong glass with impact resistance

5.9 DESIGN PROCESS

CONCEPT

The design process started with designing different methods in how the façade could transform or rotate into a balcony. This lead to two possible methods. The first method uses the façade and fold the glass to shape a balcony. The second method is to have a separate element in front of the façade, this element transforms into a balcony. These where the two starting directions for the concepts.

This design view lead to 11 different concepts. That uses one of the two methods. Concept 1 to 5 uses the façade to form the balcony, and concept 6 to 10 uses the separate element in front of the façade.

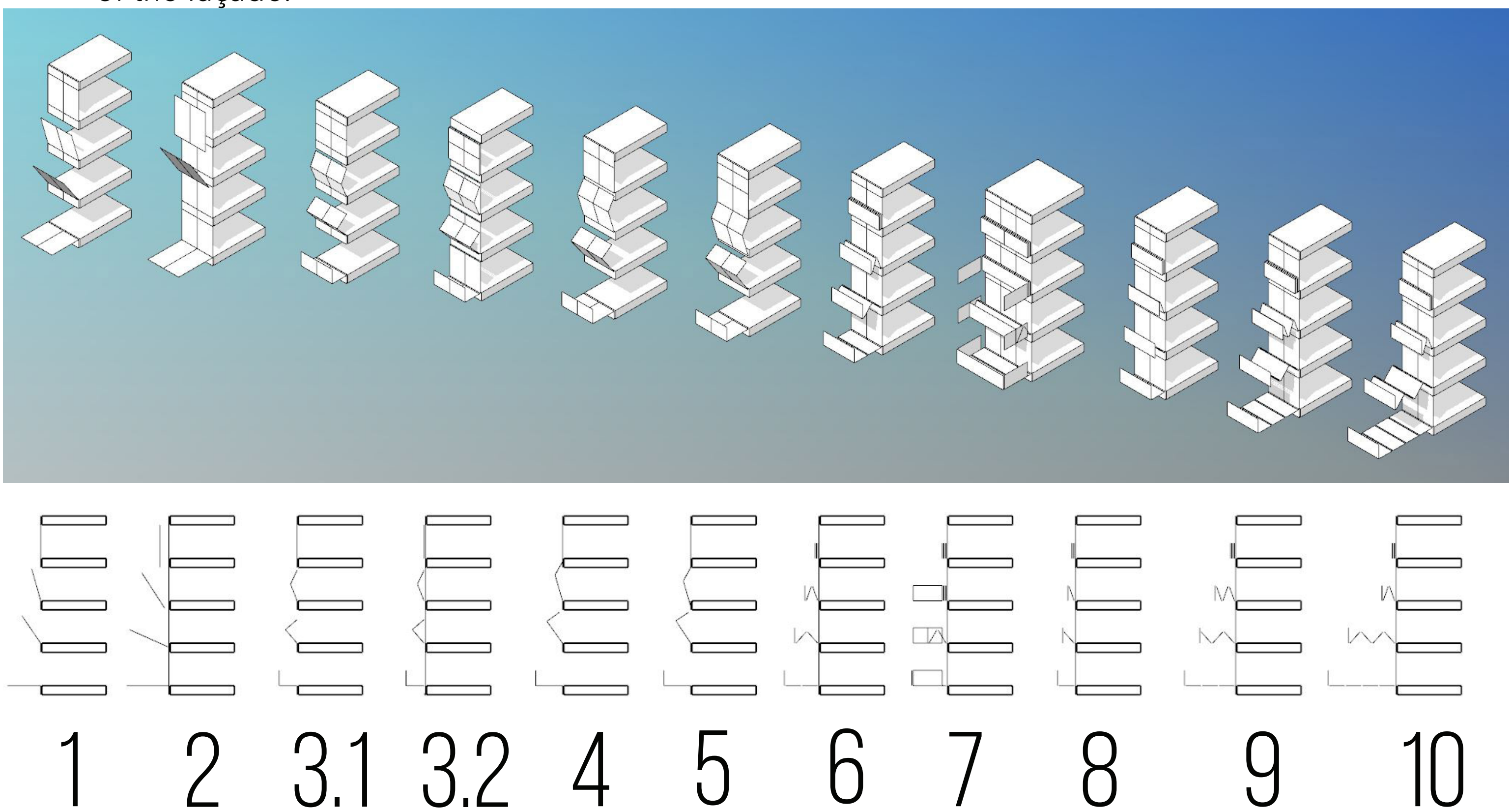


Figure 5.9.01 Sketch designs (own image)

Concept 1
The whole façade hinges at the height of the floor. Question for this concepts is whether there can be just one piece of glass from floor to ceiling that can serve as the floor for the balcony, or does the glass need to be divided with a horizontal mullion? If so this will disturb the view when the concept is in closed (vertical) position. Also there are no integrated balustrades.

Concept 2
Is the same as concept 1 except that it consist out of a double façade. There is the traditional façade that serves as the thermal barrier. The element in front of the façade rotates outwards to form the floor of the balcony. A big pro is that the glass used for the floor of the balcony only has to be laminated. With no thermal barrier the glass can be made a lot cheaper.

Concept 3.1
This concept uses the same principle as the Bloomframe. The depth of the balcony is limited by the height of the ceiling. Plus point in the integrated balustrade. On the fold line there is a horizontal mullion. Which blocks the view.

Concept 3.2
Identical to concept 3.1. Except that it consist out of a double façade. One as thermal barrier, the other as transformable balcony.

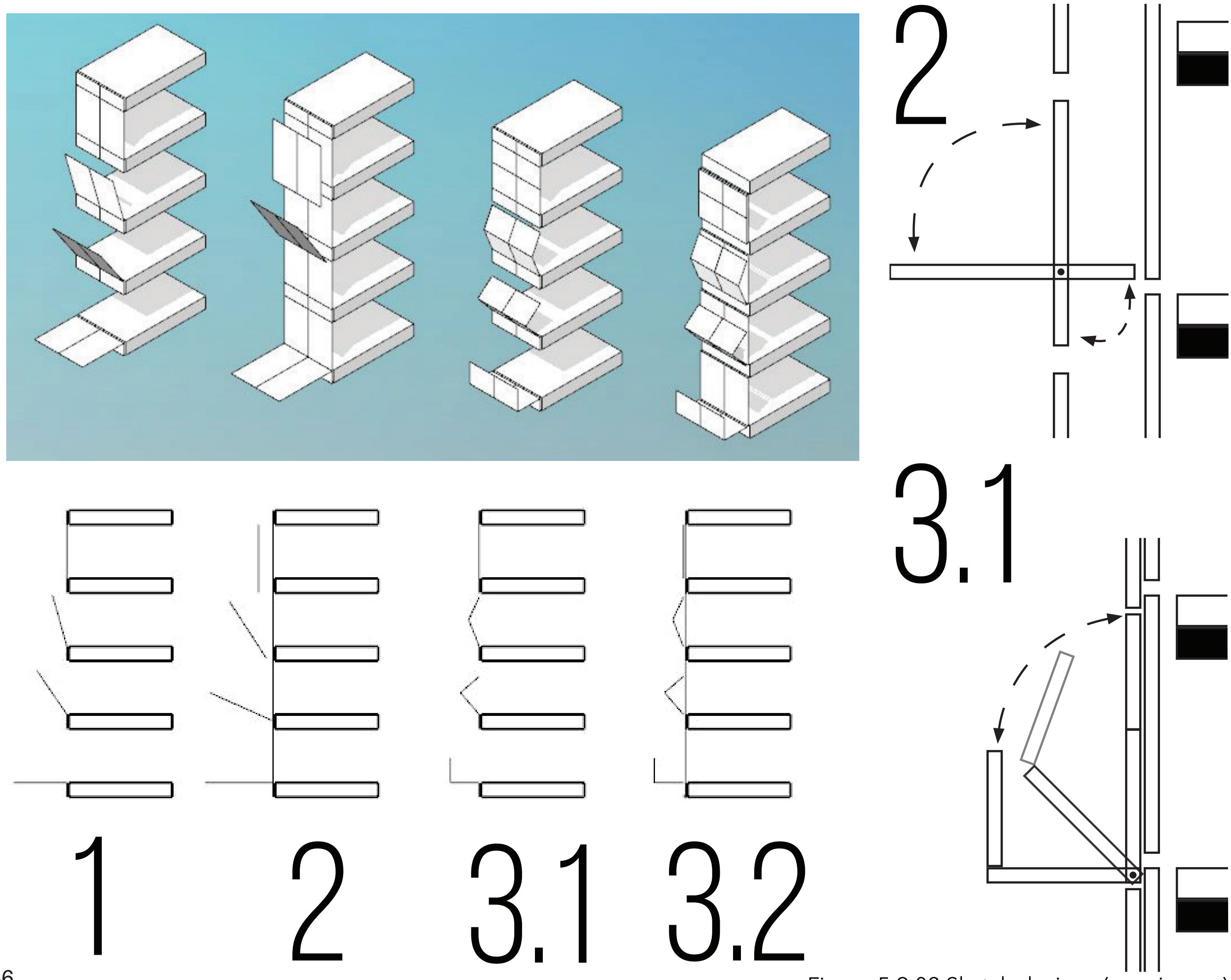


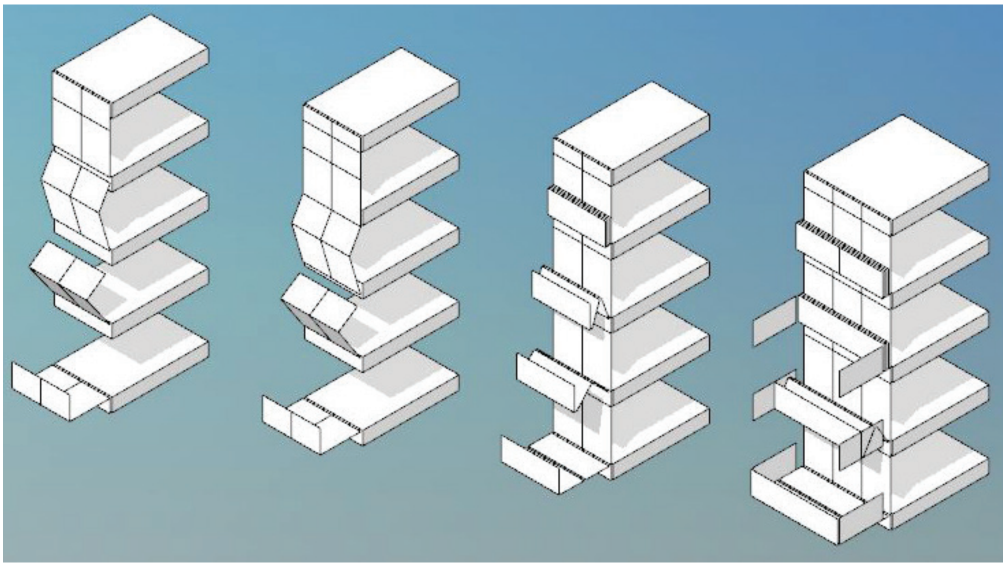
Figure 5.9.02 Sketch designs (own image)

Concept 4
This design uses the spandrel above to increase the total depth of the balcony. The balcony depth is directly related to the floor level. To increase the depth of the balcony you will have to increase the floor height. The top part of the concept transform to be the balustrade of the balcony. The balustrade is 1200mm in height. Meaning that with a spandrel of 700mm there is still 500 mm needed to reach the 1200. The consequence of this concepts is that there is a horizontal mullion at 2100+ floor level. This disturb the view when the façade is closed.

Concept 5
Identical to concept 4 except that is uses the spandrel below to increase the total depth of the balcony. First the whole façade has to hinge outward, pulled upwards to make the balcony levelled with the inside floor. And finally folded down to make it horizontal. This will be a difficult construction to produce with a lot of moving components. The horizontal mullion of this concepts sits at 500+ floor level. Still a disturbance in the view.

Concept 6
A totally different concept that consist out of 3 glass elements. Each 1200mm high that fold out to form a balcony. Ideally these 3 glass elements will only be supported at the side of the balcony. This would give a minimal visual interruption when the balcony is folded in. This depth of the balcony is no longer related to the height of the floor. But a plural of 1200mm. Also when the balcony is vertical it functions as a French balcony.

Concept 7
Identical to concept 6 with 2 additional glass panels in front of the package. These glass panels fold out first to form the side balustrades.



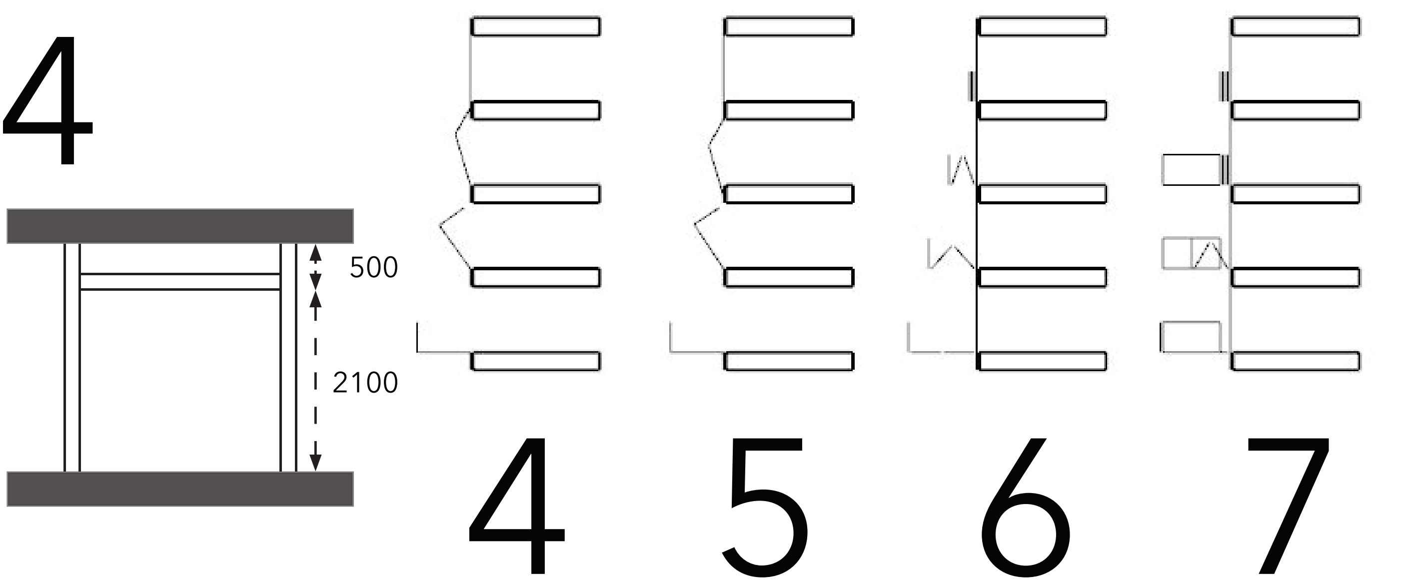


Figure 5.9.03 Sketch designs (own image)

Concept 8 to 10

All these concepts are identical to concept 6. The difference is the amount of glass floor elements. This creates different depths for the balconies. Concept 8 has only one glass floor element. This makes the depth of the balcony 1200mm Concept 6 uses 2 floor elements which gives a depth of 2400mm. Concept 9 uses 3 elements, results in 3600mm and finally concept 10 uses 4 elements results in a depth of 4800mm.

This is just a quick render of the concept. The bigger a balcony is the heavier the construction needs to be. Also big balconies have a tendency to resonate in their own frequency.

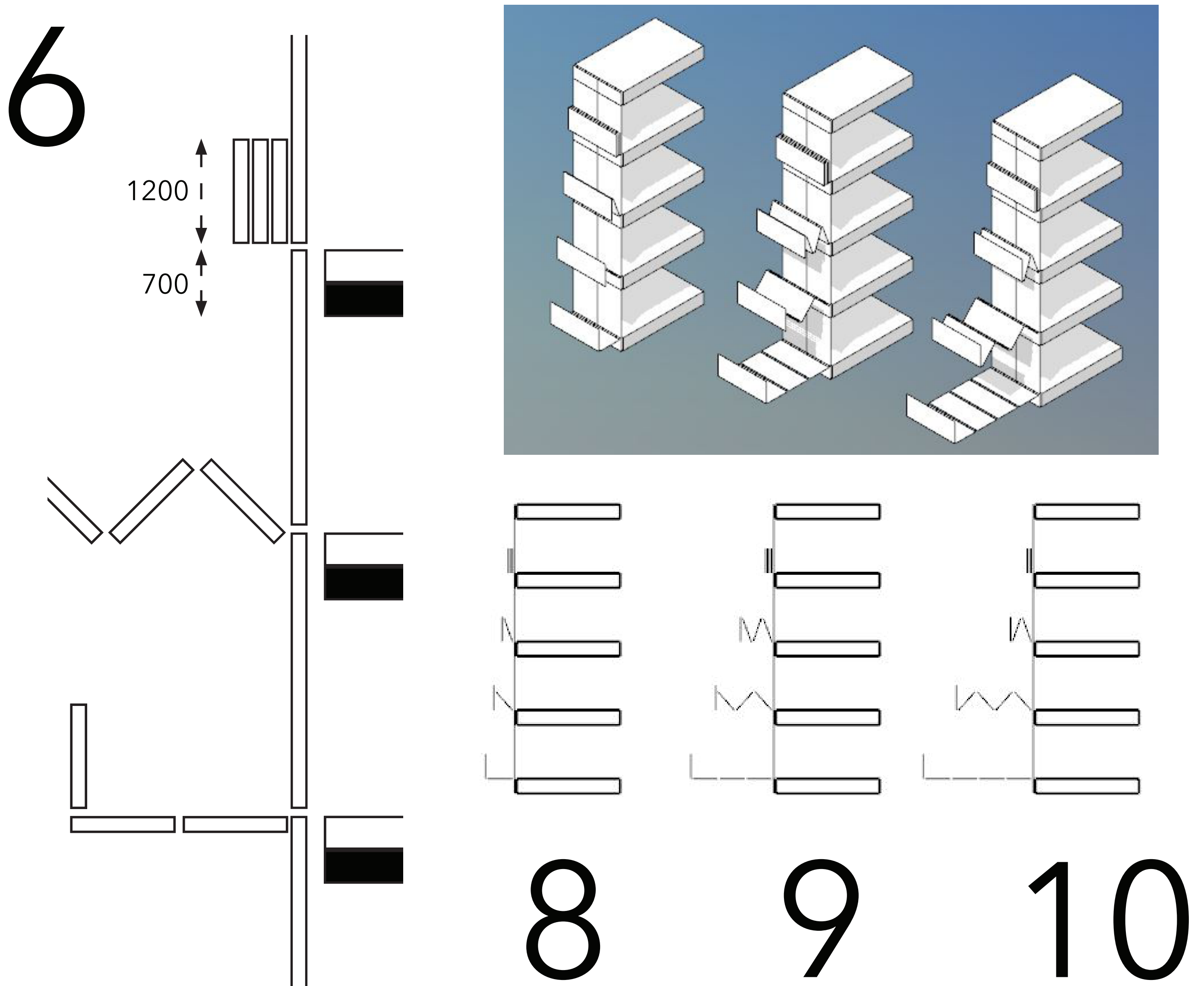


Figure 5.9.04 Sketch designs (own image)

To determine which concept is the best, a list was made. This list was divided into 4 segments; safety, aesthetic, practicality/usability and comfort.

The safety requirements are hard requirements. If a design does not comply to the safety requirements, the design is discarded.

Concept 1,2 and 5 fail on the safety requirements. These concepts are discarded.
Design 6 to 10 are chosen for further development. They all relay on the same concept.
This choice was made based on the following points,

- Balcony isn't the thermal barrier
- The glass in the balcony does not have to be isolated (Cheaper and lighter)
- Balcony depth is separate from the floor height, the depth can be different.
- Multiple functions (French balcony, balcony, window.
- Extra usability with the permanent façade.
- Balcony can be used even when it is cold outside and when it is raining.

The main difference between design 6 to 10 are the amount of glass floor elements. The choice was made to further develop design 6. This design has a depth of 2400mm, This dimension gives lots of different usability's to the balcony. And because this graduation project has a limited time frame, the best approach is to only develop one concept.

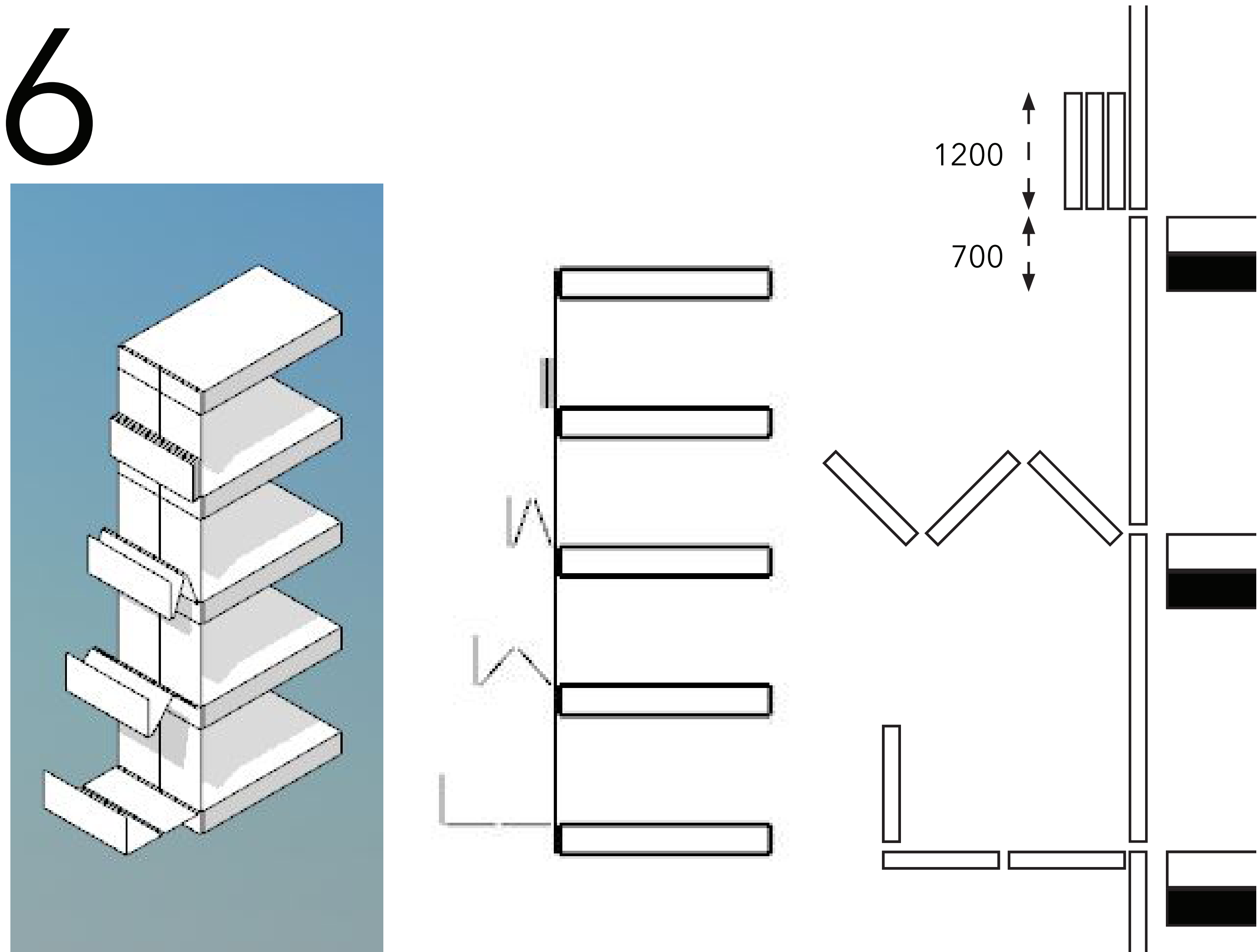


Figure 5.9.05 Sketch designs (own image)

Category	Part	Balcony types 1	2	3.1	3.2	4	5	6	7	8	9	10
Safety	Stays attached to the façade	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Always have fall protection	No	No	Yes	Yes	Yes	Medium	Yes	Yes	Yes	Yes	Yes
aesthetic	unobstructed view	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes
	Balcony depth [M]	2,6	3,3	1,4	1,4	2,1	2,1	2,4	2,4	1,2	3,6	4,8
practicality	cleaning	5	5	5	5	5	5	1	1	1	1	1
	Single façade	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	No
	Balcony as thermal barrier	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	No
Comfort	frequency resonance (own)											
	deflection											

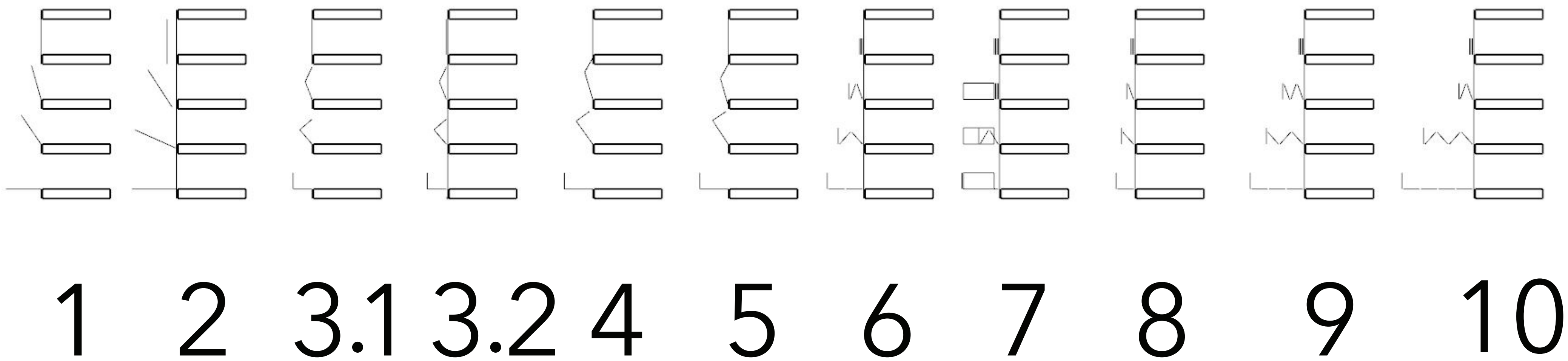


Figure 5.9.06 assessment list (own image)

CONSTRUCTION

The concept consist out of glass elements of 1500 x 1200mm laminated glass sheets. Supported at the outside (1200mm side). This means that the glass spans 1500mm. Calculation where made to determine if glass could handle such a span. Calculation where made with the assumptions of laminated glass consisting of 2 sheets of 12mm glass. For safety reasons the calculation where made with 1 sheet (top) broken, thus supporting no weight. The load case consist out of a full load of people meaning 3,5 kN/m surface load. With a safety factor applied the total surface load is 5.25kN/m.

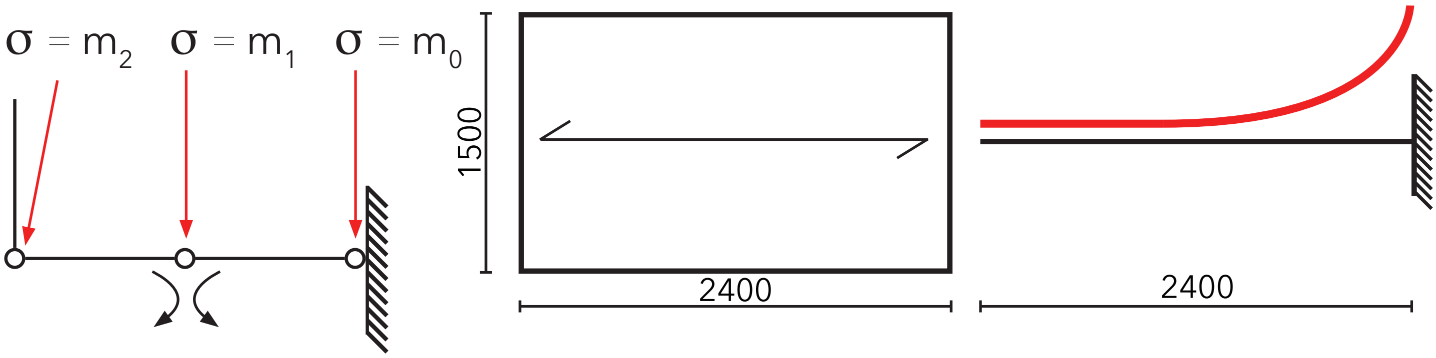
The calculation result in a force of 51,4 N/mm2 on the glass. According to Scheldebouw fully heat strengthened glass (toughened) can handle 69,7 N/mm2 of force.

There was also a calculation made for the beams, this resulted in a steel tube profile of 80x80x8mm.

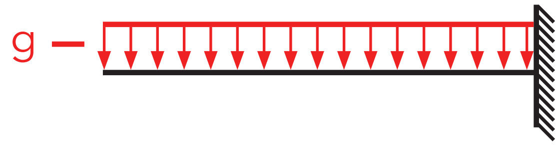
The last calculation needed was the moment force, that is present at the hinge points of the balcony. for the calculations see the appendix. M0= 8.6 kN, M1= 2,9kN M2= 0

These forces will appear in the balcony. A suitable construction method is needed to support these forces, and transfer the forces to the main construction of the building.

Beam calculation:



$$g = 5{,}25 * 0{,}75 = 3{,}94 \text{ kN/m}$$



$$m = {}^{1}/_{2}\, gl^2$$
$$m = {}^{1}/_{2} * 3{,}94 * 2{,}4^2$$
$$m = 11{,}34$$

$$\sigma = \frac{m}{w} \rightsquigarrow w = \frac{m}{\sigma}$$

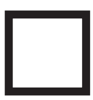
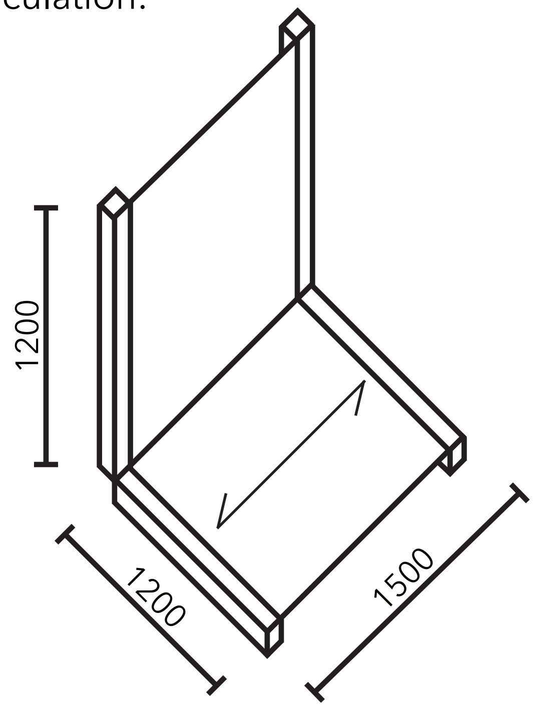
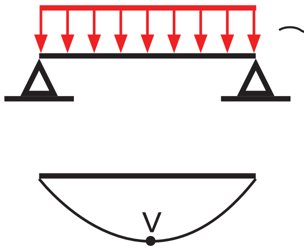
$$= \frac{11{,}34*10^6}{355} = 32*10^3 \text{ mm}^3 \rightsquigarrow$$  80x80x8mm steel square tube

Figure 5.9.07 schematic force transfer (own image)

Glass calculation:





$\rightarrow$ 3,5 * 1,5 = 5,25 kN/m

$$v = 1/8\ ql^2 = 1/8 * 5{,}25 * 1{,}5^2 = 1{,}48 \text{ kN/m}$$
$$w = 1/6 * 1200 * 12^2 = 28800 \text{ mm}^3$$
$$\sigma_m = \frac{1{,}48*10^6}{28800} = 51{,}39 \text{ N/mm}^2$$

Figure 5.9.08 schematic force transfer (own image)

SCHELDEBOUW

Design strength values for surface and polished edges $k_e = 1.0$

Glass type	$f_{g;k}$ **[MPa]**	$f_{g;d}$ **[MPa]**							
		Wind	Snow heat	Snow un-heat	Imposed normal	Imposed crowded	Tempe-rature	Barom-etric	Dead
Annealed	45	25.0	12.2	11.2	22.2	19.2	14.2	12.5	7.2
	$f_{b;k}$ [MPa]	$f_{g;d}$ [MPa]							
Heat Strengthened	70	45.8	33.0	32.0	43.0	40.0	35.0	33.3	28.0
Toughened	120	87.5	74.7	73.7	84.7	81.7	76.7	75	69.7
Enamelled (HS)	45	25.0	12.2	11.2	22.2	19.2	14.2	12.5	7.2

Design strength values for clean cut, arrised and grounded edges $k_e = 0.8$

Glass type	$f_{g;k}$ **[MPa]**	$f_{g;d}$ **[MPa]**							
		Wind	Snow heat	Snow un-heat	Imposed normal	Imposed crowded	Tempe-rature	Barom-etric	Dead
Annealed	45	20.0	9.8	9.0	17.8	15.4	11.4	10.0	5.8
	$f_{b;k}$ [MPa]	$f_{g;d}$ [MPa]							
Heat Strengthened	70	36.6	26.4	25.6	34.4	32.0	28.0	26.6	22.4
Toughened	120	70.0	59.8	59.0	67.8	65.4	61.4	60.0	55.8
Enamelled (HS)	45	20.0	9.8	9.0	17.8	15.4	11.4	10.0	5.8

Figure 5.9.09 Design strength glass (Scheldebouw, 2019)

CONSTRUCTION CONCEPT

There are many potential construction methods that can be used to support this balcony.
But there are some requirements. The construction must be placed outside or incorporated into the profiles. Meaning that no constructive element is hidden under the ceiling or floor. The construction off course needs to be strong enough, have a fail-safe and low maintenance. Ideally the construction would be integrated into the frame of the balcony. The goal is to make it as slim as possible. Not in view and to design a parallel controlled movement.
Different construction designs where analysed :

- Scissor frame
- Chain and sprocket
- Hydraulic cylinders
- Hydraulic rotary actuator

Scissor frame
A scissor frame is build up out of crosses. These crosses hinge in the middle. It has the benefit of a parallel movement. It only allows 1 directional movement,.ew. The frame could be placed horizontal or vertical. But both ways are not ideally for a balcony. The mounting positions of the scissor frame have to be movable, a guide rail is needed. The frame will always be in sight. Also the way the balcony transforms makes it difficult to be supported by a scissor frame.

Because of the many hinges, present tolerance's can make it difficult to keep the balcony levelled. Scissor construction are used for windows. These windows have scissor hinges all the way around the window frame. Also the total movement is limited, normally used for small distances.

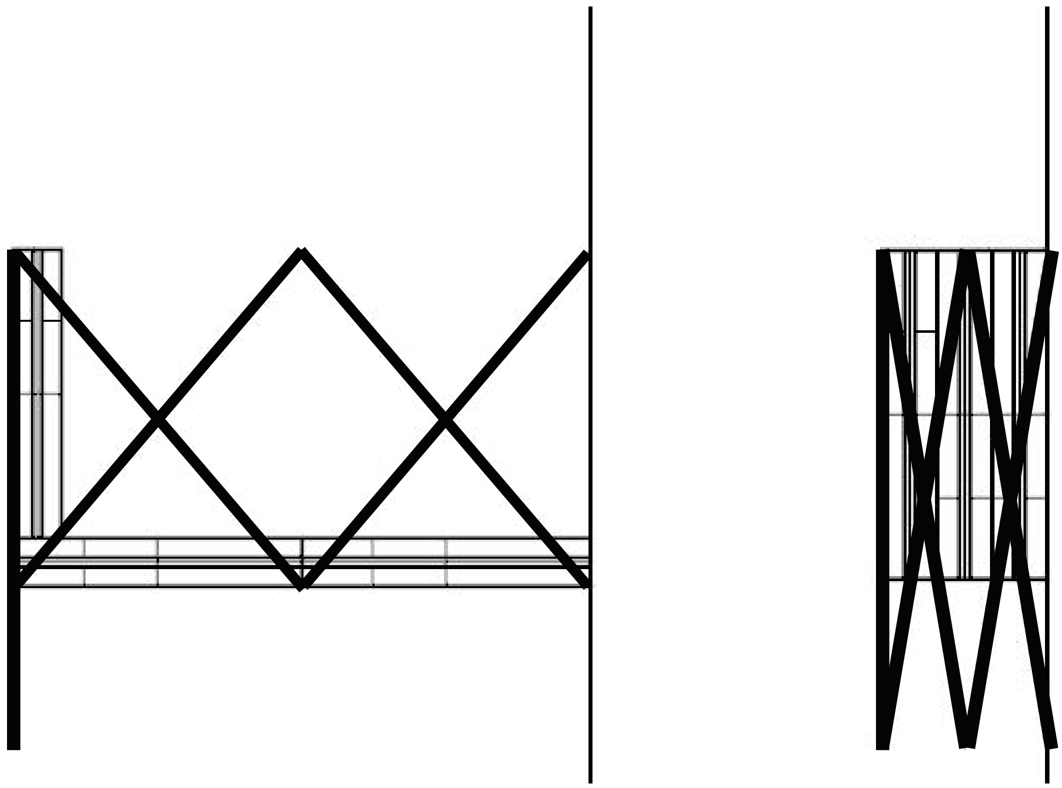
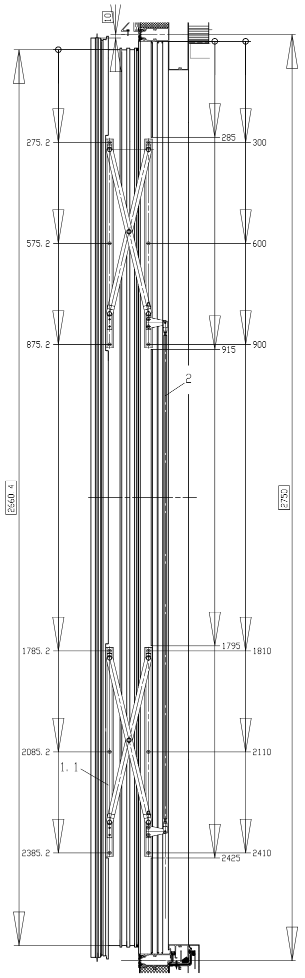


Figure 5.9.10 Scissor frame (own image)

Figure 5.9.11 Scissor window (youtuberseo, 2019)



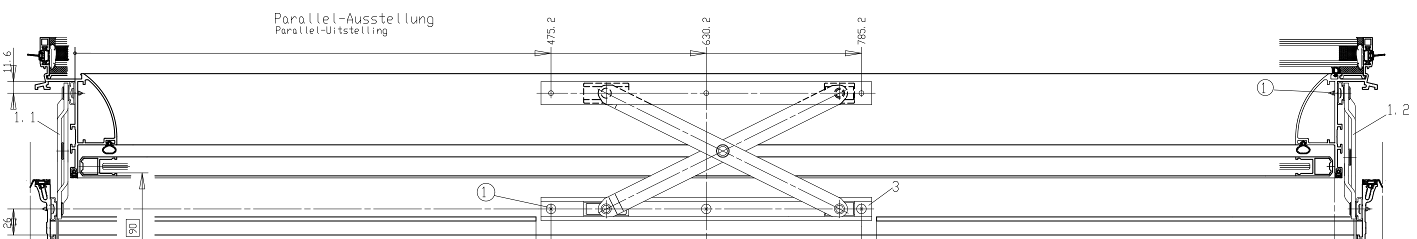


Figure 5.9.12 Scissor frame Scissor details (Scheldebouw, 2019)

Chain and sprocket
The chain and sprocket construction consist out of a drive shaft (1), two different size sprocket and two chains. The sprockets that sits over the drive shaft stays stationary (2). The drive shaft (1) rotates 90 degrees clockwise. This rotation lowers beam (3), creating movement in the chain (4). The chain makes sure that the next set of sprocket rotates (5). The chain ration is 2:1.

This system could work with a slight modification. In the image the last steel beam rotates to a horizontal position, but for this prototype the beam needs to stay vertical. Because it is the balustrade. Changing the chain ratio could be the answer.

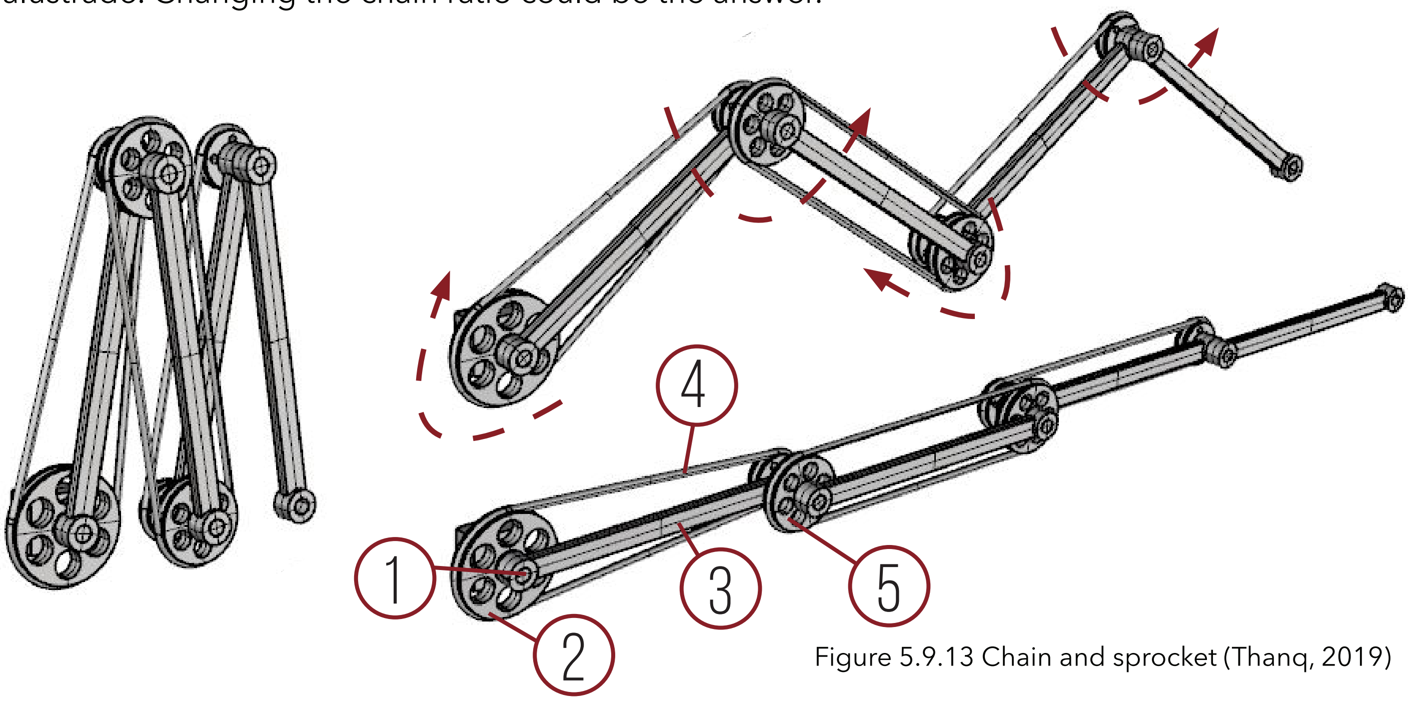


Figure 5.9.13 Chain and sprocket (Thanq, 2019)

An alternative to this construction are 2 sprockets and a fixed steel rod. Because the rod is fixed the sprockets get turned when the construction is lowered. The lowering movement happens by own weight. And is pulled back up by a steel cable.

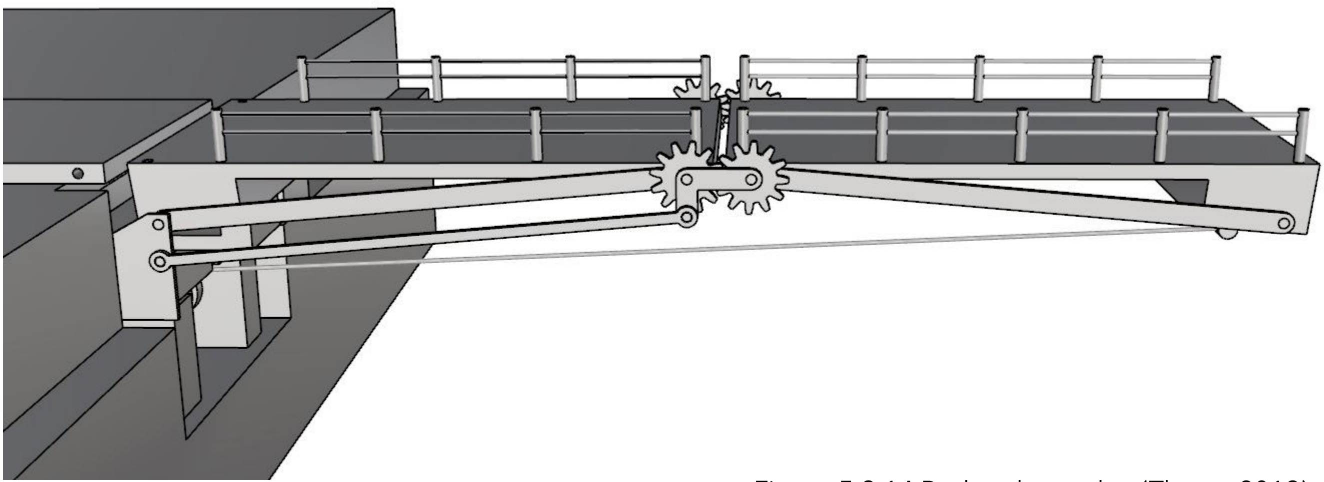


Figure 5.9.14 Rod and sprocket (Thanq, 2019)

Hydraulic cylinders.
Hydraulic telescopic cylinders consist out of multiple cylinders that slide over each other. Hydraulic fluid is pumped into the cylinders which result into a lineal movement. Hydraulic cylinders can handle high amount of forces. They are used for excavator machines and other heavy machinery. Hydraulic fluid cannot be compressed which makes it ideal for high force application.
In this concept two telescopic cylinders will be used. One at each side of the balcony, the cylinders moves the balcony in it outward position.

Figure 5.9.15 Hydraulic telescopic cylinders (German alibaba, 2019)

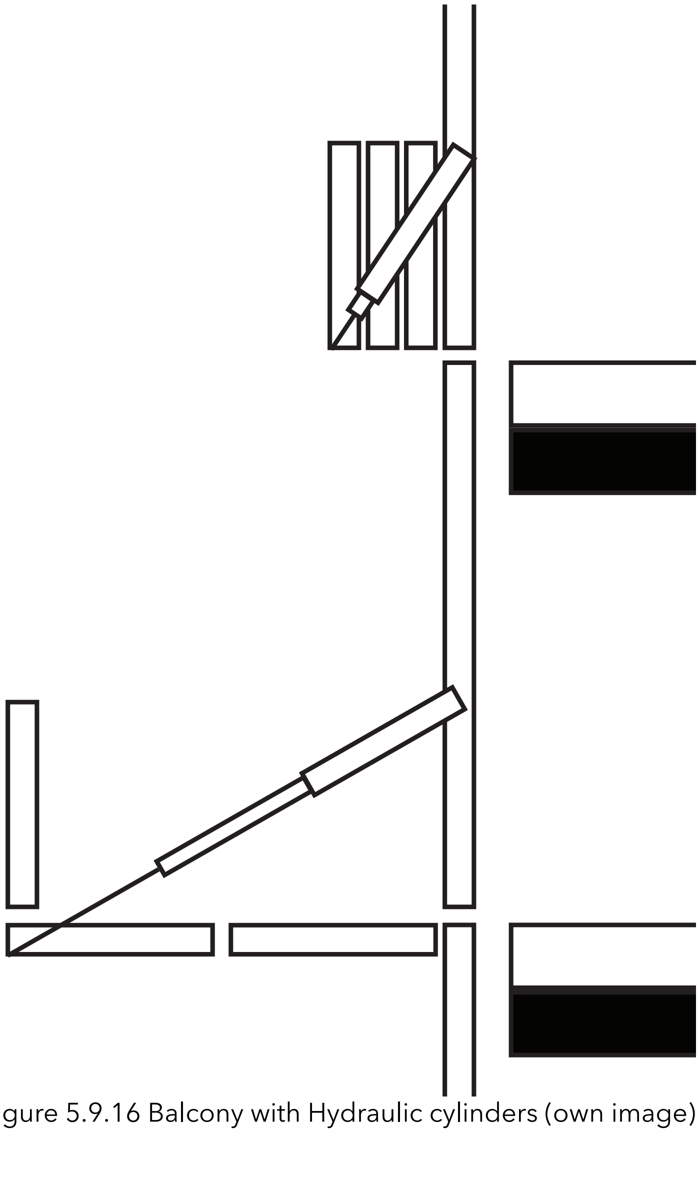


Figure 5.9.16 Balcony with Hydraulic cylinders (own image)

Hydraulic rotary actuator
Hydraulic rotary actuator work on a similar concept as the hydraulic cylinders. But instead of a linear movement the rotary actuators use hydraulic fluid to create a rotational force. These rotary actuators are relative small (365mm) and can handle moment forces up to 4.75Knm This makes them ideally for the balcony. They can be precisely controlled. Stay in position, even when the hydraulic line to the actuator gets cut. Plus they can handle a lot of force. Little maintenance is needed.

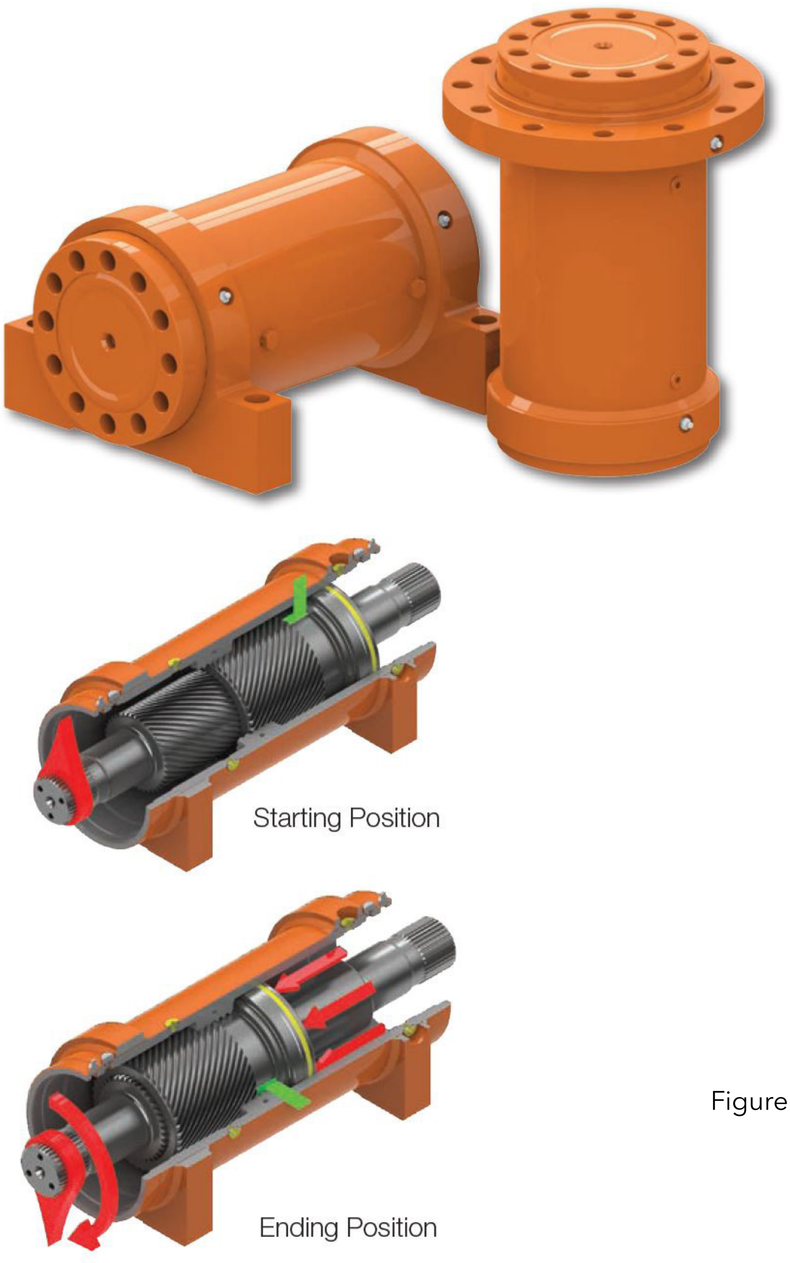


Figure 5.9.17 Hydraulic rotary actuator (Parker, 2019)

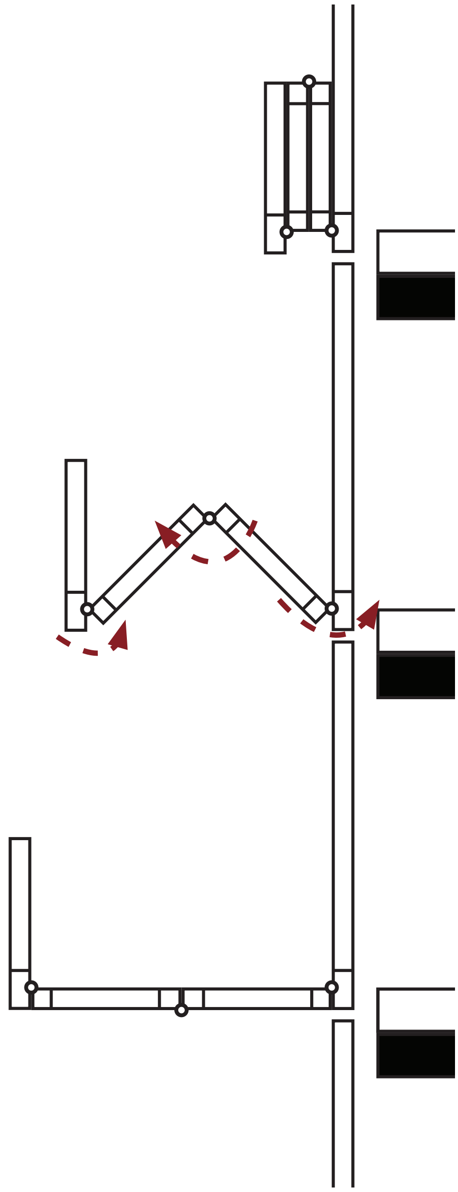


Figure 5.9.18 Balcony with rotary cylinders (own image)

LAMINATED GLASS

The final laminated glass sheet composition has to be made. The balcony consist out of three laminated glass elements. Two elements are used as floor, and one element is used as a balustrade. The laminated glass composition can be different for each function. The floor function will need to handle more load, this will result in a stiffer laminated composition.

The two glass floor elements can deflect independent. When looking at the extreme condition that only one glass floor elements is fully loaded, a height difference will occur between the glass floor elements and/or between the building floor. This height differs occurs due to deflection of one glass floor element and can lead to a tripping hazard. Ideally the deflection would be as small as possible. To prevent a tripping hazard. The maximum deflection has to stay under 15mm. Preferable even be less than 10 mm. To ensure that the deflection stays under 10mm, calculations have to be made. The program Mepla was used to calculate the maximum deflection and stresses in the glass.

The load case consist out of a full surface load of people (350 kg/m2) with a point load in the middle of the glass (2kN) on a surface of 10x10cm. The standardized float glass thicknesses are: 1,9 / 3 / 4 / 5 / 6 / 8 / 10 / 12 / 15 / 19mm. For safety issues the glass flooring should still carry the load even when one glass sheet breaks. This means that when the top layer breaks the other layer are still strong enough for people to safely clear the balcony.

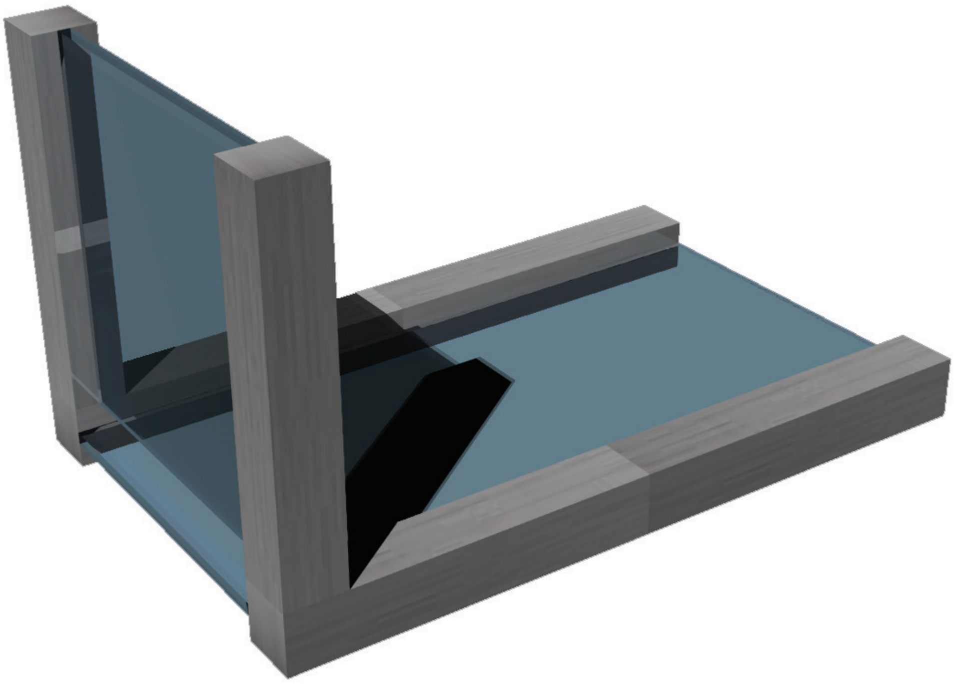


Figure 5.9.19 Balcony first visualization(own image)

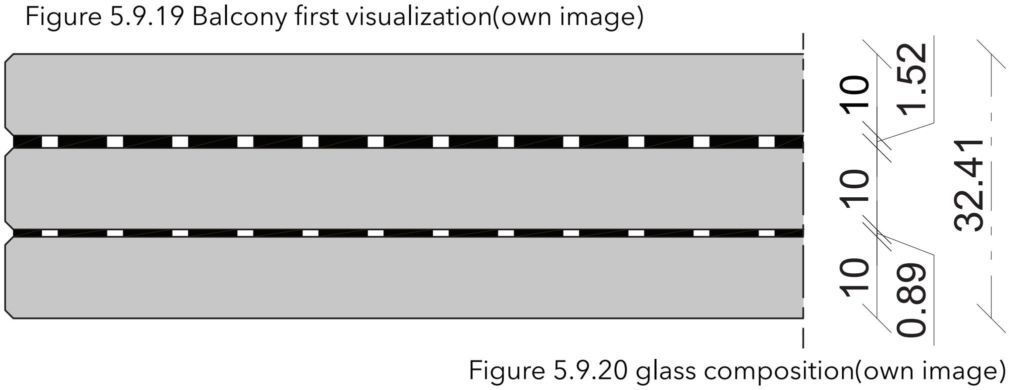


Figure 5.9.20 glass composition(own image)

Glass floor

After calculated different laminated glass compositions with Mepla, the choice was made for 3 layers of 10 mm glass with 2 different foils between the glass sheets (figure 5.9.20). 2 layers of SGP foil in between the glass layers. This leads to the least amount of deflection. Under full load the deflection in the middle of the glass is 2.6mm. When 1 glass breaks the deflection is 7,8mm. This means that the people standing on top off de glass floor will not notice the deflection. And will feel safe when walking and standing on top of the balcony.

The choice of 10 mm glass was made due to the stresses that occur in the glass. The stresses that occur in the glass are 21,4MPa in total. Load case is DL (dead load 1,63MPa) + LL (live load 5,95MPa) and PL (point load 6,87MPa). Multiplying with the safety factor 1,35 (DL) and 1,5 (LL+PL) results in a total of 21,4MPa.

Scheldebouw uses their own standardized design strength values for glass. In figure 5.9.21 the different values are shown.. For the top 10 mm glass sheet the choice was made for Toughened (T) glass, meaning the glass is fully heat strengthened. T glass can handle the most stress, this gives the least amount of change for failure on impact (falling objects, points loads etc.) The other two glass sheets are heat strengthened (HT) meaning half heat strengthened glass.
To support the stress of 21,4MPa HT glass is sufficient, the table says HT glass support up to 28MPa when used for dead load.

When the top layer of the glass composition fails the deflection increases to 7,8 mm, and the load has to be supported by 2 glass layers instead of 3. This means that stress increases to 38,2MPa. The safety factor for the life load (people) is removed. Because people will not be using this balcony the same way as before. This means that the balcony will no longer be packed with people. But the balcony still needs to handle a full load case for 5 minutes to ensure that the balcony can be cleared. In figure 5.9.21A the post crowded (30 minutes load) values are used. This means that HT glass can support 40MPa.

SCHELDEBOUW

Design strength values for surface and polished edges $k_e = 1.0$

Glass type	$f_{g;k}$ **[MPa]**	$f_{g;d}$ **[MPa]**							
		Wind	Snow heat	Snow un-heat	Imposed normal	Imposed crowded	Tempe-rature	Barom-etric	Dead
Annealed	45	25.0	12.2	11.2	22.2	19.2	14.2	12.5	7.2
	$f_{b;k}$ [MPa]	$f_{g;d}$ [MPa]							
Heat Strengthened	70	45.8	33.0	32.0	43.0	40.0	35.0	33.3	28.0
Toughened	120	87.5	74.7	73.7	84.7	81.7	76.7	75	69.7
Enamelled (HS)	45	25.0	12.2	11.2	22.2	19.2	14.2	12.5	7.2

Design strength values for clean cut, arrised and grounded edges $k_e = 0.8$

Glass type	$f_{g;k}$ **[MPa]**	$f_{g;d}$ **[MPa]**							
		Wind	Snow heat	Snow un-heat	Imposed normal	Imposed crowded	Tempe-rature	Barom-etric	Dead
Annealed	45	20.0	9.8	9.0	17.8	15.4	11.4	10.0	5.8
	$f_{b;k}$ [MPa]	$f_{g;d}$ [MPa]							
Heat Strengthened	70	36.6	26.4	25.6	34.4	32.0	28.0	26.6	22.4
Toughened	120	70.0	59.8	59.0	67.8	65.4	61.4	60.0	55.8
Enamelled (HS)	45	20.0	9.8	9.0	17.8	15.4	11.4	10.0	5.8

Figure 5.9.21A Design strength glass (Scheldebouw, 2019)

The final glass compositions for the floor elements is 3 sheets of 10 mm glass, with 2 layers of SGP between them. Top glass layer is toughened, other layers are heat strengthened.
But when informing with a glass supplier a problem occurred. SGP foil normally only gets used on the tin side of float glass. If SGP foil is used on the air side the glass will have to be treated first with an adhesive primer. This glass supplier does not do offer this work. SGP foil is normally only used on the tin side of float glass. If SGP foil has to be used on the air side, the glass will have to be treated first with an adhesive primer. The glass supplier does not offer this primer treatment. SGP foil is already more expensive than PVB foil. And an extra adhesive primer will only make it even more expensive.A solution was found by using SGP and PVB foil in the final glass composition. The composition still exist out of 3 sheets of 10mm glass, but between the top glass sheets 4 PVB foils are laminated. 2 layers of SGP foil is used between the bottom 2 glass sheets.
The deflection stays the same. But the total cost will be reduced.

Glass balustrade.
The balustrade has the main function of fall protection. This means that in all cases fall protection must be present.. Even when the glass fails, meaning that SGP foil has to be used. In worst-case scenario that all of the glass in the balustrade fails the SGP foil ensures that the balustrade stays vertical. This will ensure fall protection in any situation.
Making the calculations with Mepla leads to a glass composition of 2 sheets of 10 mm glass with 2 layers of SGP foil in between.
Additional calculations can be found in the appendix.

Floor										
Span 1,5*1,2 meter	Dead load		Live load		Point load		Total with safety		Strength test	
Laminated glass build up	σ	δ	σ	δ	σ	δ	σ	δ		
3 x 10mm glass layers PVB (0.76)	3,92	-2,5	12,42	-6,8	14,3	-3,62	45,372	-12,92	45,4 /69,7 =	0,651
2 x 10mm glass layers PVB (0.76)	4,08	-2,6	22,36	-12,12	23,25	-6,31	73,923	-21,03	73,9 /40 =	1,848
3 x 10mm glass layersPVB (1.52)	4,24	-2,74	14,5	-14,5	15,32	-4,39	50,454	-21,63	50,5 /69,7 =	0,724
2 x 10mm glass layers PVB (1.52)	4,31	-2,799	24,73	-14,14	24,37	-7,27	79,4685	-24,21	79,5 /40 =	1,987
3 x 10mm glass layers SGP (0.89)	1,54	-0,51	6,15	-1,37	6,75	-0,69	21,429	-2,57	21,4 /69,7 = 21,4 /28 =	0,307 0,765
2 x 10mm glass layers SGP (0.89)	2,19	-0,88	14,18	-4,61	14,08	-2,28	38,2565	-7,77	38,3 /40 =	0,956
3 x 10mm glass layers SGP top (0.89) pvb (1,52)bot	1,54	-0,54	6,15	-1,34	6,75	-1,36	21,429	-3,24	21,4 /69,7 = 21,4 /28 =	0,307 0,765
2 x 10mm glass layers PVB (1.52)	4,31	-2,799	24,73	-14,14	24,37	-7,27	79,4685	-24,21	79,5 /69,7 = 79,5 /40 =	1,140 1,987
3 x 10mm layers top pvb (1,52) bot SGP (0.89)	1,63	-0,55	5,95	-1,33	6,87	-0,67	21,4305	-2,55	21,4 /69,7 = 21,4 /28 =	0,307 0,765
2 x 10mm glass layers SGP (0.89)	2,19	-0,88	14,18	-4,61	14,08	-2,28	38,2565	-7,77	38,3 /69,7 = 38,3 /40 =	0,549 0,956

Balustrade						
Span 1,5*1,2 meter	Line load		Total with safety		Strength test	
Laminated glass build up	σ	δ	σ	δ		
2 x 10mm glass layers SGP (0.89) 1kN/m	10,39	-6,28	14,0265	-6,28	14,0265 /40 =	0,351
2 x 10mm glass layers SGP (0.89) 2kN/m	21,44	-12,31	28,944	-12,31	28,944 /40 =	0,724
2 x 8mm glass layers SGP (0.89) 1kN/m	15,95	-11,11	21,5325	-11,11	21,5325 /40 =	0,538
2 x 8mm glass layers SGP (0.89) 2kN/m	32,06	-20,83	43,281	-20,83	43,281 /69,7 = 43,281 /40 =	0,621 1,082

Figure 5.9.21B glass composition (own image)

PROBLEM

Having found the ideal construction with a high possibility of a working concept. The next step would be to buy the construction method and draw details how the balcony would work. This would lead to a possible prototype and 1 to 1 scale testing of the concept. Scheldebouw was willing to invest in a prototype and already sent out price indication for the glass sheets. The first setback came when informing of the delivery time for the hydraulic actuators. They (hydraulic actuator company) estimated a delivery time of 16 to 18 weeks. This already made it impossible to make a prototype during this graduation project. The second setback also the biggest setback was the price of these actuators. A total of 6 actuators are needed for 1 balcony. The price for 6 actuators is €30000. That is extremely expensive, and with the additional cost of the glass, profiles, assembly, and overhead would make the final balcony commercially uninteresting.

This led to a moral dilemma. The mentors of the TU Delft had no issue with the cost of the construction, mainly because the project was designed for the high end residential market. It is a luxurious product, that may cost a lot of money. There was also no price cap prearranged. But for the company the feasibility of the product vanished. There were two possible directions to continue the project. The first direction was to continue with the expensive construction, and create detailed drawings at the level suitable for a prototype. The second direction was to take a big step back and try to find alternative construction designs, that are cheaper to produce. The choice was made for the second direction because the first direction did not show any financial viability. Construction designs that are cheaper to produce will show a higher possibility for a prototype. A key point for the company. This broadening of the research did consume quite some time, thus leading to more conceptual drawings and less detailed design.

The next step in the design process is to go back to possible construction methods. Look for alternative construction methods that can work. What are the cost of these systems? How to they function? What are the dimensions of these constructions? Maintenance? These are question that need to be answered, before are new construction method can be chosen.

CONSTRUCTION CONCEPT 2.0

Of the previously discussed methods, the chain and sprocket and the hydraulic cylinder construction, may still further be researched. There is also the possibility of a chain system. Of these three concepts a scale model was made to investigate the functional possibilities. The hydraulic rotary actuator system is still a valuable option and is not excluded during this design step. Because this construction concept is stil a possible solution. Only the price is the issue.

Possible construction concepts are:

- Winch
- Chain and sprocket
- Hydraulic cylinders
- Hydraulic rotary actuator

WINCH

The winch principle works with 2 different steel chains. 1 steel cable (green cable figure 5.9.22) is connected to the hinge in the middle. While the other steel cable (red cable figure 5.9.22) is connected to the hinge at the end of the balcony. The balustrade is integrated into the construction model. There are stiff beams between the balustrade and the frame of the glass floor elements. This means that the balustrade will always stay parallel to the floor. Meaning that the balustrade can be integrated in the construction method. A integrated balustrade that moves simultaneously with the construction ensures that there is always fall protection. The red cable can also benefit and use the balustrade to attach a pulley. The angle that is created by this is sharp enough for the steel cable to support the second glass element and the glass balustrade.

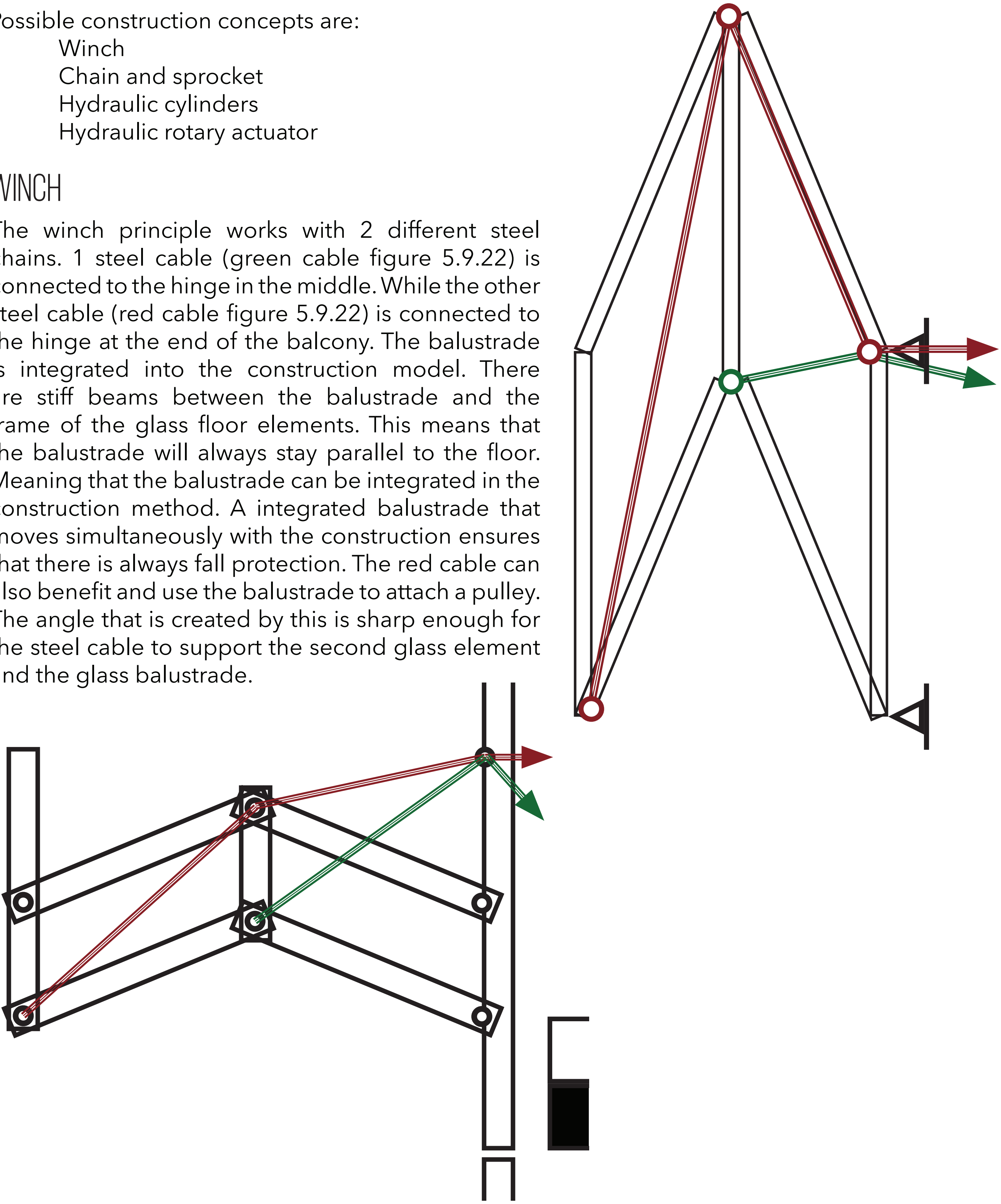
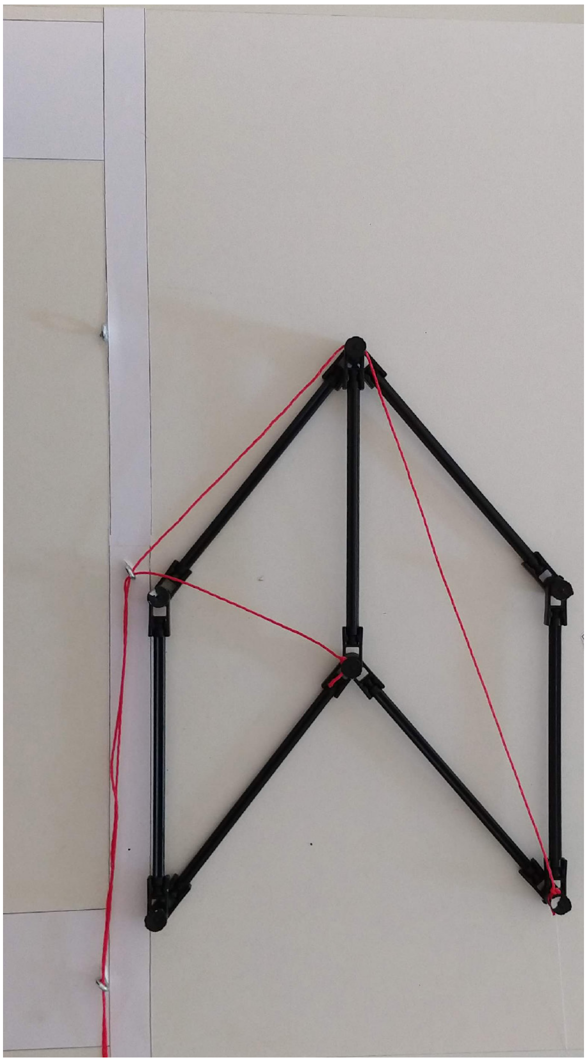


Figure 5.9.22 Winch construction (own figure)

The red cable acts in the opposite way as the green cable. As the green cable gets longer, the construction folds out. At the same time the red cable gets shorter, pulling up the second glass floor elements of the balcony and keeping it levelled, even when the balcony is put under load.

The detail and the top view shows how this concept looks. There are small steel cables that run next to the balcony, meaning that on the balcony you do not see the construction method. If you look over the balustrade it is noticeable. But because it is just a small cable (estimated 1cm in diameter) it is a very slender construction. The steel cables do need to be over engineered to ensure that the balcony will be safe.



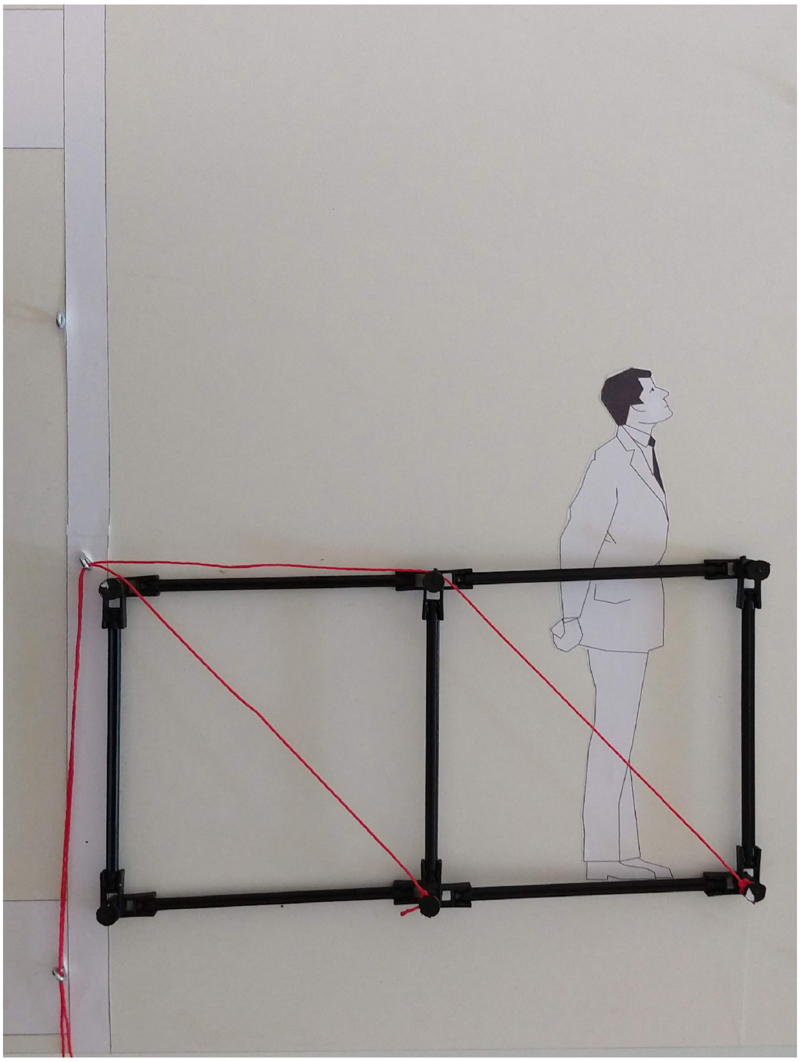


Figure 5.9.23 Winch construction (own figure)

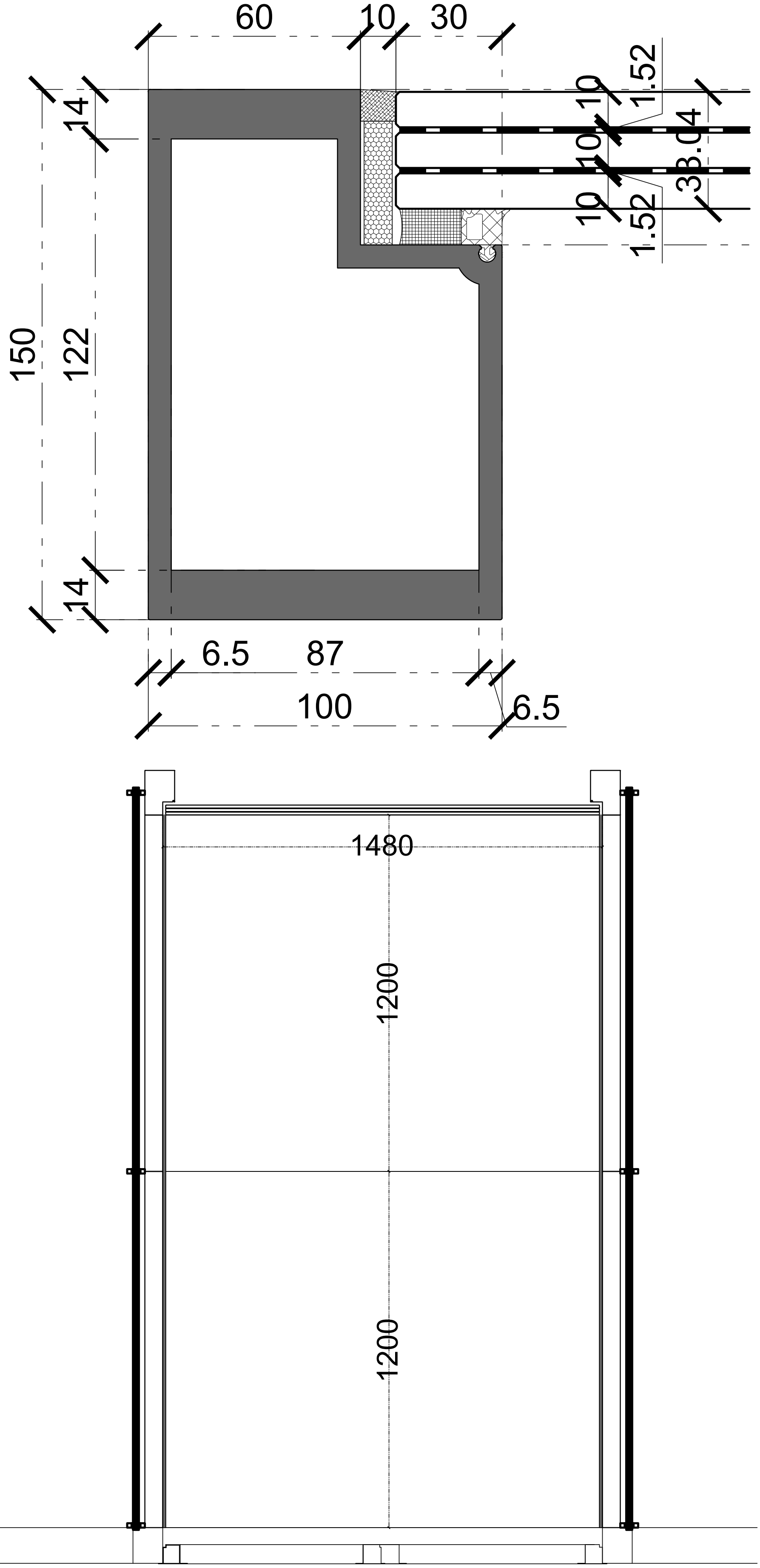


Figure 5.9.24 Winch construction (own figure)

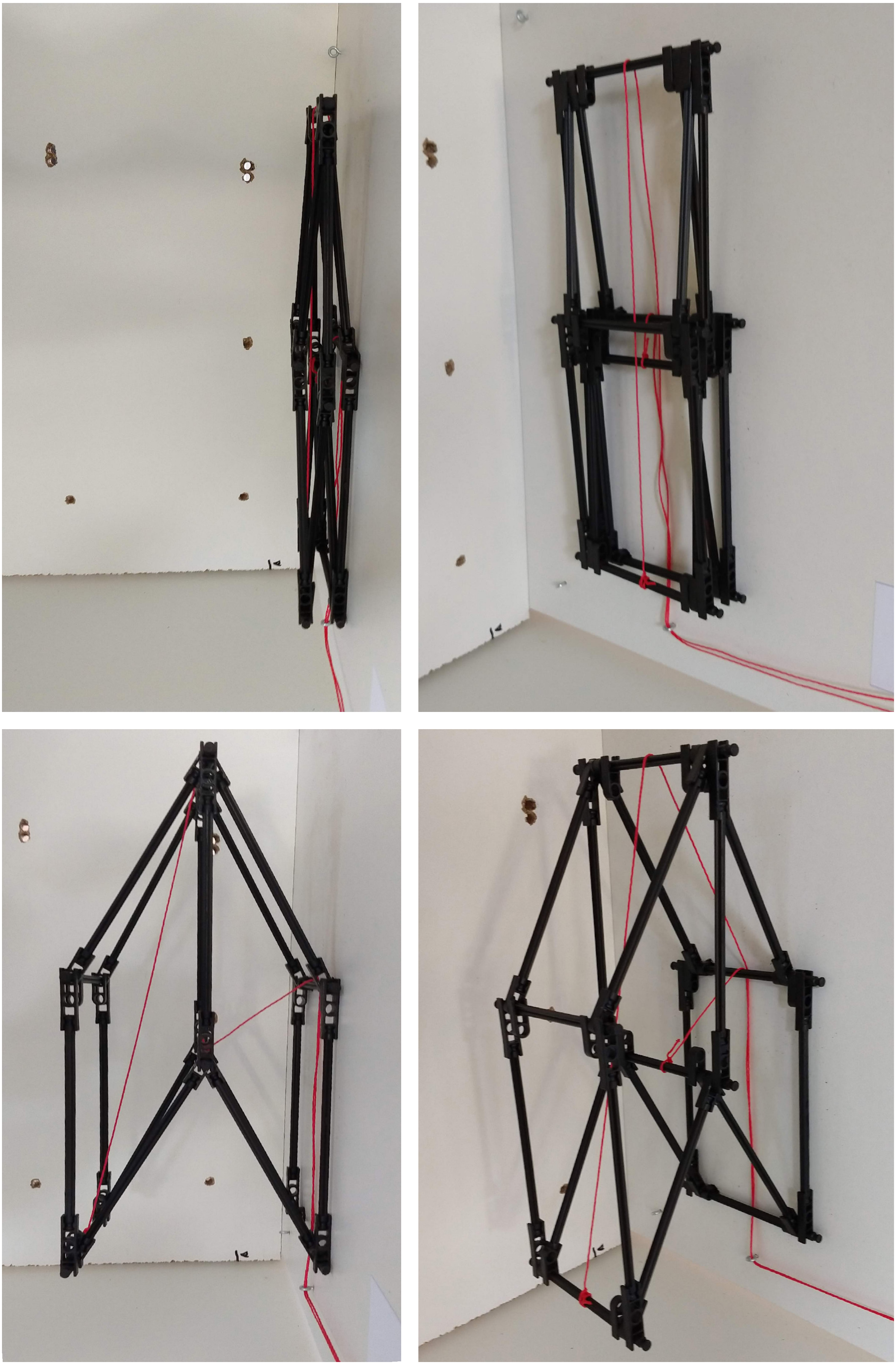


Figure 5.9.25 Winch construction (own figure)

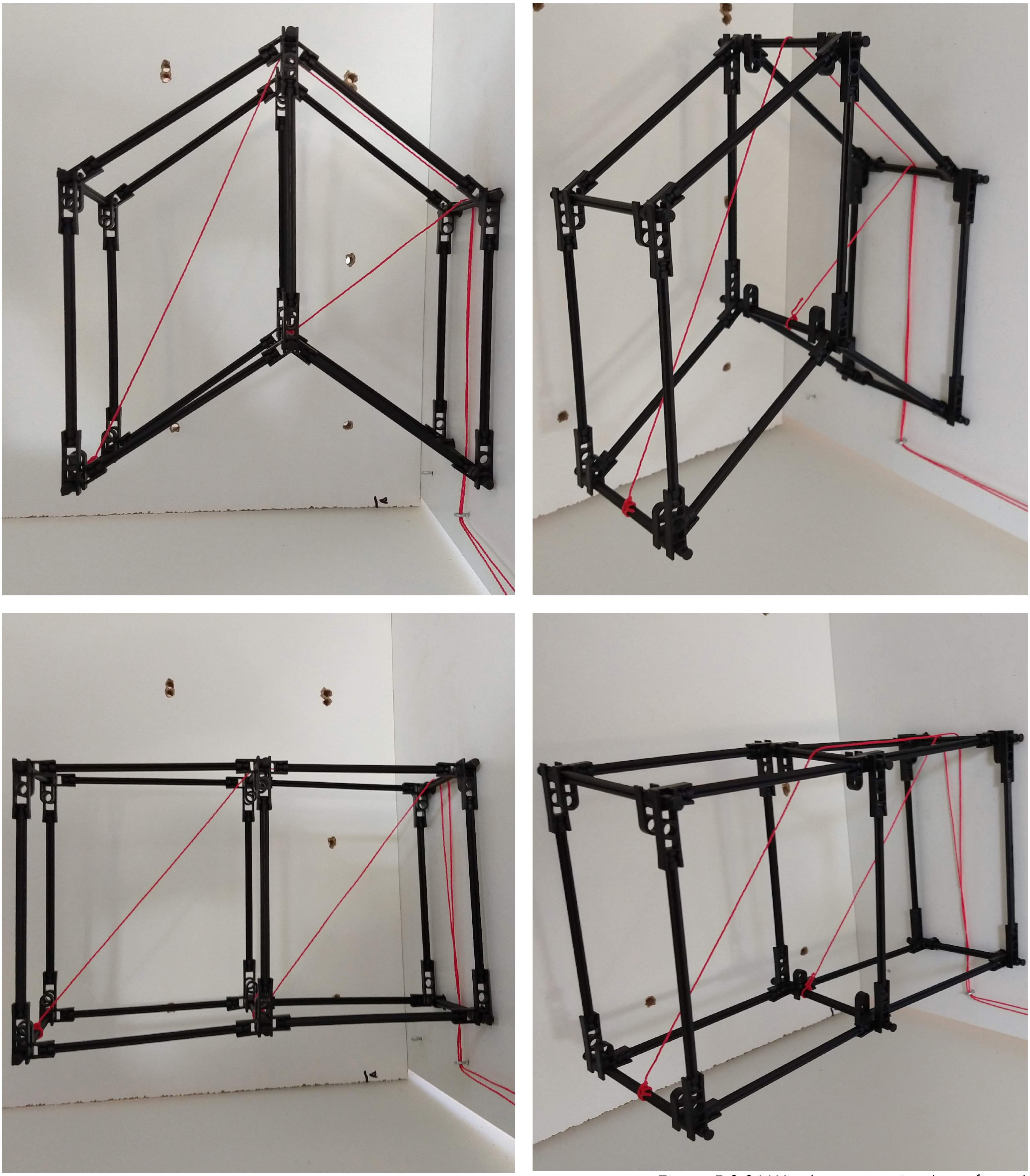
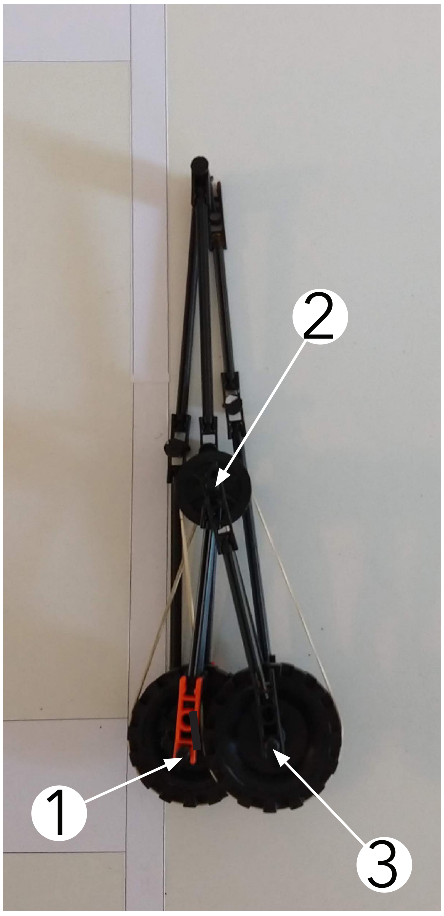


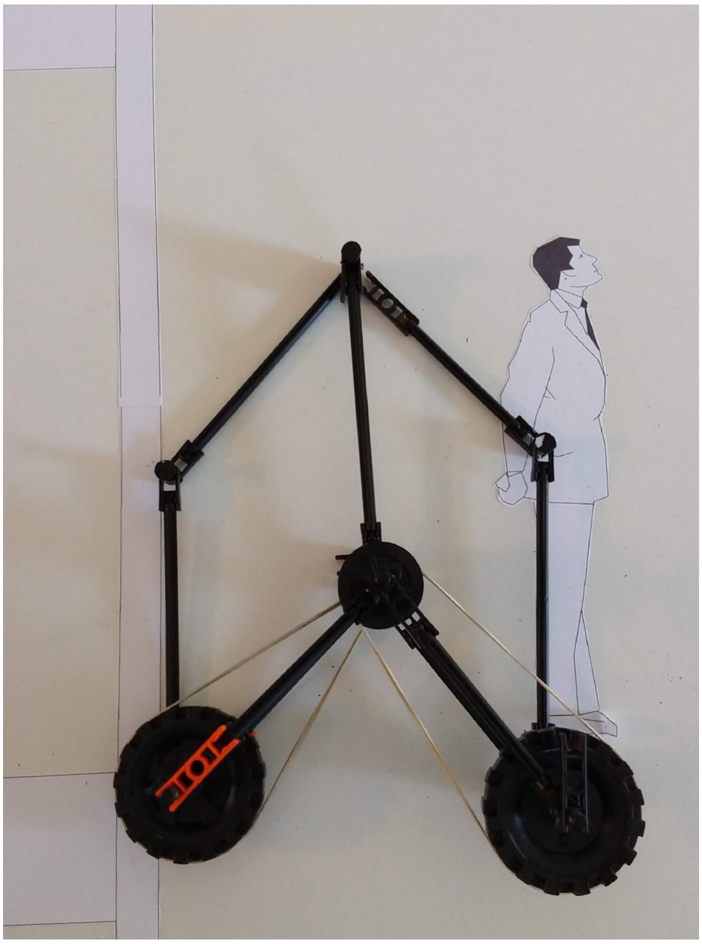
Figure 5.9.26 Winch construction (own figure)

CHAIN AND SPROCKET

The Chain and sprocket construction works. This model is built to show the principle of the construction. Rod 1 is the drive shaft. It rotates 90 degrees clockwise. This pulls the chain (rubber band) which in turn rotates rod 2. This rotates 180 degrees counter clockwise. This reaction continues to rod 3 which rotates 90 degrees clockwise. The sprocket ratio is 2:1:2. The side balustrade is also included in the model. The balustrade works the same way as with the winch system. Meaning that the movement of the construction also moves the balustrade into place.

The detail and the top view does shows how the concept looks. The base profile has an aluminium cap connected to it, this hides the steel chain. At the hinge points of the balcony there are tooth sprockets attached. These sprockets will be visible when people look over the balustrade. The chain used on this system has to be regularly oiled and inspected. Also chains stretch overtime, so regularly maintenance is essential.





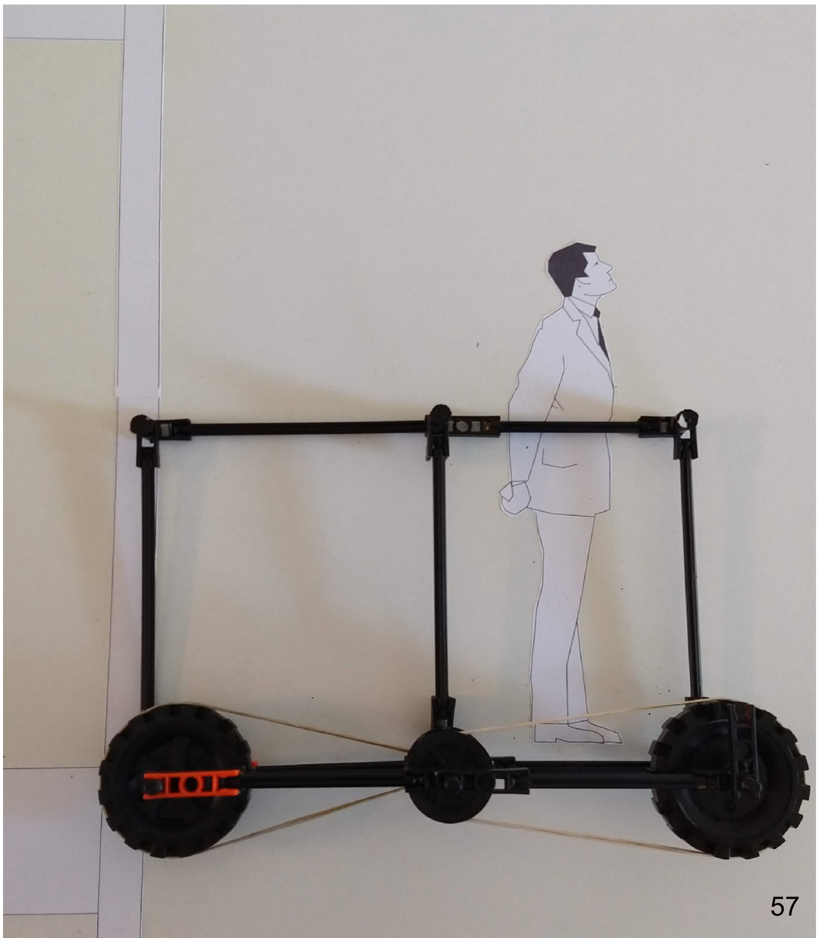


Figure 5.9.27 chain and sprocket (own figure)

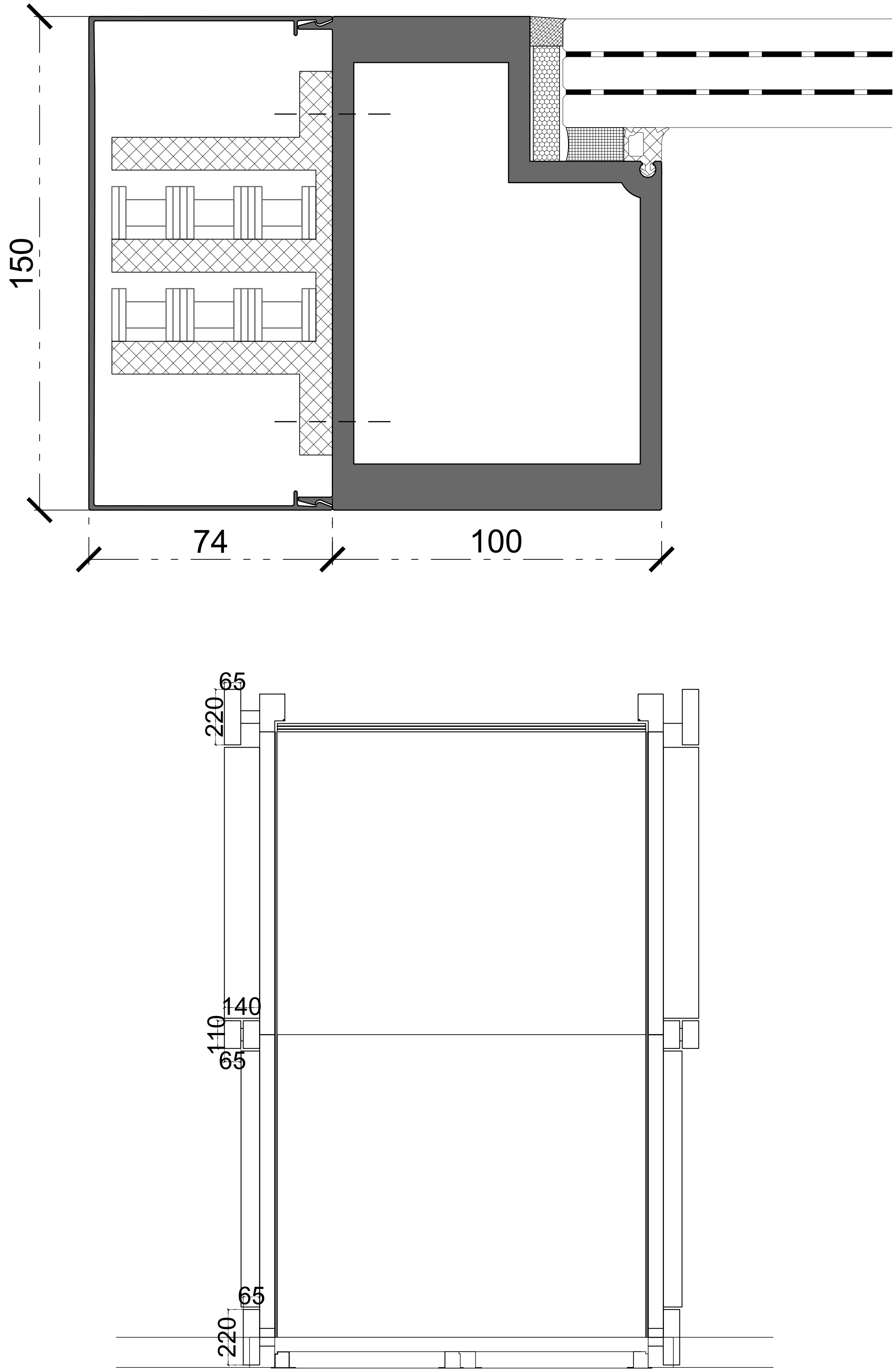
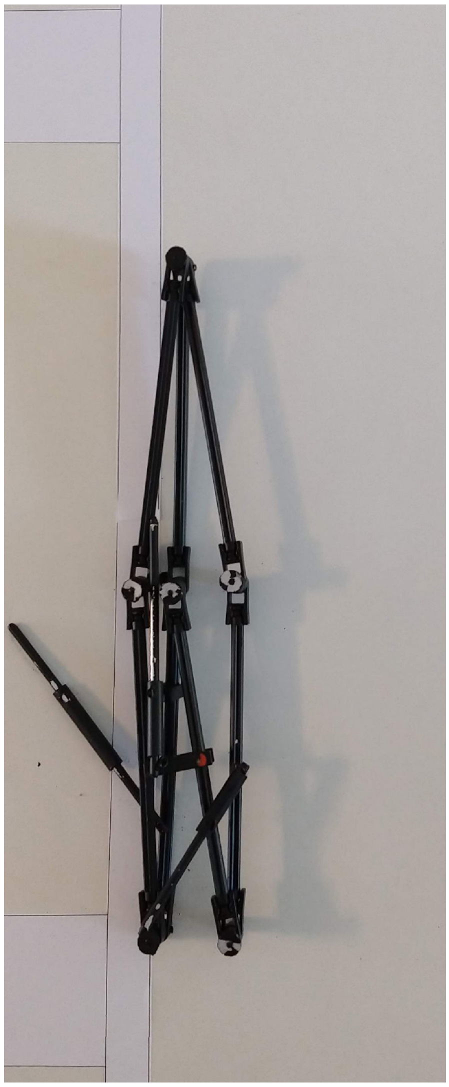


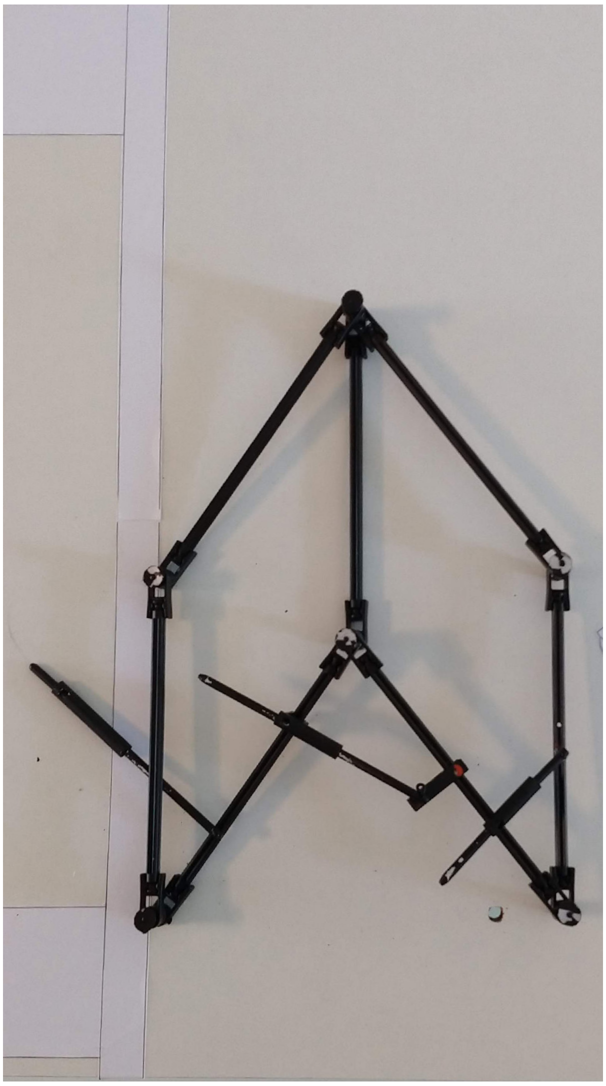
Figure 5.9.28 chain and sprocket (own figure)

HYDRAULIC CYLINDERS

Three hydraulic cylinders are needed on each side of the balcony. The first two cylinders lower the balcony. The second two cylinders ensure that the floor elements fold out. And the last two cylinders hold the glass balustrade vertical. Just as with the previous construction concepts the balustrade is integrated in the design. Meaning that the movement of the construction also moves the balustrade into place.

On the drawing the sizes of the cylinders are visible. The base profile has an aluminium cap clipped on. This gives space for the hydraulic lines. These lines are essential to operate the hydraulic cylinders. But as seen in the top view, the cylinders are quite big. Hydraulic cylinders have the benefit that they do not move, when no hydraulic oil is pumped into the cylinders. meaning that the oil pomp only has to be activated when the balcony needs to fold in or out. The hydraulic cylinders are very large and have flexible lines running to them. This gives the balcony more of an industrial look.





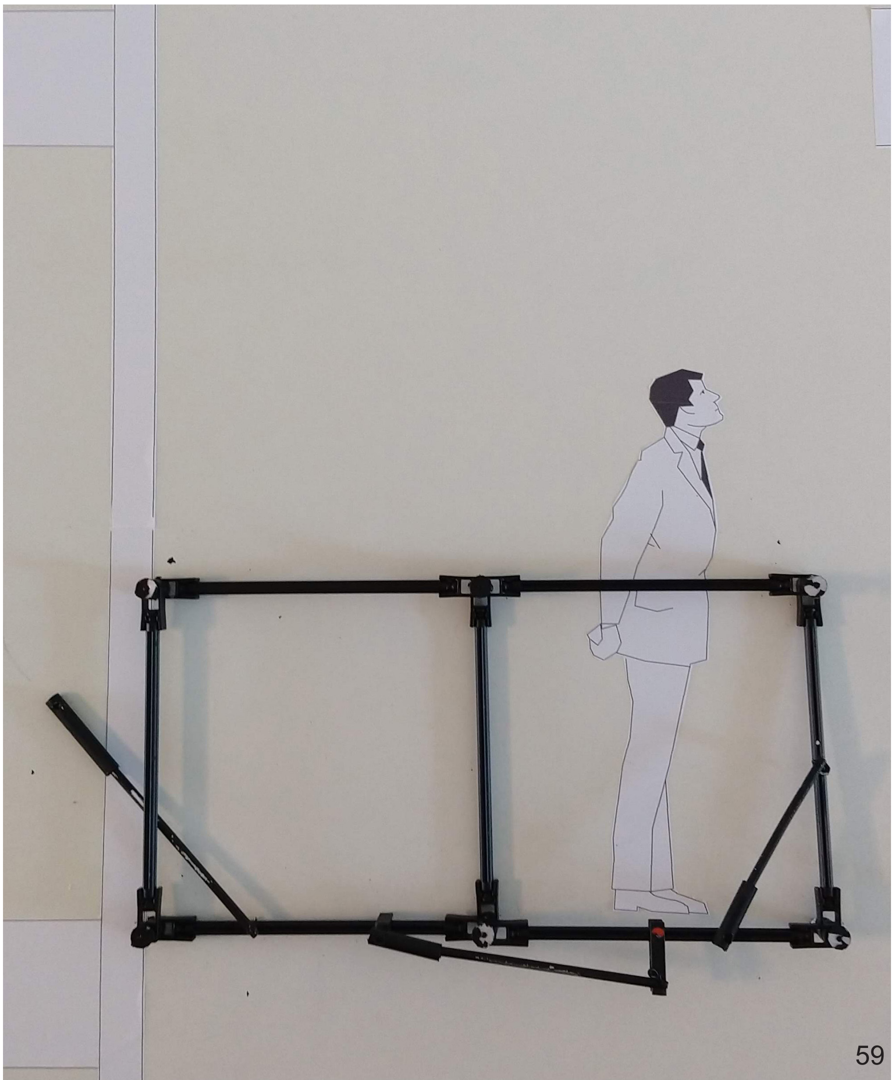


Figure 5.9.29 Hydraulic cylinders (own figure)

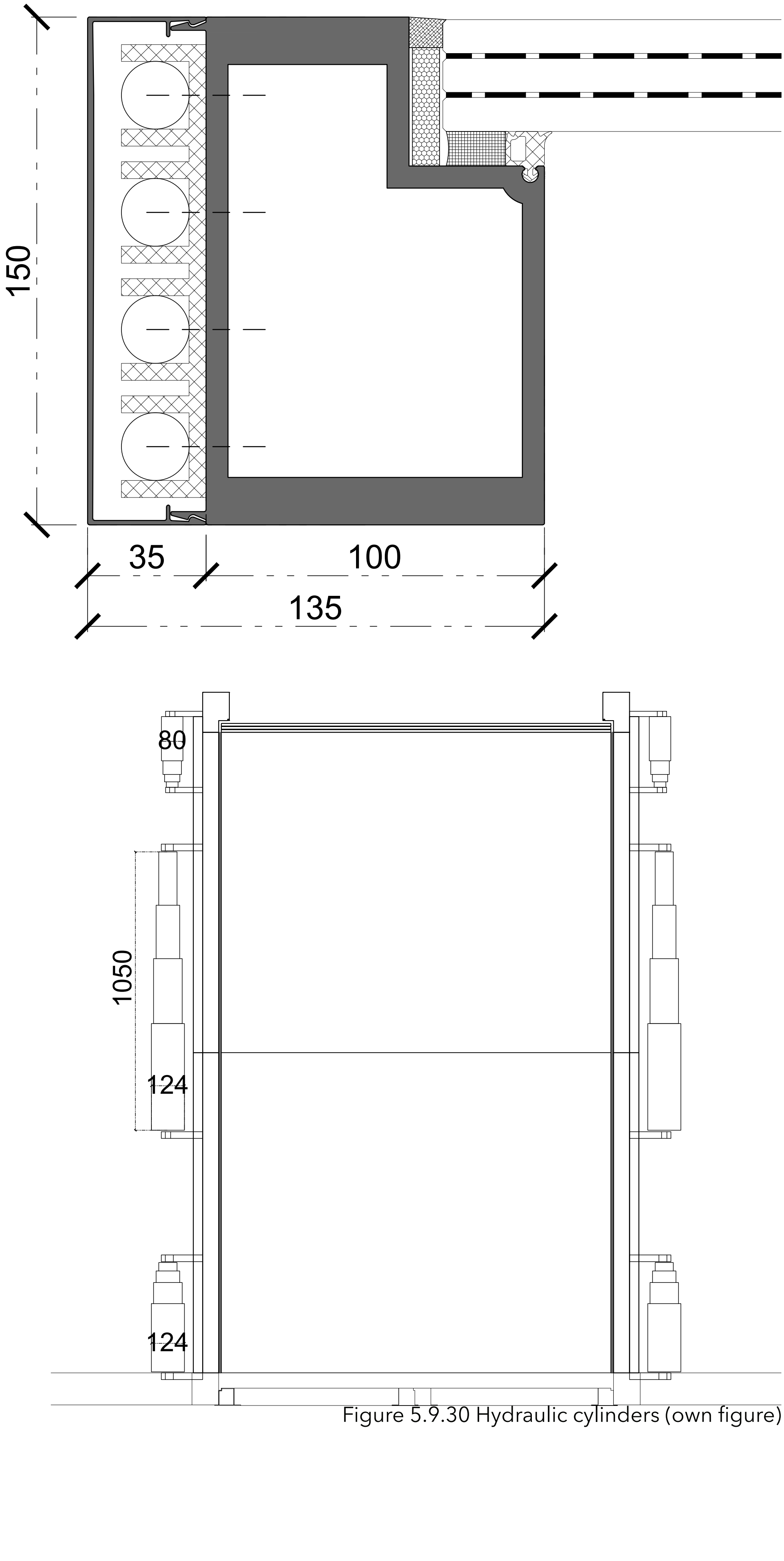
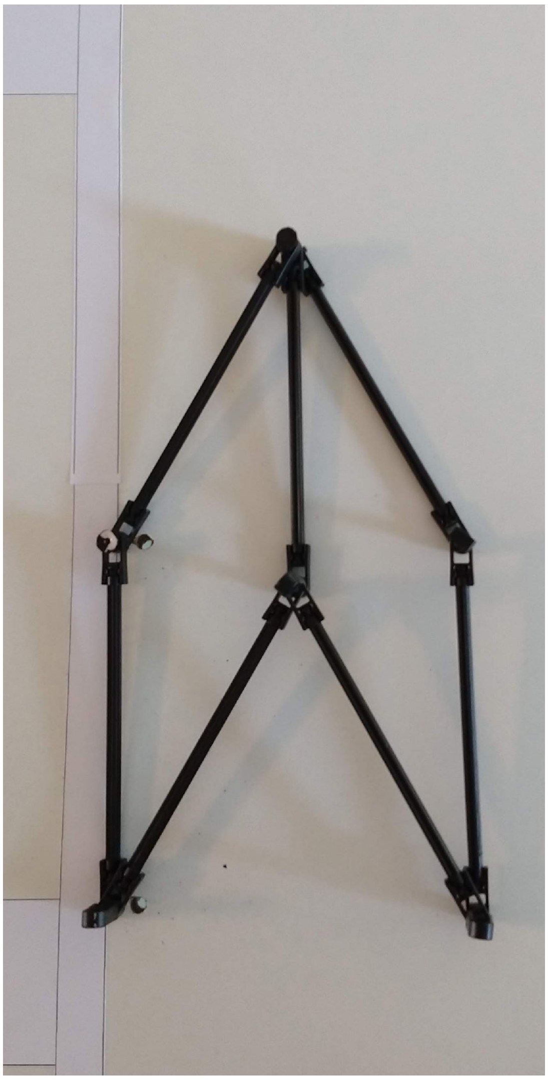


Figure 5.9.30 Hydraulic cylinders (own figure)

HYDRAULIC ROTARY ACTUATOR

The last construction concept is the hydraulic rotary actuator. Just as the concept with the hydraulic cylinders the concept consist out of three actuators per side of the balcony. Controlling the movement of the balcony, the folding of the floor elements and the positions of the glass balustrade. And again the balustrade is integrated in the design.

The sections of the profile is the same at the previously concept. An extra aluminium cap to hide the hydraulic lines. The difference is the size of the hydraulic elements. When looking at the top view the size difference is clearly noticeable. Only at the hinges relative small actuators are placed. These are powered by the hydraulic fluid. And control the movement.



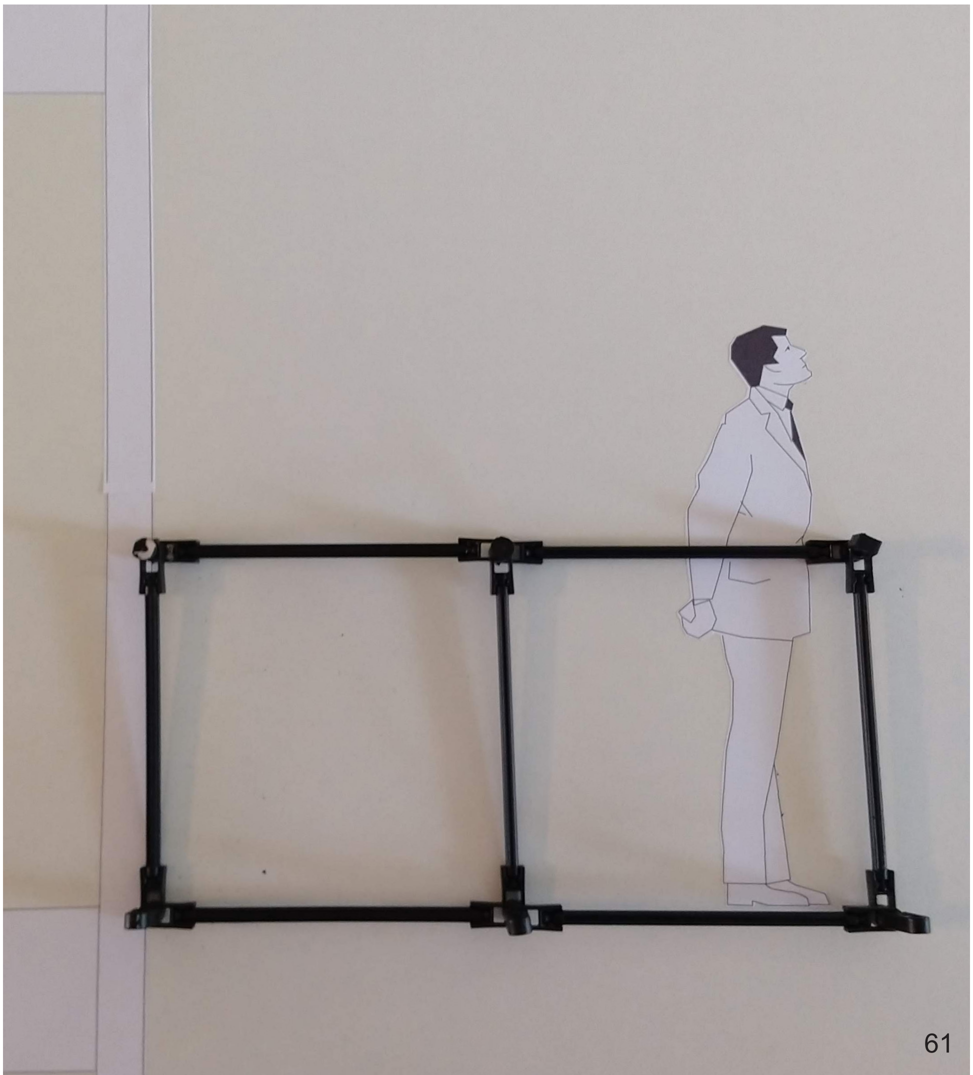


Figure 5.9.31 Hydraulic rotary actuator (own figure)

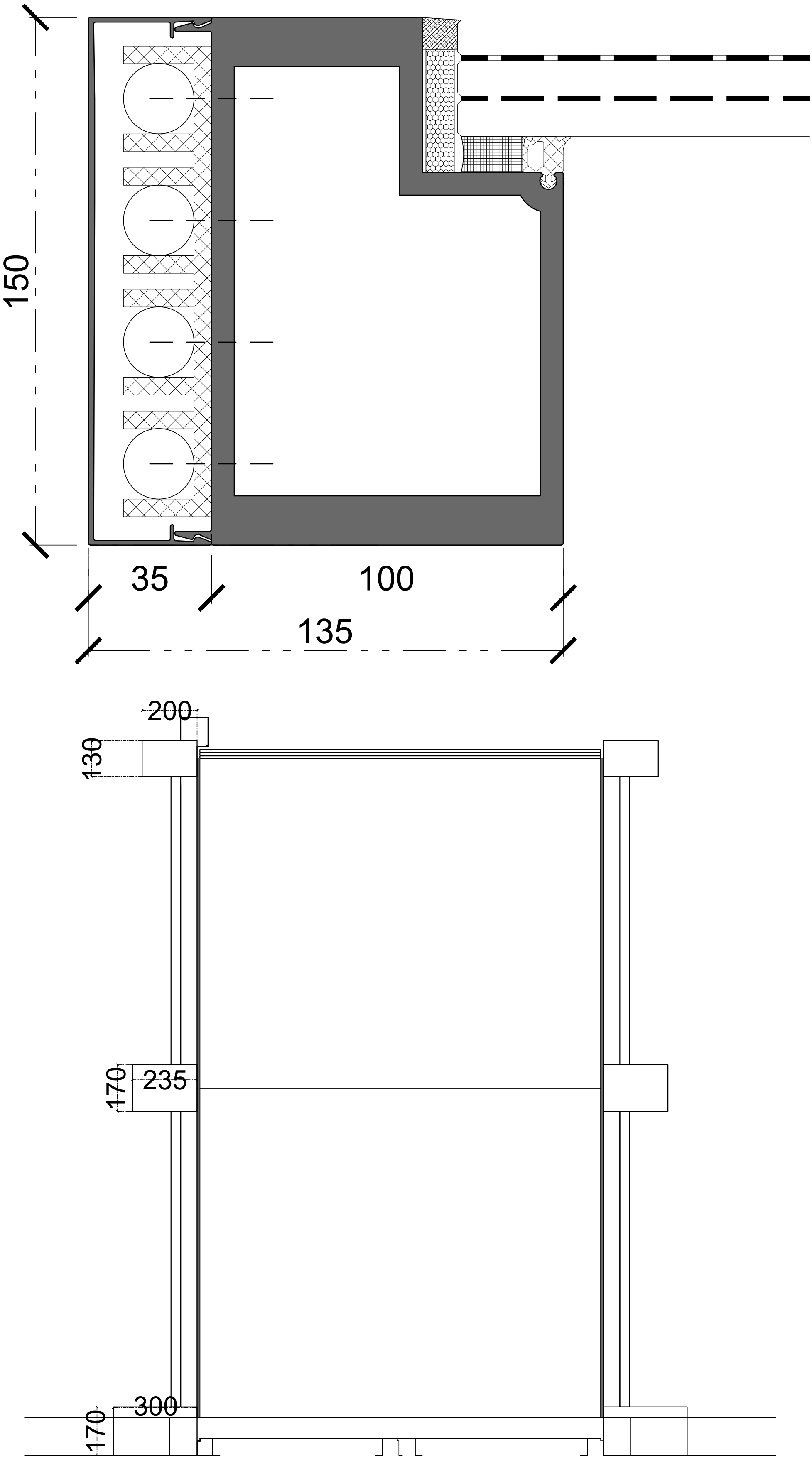


Figure 5.9.32 Hydraulic rotary actuator (own figure)

COMPARISON

Costs also play a major role in the choice for the construction. Financially the balcony needs to be feasible. A estimation has been made in how much the different construction systems would cost to produce. Each construction system consist out of a lot of different components. The hinge system consist out of steel cables, electric motor, pulleys, cable tensioners, drum to roll up cable etc. The total cost of the different systems are:

Winch	€ 2.000,-
Chain And Sprocket	€ 4.400,-
Hydraulic Cylinders	€ 4.500,-
Hydraulic rotary actuator	€ 32.200,-

Construction Winch						
Part		Cost	Unit	Amount		Total
Steel cable	€	20,00	€/m	20	€	400,0
Electric motor	€	1.000,00	€/pcs	1	€	1.000,0
unforeseen costs	€	600,00	€/pcs	1	€	600,0
Total					€	2.000,0

Construction Chain & Sprocket						
Part		Cost	Unit	Amount		Total
Sprocket	€	150,00	€/m	8	€	1.200,0
Chain	€	100,00	€/m	5	€	500,0
Electic motor	€	200,00	€/pcs	1	€	200,0
engine reduction	€	2.000,00	€/pcs	1	€	2.000,0
Duplex RVS axle	€	250,00	€/pcs	2	€	500,0
Total					€	4.400,0

Telescopic hydraulic cylinders						
Part		Cost	Unit	Amount		Total
Telescopic hydraulic cylinders	€	550,00	€/pcs	6	€	3.300,0
Hydraulic pump	€	800,00	€/pcs	1	€	800,0
Hydraulic lines	€	20,00	€/m	20	€	400,0
Total					€	4.500,0

Hydraulic rotary actuators						
Part		Cost	Unit	Amount		Total
Hydraulic rotary actuators 10.700Nm	€	7.000,00	€/pcs	2	€	14.000,0
Hydraulic rotary actuators 4.700Nm	€	5.000,00	€/pcs	2	€	10.000,0
Hydraulic rotary actuators 1.9200Nm	€	3.500,00	€/pcs	2	€	7.000,0
Hydraulic pump	€	800,00	€/pcs	1	€	800,0
Hydraulic lines	€	20,00	€/m	20	€	400,0
Total					€	32.200,0

Figure 5.9.33 Cost calculation (own figure)

The winch is the cheapest construction method with a huge margin. A second point to consider is the fail safe and override potential. The winch and the chain and sprocket method can use a hand crank to override the electric motor. This way the balcony can be controlled even when a power outage occurs. If a hydraulic line breaks the balcony is stuck in that position. It does not have a manual override.. Every concept has to be strong enough that even when one half fails the other side can temporally support the balcony as lang as it takes for all the people to clear the balcony.

Taking all the different aspects into consideration the best construction method is the winch concept. The main reason is that this concepts has the least amount of movable parts, is the smallest construction, the cheapest to produce and has a manual override from within the building.

COST TOTAL BALCONY

Before the design is further developed a cost indication is important to see if the balcony can be feasible. Just as with the construction the costs have been broken down to individual components. The cost of each component is a rough indication that Scheldebouw uses when designing an element. Off course prices can change when the actual components will be ordered. Man hours are also included in the total cost price.

The total cost of the balcony with the hinge construction is €9300. This makes it just a little bit more expensive as the already available permanent balconies Scheldebouw uses. This may result in an economic feasible concept.

Total balcony						
Part	Cost		Unit	Amount	Total	
Control Panel	€	600,00	€/pcs	1	€	600,00
fall-through protection	€	300,00	€/pcs	1	€	300,00
Glass 3layes (floor)	€	420,00	€/m2	3,6	€	1.512,00
Glass 2 layers (baluster)	€	240,00	€/m2	1,8	€	432,00
Aluminium profile	€	5,40	€/kg	82,5	€	445,50
Hinge points	€	180,00	€/ps	6	€	1.080,00
foldable baluster	€	5,40	€/kg	132,5	€	715,50
Rubber strip	€	2,40	€/m	6	€	14,40
aluminium u profile	€	12,00	€/ps	1	€	12,00
man hours	€	60,00	€/ps	16	€	960,00
reinforced t bracket	€	600,00	€/ps	1	€	600,00
manual override	€	600,00	€/ps	1	€	600,00
Construction Winch	€	2.000,00	€/ps	1	€	2.000,00
Total					€	9.271,40

Figure 5.9.34 Cost calculation (own figure)

CONCEPT

With this price indication the final concept can be designed.
The first element is the aluminium extrusion of the beams. This extrusion also houses the hinges. The extrusion is designed in such a way that the hinge which slides into the profile always has the bold holes at the same height. The hinge element is the same for the above and below configuration.

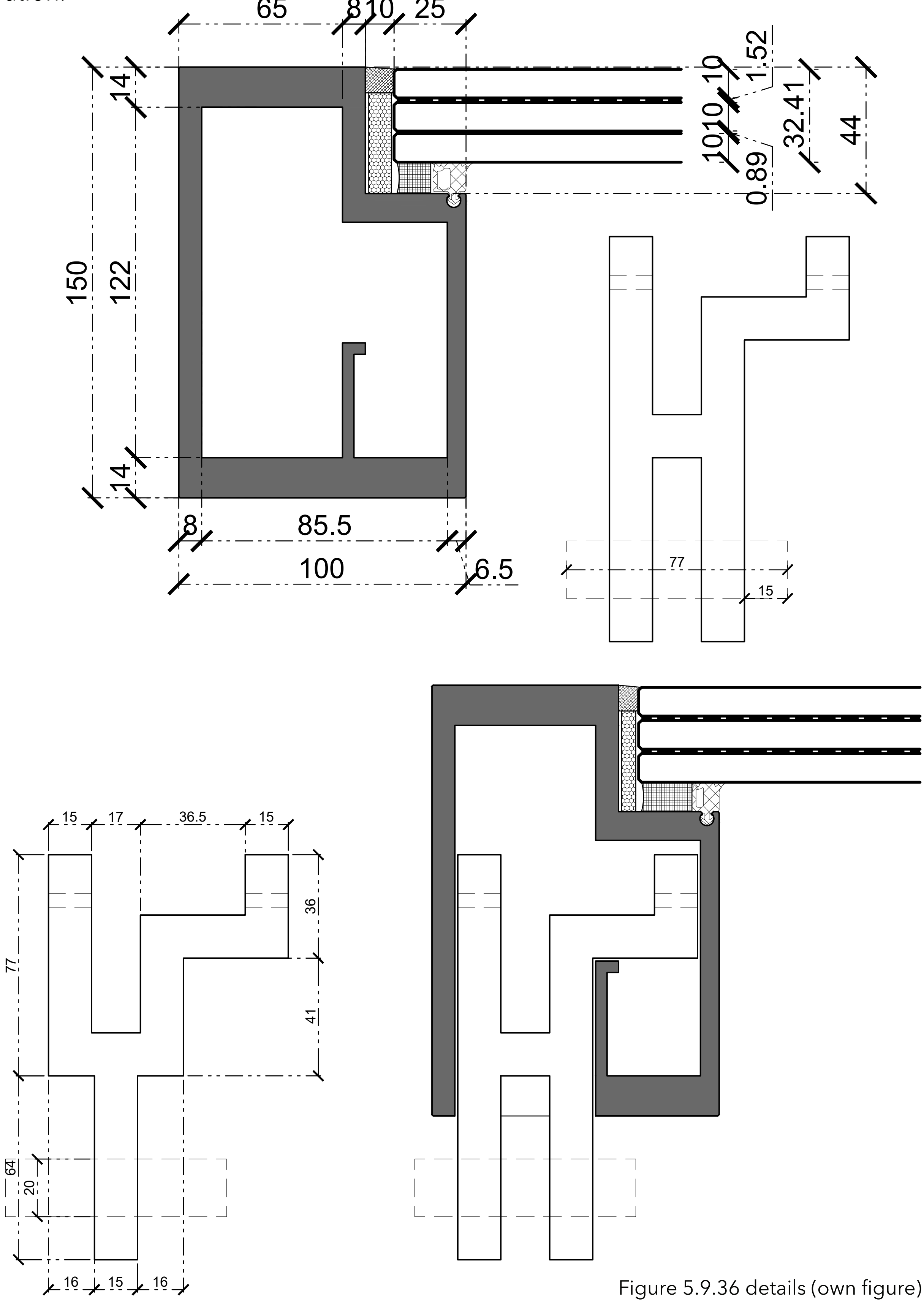


Figure 5.9.36 details (own figure)

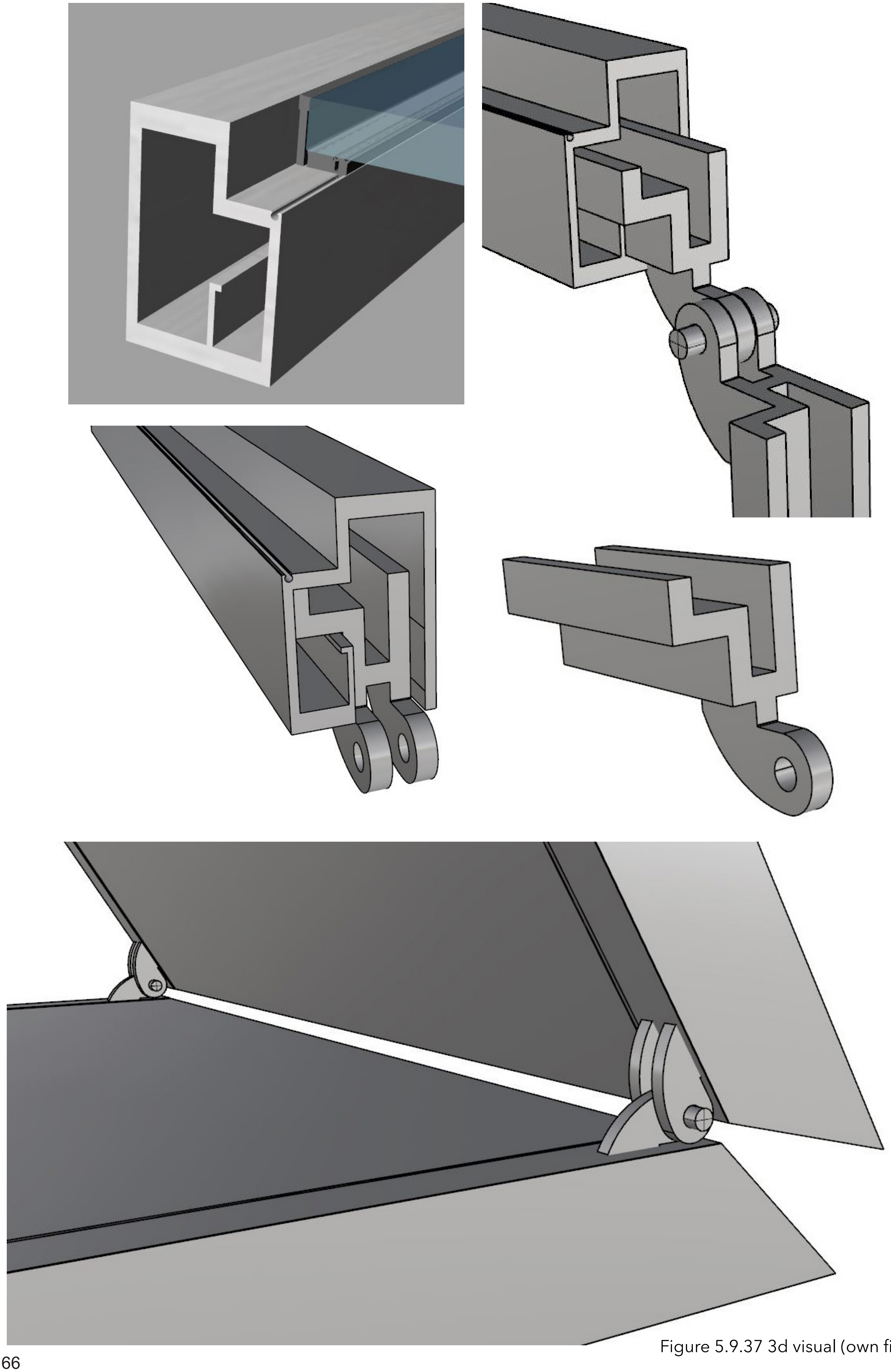
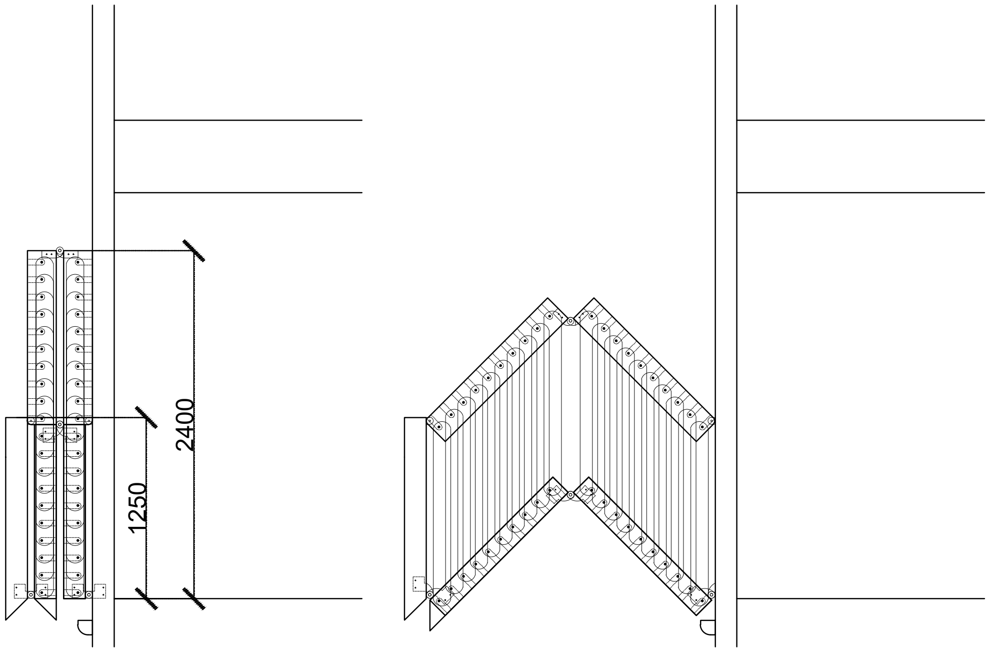


Figure 5.9.37 3d visual (own figure)

The second major design part is the side balustrade. The balustrade folds the same way as the main construction of the balcony. So the balustrade does need to fold. A concept was developed for individual aluminium sheets that slide in front of each other when the balcony is in the upright position. When coming down the elements slide next to each other.

To mount this balustrade to the main beam a U shape extrusion is designed. It consist out of 4 elements. The outer U shape. A long aluminium plate with groves in it. These groves are guide lines for U shaped brackets that connect the aluminium sheets, and allow the sheets to hinge. The balustrade has a sleek design, meaning that there are very little fasteners visible.



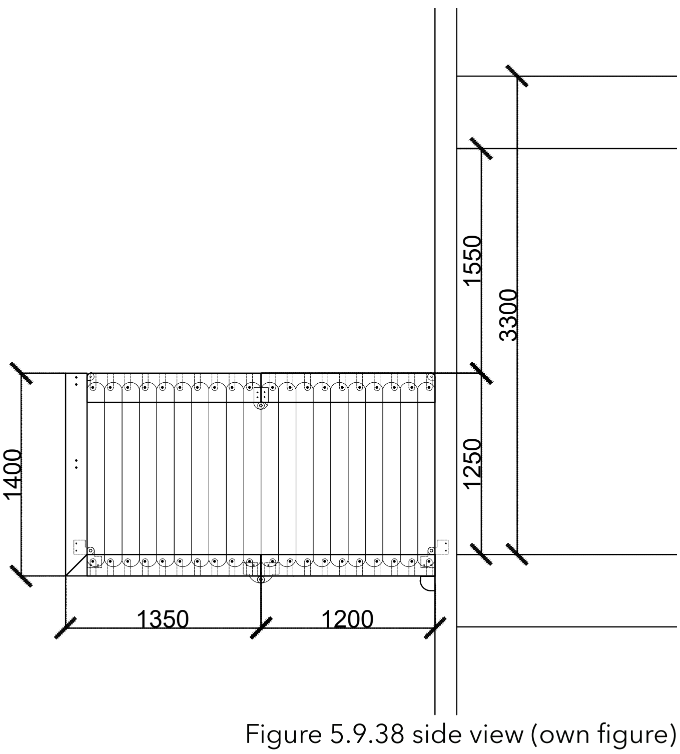


Figure 5.9.38 side view (own figure)

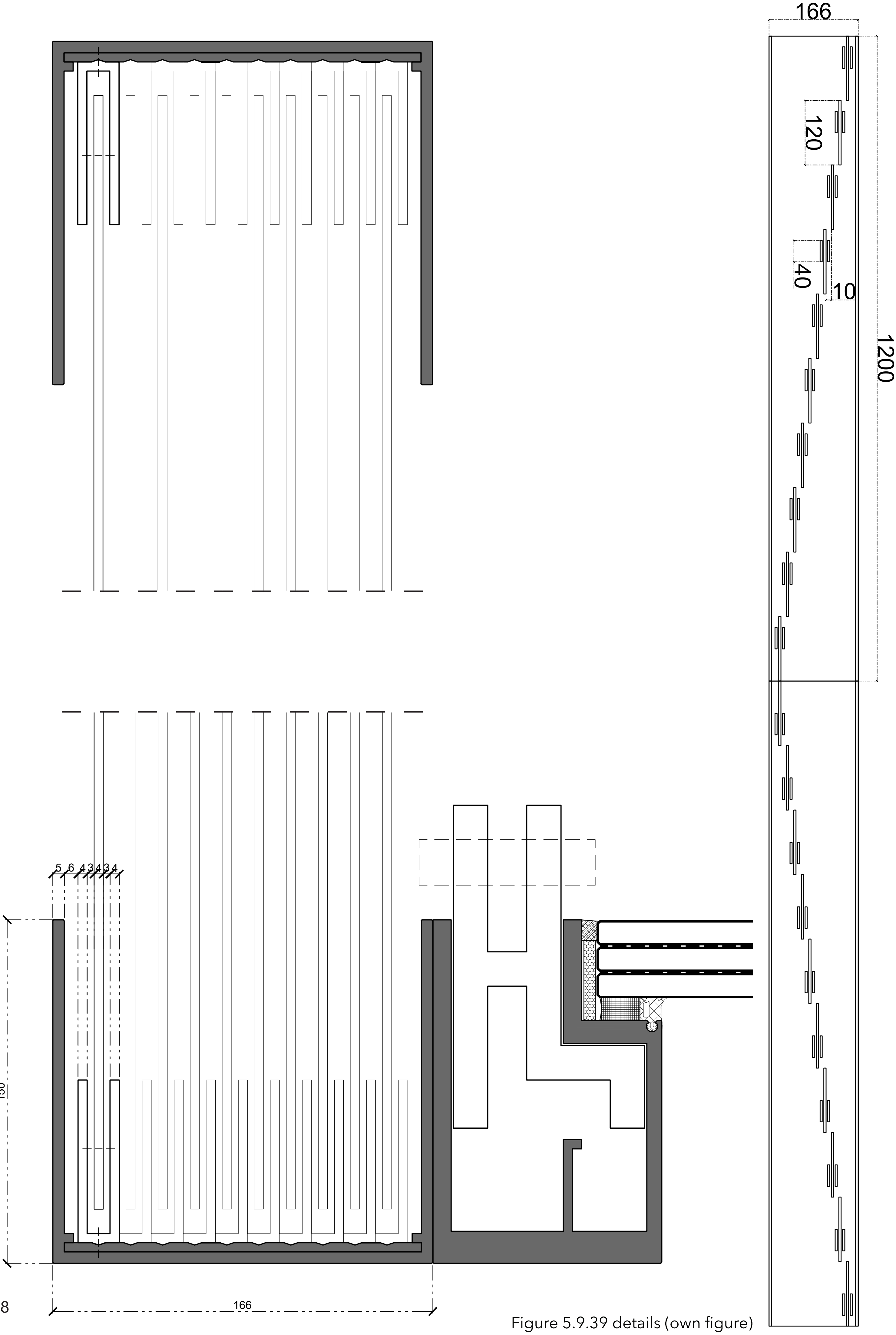


Figure 5.9.39 details (own figure)

To mount this balustrade to the main beam a U-shape extrusion is designed. It consist out of four elements. The outer U-shape aluminium extrusion (1), a long aluminium plate with groves in it (2), small U-shape aluminium brackets with ridges (3) that slot into the aluminium plate (2) and the aluminium sheets (4). These groves are guide lines for U-shaped brackets that connect the aluminium sheets, and allow the sheets to hinge. This balustrade is designed so that there are the least amount of fastening elements visible.
The hinges in the balustrade hinge parallel to the hinges of the floor. This prevents any internal forces from happening during the folding procedure. It is important that the hinges are parallel to each other and that the distance between the bottom and upper hinges is the same. The positioning of the hinges in the balustrade ensures that when the balcony is folded out the railing on top of the balustrade is flat. The only way to do this is to lower the middle hinge below the railing.

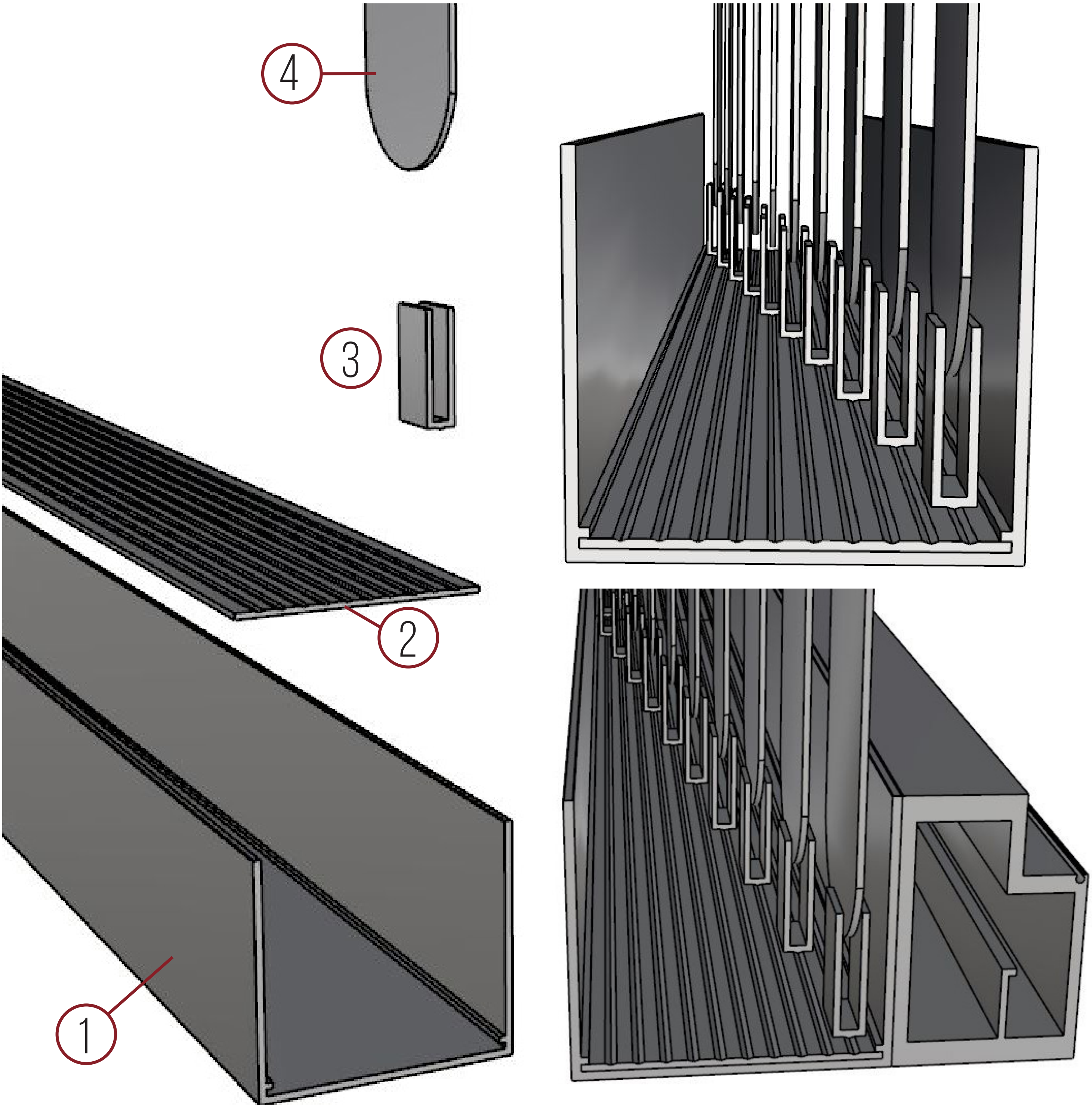


Figure 5.9.40 3d visual (own figure)

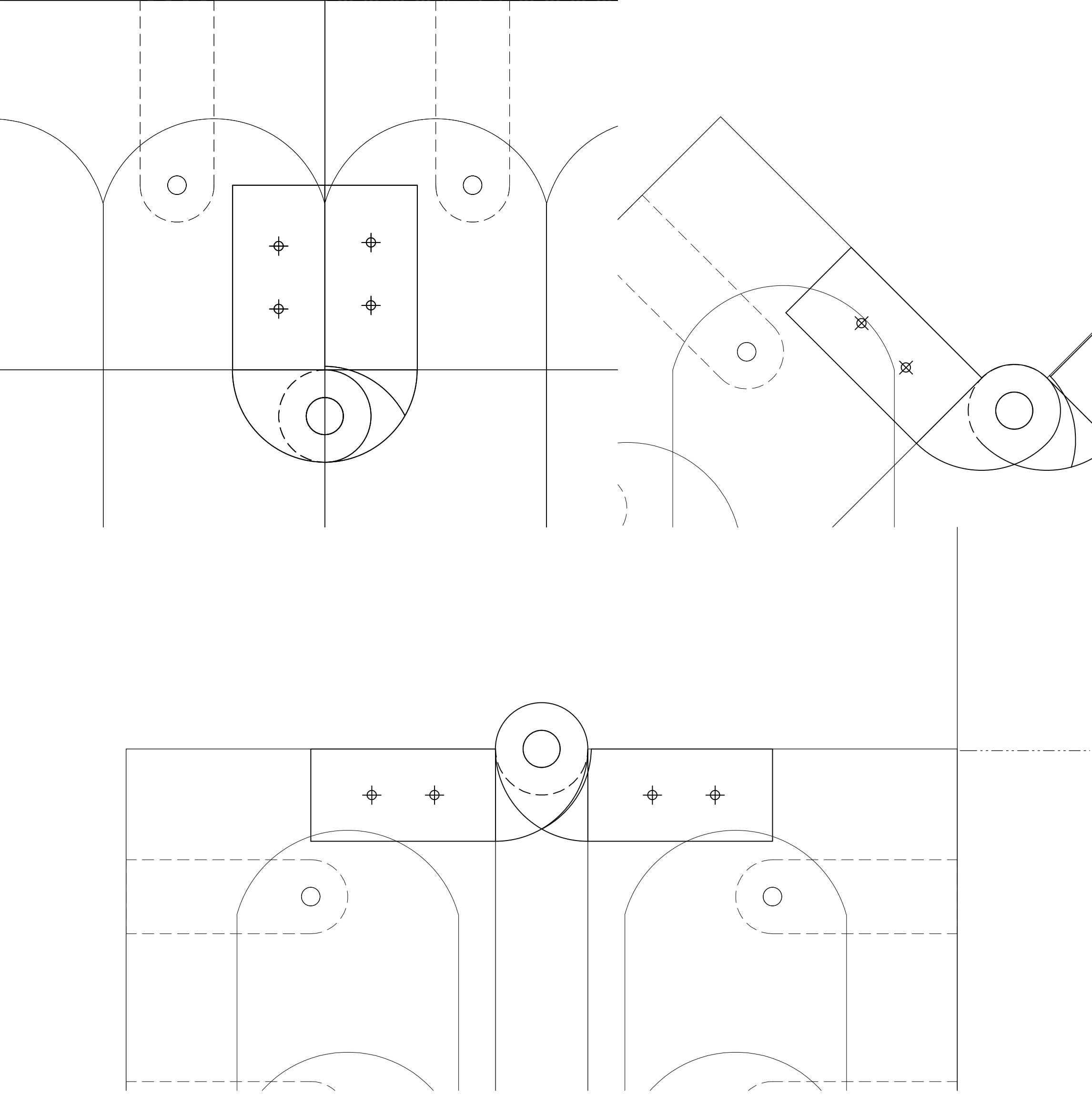


Figure 5.9.41 details (own figure)

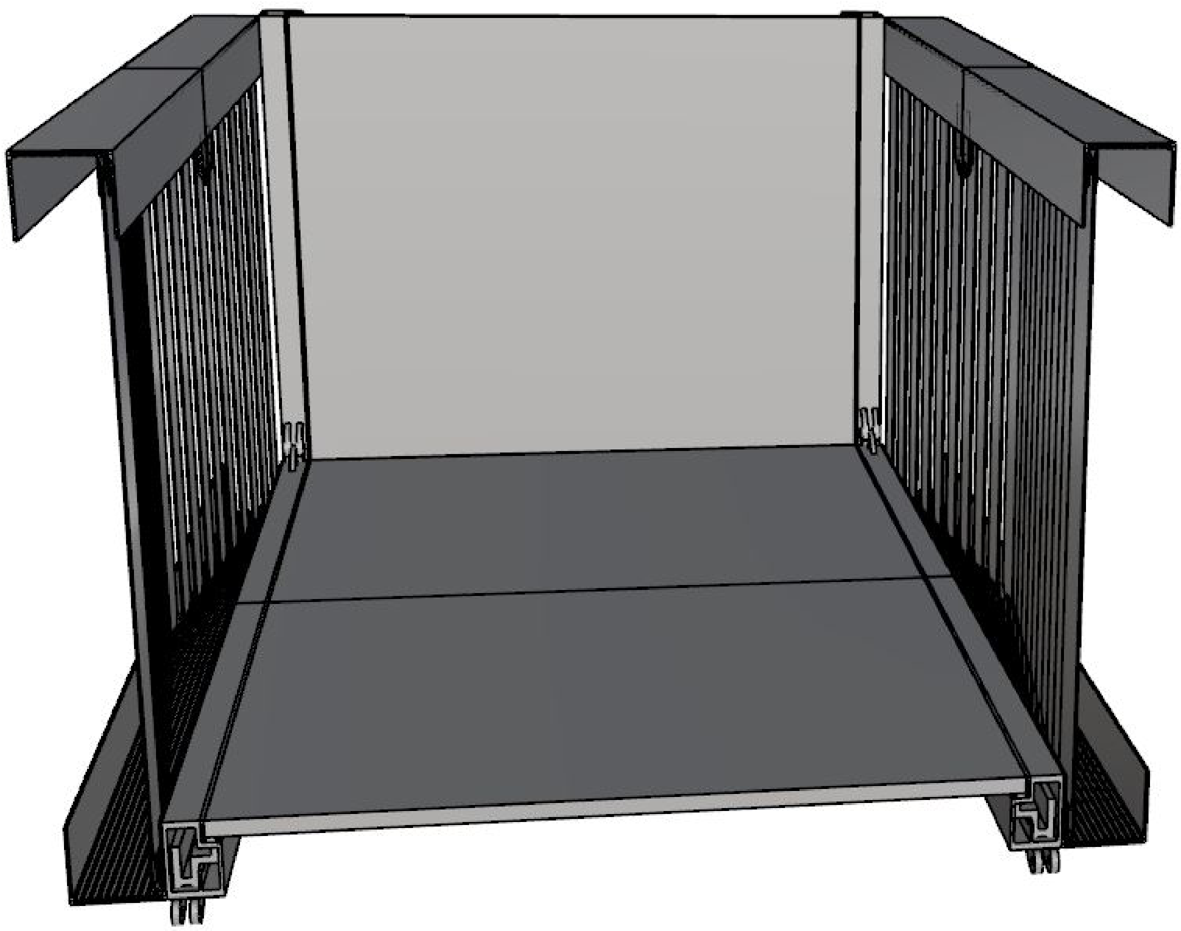


Figure 5.9.42 3d visual (own figure)

The building sequence is inspired by the Scheldebouw type 3 balcony system. In this system a large t bracket is used to install the balcony in one piece. The winch balcony is situated in front of the façade. Meaning that the best way to install this balcony on site is to make one large element. Combining the Winch and façade into one single element. A typical unitized façade element consist out of a spandrel and glass/wall element, the joint of separate elements at floor level. The element spans from floor to floor.
The winch system is different. It also consist out of a spandrel and glass element, but the joint is at ceiling level. Meaning that instead of the spandrel above the glass, the spandrel below the floor is incorporated into a single element. This element spans form ceiling to ceiling.

The reason for this is that because the extra weight of the Winch, requires a heavier T bracket at floor level. There is also room needed to hide the electric motor and the drum to roll up the cable. The motor and drum can be hidden in the spandrel below the floor. The spandrel also hides the bigger T bracket. The other benefit of this division is that the element can be installed as one piece on the building site. Only a power connection has to be made. The whole control panel, manual override and installation of the Winch can take place in the controlled environment of the factory. Fitted to the façade element, and transported as one element to the building site.

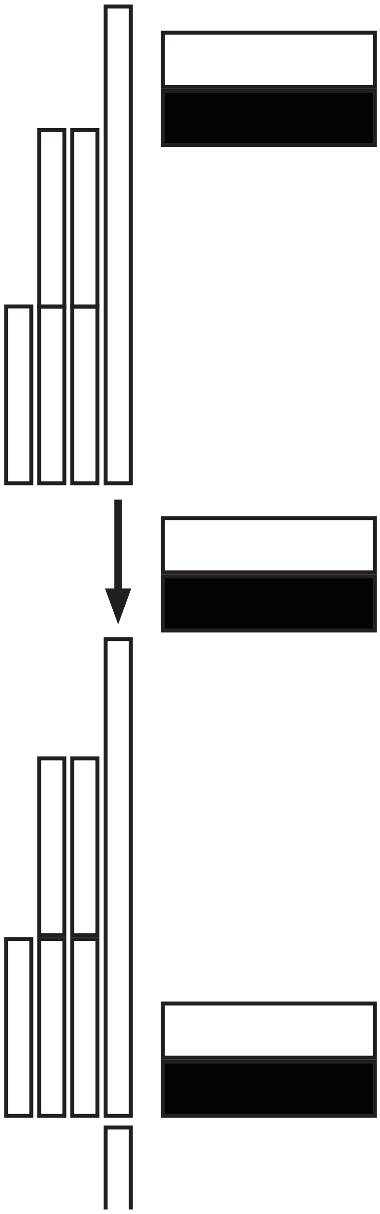


Figure 5.9.43 large Bracket (Scheldebouw, 2019)

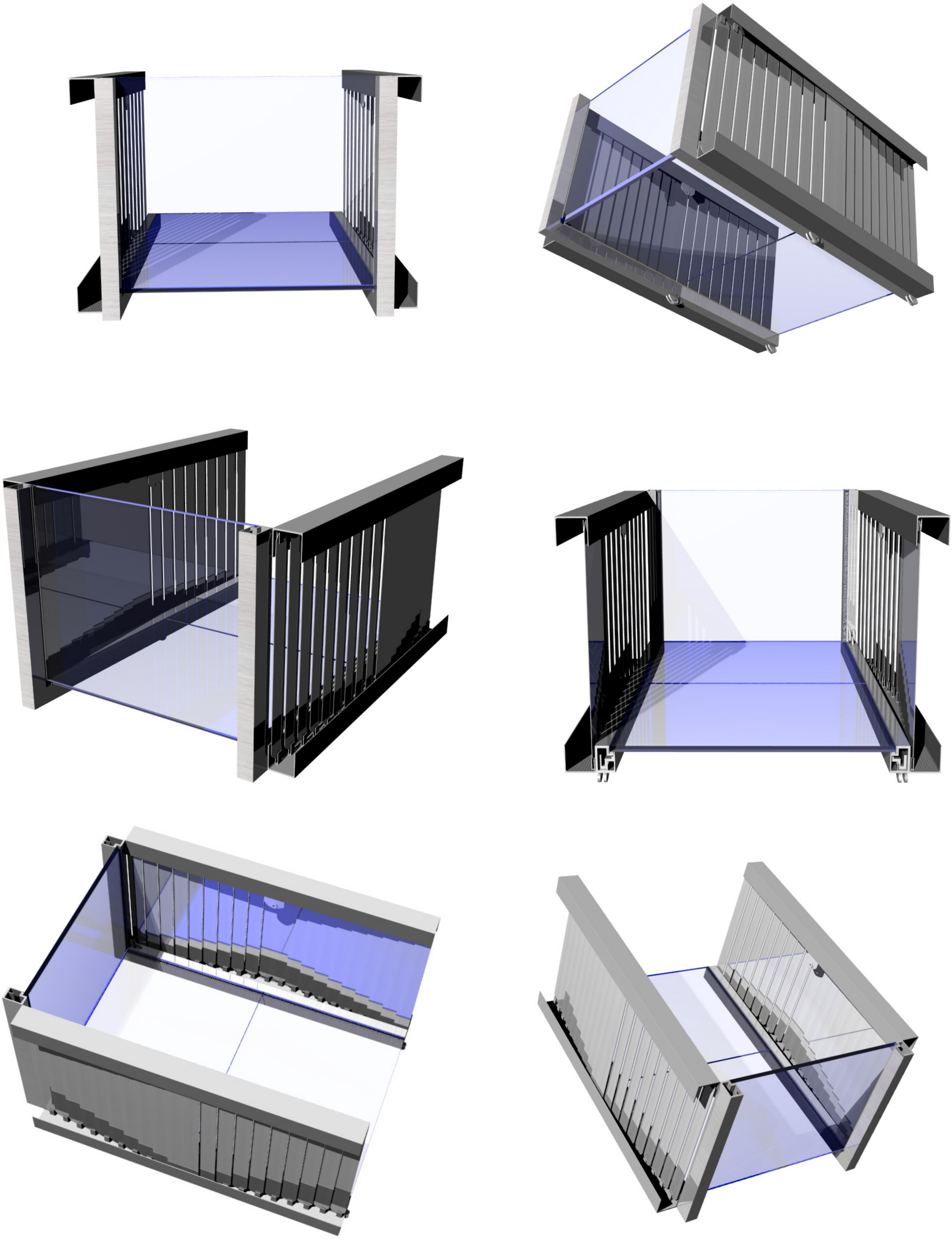


Figure 5.9.44A 3d visual (own figure)

GLASS OPTIONS

The final glass composition has different options to choice from. Different colors can give different aesthetics. The second option is to include a pattern. This pattern can be integrated in the glass, but also added on top of the glass. When added on top the pattern can also functions as a anti slip material. There are a lot more options available than shown in the images below, these are just a sample of the potential possibilities.

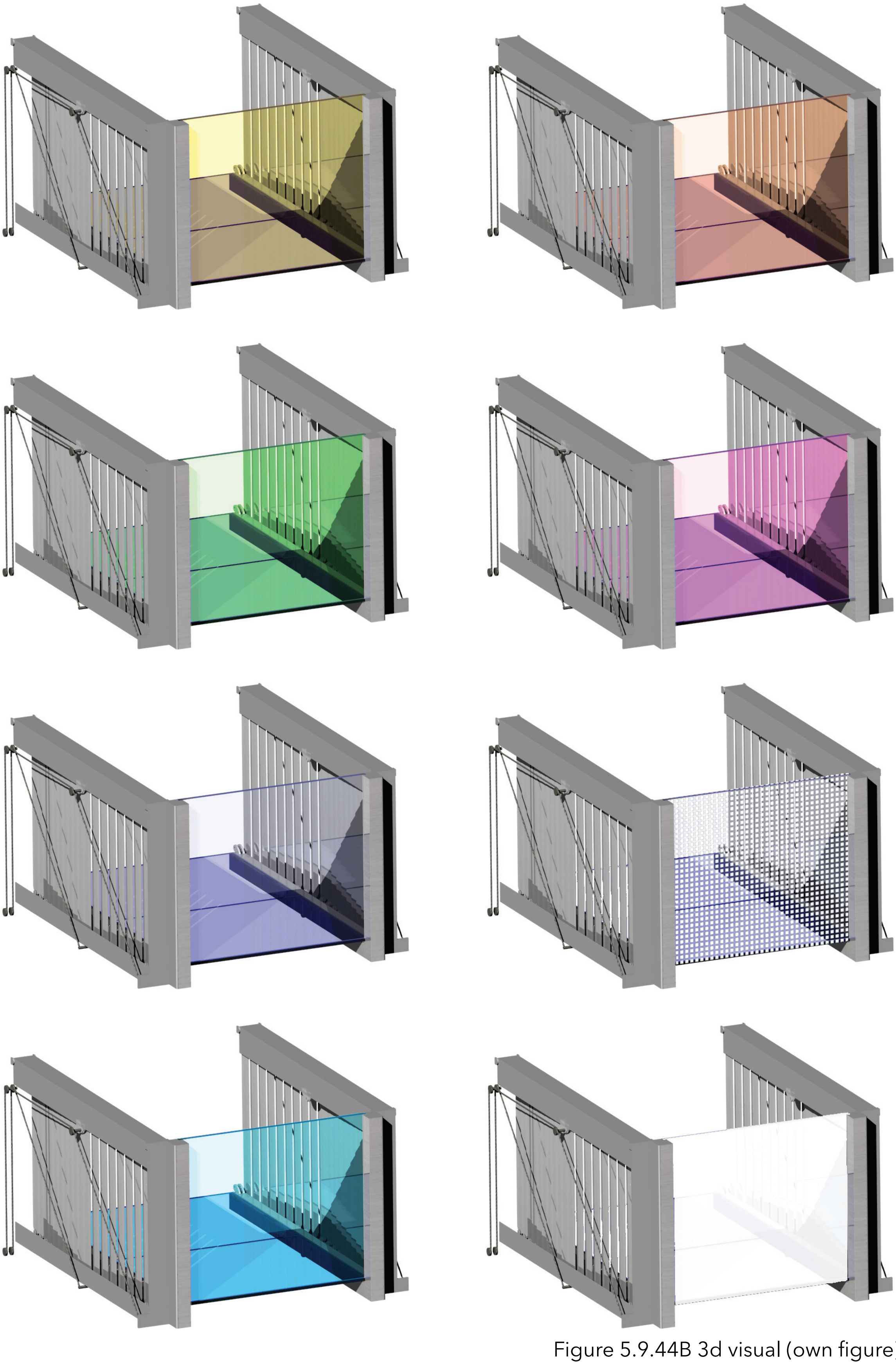


Figure 5.9.44B 3d visual (own figure)

CAN THE TRANSFORMABLE FAÇADE BE SCALED IN WIDTH?

The balustrade is designed to be 1,5meters in width. The design can be made in a wider version. Without changing much of the design. 2 meter width could be achievable. But a wider variant in the 3 meter range will most likely not be feasible. The glass needed for the version would consist out of lamination of 3 sheets of 19mm glass. This would make the total weight of the glass much higher. Also the glass costs would show a quadruple increase per m2. Technically the balcony can be made with a width of 3 meters, but then the balcony will not be feasible. For a 3 meters variant a different concept needs to be developed for the construction. A extra beam in the middle of the balcony could be a solution. Most likely the need for an electric lockable hinge would be needed to make it structurally safe. Adding glass fins to reduce the thickness and weight of the glass could also be a possible solution. Or change the span direction of the glass.

Floor										
Span 3*1,2 meter	Dead load		Live load		Point load		Total with safety		Strength test	
Laminated glass build up	σ	δ	σ	δ	σ	δ	σ	δ		
3 x 10mm glass layers SGP	5,48	-5,41	24,71	-20,67	21,01	-10,25	75,978	-36,33	75,978 /69,7	1,090
2 x 10mm glass layers SGP	4,08	-2,6	22,36	-12,12	23,25	-6,31	73,923	-21,03	73,923 /40 =	1,848
3 x 12mm glass layers SGP	4,65	-3,96	17,21	-12,3	15,02	-6,09	54,6225	-22,35	54,6225 /69,7	0,784
2 x 12mm glass layers SGP	6,94	-8,04	40,79	-41,72	31,97	-20,78	118,509	-70,54	118,509 /40 =	2,963
3 x 15mm glass layers SGP	3,82	-2,71	11,1	-6,48	9,93	-3,21	36,702	-12,4	36,702 /69,7	0,527
2 x 15mm glass layers SGP	5,62	-5,35	25,74	-21,97	20,95	-10,89	77,622	-38,21	77,622 /40 =	1,941
3 x 19mm glass layers SGP	3,09	-1,82	6,99	-3,27	6,39	-1,62	24,2415	-6,71	24,2415 /69,7	0,348
2 x 19mm glass layers SGP	4,5	-3,48	15,89	-11,04	13,35	-13,35	41,99	-27,87	41,99 /69,7	0,602
									41,99 /40 =	1,050

Balustrade						
Span 3*1,2 meter	Line load		Total with safety		Strength test	
Laminated glass build up	σ	δ	σ	δ		
2 x 10mm glass layers SGP (0.89) 1kN/m	14,34	-20,87	19,359	-20,87	19,359 /40 =	0,484
2kN/m	29,51	-40,61	39,8385	-40,61	39,8385 /40 =	0,996
2 x 12mm glass layers SGP (0.89) 1kN/m	10,06	-13,06	13,581	-13,06	13,581 /40 =	0,340
2kN/m	20,78	-25,85	28,053	-25,85	28,053 /40 =	0,701
2 x 15mm glass layers SGP (0.89) 1kN/m	6,58	-7,27	8,883	-7,27	8,883 /40 =	0,222
2kN/m	13,43	-14,51	18,1305	-14,51	18,1305 /40 =	0,453
2 x 19mm glass layers SGP (0.89) 1kN/m	4,24	-3,88	5,724	-3,88	5,724 /69,7 =	0,082
					5,724 /40 =	0,143
2kN/m	8,58	-7,77	11,583	-7,77	11,583 /69,7 =	0,166
					11,583 /40 =	0,290

Figure 5.9.45A glass calculation (own figure)

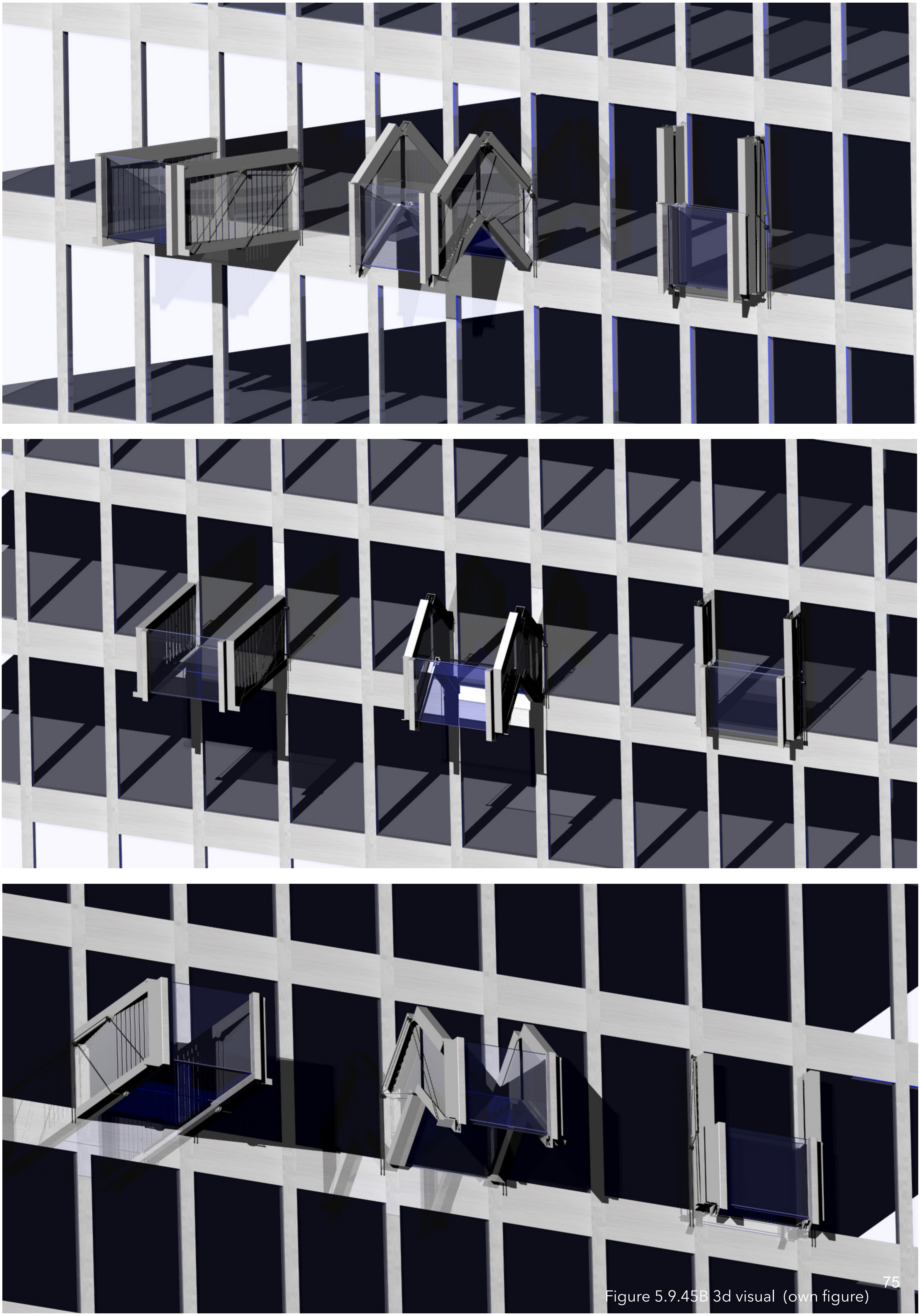


Figure 5.9.45B 3d visual (own figure)

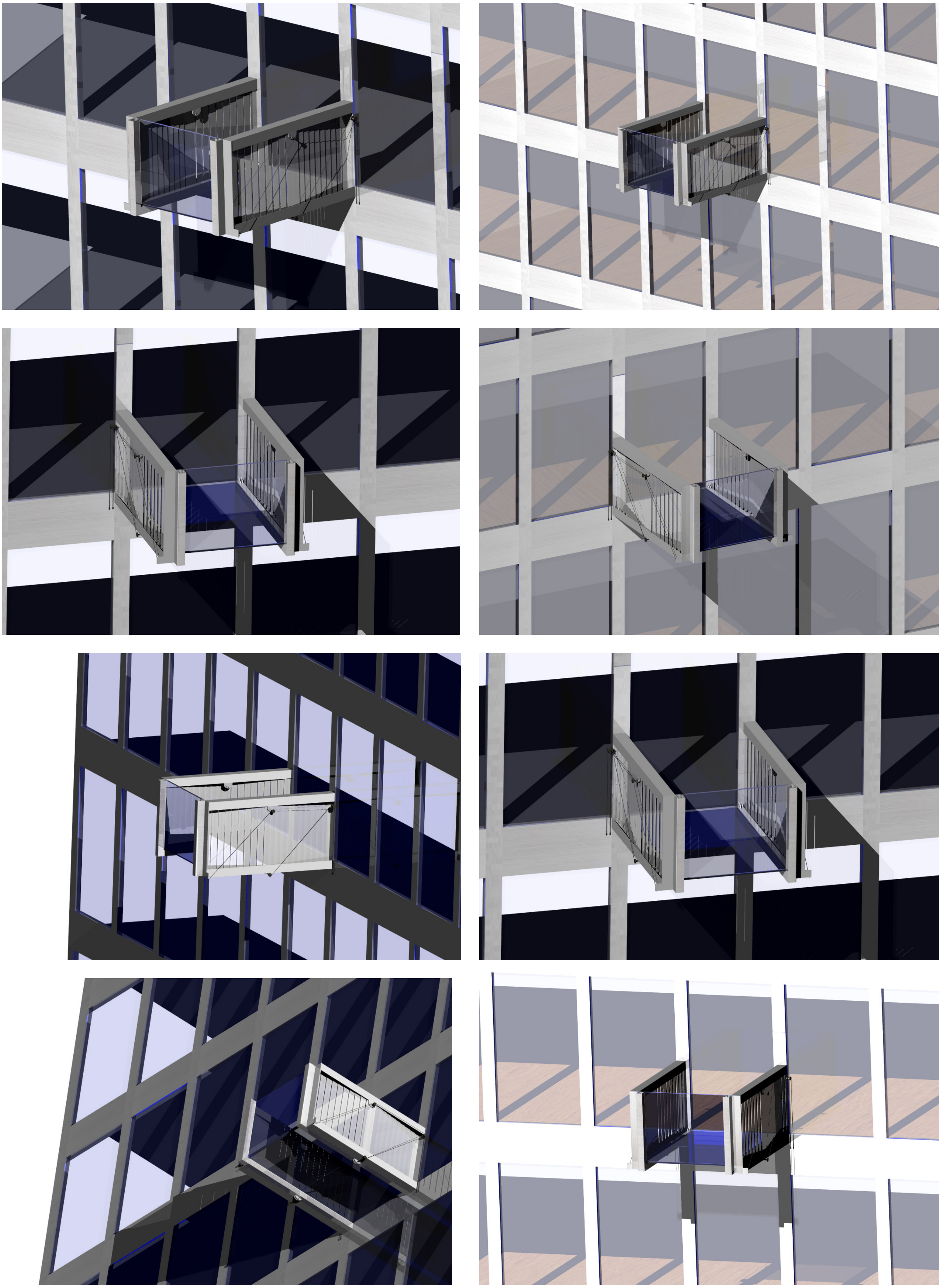


Figure 5.9.45C 3d visual (own figure)

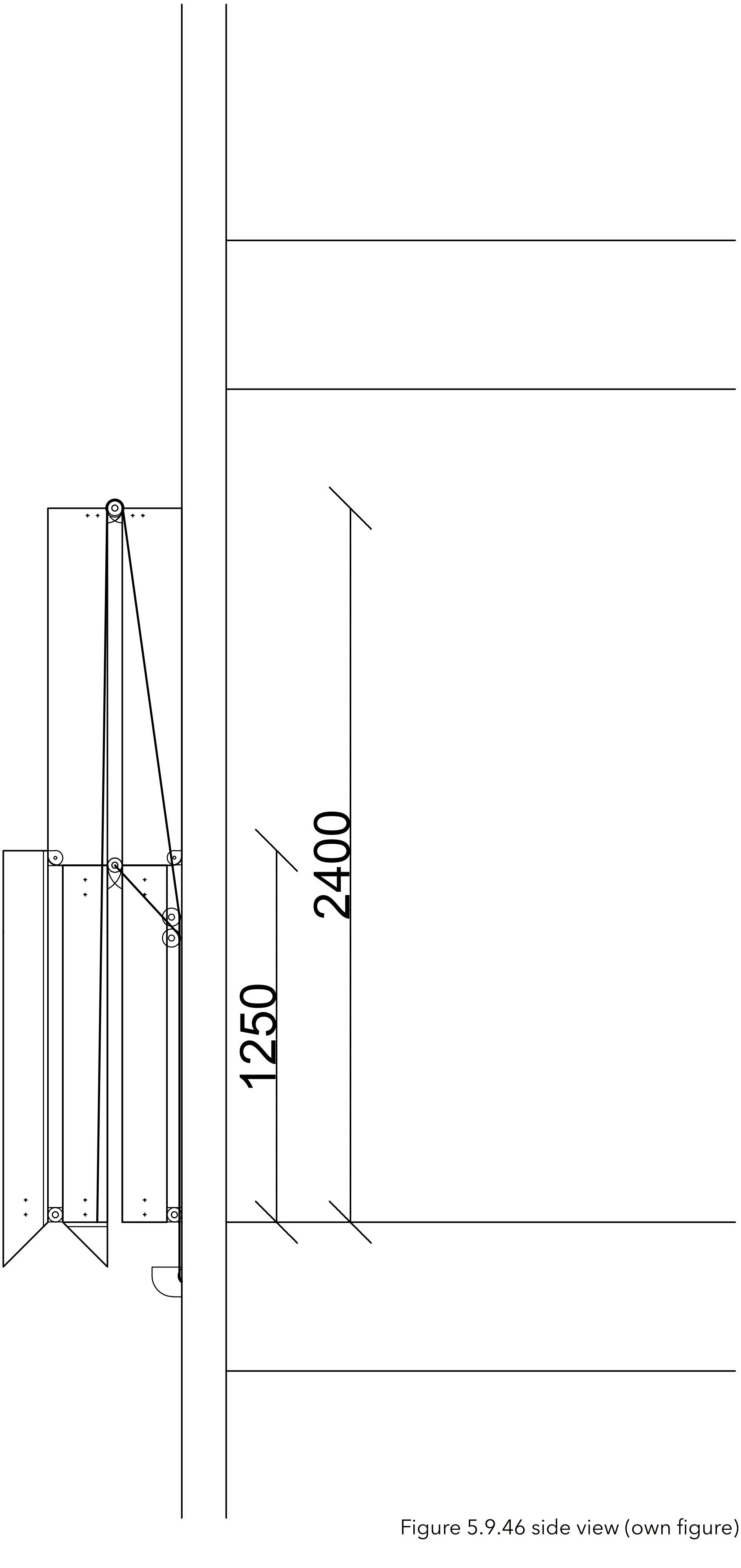


Figure 5.9.46 side view (own figure)

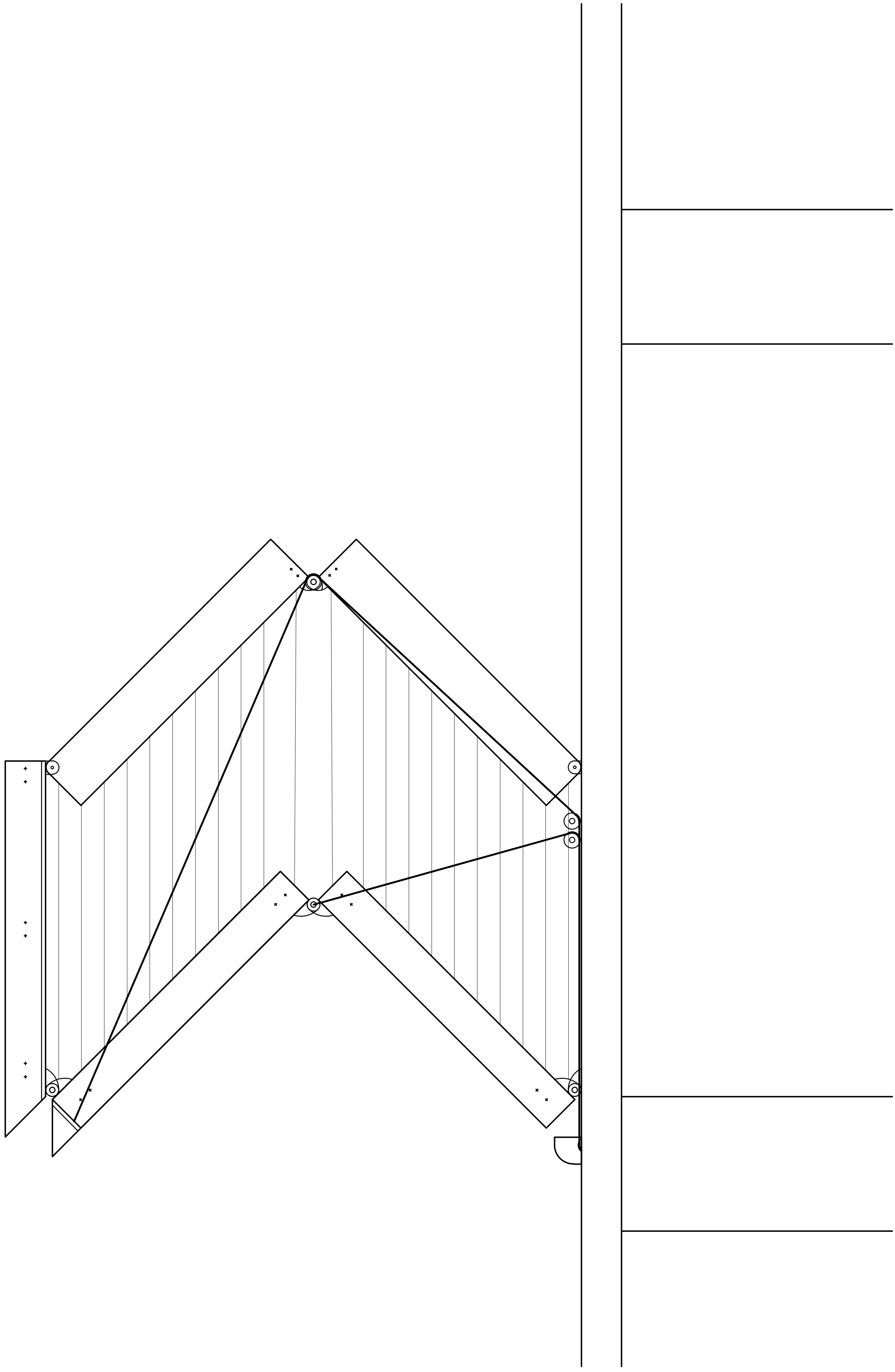


Figure 5.9.47 side view (own figure)

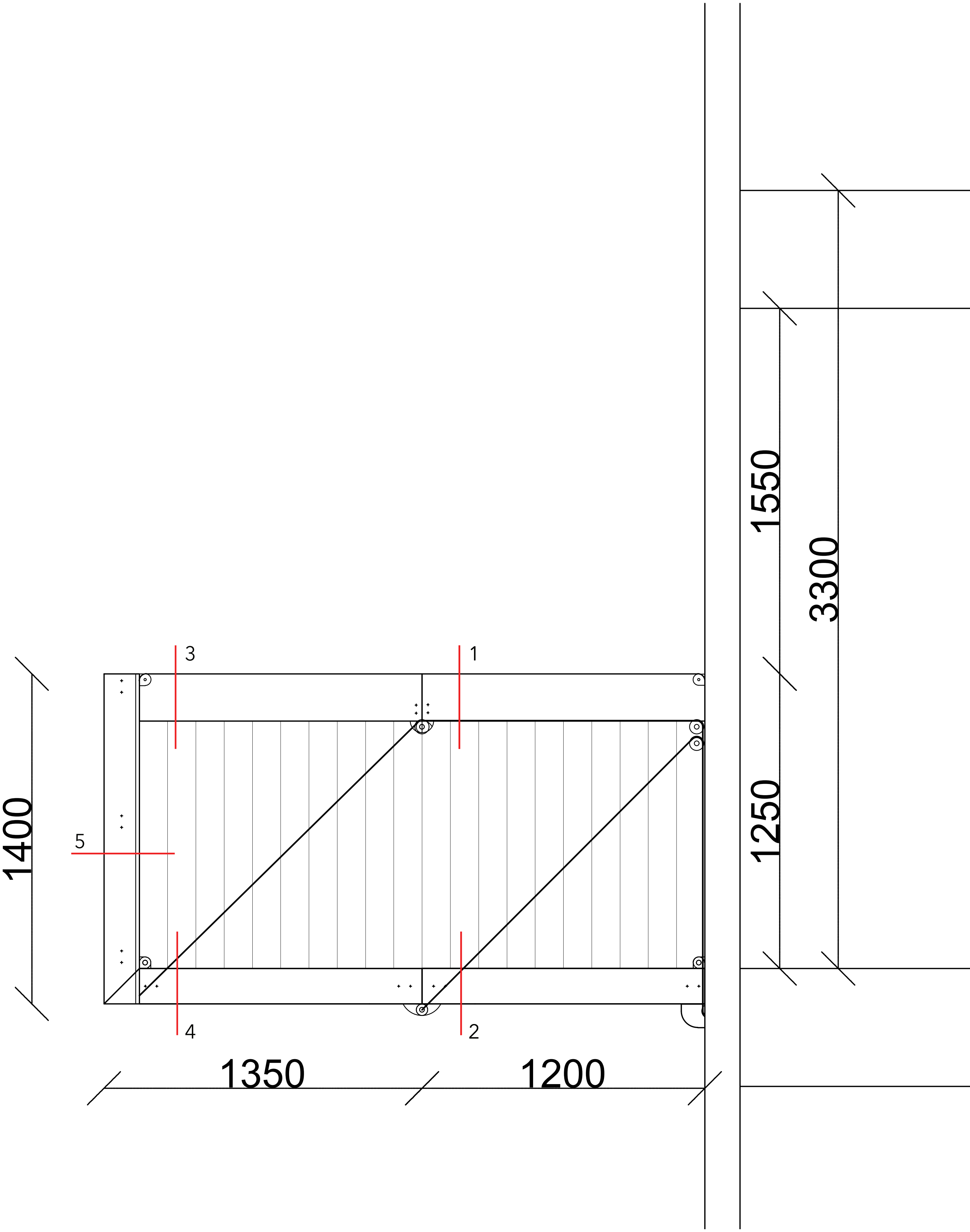


Figure 5.9.48 side view (own figure)

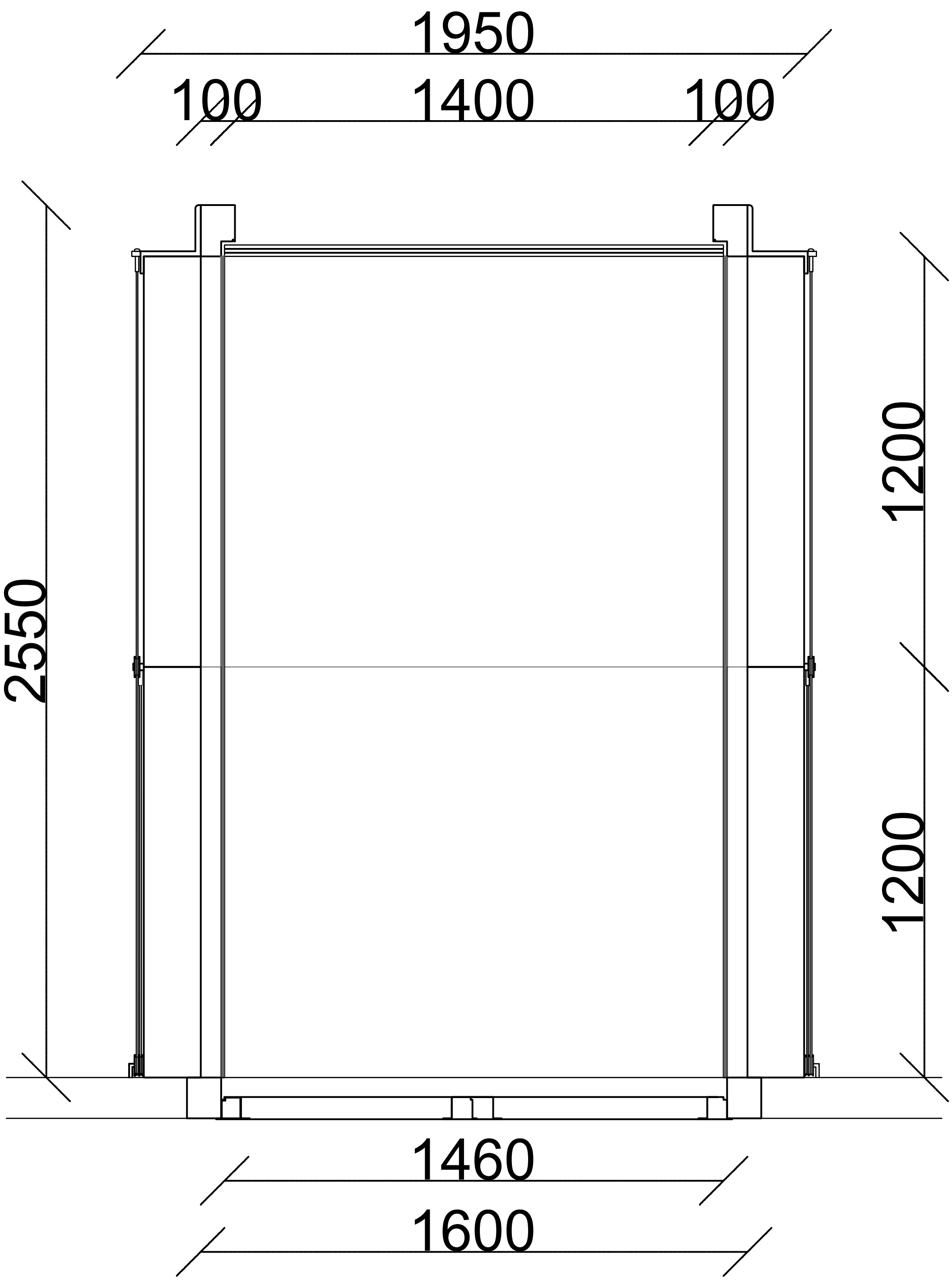


Figure 5.9.49 top view (own figure)

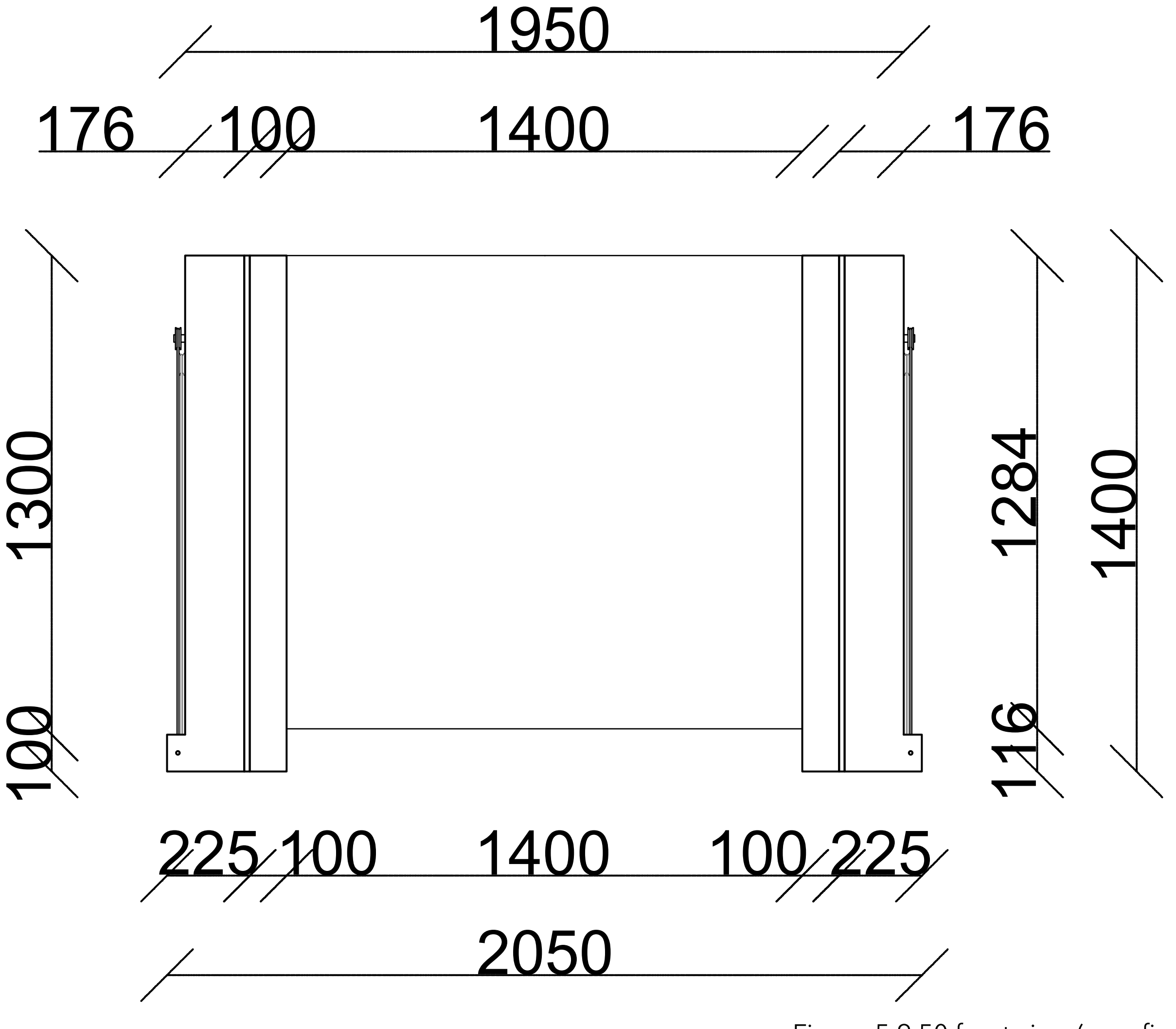


Figure 5.9.50 front view (own figure)

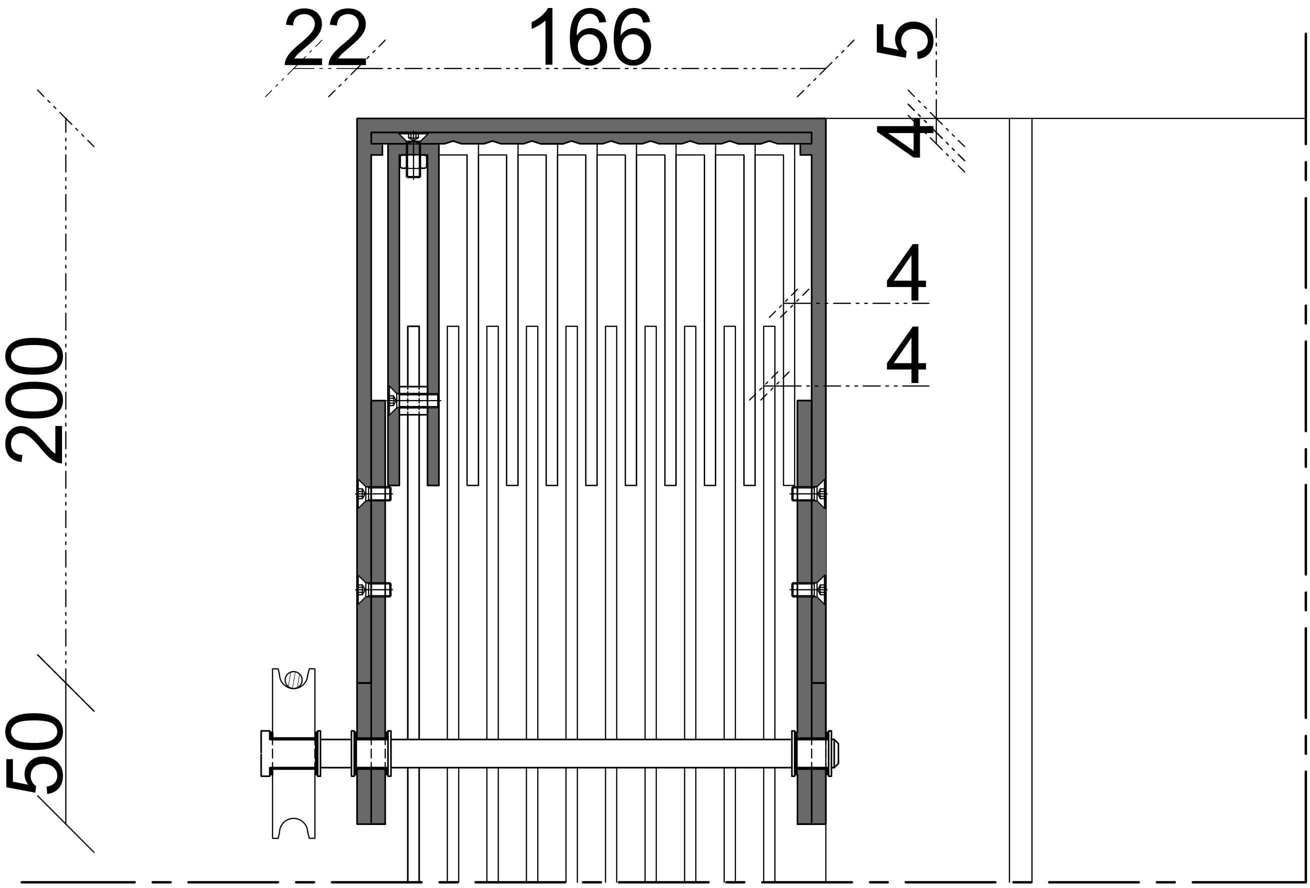


Figure 5.9.51 Detail 1 (own figure)

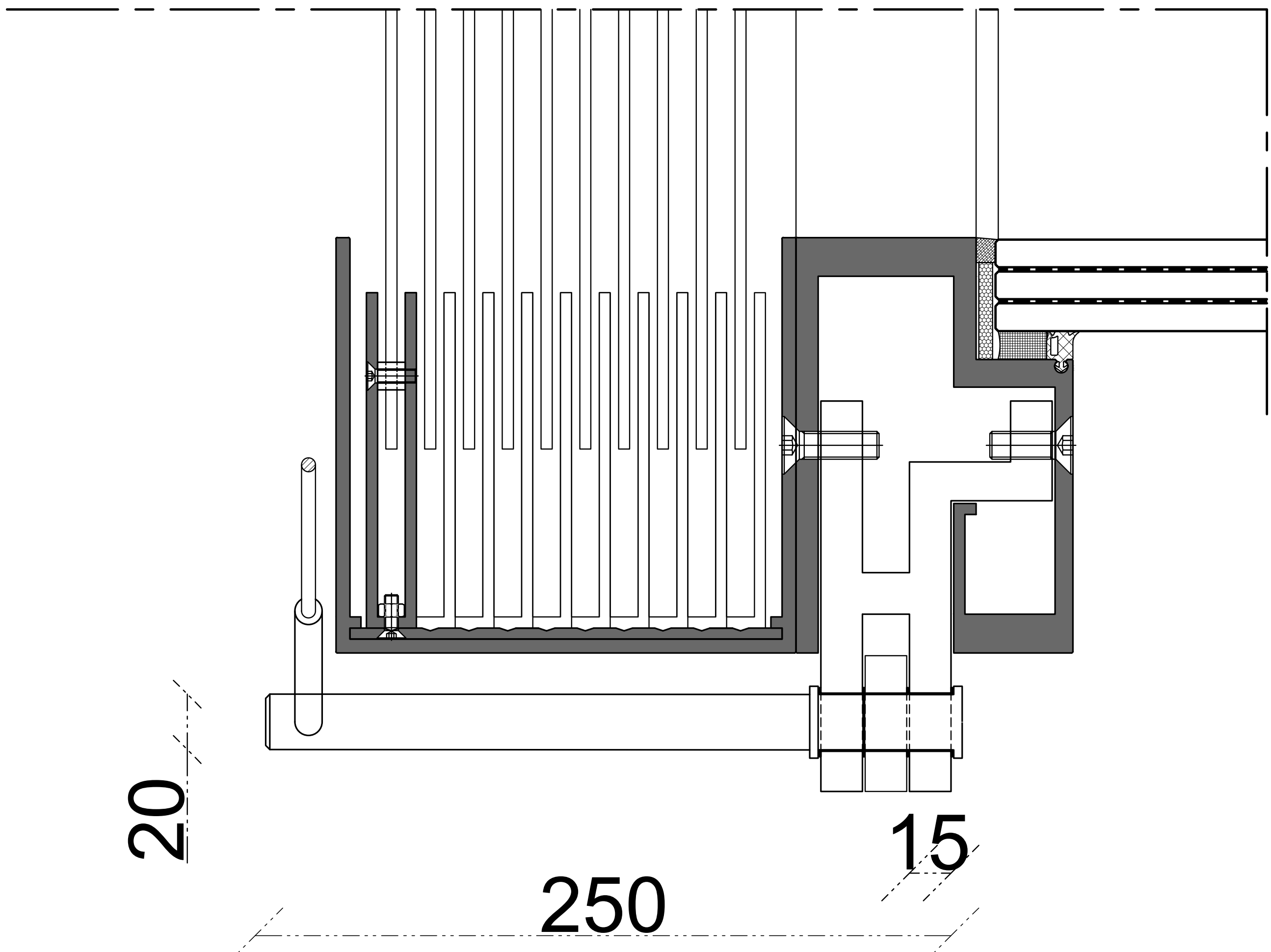


Figure 5.9.52 Detail 2 (own figure)

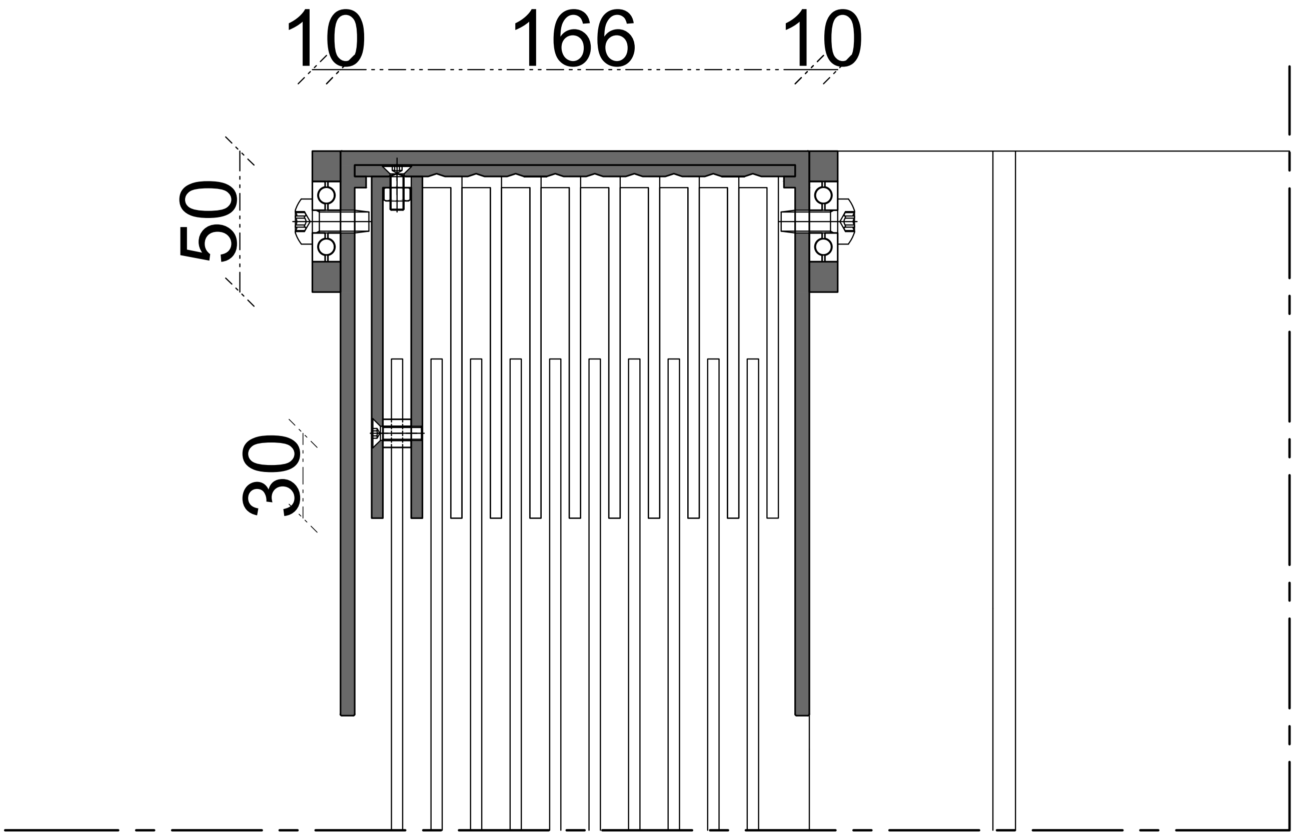


Figure 5.9.53 Detail 3 (own figure)

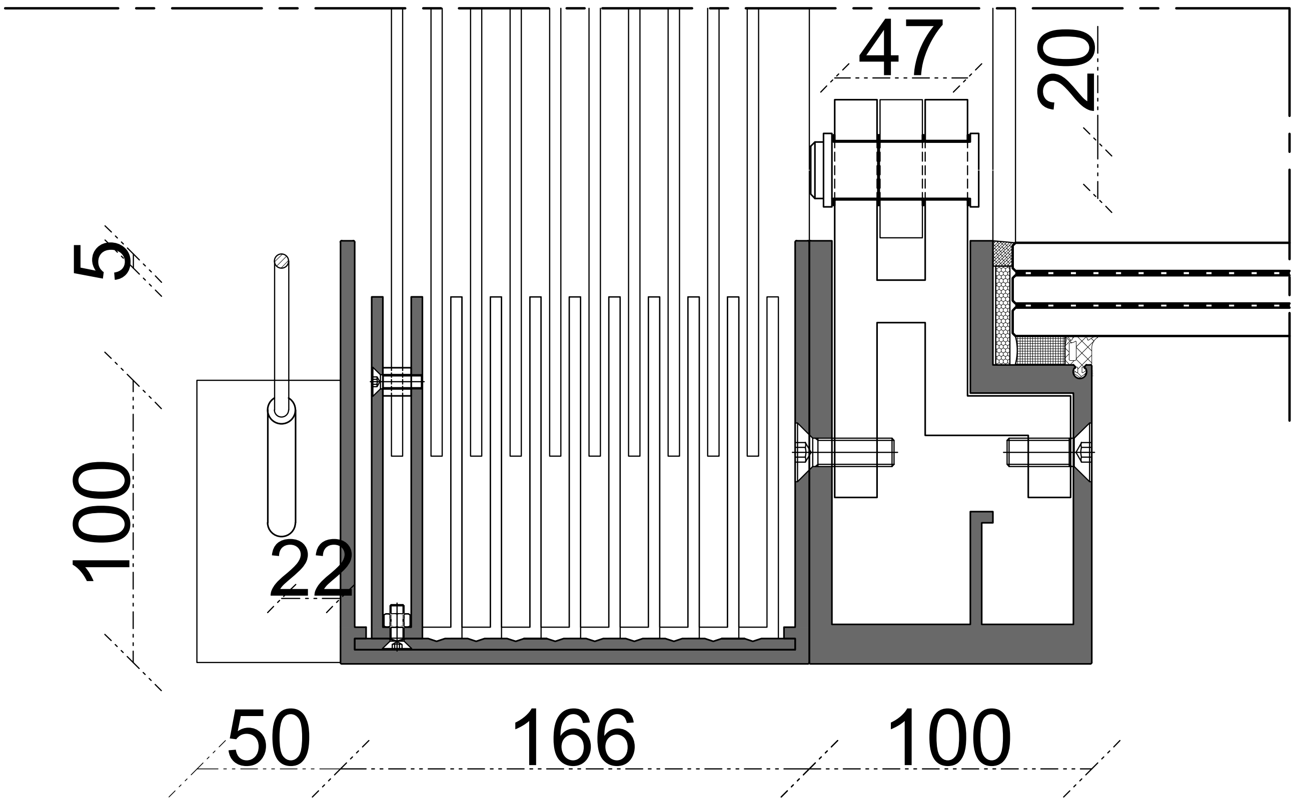


Figure 5.9.54 Detail 4 (own figure)

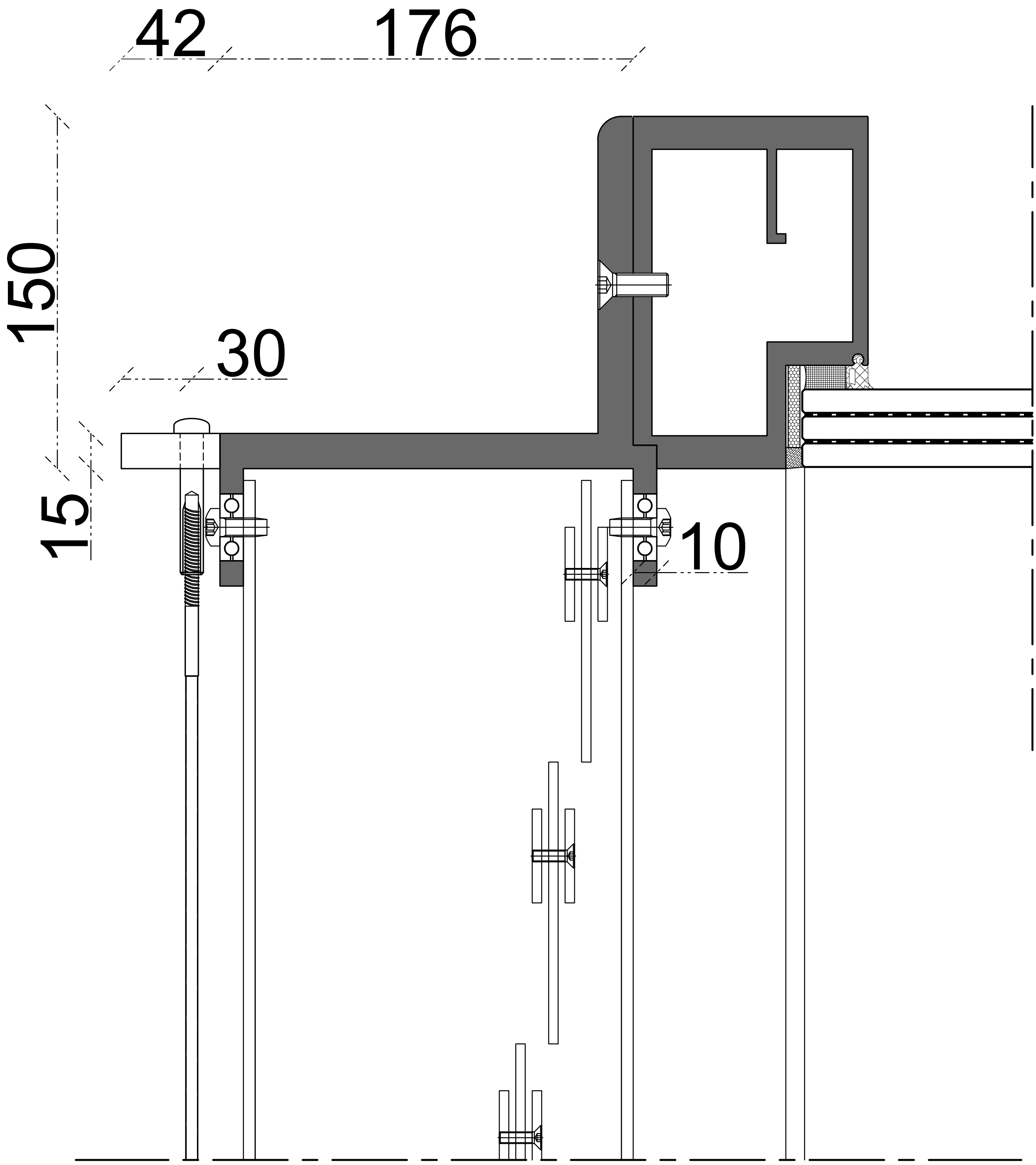


Figure 5.9.55 Detail 5 (own figure)

6 CONCLUSION

What is the additional value of a temporally balcony?
A temporally balcony creates a dynamic building façade, changing by the residents and influenced by the weather, giving multiple views. Furthermore it leads to an increase of outdoor space in high rises.. In addition a temporally balcony does not fall under the normal building code. Thus giving it a change to be placed on façades where no permanent balconies are allowed.

What are the alternatives on the market?
In the unitized façade world there is currently no transformable temporally balcony. The only relevant alternative is the Bloomframe. However the Bloomframe is not designed for a unitized façade system.

In what way can the façade transform? Is the balcony intergrade in the façade?
There are two main ways a façade can transform into a balcony. The first way is to use the whole façade that folds outwards to form a balcony. The second way is to have a foldable construction in front of the façade. This foldable constructions transforms into the balcony. The second way was chosen for developing a concept. meaning that the balcony is not a integrated part of the façade. It is a separate element that is in front of the façade.

This choice was made based on the following points,

- Balcony is not the thermal barrier
- The glass in the balcony does not have to be isolated
- Balcony depth is separate from the floor height, the depth can be different.
- Multiple functions (French balcony, balcony, window.
- Extra usability with the permanent façade.
- Balcony can be used even when it is cold outside and when it is raining.

What is the best glass composition?
There are two different glass compositions used in the design. The first composition is used for the floor, and the second composition is used for the balustrade.
The laminated glass composition used for the floor is 3 layers of 10mm glass sheets. Between the top glass layers 4 sheets of PVB foil laminated and between the bottom are 2 sheets of SGP foil laminated.

In what way can the construction function?
In what way can the construction function?
There are many different ways the construction of the balcony can function. However
the basic principle is the same. The laminated glass elements are supported on extruded aluminium profiles. These profiles transfer the forces through hinges and additional construction elements, through the T brackets, through the façade brackets into the main construction of the building. The additional construction elements support the construction, ensures the movement of the balcony, and is a failsafe feature.

In this paper four different construction methods are researched.
The first method is by using steel cables, pulleys and an electric motor to create a hinge. This construction method is cheap and can precisely be controlled.

The second method is to use chains, sprockets, electric motor, reduction box and heavy duty shafts. This is a more complex construction, and is more expensive. There will be sprockets visible at the sides of the balcony. This will give it a sort of steampunk look.

The third method is to use six telescopic hydraulic cylinders, an hydraulic pomp and hydraulic lines. Three cylinders at each side of the balcony. These cylinders control the movement of the balcony and require hydraulic pressure to be operated.

The forth method is to use six hydraulic rotary actuators, hydraulic pomp and hydraulic lines. These actuators are the hinge points and are a lot smaller than the hydraulic cylinders. But because they need to handle a lot of moment force and are relative small the cost of these rotary actuators are high.

Every construction can handle the forces of the balcony. Total costs vary for each construction. The first method, the winch system is the system with the least amount of parts, is the cheapest to produce, and is the smallest construction option. This makes it technically and economically the best construction type to be used for the balcony.

What is the total cost of the transformable façade, and is it feasible?
The total cost of the transformable façade element is estimated at €9200. The balcony has two functions. The first one is a French balcony, the other is a normal balcony of 3,6m2.
A permanent balcony mentioned in chapter 5,1 costs between €7000 - €12.200, in m2 price around €625 - €2220. The transformable façade cost around €2500 m2, making it a little bit more expensive than a permanent balcony. The small difference makes the balcony feasible.

The Bloomframe is a balcony and façade in one. The minimum cost is about €10.000 for the smallest version (1,9m^2 balcony). The Winch balcony (3,6m^2 balcony) cost €9200 without the façade, and can be used with any façade cheap or expensive.
Both balcony constructions are hard to compare.

Can the transformable façade be scaled in width?
Currently the balcony is designed with a width of 1500mm, but can be scaled in width. Technically the balcony can be made with a width of 3 meters, but cost of the glass would more than quadruple per m2, this makes the balcony not feasible. Scaled up to three meters can be achieved with a laminated glass package of 3 sheets of 19mm glass. Bigger than three meters cannot be made with standardized float glass thicknesses. It will need custom made glass, resulting in even more expensive glass, making the total cost of the balcony much higher.

7 RELEVANCE

The way to handle the development of a new product, research true design, and finding important references to enhance the project are all major subjects of the master track Building Technology of Delft University of Technology, and where all encountered and applied during this graduation project.
The emphasis of this graduation project focussed on the tracks façade design (product development) and structural design.
Climate design always plays a role when designing a façade, but the main focus will be on Façade Design supported by Structural design.

Scientific framework for the graduation project is to develop and design a product with a lot of different values and rules. What are the requirements? What are the costs?
Not only the product but also the feasibility is very important. It is relatively easy to design a concept which works without taking costs into consideration.
Dealing with different technical possibilities, technicalities, feasibility, cost, creativity, practicality, dimensions, fabrication time etc., makes the design process not only a difficult one but furthermore and most important a very very interesting one.

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9 REFLECTION

This graduation project is part of the master track Building Technology.
The main focus of Building Technology is to design, research, innovate, integrate, build and test different elements of the build environment. These elements can range from the small type of aggregates used in concrete to huge façades of skyscrapers.
There are three main tracks; façade design, construction design and climate design.

The goal of this research is to make a feasibility study of a transformable unitized façade element. This façade element transforms from a vertical position to a horizontal balcony.
The main focus is on the operation of the concept. What is the function when the element is retracted (vertical)?
How does it support itself when it is extended (horizontal) into a balcony, with a life load?
The focus of this study will be façade fitting, profiles, construction (dimensions, strength, movement, etc.), dimensional comparison with the current unitized façade elements, practicality of the design and cost of production of the design. This graduation project especially uses the tracks façade design (product development) and structural design. Climate design always plays a role when designing a façade. But the main focus will be on Façade Design supported by Structural design.

Research through design was the approach to this graduation project. The main benefit of research through design is that the design process rises questions which need to be researched. This resulted in the research topics. For instance which transformable systems and objects already exist? Can these systems be used for a transformable façade element? How big, strong and thick do the structural elements need to be to support people? Furthermore you have to be careful not to miss important research elements. A SWOT analyses was used to validate the design method.
The strengths of this research is the development of a new product. There is only one competitor which is the Bloomframe design, but that design is not a real competitor because it is not suitable for a unitized façade system. This means it will be the first and only (for now) transformable balcony system which is designed and built to function in a unitized façade system.
The weakness lies in the design process. It is easy to design a complicated concept which works but is very expensive and sensitive for failure, or neglect the quality and finish of the product. There is a high need to reflect on the design, establishing well defined design requirements can ensure the design decisions are well-founded. The whole design can lead to a waste of money and time for the company, or lead to an investment in a product the market is not ready or established for.
The big opportunity is the fact that it is a new product, designed for a growing market. This can result in a high demand. It also shows that Scheldebouw is researching and investing in new products to enhance the unitized façade market. It also creates a new way in how buildings can be dynamic in its appearance having a different look each hour and day.
One of the biggest threats is that the production of the transformable unitized façade element may be seen as a modified version of the patented Bloomframe design. Thus exists the possibility that Scheldebouw can be sued when they decide to build and market this new design. Another threat is market demand. The market may not be ready for a new façade element, giving no guaranty that the product will sell. A good marketing study has to be done. This product is also a new building element which most municipalities have not encountered before. This can lead to difficulties in getting the appropriate approvals for installation of the transformable balcony.

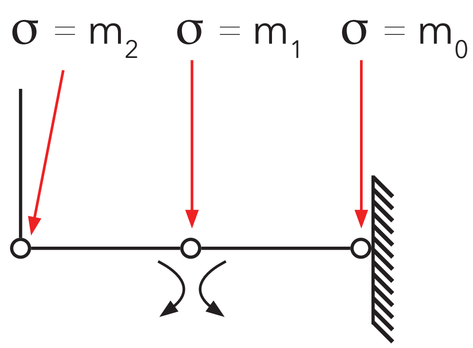
Research trough design led to a design that the mentors and the company where very enthusiastic about. But the construction used in this design turned out to be too expensive. This led to a moral dilemma. The mentors of the TU Delft had no issue with the cost of the construction, mainly because the project was designed for the high end residential market. It is a luxurious product, that may cost a lot of money. There was also no price cap prearranged. But for the company the feasibility of the product vanished into thin air. There were two possible directions to continue the project. The first direction was to continue with the expensive construction, and create detailed drawings at the level suitable for a prototype. The second direction was to take a big step back and try to find alternative construction designs, that are cheaper to produce. The choice was made for the second direction because the first direction did not show any financial viability. Construction designs that are cheaper to produce will show a higher possibility for a prototype. A key point for the company. This broadening of the research did consume quite some time, thus leading to more conceptual drawings and less detailed design.

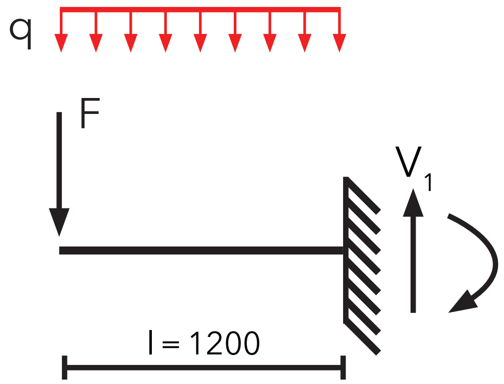
The transformable façade element can enhance the building environment, it can create a dynamic façade. A potential new type of balcony that sits in a grey area of the building code; is it a façade or a balcony? This can help to convince municipalities to allow balcony's previously banned. The concept can be made into a workable prototype within a year. There is also need for some further testing to ensure the safety of the balcony

The graduation project took place at the company and Delft Technical University. There were some differences between working at the University and at a company. One of the biggest difference is the work mentality. You have to be at the office between 7:30 and 8:30. You are expected to work for 8 hours + 1 hour break. This means that your working day is finished between 16:30 and 17:30.
Everybody at the office is working, not playing with their phone's, surfing on the internet or watching video's. This means that you feel pressured to concentrate on your own work. Almost everybody thinks in a practical way, and not in an experimental or conceptual way. This led to less support during the conceptual design and construction. But during the drawing face, detailing and such, the college's at the office where very helpful. They do see potential problems quickly and suggest the best possible solutions for the details. It is also very motivating to get paid to do research and design. This feels like you are contributing to a company and are appreciated for your work. And the experience and connections are a welcome addition to my CV and future career.
The main goal of the collaboration with Delft Technical University, the company and me is to produce a concept that can be expand upon to produce a prototype.
But there are off course also less positive sides to a graduation at a company. At the beginning you do not know if you fit in. This can lead to a less pleasant work environment where you cannot concentrate on the graduation project. Also the absence of fellow students that treat the same path as you, is noticeable. It is easier to stay on track if you work next to fellow students, because they also need to stay on track and make progress, You walk together so to speak.
The work mentality ensures that you cannot take a break if you need a rest from the graduation project. The only way to do this is to take a leave of absence. You also need to travel from and to work each day. In my case I had a daily travel commute of one hour, leaving home at the early hour of 7 and returning at home at 17.30 in a strict order every day. And when I had a meeting at the university the travel commute was four hours. This, of course, depends on where the company is located and where you live.

APPENDICES

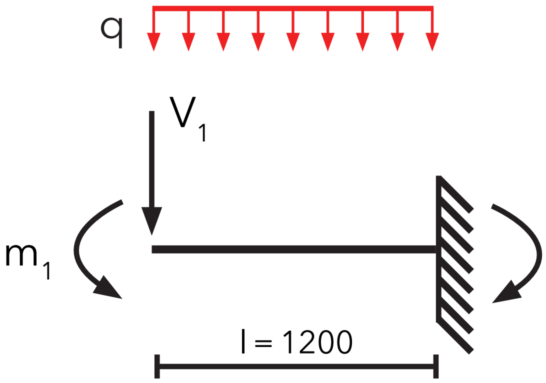
CALCULATION MOMENT FORCES



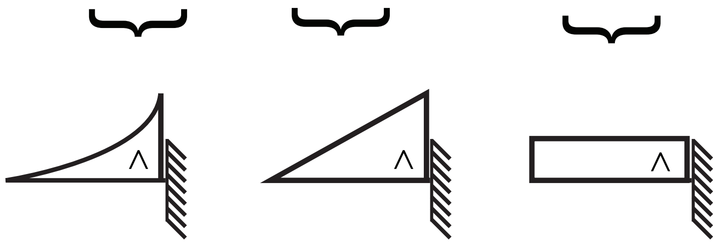


$m_1 = {}^1/_2\, ql^2 + F * l$

$V_1 = q*l+F$



$m_0 = {}^1/_2\, ql^2 + \quad V_1*l \quad + \quad M_1$



(beam) (glass) (safety)

F = (0,144 * 1,2 + 0,9*1,2*0,75) * 1,35

F = 1,33 kN

q = (0,144*1,2+1,35*1,2*0,75)*1,35

q = 1,88 kN

$M_1 = {}^1/_2\, ql^2 + F * l = {}^1/_2 * 1,88 * 1,2^2 + 1,33 * 1,2$

$M_1 = 2,9496$ kNm = 2950 Nm

$V_1 = q * l + F$

$V_1 = 1,88 * 1,2 + 1,33$

$V_1 = 3,586$ kN

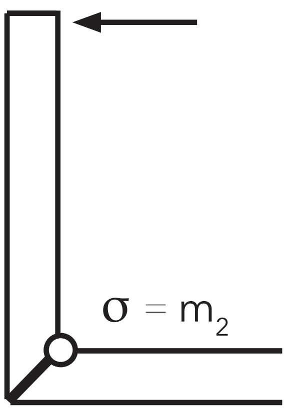
$M_0 = {}^1/2ql2 + V1l + M1$

$M_0 = {}^1/_2 * 1,88 * 1,2^2 + 3,586 * 1,2 + 2,946$

$M_0 = 8,6064$ kN

M2 = 0

Because there is no moment forces in the hinge, the moment forces transfer true the beams.



CALCULATION DIMENSIONS PROFILE

ST 335
I_x = 286 cm^4
$T_{0,2}$ = 235 N/mm^2
E = 210000

100x100x5mm steel square tube

Alu 6063-T6
I_x = 1186 cm4 ← minimun I_x value
$T_{0,2}$ = 170 N/mm^2
E = 70.000

Aluminium profile 150x100x8 I_x = 1128
Aluminium profile 150x100x10 I_x = 1350

Ix value of the profile is determined by a AutoCAD plugin tool of Scheldebouw. The final thickness of the extruded aluminium profiles has different wall thicknesses.

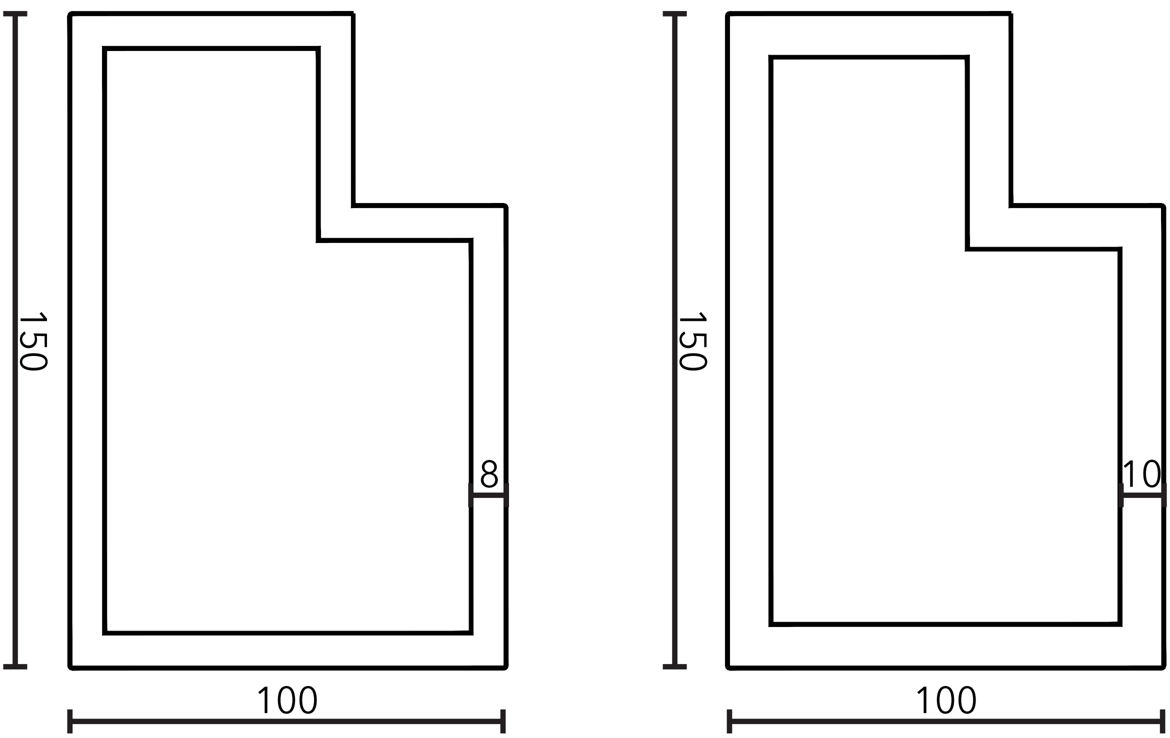
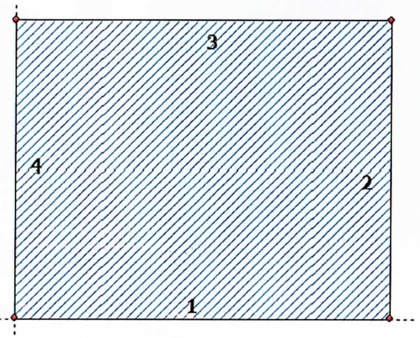


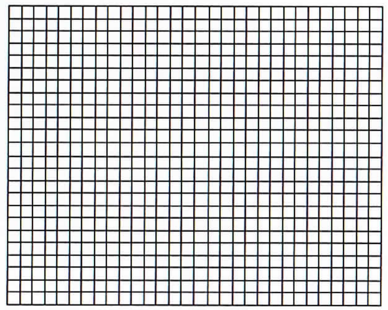
Figure 9.1 Beam section (Own figure)

CALCULATION GLASS

Calculation for the "Bloomframe" balcony floor with following properties:

- Dimensions 1200x1500
- 101010.1.1 HT HS HS SGP 0.89mm
- Two sided supported in large direction (1500mm)
- Load equal to 3.5 kN/m^2 in SLS
- SGP shear value for dead load: 40 degrees, 10 years, 8.84 MPa
- SGP shear value for life load: 30 degrees, 1 hour, 178MPa (note that for 40 degrees this value drops to 27.8MPa)





Geometry:

Edge	Borderpoint mm	mm	Arccenter mm	mm	Direction of rotation +/-
1	0.00	0.00			
2	1500.00	0.00			
3	1500.00	1200.00			
4	0.00	1200.00			

Supports:

Edge supports:

Edge	Type of supports	
2	w	: fixed - u,v,φ,θ : free (simply supported)
4	w	: fixed - u,v,φ,θ : free (simply supported)

Spring supports:

Package	Layer	x mm	y mm	z mm	C_x N/mm	C_y N/mm	C_z N/mm	C_φ Nmm	C_θ
1	1	0.0	0.0	0.0	1.000e+00	1.000e+00	0.000e+00	0.00e+00	0.00e+00
1	1	1500.0	0.0	0.0	0.000e+00	1.000e+00	0.000e+00	0.00e+00	0.00e+00

Layers:

Layer order:

Package	Layer	Description
1	5	Float glass
1	4	SGP, 60°C, long time loading
1	3	Float glass
1	2	SGP, 60°C, long time loading
1	1	Float glass

Figure 9.2 Mepla calculation (own figure)

Results

• Loadcase combination

Description		outside/top	inside/bottom	
w(1)	= Wind	-3.500	0.000	[kN/m²]
g	= Dead weight	α =	0.0°	

LC	Description
1	Dead weight
2	Life load 3.5kN/m^2
3	SLS (1.00 DL + 1.00 Q)
4	ULS (1.35 DL + 1.50 Q)

LC	DW	Wind	Snow	Line	Point	Climate		Shear	Proof
1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	8.84	---
2	0.00	1.00	0.00	0.00	0.00	0.00	0.00	178.00	---
3	1.00	1.00	0.00	0.00	0.00	0.00	0.00	8.84	---
4	1.35	1.50	0.00	0.00	0.00	0.00	0.00	8.84	---

• Calculation results - utilization - until loadcase 4

• Without proof

Package	Layer	Side	Loadcase	σ
1	5	(top)	4	0.68
		(bottom)	4	1.09
1	3	(top)	4	0.73
		(bottom)	4	6.01
1	1	(top)	2	2.17
		(bottom)	4	12.59

• Loadcase result

•[1] Dead weight

Package	Layer	σ	w min	w max
1	5	0.08	-0.51	0.00
		0.13		
1	3	0.09		
		0.72		
1	1	0.14		
		1.54		

} SGP σ= 8,84 MPa

•[2] Life load 3.5kN/m^2

Package	Layer	σ	w_min	w_max
1	5	0.32	-1.37	0.00
		0.47		
1	3	0.37		
		2.04		
1	1	2.17		
		6.15		

} SGP σ= 178 MPa

•[3] SLS (1.00 DL + 1.00 Q)

Package	Layer	σ	w_min	w_max
1	5	0.46	-2.82	0.00
		0.74		
1	3	0.50		
		4.05		
1	1	0.78		
		8.55		

•[4] ULS (1.35 DL + 1.50 Q)

Package	Layer	σ	w_min	w_max
1	5	0.68	-4.15	0.00
		1.09		
1	3	0.73		
		6.01		
1	1	1.13		
		12.59		

δ = 0,51 +1,37 = 1,88 mm

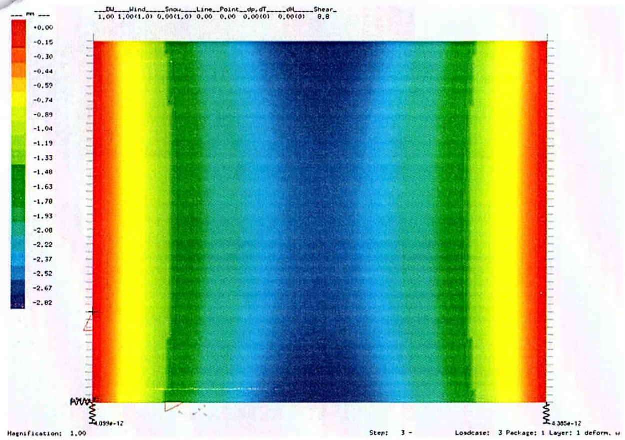
σ = 1,54*1,25 + 6.15*1.50 + 11.3 = 0,40

σ_{rd} = 28MPa (DL) > 2,1 MPa

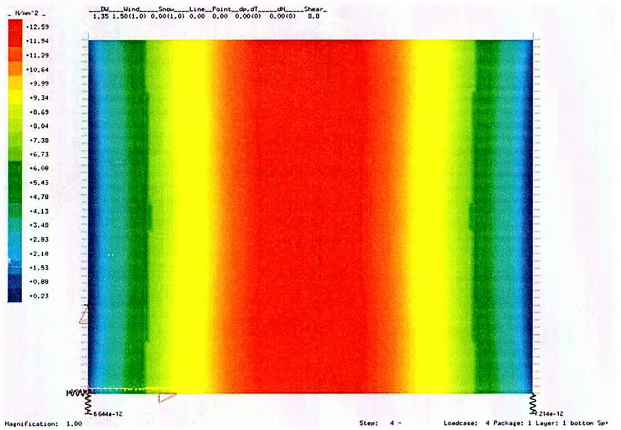
σ_{rd} = 40MPa (LL) > 9,2 MPa

$\frac{12,6}{28} = 0,45$

$\frac{2,1}{28} + \frac{9,2}{40} = 0,31 \leq 1,0$



Deflection (SLS) 2.82 mm < L/500



Stress (ULS) 12.59 < 28.0 MPa HS

Figure 9.3 Mepla calculation (own figure)

Max deflection

$q_{dw} = 30mm*2500kg/m^3*10^{-3}*9.81 = 0,74\ kN/m^2$

$q_{ll} = 3,50\ kN/m^2$

} 4,24 kN/m/m = 4,24 N/mm/m

$$\delta_{max} = \frac{5ql4}{384EF} = \frac{5*4,24*1500^4}{384*70000*I}$$

$I_{loose} = {}^1/_{12} * 1000 * 10^3 * 3 = 250000\ mm^4$

$I_{rigid} = {}^1/_{12} * 1000 * 30^3 = 2250000\ mm^4$

} $1,77mm < \delta < 15,97mm$ → SGP rigid

max stres

$q_{dw} + q_{ll} = 0,74*1,35+3,50*1,50 = 6,25\ kN/m^2 = 6,25\ N/mm/m$

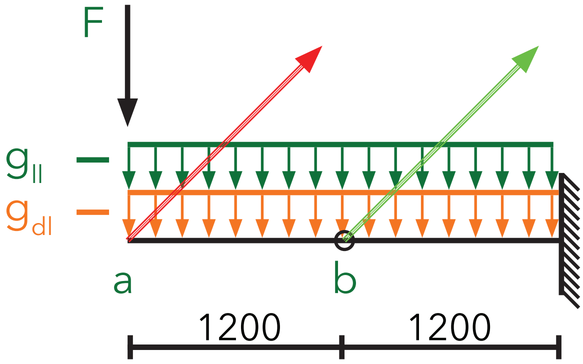
$$\sigma = \frac{m}{w} = \frac{1/8*6,25*1500^2}{1/6*1000*h^2}$$

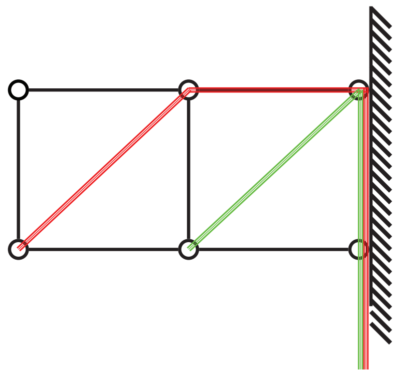
$h_{loose} = 3*10$

$h_{rigid} = 30$

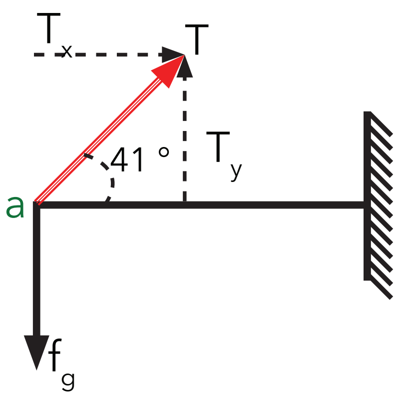
} $11,7\ MPa < \sigma < 35,1\ MPa$

CALCULATION STEEL CABLE (KEY ELEMENT)





$F = 0{,}208*1{,}2+0{,}025*0{,}75*20*1{,}2 = 0{,}526 * 1{,}35 = 0{,}710$ kN
$g_{dl} = 0{,}208+0{,}025*0{,}75*30*1{,}2 = 0{,}883 * 1{,}35 = 1{,}192$ kN/m
$g_{ll} = 3{,}5*0{,}75 = 2{,}625 * 1{,}5 = 3{,}938$ kN/m
$a = F+g_{dl}*1{,}2+g_{ll}*1{,}2 = 0{,}71+0{,}76*1{,}2+3{,}938*1{,}2 = 6{,}866$ kN ↓



$$Ay = \frac{\sum F_y}{m}$$

$$\sigma = \frac{T\sin41 - Fg}{687kg}$$

$$T = \frac{Fg}{\sin 41} = \frac{mg}{\sin41}$$

$$T = \frac{(687kg)*(9{,}8m/s)}{\sin 41} = 10262{,}2N$$

Steelcable fiber core 6x7 + PVC
4mm steelcables, 5mm with pvc has a Pulling force in kilos of 2967kg. Almost 2,9 times stronger.

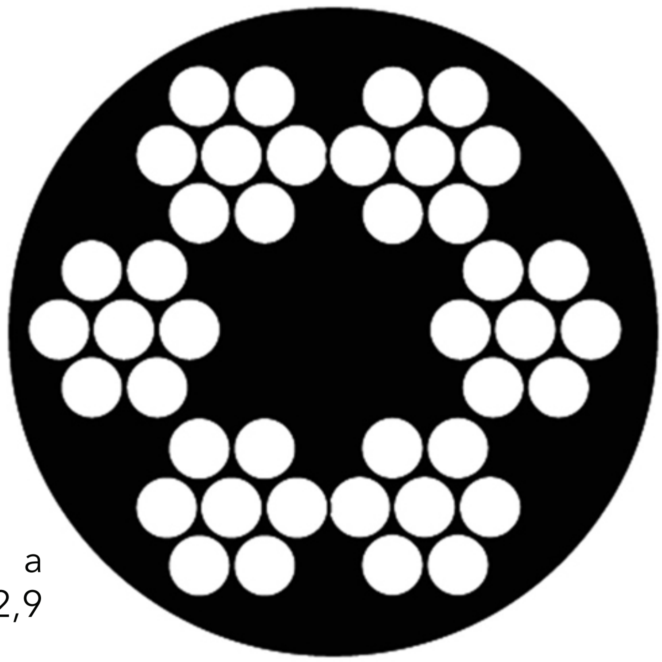


Figure 9.4 Steel cable fiber core (certex, 2019)