

***Towards a project specific innovative design approach
The current architectural designs shows us that a new approach of façade
engineering is needed to reach the visual quality the architect has in mind.***

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Note Before

My name is Luuk Jansen 23 years old, born in Nijmegen and grown up in Groesbeek. I'm a pro level cyclist at Restore Cycling Team and I am Dutch derny champion. Currently I'm building engineer at ABT BV., CEO of LJMK Architects and student assistant at TO&I.

I am always fascinated for technique whether it is a building construction, façade construction or bicycle parts. But façade construction has always my main interest and therefore I wanted to do something with façades and façade design in my graduation.

Summary

In this report you will find the research I did to innovative façade design processes. To come up with an innovative façade engineering for the Tianjin library in china and make a proper comparison to a more product specific engineering, I first need to learn more about façades in general. To achieve this I read several books, talk to different companies and look into some cases.

These books learn my about:

- requirements from the context and climate.

- Requirements from the Dutch building legislation, on topics as insulation, noise level, ventilation and daylight.

- Comfort requirements, on topics as temperature, daylight and air refreshment/ventilation.

With these requirements in mind I was able to do a project specific façade engineering for the case and make a comparison between a project specific façade engineering and a product façade engineering. The outcome was positive to a project specific engineering.

After this design process and the interviews with the different companies (ABT, MVRDV, Schüco, FBA, Sorba and Alcoa) I found a way how to achieve a project specific design where the concessions the architect has to do are as little as possible. This in contrast with the current process where the architects has to do a lot of unwanted concessions.

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Background and relevance

In the current architectural designs I see an increasing complexity in façade design. See for example Boijmans van Beuningen by MVRDV or the designs of Zaha Hadid.



Figure 1: design Boijmans van Beuningen by MVRDV - source: ontwerpwedstrijden.nl

Not only the complexity of the visual part of the façade is growing but also the performance demands are increasing. For example see the Dutch building legislation where since 1 Januari 2016 there is a higher RC and EPC required.

1 januari 2015: aanscherping EPC en hogere Rc-waarden

30-10-2014 Het beleid van de Rijksoverheid is erop gericht dat nieuwe woningen in 2020 (bijna) energieneutraal zijn. Op 1 januari 2015 wordt een belangrijke tussenstap gezet om (bijna) energieneutraal te bereiken.

Rijksoverheid

De energieprestatiecoëfficiënt (EPC) voor woningen wordt aangescherpt naar 0,4. De EPC-eisen voor utiliteitsgebouwen worden 50% aangescherpt ten opzichte van het niveau van 2007. Daarnaast worden er hogere eisen gesteld aan de thermische schil van een gebouw.

Voor het realiseren van een EPC $\leq 0,4$ kunnen diverse bouwkundige en installatietechnische maatregelen worden getroffen. Denk hierbij onder andere aan de thermische schil, het verwarmings- en tapwatersysteem en energiezuinig ventilatiesysteem. Het combineren van bouwkundige en installatietechnische maatregelen leidt tot een optimaal energieconcept.

Thermische schil

Naast de aanscherping van de EPC-eisen voor woningen en utiliteitsgebouwen worden ook de minimale eisen aan de warmteweerstand (Rc-waarden) in het Bouwbesluit 2012 verhoogd. Per 1 januari 2015 gelden, hoogstwaarschijnlijk, de volgende minimale Rc-waarden voor nieuwbouw:

- Vloeren Rc $\geq 3,5$ m²K/W (niet gewijzigd)
- Gevels Rc $\geq 4,5$ m²K/W
- Daken Rc $\geq 6,0$ m²K/W

De minimale Rc-waarde wordt per constructie gedifferentieerd. Deze differentiatie is opgenomen omdat het kosteneffectiever is om hogere isolatiewaarden toe te passen in een dak dan in een gevel of vloer. Het beperken van de energievraag door goed te isoleren vormt de basis voor een goed energieconcept.

Voor ramen en deuren wordt de eis aan de U-waarde daarentegen wat versoepeld. De huidige U-waarde eis van 1,05 W/m²K geldt momenteel op constructieniveau. Het bleek bijvoorbeeld bij de veel toegepaste schuifpuien in woningen lastig om aan de regels te voldoen. Omdat energiebesparing door de hele gebouwschil wordt bepaald, is besloten om per 1 januari 2015 de 1,05-eis te laten gelden voor de gemiddelde U-waarde. Daarbij mag de U-waarde van een individuele constructie niet hoger zijn dan 2,2 W/m²K.

Bron: Nieman Raadgevende Ingenieurs

Figure 2: increasing performance demands - source Nieman Raadgevende Ingenieurs

Because of these increasing performance demands of façades and the increasing complexity in visual language, it is no longer possible to use for each façade a common standardised system, or the architect has to do tremendous concessions to visible quality.

In a pre-research in an early stage of the design I found out that the current way of making a façade design is by developing variants seeking the edges of standardised systems to achieve the visual of the architect and satisfy the performance demands.

In my research I will investigate if this is the right method or if there is a need for new design methodologies, in which innovative façade designs will be made possible, and thereby meet the architectural and performance demands more easily.

Luuk Jansen (4065573): an innovative façade design approach.

Methodology

Trygve Faste stated that design research is not a kind of research but research is always a kind of design. Design research is creative research, it forms a subset of possible design orientated strategies/solutions. (Faste T., 2012)

Research through design: A combination of processes and research activities in an artifact as the embodiment of design research knowledge. In other words research activities in a design process leading to substantial knowledge about a subject, which has not achieved when using theoretical methods. Often this research by design is subconscious. (Faste T., 2012)

“Research through design is not limited to traditional research documentation and, in this regard, is closely related to research through practice in disciplines such as studio art where similar processes result in the creation of experienced artifacts. (Koskinen et al. 2011).

“Because artists and designers use research to understand the topics they are working on as a process of creation and self-reflection, they are able to improve their design research practice in ways similar to diagnostic design research methods.

A major difference, however, is that design process knowledge is embedded in the designer’s internal toolkit as well as in the external world as a result of the generated designs. In this regard embedded design research enables the enhanced performance of future design action through knowledge disseminated through broader means than that of traditional research. It encompasses artifacts in addition to indirect oral traditions, and propagates in aesthetically and emotionally meaningful ways. Indeed, design objects are presented as arguments for interpretation by their intended audience, forming a critical triad of discourse between the designer, the artifact, and the social environment that the artifact influences. As Biggs (2002) observes, “This implies the notion that the artifact can embody the answer to the research question.” Embedding knowledge in the designers’ activity not only enhances design research, it plays a vital role in the dissemination of knowledge across all forms of experience.” (Faste, T. 2012)

In other words every research starts with a design, wanted or not. The research by design is a powerful tool coming up with solutions on certain problems than traditional research due to making subconscious choices visible and exploring innovative new out of the box ideas which with theoretical research is not possible. A research by design is also more communicative across all the segments.

A research by design starts with a theoretical framework. This theoretical framework shows understanding of theories and concepts that are relevant to the topic.

The theoretical framework improves the strength of the study in the following ways:

1. Explicit statement of theoretical assumptions.
2. Connects the research to existing knowledge.
3. Forces to formulate questions on the how and why.

(college of education, Alabama state university, 2013)

Developing the framework:

1. What are the problems which leads towards the research?
2. What are the key variables of the research?
3. Review relevant literature.
4. Research by design
5. Discuss the assumptions and outcomes of the research by design.
6. Answering the questions.

The purpose of the framework is to limit the scope of the relevant data which occur during the research. Also give a clear purpose of your research and keep the main goal on all steps in mind. (Torraco, R. J, 1997)

Starting with a clear design framework leads to a more structuralized research, which possible leads to a better outcome and gives a clear solution towards the problem which leads doing this research.

Problem statement

Out of research (talking to several companies including ABT and Schüco) occurred a very conservative attitude against façade engineering.

Often a standardised system is chosen from a certain company, this system has its own characteristics and only some of these characteristics matches the architectural vision.

Therefore this system is adapted to meet the appearance the architect has in mind. In this process an architect often has to do several concessions in the esthetical quality they had in mind.

There are a lot of other elements which stop innovation in façade design. Most of the time the client asking for certain certification, testimonials and guarantees. For new innovative façade systems it is difficult to get this required documents in time and on budget for the particular project. Therefore architects has to go with standardised systems.

In my research I am asking myself whether this is the right way to look at façade engineering, or should we think of a different approach.

During my research by design I will start with the architectural façade principles in a certain case to come up with a specific materialisation and building system suited for this specific façade for this case. Trying to get as close as possible to the architectural principles but stay honest about feasibility, durability and makeability.

Instead of choosing a material and a system and then tweak this to match the architectural design, but there is always a concession from the architect, to make this work with a standardised system.

Goals

Main objectives

1. Make a comparison between an approach outgoing from a common system and a more innovative approach.
2. Using a research by design to get a complete picture of the problems of using an innovative approach and how to get rid of this problems.

Sub objectives

1. Get to know new innovative materials.
2. Learn about façade design methodology
3. What needs to be done to make it possible to use innovative façade designs without additional charges compared to the common system?

Final products

A comparison between a traditional method and a more innovative method, to check if a new method is achievable concerning time, costs and to achieve the visual of the architect.

Main and sub Questions

Main question

Does a project specific approach perform better than a product specific approach on architectural and other requirements?

(Does a technical elaboration of the façade without looking at standardized systems in an early state lead to a better approximation of the façade principles by the architect relative to a technical elaboration where in an early state a standardized product, material or engineering company is chosen and changed to meet the requirements of the architect?)

Sub questions:

1. Which requirements should a façade meet?
2. Which engineering methods successfully transform an architectural concept to a buildable façade?
3. Which steps have to be taken using standardized products to transform the architectural concept to a buildable façade?
4. Which steps have to be taken starting from scratch to transform the architectural concept to a buildable façade?

Literature research

My literature research is split into three parts:

1. Reading a couple of books about the general principles and properties of façades.
 - a. Context the façade is in.
 - b. Basic principles: layered build up, openings.
 - c. User comfort/requirements.
 - d. Energy production
 - e. Existing systems
2. Looking into a couple of cases about innovative design.
 - a. Case 1: 3d model architect as startpoint.
 - b. Case 2: pre-rationalisation.
 - c. Construction follows form.
 - d. Starting from the material
3. Talking to a couple of companies about innovative façade design.
 - a. Alcoa
 - b. Schüco
 - c. Sorba
 - d. ABT
 - e. Faulknerbrowns architects

This research is the starting point of the façade engineering for the Tianjin educational centre in Tianjin China. With the literature research I hope to find a clear inside in how façades works, what the performance profile should be. Next to the façades on itself, I also want to look into the process of façade engineering and then especially to innovative processes, to get a global idea how innovative façade design is done and how it can be approved or used to get a better design.

Context

The façade protects from the hostile outer environment and forms a barrier between outside and inside. This separation has to take care of, ventilation, light entrance and a visible connection between the interior and the exterior. (Herzog, T., Krippner, R., & Lang, W. 2004)

For façade engineering and design we can assume that the exterior/climate cannot be changed, so these should be considered as primary conditions in a design. Internal conditions are most of the time not known from the start, during the process they will change. Because the outer and inner conditions have large impact on each other, the façade should be a very flexible system. (Herzog, T., Krippner, R., & Lang, W. 2004)

A façade is like a suit, tailored for its specific location and use. (Lovell J.,2010) To come to a successful façade design you have to consider the context. The context has its own unique set of requirements and climatic conditions (Temperature, air pressure and humidity)

A climatic analyse has to be done to come up with a couple of different climatic strategies for the 4 seasons during the year. (Lovell J.,2010)



Figure 3: typical African hut source: http://2012books.lardbucket.org/books/regional-geography-of-the-world-globalization-people-and-places/section_10/d0a9762586205edfeb0c354bd0e29469.jpg

Figure 4: Typical African people with typical clothing source: <http://www.panoramio.com/photo/82997498>



Figure 5: Iglo source: Fxfilexplore.com%2F2011%2Ffiglo-the-eskimos-house%2F&psig=AFQjCNHW4GldsGLqo2ZBVkUOrOQ7OjycHA&ust=1441546067885453

Figure 6: Eskimo's source: Fetenews.wordpress.com%2F2012%2F06%2F14%2Finuit-culture%2F&psig=AFQjCNHmW2jC2_YHWCWs5VtefXBpVB_e8w&ust=1441545826206137_e8w&ust=144154526206137

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Figure 7: an amazon hut source:

www.bandwmag.com%2Fgalleries%2Fcolor%2Fcontests%2F8%2Fcategories%2F4%2Fphotographs%2F22910&bvm=bv.102022582,d.d24&psig=AFQjCNEsNiemxm-77rpexj11vKha29EQ&ust=1441546375894946

Figure 8: Amazon/bush people source: flickr.com

Requirements which cannot be addressed by position and orientation of the building/façade can be influenced by technical systems, this will increase the energy consumption and maintenance costs. (Herzog, T., Krippner, R., & Lang, W. 2004)

Sun

The amount of sun and the angle of incidence are dependent on location, season and time of the day. (Herzog, T., Krippner, R., & Lang, W. 2004) Therefore it is important to take this into account while designing a façade.

another point of interest in a façade design is the relation with the needed heat to make a comfortable inner climate, to get the most out of this free, inexhaustible source of energy.

The sun reacts different on every material or surface treatment. Dark surfaces will absorb more of the solar warmth but light materials will reflect more of it.

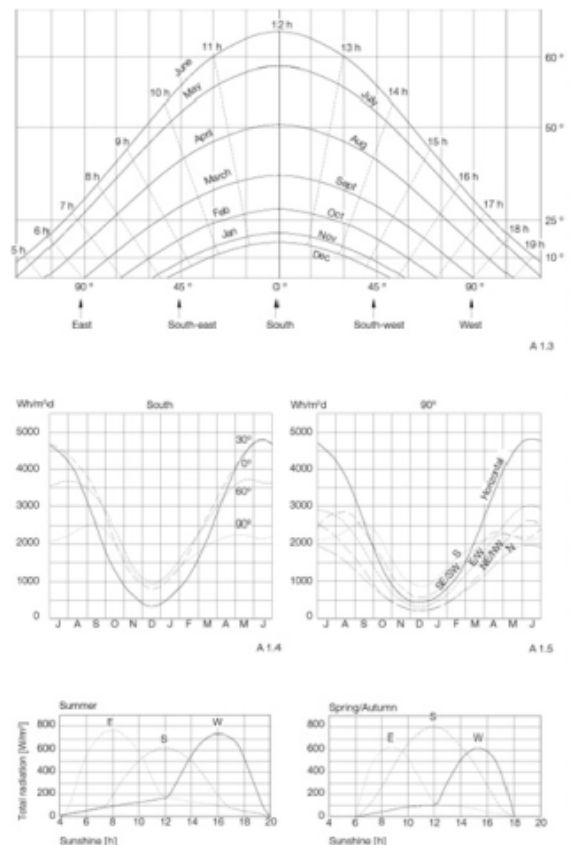


Figure 9: solar radiation and azimuth. Source: façade construction manual.

Basic Façade principles

Façades have a certain performance profile, which can be addressed to different functions and requirements. The goal in a façade design is to make an efficient as possible combination of individual components in such way that they enhance each other. (Herzog, T., Krippner, R., & Lang, W. 2004)

These requirements can be separated in functional criteria (light permeability, air permeability, energy production, adaptability and user control) and design criteria (layered buildup and amount/position of openings) These design criteria have an enormous impact of the look of the façade and therefore these will be explained more deeply.

From monolithic to multi layered build up

In the current practice façades are build up in different layers from different materials in different thickness. This layered buildup is needed because of the growing performance demands, for each different function the best suited material is chosen. Because the layers are separated from each other the façade can easily adapt to new insights or requirements, a layer can swapped easily with another material. (Herzog, T., Krippner, R., & Lang, W. 2004)

But there are also some risks in a layered buildup where attention has to be paid to else the performance of the façade decreases:

1. Increasing amount of contact area with other materials with the risk that materials are not compatible with each other.
2. Fake air cavities can be made, which decreases the insulated performance drastically.
3. Connections can penetrate other layers and thereby weaken these layers.
4. Higher production costs.
5. Increasing maintenance costs.
6. Increasing coordination between different companies.

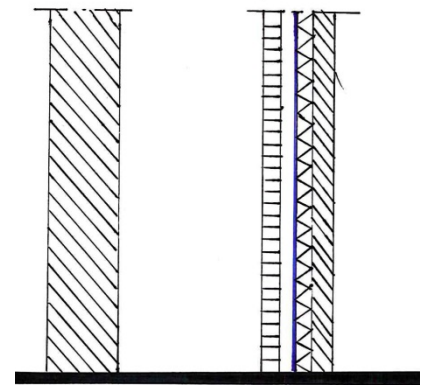


Figure 10: Layered build-up source: Drawing Luuk Jansen

Openings

When there is air and light needed inside a room openings in the façade are inevitable.

The position and size of the opening depends on the interior of the building

Light: the amount of daylight decreases when you are further away from the opening. The amount of light entering also depends on some external factors like orientation, time of the day and surrounding factors like trees etc.

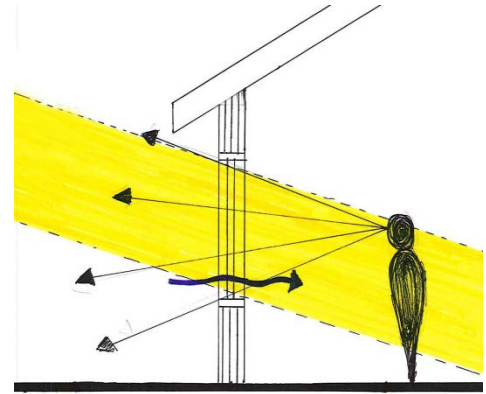


Figure 11: openings source: drawing Luuk Jansen

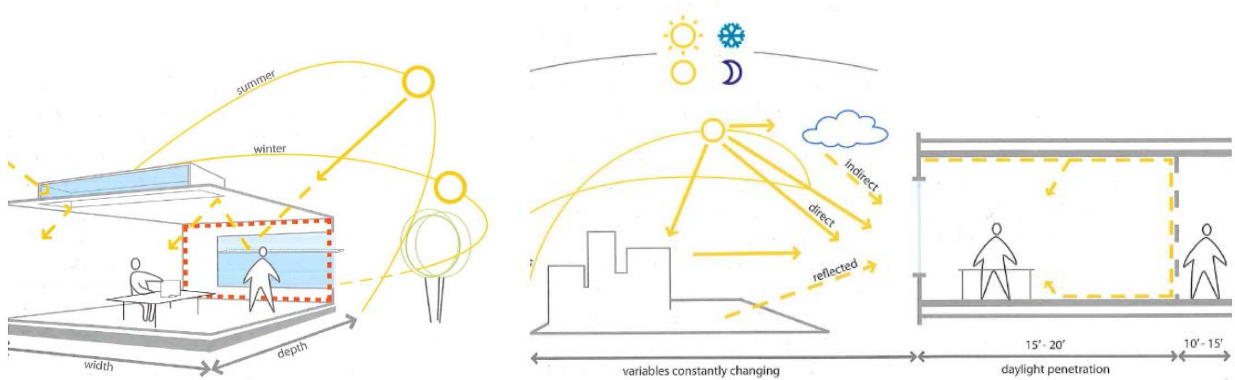


Figure 12: Daylight in relation with inner space source: building envelopes an integrated approach

Air (ventilation): easily said ventilation is the exchange from inside air with outside air. The wind has an enormous influence on this, because of pressure difference (created by wind suction or wind pressure) between inside and outside a flow will occur. (Herzog, T., Krippner, R., & Lang, W. 2004)

2 types of ventilation:

One sided: two openings as far away from each other vertically.

Cross ventilation: two openings, as far away from each other horizontally, because of pressure difference between the two sides of the building an air flow will be.

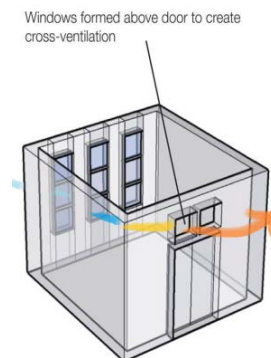
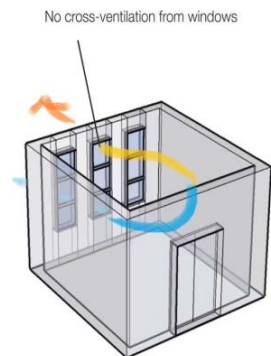


Figure 13: cross and no cross ventilation. Source: <http://elizabethgatlin.com/tips-and-tricks/natural-ventilation-tricks-to-cool-off-your-summer/>

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User Comfort

Comfort can be considered as happiness of body and mind affected by sensory stimuli. (sight, smell, hear, taste and touch) (Lovell, J. 2010)

The amount of comfort can positively be influenced to give the users an idea of control, for example a window that can be opened or the solar shading is manually operated. (Lovell, J. 2010) When control decreases the chance of sick building syndrome increase, Sick building syndrome means illness of one person or a group of persons which cannot be addressed to a certain disease but comes because these persons stay a certain time in a certain building (according to gezondheidsnet.nl)



PERSONAL

- Atopy (allergies, asthma, eczema)
- Seborrheic dermatitis
- Gender
- Increased tear-film break-up time

WORK-RELATED ACTIVITIES

- Work stress
- More time spent at photoduplication
- Carbonless copy paper
- More time at video display terminals
- Increasing amounts of time spent at work-station
- Lower job status and pay

BUILDING FACTORS

- Mechanical ventilation
- Inadequate maintenance
- High-fleecing surfaces (high surface area surfaces such as carpets and drapes)
- Carpets
- Recent renovation
- Inadequate operations strategies

Comfort requirements which can be influenced with the façade are: temperature, humidity, light, noise, view outside, wind current and air freshness.

Figure 14: sick building syndrome. Source: http://www.iloencyclopaedia.org/component/k2/item/493-sick-building-syndrome#SYS_fig2

Theoretically a comfortable building is a building with an inside temperature of 20 – 25 degrees Celsius and a humidity of 30 – 70%.

Temperature

But in practice it is more difficult because the comfort experience is influenced by many more criteria like: internal and external temperature, humidity, air speed, type of clothing, type of activity, age, physical condition, metabolism, perception and memory. (see the image on the right)

Next to this the human body is capable to adapt its metabolism in a couple of weeks to the climate it is in, therefore a much wider temperature range is considered comfortable. This phenomenon is called adaptive comfort. It also depends on the season and environment which temperature is suited. (Schittich, C. 2006)

With the founding of mechanical climate control, the roll of the façade becomes less important for climate control of the room it encloses, because the heat loss/cooling load is compensated by these mechanical installations. These systems are most of time not controllable by the user and therefore 80% of the users should consider it comfortable to function as a proper system and not causing a sick building syndrome. (Schittich, C. 2006)

This means that the optimal theoretical temperature is 20 to 25 degrees Celsius. But in summer a temperature of 27 degrees Celsius is acceptable, provided that humidity and surface temperature is controlled. In winter 18 degrees is acceptable.

The surface temperature is preferable maximal 2 a 3 degrees Celsius more or less then the air temperature. (Schittich, C. 2006)

Daylight

Daylight has a great influence on health, productivity and comfort. Openings in the façade allows daylight to enter the building.

A major problem is de development of artificial light. Artificial light allow for deeper buildings to maximize rentable floor space. The buildings are no longer optimized for daylight income. But daylight is very important to function as a human being. (Lovell, J. 2010)

Sometimes designers also forget the orientation of the building in relation with the position of

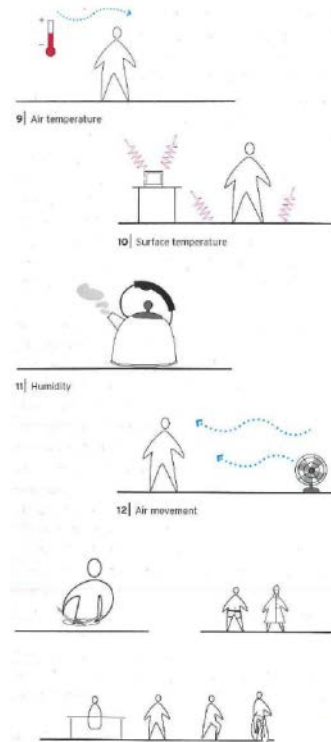


Figure 15: comfort factors
source: the future envelope 3.

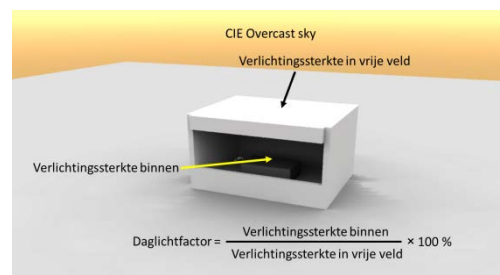


Figure 16 : daylight factor source: daglichtontwerp.nl

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openings, this means that solar shading always needs to be closed to protect from glare and thereby more artificial light is needed.

An important parameter to be considered is daylight factor (df). This value states the effectiveness of daylight in relation with artificial light. 2-5% is considered as good. (daglichtontwerp.nl)

Next to daylight entrance solar radiation also has to be taken into account. These two values solar radiation entrance (ZTA) and daylight entrance (LTA) influence each other, glass with a low ZTA value most of the time also has a low LTA value.

Potentials: balanced daylight entrance increases comfort and decreases the use of artificial light, therefore less power is needed. As a rule of thumb designers can consider 25 to 30% of the façade or 10 to 20% of the floor area as openings as a proper amount. (Lovell, J. 2010)

Possibilities: With the increasing capacity of computers, better simulations can be made and therefore designers have more powerful tools to make an estimation if the façade is suitable. Computers also can be used to develop adaptive systems to make façades which is optimized for every day of the year. (Lovell, J. 2010)

In practice this means dependent on the use, for normal activities 300 lux luminance, for workplaces next to a window 500 lux, for office gardens 700 lux with a high reflectance and 1000 lux with low reflectance. (daglichtontwerp.nl)

The light intensity should be between $\frac{2}{3}$ and $\frac{1}{10}$ of the field intensity, else the contrast will get too big which means dazzle and glare. (Schittich, C. 2006)

Air

To function as a human being it is important to have a certain amount of fresh air, with an average humidity.

This amount is around 40-60 m³ to provide one person with fresh air for an hour. For rooms where no people are staying is 0,3 times the room an hour sufficient. With a humidity of 30-70%.

With natural ventilation an opening of 200cm²/m² floor space should be sufficient, take into account that the maximum airspeed below 0,15 m/s should stay, else draft will occur making the place really uncomfortable. (Schittich, C. 2006)

Energy

Energy flows

By making an efficient and smart façade design, the cooling load and heat load can be minimized, whereas the total energy use dropped by 40%. (Schittich, C. 2006)

An important part of the façade is to protect the users of the building from glare, to make them work more efficient and experience a bigger comfort. The main function of anti-glare systems are to make sure the contrast is not too big in the interior space.

There are a lot of different suitable systems like curtains, horizontal and vertical louvres, screens, translucent glazing and electromagnetic glazing. All these systems have an impact on energy but also in the amount of light penetrating.

This solar shading has a far going impact on energy consumption of the building. For example external solar shading on the east and west façade will reduce the cool load with 50%, in comparison with façades without any solar shading. When this solar shading is placed to the inside the reduction is only 20%.

Internal solar shading in summer is not done, this because the cooling load will rise dramatically due to the absorption, in winter this will help to reduce the heating costs. (Schittich, C. 2006)

For example: a system with anti-glare protection and external solar shading, will increase the heating costs due to the missing absorption but also the cooling load will increase due to the anti-glare protection.

So the best solution will be a system which is adaptable to function throughout the whole year. (Schittich, C. 2006)

Energy production

To compensate energy losses there are systems to produce energy with the façade. Solar energy is the most logical way to do this because a lot of solar energy is presented on the façade. To use solar energy there are a lot of factors to take into account: day of the year, season, cloudy or clear sky. (Schittich, C. 2006)

There are 2 different kinds of systems:

1. Direct use (passive): solar energy is directly used without systems which transform the energy.
2. Indirect use (active): adding active systems which transform solar energy into heat or electricity.

There are mainly two active systems to collect solar energy and transform it into useable energy.

1. Solar collectors: A solar collector is a system which transforms solar energy into heat, distributed through a medium. (water or air) To maximize the energy production the angle of the panel and the orientation are important parameters to take into account. The energy production is around the 250-450 kWh/m² per year.
2. Photovoltaic cells: A photovoltaic cell transforms solar energy, directly into electricity. There are a lot of types, made from different materials and with a different efficiency (max 28% for silicon panels) For both systems it is important to consider the use in an early stage of the design else the performance will always be less. (Schittich, C. 2006)

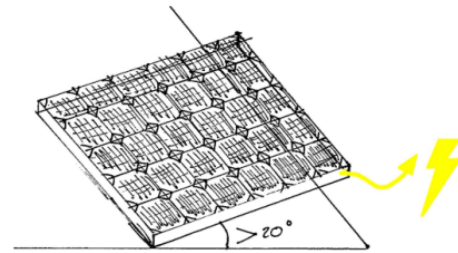


Figure 17: solar collector source: luuk Jansen

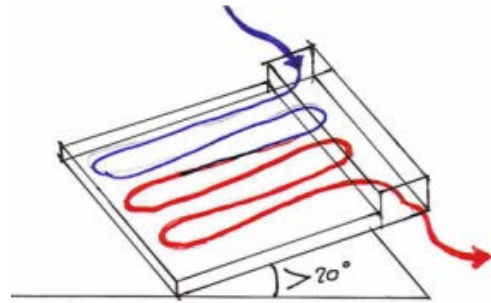


Figure 18: PV-cell source: Luuk Jansen

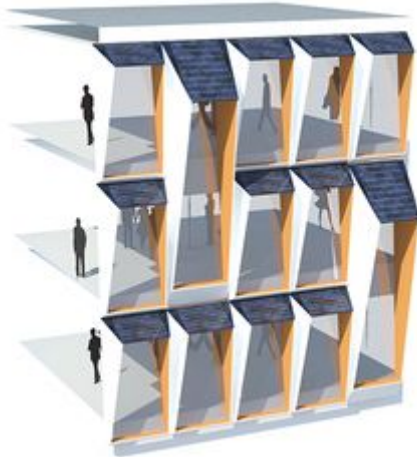


Figure 19: FIBP source: UNSTUDIO



Figure 20: Xiancheng industry source: UNSTUDIO

Existing systems and solutions

Because we are looking for an innovative façade design and approach I only want to name this part of the literature study, because it only will influence my thought with existing systems, in the end this book is used as an source for inspiration, not as an actual part of the research.



Figure 21: façade systems source: modern construction envelopes.

Cases

Case 1: 3d model of the architect as startpoint

Architect	ONL Architecten
Location	A2 Utrecht
Completion	2006
properties	Sound barrier with car showroom, because of a file to factory process 44000 different parts are made to make the shape buildable.
description	<p><i>The design is a pure example of Non Standard Architecture realized on a big scale. Basic principle for the NSA is that all compiled components are in principle different. The exception is the rule. If there are two similar components, it is not on purpose and not relevant. But all exceptions take place in a rigidly defined parametric design system. The adagium “one building, one detail” applies here. NSA is based on the new industrial production method of mass customization. Repetition of similar elements is no longer an economic advantage and it is not a valid argument for the aesthetics of the repetition. Repetition of the same elements is not anymore identical to beauty. The beauty of the NSA principle is now in the shaping of the control of series of thousands of different elements. To acquire these new techniques ONL learned from the designing of industrial products which moves or are moved with a certain speed. One example of this are the folding lines which fade out into the curved surface. Non Standard Architecture is the architecture of smooth transitions.</i></p> <p><i>The engineering of the geometry was developed in-house at ONL. ONL is entirely responsible for the precise data for the tens of thousands of integrated elements. For this purpose ONL has programmed an effective File to Factory process through the writing of project specific scripts. The scripts describe the geometry exactly and the data is registered in a database. This data is read by the software controlling the production machinery. There is a direct link between the 3d model of the architect and the production machines of the manufacturer. The steel manufacturer has subsequently written scripts for the further specification and production of the nodes.</i></p> <p><i>ONL and Meijers Staalbouw have developed a system of a point cloud of nodes and connection beams. Two different variants are developed for the Acoustic Barrier and the Cockpit, due to the</i></p>

different conditions for both constructions. The Acoustic Barrier has as only demand to consist of 10 kg/m² mass without noise leak. The Cockpit has insulated glazing and through the 'inflating' of the volume the dimensions for the connection beams and the triangular glassplates are twice as big. Both constructions have in common that the complexity is completely integrated in the nodes so that the connection beams are maximally simple. The triangles are also produced as flat surfaces. Double curved glass are not only more expensive, but wouldn't enforce the overall image.

Meijers Staalbouw has offered the whole Acoustic Barrier as a product with a fixed price in close collaboration with ONL. There has been no extra labour. Also for the Cockpit Meijers Staalbouw offered the whole shell [steelconstruction + concrete floors + glass façades + aluminium façades] for a fixed price without mentionable extra work required. The traditional tendering doesn't work with designs in which construction and geometry are integral part of the architecture. The knowledge of the production and the manner of communication between the architect and the manufacturer needs to be processed in the preliminary stage of the design. This cannot be postponed till the tendering. The Hessing Cockpit building and the Acoustic Barrier would be twice as expensive if they would be tendered on the market as a traditional bidding. The shell of the Cockpit as well as the whole Acoustic Barrier are realized within the budget agreed upon. (archdaily, retrieved from <http://www.archdaily.com/15400/acoustic-barrier-onl/> on 7 mei 2015)

Images



Figure 2: structural note (archdaily)

Luuk Jansen (4065573): an innovative façade design approach.

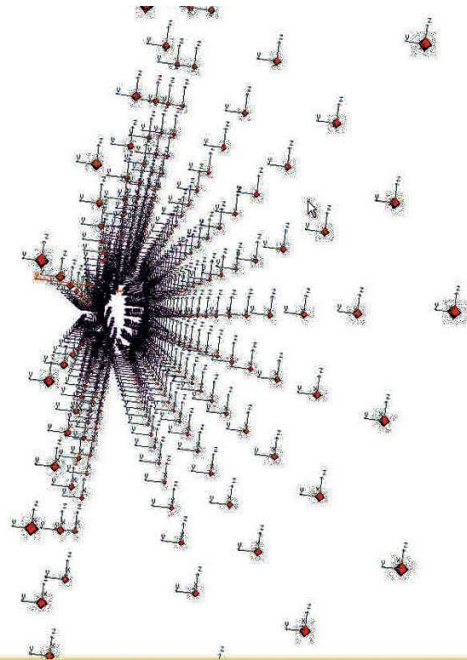


Figure 3: pointcloud model (de architect)

Explanation of the detailing

“The cockpit building and the sound barrier are a network of interconnected variable details, a volume change occurring in the sound barrier is the result of not merely changing one variable. It is the result of a coordinated change in the network, variables are gradually changed and controlled by the underlying control model. Individually, these changes are non-linear, sometimes even counter-intuitive. Grouping the changed variables into a catalogue, like one often does with regular building products like windows etc. is futile, there are too many variables too account for.

Instead, we embraced the fact that indeed everything is different and we catalogued the amount of variables that can be changed in the factory process as is.

The illustrated detail is interesting because it is an excellent example of convergence both in detail and in process. The partners involved in developing a good detail on our control structure were Meijers Staalbouw and Pilkington Benelux.

The illustrated A2 façade is an open construction clad with structural glazing. It was understood that this detail could not be delaminated. Delamination would mean viewing the façade as not one but two shells, a construction shell and a glass shell. Usually this is done because of the fact that steel construction and glass application consider fundamentally different margins of error acceptable. In steel construction of this scale margins of 10-20 mm are acceptable, for structural glazing however one considers margins of 3-6 mm.

acceptable. Delamination proved to be very inefficient, for it implies a secondary construction that neatly follows the primary construction. Pilkington would have to invest effort increasing a secondary construction with its desired margins based on our 3d control model whereas Meijers would have to invest the exact same effort also based on our control model.

Instead of delaminating it was decided to converge the details into one detail to be constructed by Meijers which would incorporate mounting pins for the structural glazing. Theoretically this proved to be possible.

Using custom built scripts Meijers was able to construct all details on top of the control structure provided by us.

Red is the main reference grid, green is the derived heart line of the construction, cyan is the orientation of the detail. In the meantime, based on extreme parameters, Pilkington tested her assumptions on glass assembly and joint flexibility in a one to one (albeit wooden) mock-up in their workshop: Dow Corning Silicones' properties tested. Pilkington has ordered all necessary glazing based on the red reference grid, although it is understood that between the theoretical measure and the actual dimensions deviations might occur as a result of various unforeseen factors (shipping, non-round round profiles etc.), the glass production factory is at the time of this writing compiling optimal nested cutting patterns of all glass elements based on the theoretical measures. When the first part of the construction is erected on site, a measuring crew will measure specific reference points incorporated in the construction, which are compared with the theoretical dimension. In the case of a deviation, the difference is communicated with the factory.

This extra control system is brought into place as a means to compensate for the fact that the desired margin of error might not be exceeded. At the time of this writing the actual assembly of the steel construction is planned in four weeks and even though we are convinced that the desired margins in the steel construction will not be exceeded, at this moment we cannot rule out the possibility that the control team will find deviations." (Boer s., 2004)

Comparison of the architectural design and the In this example the design the architect made is literally translated to the real building. Because of

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final building:

this file to factory process the architect has lot of control over the actual outlook and outcome of the building process, also the complexity is reduced cause of the use of one specific detail which can be used for most of the situations, this detail is controlled by these points, curves and vectors. The computer model of these nodes are directly transformed in code the machines can use to made all the different needed components, In this case the construction contractor makes a piece of software which automatically make the 44000 connection points, transferred this to the machine and bend, cut and weld these together.

Which design methodology is used:

File to factory, so the architect makes a 3d model, this 3d model is translated to curves, vectors and points, with these curves, vectors and points, the steel engineer can make the structural nodes and then directly send to the cnc mill, the glass contractor can use these vector, curves and points to directly make the machines the right glass panels. In this way a very complex building can be built on a smart way with maximal use of machines.

Case 2: pre rationalisation

Architect	Foster + Partners
Location	London, United Kingdom
Completion	2004
properties	High rise rotated tower
description	<i>“London’s first ecological tall building and an instantly recognisable addition to the city’s skyline, this headquarters designed for Swiss Re is rooted in a radical approach – technically, architecturally, socially and spatially. Forty-one storeys high, it provides 46,400 square metres net of office space together with an arcade of shops and cafés accessed from a newly created piazza. At the summit is a club room that offers a spectacular 360-degree panorama across the capital.</i>

Generated by a circular plan, with a radial geometry, the building widens in profile as it rises and tapers towards its apex. This distinctive form responds to the constraints of the site: the building appears more slender than a rectangular block of equivalent size and the slimming of its profile towards the base maximises the public realm at street level

Environmentally, its profile reduces wind deflections compared with a rectilinear tower of similar size, helping to maintain a comfortable environment at ground level, and creates external pressure differentials that are exploited to drive a unique system of natural ventilation.

Conceptually the tower develops ideas explored in the Commerzbank and before that in the Climate office, a theoretical project with Buckminster Fuller that suggested a new rapport between nature and the workplace, its energy-conscious enclosure resolving walls and roof into a continuous triangulated skin. Here, the tower’s diagonally braced structure allows column-free floor space and a fully glazed façade, which opens up the building to light and views.

Atria between the radiating fingers of each floor link vertically to form a series of informal break-out spaces that spiral up the building. These spaces are a natural social focus – places for refreshment points and meeting areas – and function as the building’s ‘lungs’, distributing fresh air drawn in through opening panels in the façade. This system reduces the building’s reliance on air conditioning and together with other sustainable measures, means that it uses only half the

energy consumed by a conventionally air-conditioned office tower.” (Foster + Partners retrieved from <http://www.fosterandpartners.com/projects/30-st-mary-axe/> at 6 mei 2015)

Images



Figure 4: first design sketches (foster + partners)



Figure 5: realised (foster + partners)

Explanation of the detailing

Vertical support is provided by 2 storey high a frames, which make up a steel diagrid structure which is efficient to windloads. These out of tubing composed A-frames are wrapped in fireproof aluminium cases, kite shaped in section, with two short sides and two long sides to connect better to the glass panels, flows better over in it.

These glass panels have a trapezoid flat shape with two different glass infills to accent the rotation which are either attached to each other or connected to the diagrid frame.

Comparison of the architectural design and the final building:

The first sketches of the architect shows a complete curved building which has a double curved façade. In the later stage of the design, the building is more rationalised in such way it can be constructed with standardised elements

Which design methodology is used:

Starting with the vision of the architects transforming it in a design which looks somehow the same but with an easier way of constructing because of all the same panels instead of thousands of different ones.

Case 3: Construction follows form

Architect	Zaha Hadid
Façade contractor	Werner Sobek
Location	Baku – Azerbaijan
Completion	Yes, may 2012
properties	Double curved flowing façade design
description	<i>“The basic idea underlying the design is that the main building develops its form from the plaza in front of it. Architecturally, the plaza is divided into strips running from east to west; these strips wrap upwards around the main building and create a free-flowing 3D shape. The geometry of the building envelope is reflected in the interior.” (Steel Construction Volume 8, Issue 1, pages 65–71, February 2015)</i>

“The design of the Heydar Aliyev Center establishes a continuous, fluid relationship between its surrounding plaza and the building’s interior. The plaza, as the ground surface; accessible to all as part of Baku’s urban fabric, rises to envelop an equally public interior space and define a sequence of event spaces dedicated to the collective celebration of contemporary and traditional Azeri culture. Elaborate formations such as undulations, bifurcations, folds, and inflections modify this plaza surface into an architectural landscape that performs a multitude of functions: welcoming, embracing, and directing visitors through different levels of the interior. With this gesture, the building blurs the conventional differentiation between architectural object and urban landscape, building envelope and urban plaza, Figure and ground, interior and exterior.

Fluidity in architecture is not new to this region. In historical Islamic architecture, rows, grids, or sequences of columns flow to infinity like trees in a forest, establishing non-hierarchical space. Continuous calligraphic and ornamental patterns flow from carpets to walls, walls to ceilings, ceilings to domes, establishing seamless relationships and blurring distinctions between architectural elements and the ground they inhabit. Our intention was to relate to that historical understanding of architecture, not through the use of mimicry or a limiting adherence to the iconography of the past, but rather by developing a firmly contemporary interpretation, reflecting a more nuanced understanding.

Responding to the topographic sheer drop that formerly split the site in two, the project introduces a precisely terraced landscape that establishes alternative connections and routes between public plaza, building, and underground parking. This solution avoids additional excavation and landfill, and successfully converts an initial disadvantage of the site into a key design feature.

Geometry, structure, materiality. One of the most critical yet challenging elements of the project was the architectural development of the building's skin. Our ambition to achieve a surface so continuous that it appears homogenous, required a broad range of different functions, construction logics and technical systems had to be brought together and integrated into the building's envelope. Advanced computing allowed for the continuous control and communication of these complexities among the numerous project participants.

The Heydar Aliyev Center principally consists of two collaborating systems: a concrete structure combined with a space frame system. In order to achieve large-scale column-free spaces that allow the visitor to experience the fluidity of the interior, vertical structural elements are absorbed by the envelope and curtain wall system. The particular surface geometry fosters unconventional structural solutions, such as the introduction of curved 'boot columns' to achieve the inverse peel of the surface from the ground to the West of the building, and the 'dovetail' tapering of the cantilever beams that support the building envelope to the East of the site.

The space frame system enabled the construction of a free-form structure and saved significant time throughout the construction process, while the substructure was developed to incorporate a flexible relationship between the rigid grid of the space frame and the free-formed exterior cladding seams. These seams were derived from a process of rationalizing the complex geometry, usage, and aesthetics of the project. Glass Fibre Reinforced Concrete (GFRC) and Glass Fibre Reinforced Polyester (GFRP) were chosen as ideal cladding materials, as they allow for the powerful plasticity

of the building's design while responding to very different functional demands related to a variety of situations: plaza, transitional zones and envelope.

In this architectural composition, if the surface is the music, then the seams between the panels are the rhythm. Numerous studies were carried out on the surface geometry to rationalize the panels while maintaining continuity throughout the building and landscape. The seams promote a greater understanding of the project's scale. They emphasize the continual transformation and implied motion of its fluid geometry, offering a pragmatic solution to practical construction issues such as manufacturing, handling, transportation and assembly; and answering technical concerns such as accommodating movement due to deflection, external loads, temperature change, seismic activity and wind loading.

To emphasize the continuous relationship between the buildings's exterior and interior, the lighting of the Heydar Aliyev Center has been very carefully considered. The lighting design strategy differentiates the day and night reading of the building. During the day, the building's volume reflects light, constantly altering the Center's appearance according to the time of day and viewing perspective. The use of semi-reflective glass gives tantalizing glimpses within, arousing curiosity without revealing the fluid trajectory of spaces inside. At night, this character is gradually transformed by means of lighting that washes from the interior onto the exterior surfaces, unfolding the formal composition to reveal its content and maintaining the fluidity between interior and exterior.

The Heydar Aliyev Center's design evolved from our investigations and research of the site's topography and the Center's role within its broader cultural landscape. By employing these articulate contextual relationships, the design is embedded within this context; unfolding the future cultural possibilities for Azerbaijan." (zaha hadid retrieved from: <http://www.zaha-hadid.com/architecture/heydar-aliyev-centre/> on 6 Mai 2015)

Images



Figure 6: overview (Iban baan)



Figure 7: Façade detail (Helene Binet)

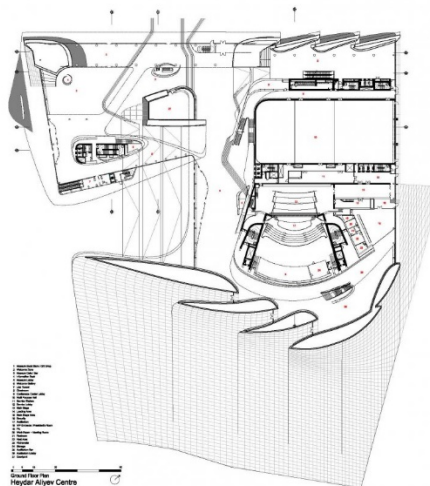


Figure 8: floorplan (Zaha Hadid)

Explanation of the detailing:

The solid skin of the building is a 3d freeform geometry. The engineers have tried to make the vision of the architect possible, by splitting this solid skin up in different layers.

The first layer is the waterproofing layer this layer

Luuk Jansen (4065573): an innovative façade design approach.

is build out of several layers, the first layer is a prefabricated weatherproofing tray system, which rests on the top chord nodes of the main roof structure space frame and thus exhibits a faceted geometry. The trays consist of two U-section purlins, a trapezoidal metal deck in between, a self-adhesive vapour barrier, a layer of rigid, non-flammable rockwool insulation boards and a weatherproofing membrane on top, in a special overlapping system covering the gaps between two adjacent trays.

On top of this waterproofing layer a secondary steel structure is built to support the open joint rain screen cladding system. This steel structure is attached to the nodes of the primary space frame structure with rods.

On top of this secondary steel structure the solid skin panels are placed. These panels are defined by architectural joint lines, which are also flowing into the main square. To give the appearance of solid stone blocks all the panels have edge returns of 12 cm on the 4 sides of the panel. To accent the horizontal lines, these joints are 40 mm wide, the vertical joints are therefore 10 mm wide. This means a very precise production process with no margin for error.

Due to production time, output capacity, etc. most of the panels are Fiber reinforced concrete (the roof part till 3 meter above the ground) the other panels are made out of fiber reinforced polymers.

The complex inner cladding is made out of fiber reinforced flexible boards on a framework of tubing with a 50x50cm grid. Which also has a complex 3d shape. (*zaha hadid retrieved from: <http://www.zaha-hadid.com/architecture/heydar-aliyev-centre/>*)

Comparison of the architectural design and the final building:

The architect had a flowing architecture in mind. I think the contractors succeeded in making the building in that way the architect wanted. Only the strong horizontal lines are a bit less visible due to the small panels which were needed to get the prefabricated panels on sight.

Which design methodology is used:

The engineers of the façade use a methodology of separation and splitting, using systems which are the most suitable for the function by the given shape.

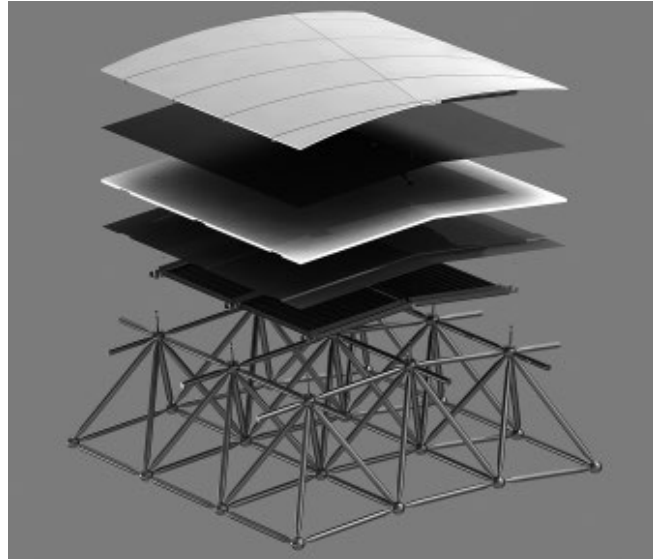


Figure 9: Exploded view of buildup (Steel Construction 8)

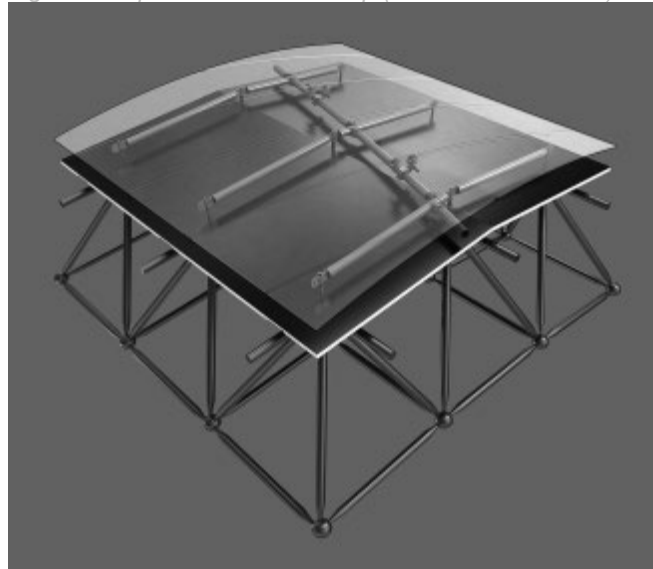


Figure 10: isometric view (Steel Construction 8)

Luuk Jansen (4065573): an innovative façade design approach.

Case 4: Starting with the material

Architect	Grimshaw architects
Location	Leicester, England
Completion	Jun 2001
properties	40 meter heigh transparent tower
description	<i>“Grimshaw’s design for The National Space Centre combines an exhibition venue of international standing and a new centre for education and research that is affiliated to the University of Leicester. An outer layer of perforated metal homogenises the structure’s external appearance, but as the visitor approaches the centre, the varying opacity of the building’s skin is revealed. The Centre contains the main public attractions and also houses the administrative, teaching and research facilities connected with the university.</i>

This building is visually related to the entrance boulevard by the spiralling geometry of its landscaped roof plane. This spiral culminates in the geodesic dome of the planetarium, which perforates the hollow-ribbed concrete roof slab and acts as a foil to the soaring vertical form of the Rocket Tower. The dimensions of its exhibits have defined the volume of the tower, with its highest point dictated by that of the largest rocket installed. The envelope is highly efficient, enclosing a complex three-dimensional space with ETFE cladding pillows and minimal secondary support mechanisms.” (Grimshaw architects, retrieved from <http://grimshaw-architects.com/project/the-national-space-centre/> on 6 mei 2015)

Images



Figure 11: view to the buidling (Grimshaw architects)

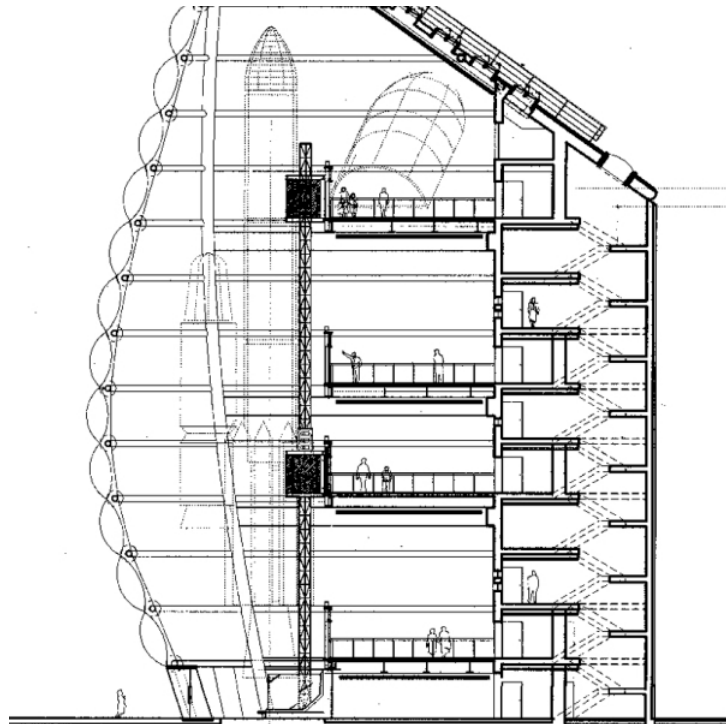


Figure 12: Section (walking architecture)

Explanation of the detailing

Comparison of the architectural design and the final building:
Which design methodology is used:

The skin of the tower is build up out of a steel framework with an multilayer ETFE cushion infill, these cushions are inflated for rigidity.

The architect start designing with the intended material in mind, and therefore the design looks exactly the same as the constructed building.

The architect starts from the intended material to make the design. So first choosing the right material and then making the architectural design.

Companies

Alcoa



Figure 13: metal cladding source: ALCOA



Figure 14: Vinoly tower source:
<http://www.e-architect.co.uk/holland/mahler4-office-tower>

The company: Alcoa is a company specialized in aluminium products, not only for façades but also for the automotive industry. Because of an increasing height of buildings there were lighter materials needed, aluminium was the perfect solution. (Knaack U., Klein T., 2010)

Architecture as an industrial product: Every building has its own unique charisma. The façade is unique but also the back construction is for every building different. Each building is a composition of the common and tested systems, each composition is unique in its kind. The unique character makes standardisation difficult. Because of a large variety of profile, façade contractors can make an unique façade again and again. The art is developing a new system that is adjustable with in the method of the system of different esthetical quality. (Knaack U., Klein T., 2010)

Chances in the architecture: Integration of a sustainable façade: an energy neutral façade, which is adjustable in chancing indoor and outdoor climates. Alcoa sees chances here because these systems exists but are not a lot use because many disciplines have to come together. Alcoa thinks that an adjustable façade whereby every discipline has its own input, is the future. (Knaack U., Klein T., 2010)

Schüco – interview Tom van Dorp



Figure 15: parametric façade concept
source: Schüco



Figure 16: Barcelona torre Telefonica source: Schüco

1. What kind of company are you and how is this related to façade design/engineering?

Schüco is a progressive company, with the headquarters in Bielefeld – Germany. Schüco is a company which develop façade systems, focused on the aluminium extrusion profiles used. These profiles are shipped to façade builders who combines the profiles in a complete façade system. Next to the profiles, Schüco also provides their own locks and hinges.

Schüco tries to profiling itself as an innovative company always trying to be a step forwards then the rest of the market. For example the latest innovations: a curtain wall with a 35 mm profile width and a parametric façade.

2. Which steps do you take to develop a standard façade?

- 1. The architect comes with a certain question.*
- 2. First seek a solution with standardised systems, in such way the architectural vision is respected. Sometimes we need to seek the extremes inside the system.*
- 3. Looking for a façade builder which can actually make this solution, they will further engineer the system according to wall thickness etc.*

3. The complexity of façades are growing, for example double curved or blob like buildings. Do you notice this?

Often complex shapes are rationalised and segmented. In such way these façades can be made with standardised products. Double curved elements are also possible but there are some boundary conditions and not everything is possible, for example the radius of the bend etc.

More and more custom solutions are used. Engineers will make a new system based on the systematics of the system.

4. How do you think to cope with the growing complexity?

1. *Project specific solutions, which means the use of special/custom dies.*
2. *Seeking the edge with standardised products and develop project specific solutions to standardised systems.*

5. Which steps are you taking to come with a successful engineering for a complex project?

1. *First we try to transform a standardised system in such way that it looks as the architect has in mind.*
2. *If this did not work, then new profiles and systems are designed, within the basic principles of a certain system. → Project size (the amount of meters profile) is important considering such a custom solution because of the price of a dies.*

6. The current way of façade design is to choose a standard system, looking for the edge of the system and try to approach the architectural vision as good as possible, is this opinion right?

This is right, but by a growing complexity or a specific aesthetic wish a project specific is more and more used.

7. Leads such an approach to a lot of discussion with the architect or has the architect to do a lot of concessions?

Often Schüco is asked to think with the architect in an early stage in the design. Schüco is trying to come up with a technical possible solution together with the architect. Often the technical feasibility is difficult because every system has his own characteristics and edges, when you do not take these into account problems with moisture or stiffness will occur.

If the architect needs to do concessions it is mostly when the contractor steps in, because then it is about the money.

8. When an architect comes with a problem which is not directly compatible with a standardised system, what will be your approach?

A project specific design is followed, Schüco engineers will come up with a completely engineered system. Then a suitable façade builder is contacted. (Usually façade builders only take the profiles and make a façade out of that, Schüco will give them some tips to use these but there are no hard rules. Sometimes a façade builder goes over the edge of the system and get problems with condensation and water displacement)

The goal is to engineer together with the façade builder a system.

9. In can imagine an approach where you develop a system with the architectural design in mind, in such way that there are no concessions needed from the architect.

The system stays the same for every project, for example curtain wall with his own characteristics. But the esthetics can be completely different.

10. Technical requirements will getting higher and higher, concerning insulation, shading etc. How are you thinking to cope with this?

U value calculation of the complete frame and u frame calculations for the frame apart.

This U Frame depends on the profiles and the amount of aluminium. Schüco thinks you should consider this for every different profile on its own and not for the system, because you should try to optimize each individual profile.

ABT – interview to Rowan van Wely and Rutger Callenbach.



Figure 17: Hilton Amsterdam source: ABT



Figure 18: Stadshuis Nieuwegein source: ABT

1. **Often a client will come at ABT with a certain system in mind, how do you handle this? Is ABT looking to a way to make this system work or will a different sort of system suggested with the same esthetic quality?**

Rowan: If a Definitive design (DO) comes in, I always try to find the deeper thought behind the system, what are the architectural decisions took to come up with this system. What does the architect want to achieve with this façade. This depends on the architect, some architects comes with a set of assumptions, ABT is then in the lead to define the system. (For example Neutelings Riedijk) Other architects come with a solution (OMA for example) then you have to come to the core of the design. The DO should not be seen as the definitive solution but as an assumption.

2. **Sometimes the client comes in an early stage to ABT with a certain problem, what are the steps you will take to come up with a suitable technical elaboration?**

Much more conceptual, starting with the assumptions and requirements and then starting the technical elaboration. We will come up with a couple of strategies which can come up with a system which meets the architectural principles. They are reviewed and then the best variant will be used for further elaboration.

3. **Complexity of the façade is growing, Blob shapes and double curved façades. What do you notice from this?**

I think complexity is not growing. We do blob shapes since the 90s. The current complexity is more the regulation and climatic requirements. More and more elements are needed to meet these requirements.

Rowan: We see less blob architecture, clients no longer that interested in shape but more in energy performance.

→ ABT is very capable to go with these tendency because all the building disciplines are present at our offices.

4. **The current way of façade design is to choose a standard system, looking for the edge of the system and try to approach the architectural vision as good as possible, is this opinion right?**

I agree. Starting with a design looking for the suitable system. After the tender the contractor will possibly come with a different system, you have to test this with the image you have in mind.

5. **In can imagine an approach where you develop a system with the architectural design in mind, in such way that there are no concessions needed from the architect.**

→ *In essence every system has the same characteristics, you only have to dig deep enough.*

→ *Everything is buildable, only the cost will grow with the complexity.*

→ *For new systems you have to do tests to get certification and such.*

→ *If there is no certification for the system, then you have to convince the client to use the system.*

→ *You can develop a system within an existing system.*

→ *The image of the architect is the main requirement but it is to the client if he wants pay for it.*

The power of ABT is that they speak the language of both the contractor as the architect and therefore we are the ideal partner to make the architectural design actual build. An architect most of the time is not capable to get this done because they speak on a more conceptual level then the contractor, which are more down to earth.

FBA – interview with two architects



Figure 19: Olympic Velodrome proposal source: FBA



Figure 20: Chill factor source: FBA

1. What kind of company are you and how are you related to façade design?

FBA is an architect, founded in 1962 with as goal to design award winning buildings which create an inspiring atmosphere. FBA is located in the UK.

2. What are the design steps you take to come up with a façade design?

- **To what extent are you taking technical feasibility of the façade into account during the early design process?**
- **If the design includes a freeform shape, to what extent a pre rationalisation are you taking into account?**

Technical architect: We try to develop all aspects of the building design together. It is important to develop a comprehensive brief that identifies the client's needs and aspirations. Almost inevitably the early stages of this process concentrate more on understanding process/people flows and area and volumetric requirements of the brief. We endeavour to develop a strong concept for the design that will help inform design decisions a more and more detail is developed. Often we develop strong forms driven by the arrangement of the functions and in response to the unique context of each project. (e.g. Nijmegen, Den Haag, Manchester velodrome, Apeldoorn, Toronto, Derby).

During the early design process the technical feasibility of the façade can normally be achieved using a number of different materials and construction techniques. The design concept, context, appearance, texture, durability, sustainability, budget and buildability will all have an impact on the façade design and material selection.

I can't say I have ever designed a 'free form' building. Velodromes generate curved façades but they are tightly controlled to ensure building efficiency in terms of area and volume enclosed. The geometry of the 'ribbon' element at Den Haag is sinuous and curving and emblematic of movement but is carefully considered in 3 dimensions and has a consistent symmetrical geometry. So on this basis we are always trying to provide an order to the design of the façade using components of an appropriate size.

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Conceptual architect: The only limit is cost. Any form has a physical discipline. It is important to understand the system before any further developments.

- 3. The current way to come up with a façade design is to take an existing system which is transformed and tweaked to make it look like the way the architect wants, are you agree with this?**

Technical architect: Yes unless the building budget (and client aspiration) allow a unique product to be developed.

Conceptual architect: No.

- 4. The façade system is subordinate to the aesthetic quality, to what extent are you taking the underlying technique into account during the design phase?**

Technical architect: The façade system/design is integral to the aesthetic not subordinate. Buildability is a fundamental consideration during the design process.

Conceptual Architect: Need to be reviewed with the building concept.

- 5. What are you missing in the current available systems and façade principles?**

Technical architect: Never really considered what is missing but we do strive to get the most out of the materials/products we use (e.g. Maximising spans, maximising glass pane sizes). I believe we will move to more off site pre fabrication of components.

Conceptual Architect: Understanding the emerging technologies and their impacts on the façade making process, as well as the implication on the products.

SORBA – Eric Hogeboom



Figure 21: Laboratory Groningen source: Sorba

1. What kind of company are you and how are you related to façade design?

Soba projects realises innovative façade in national and international. Sorba is specialist in closed façade parts, but when we can add value we also can do glass parts. Sorba only takes special products, standardised solutions are not our business.

2. Which steps are you taking to come with a successful engineering for a complex project?

Sorba is involved in projects on two moments. Sometimes the architect comes in an early stage, with a question to think with them how to realize a certain design. At this stage Sorba will make a global design, but they will not do a complete engineering because there is no agreement.

When Sorba gets the commission then they do the engineering.

Sorba has the capacity to make computer models, depending on the complexity, when there is a high risk on clashes then a detailed model will build, else a mass model is sufficient.

3. Complexity of the façade is growing, Blob shapes and double curved façades. What do you notice from this?

The question is in which way complexity is growing, often the design is rationalised in an early stage during the design. A segmented façade is better buildable and will cost less.

4. How do you think to cope with the growing complexity?

We did not have done a lot of complex projects in our eyes, but we are capable to do so.

5. The current way of façade design is to choose a standard system, looking for the edge of the system and try to approach the architectural vision as good as possible, is this opinion right?

Sorba is not doing standardised products, but in the practise around is we see this happening.

Sorba is trying to do as much in consideration with the architect to achieve the architectural design, sometimes this lead to a lot of discussion because what de architect wants is often too expensive.

6. Technical requirements will getting higher and higher, concerning insulation, shading etc. How are you thinking to cope with this?

With the requirements in mind we are looking for partners with how we can realise it.

Research by design

The core of my research is making a design for a case. Important in this research by design is the comparison between a project specific façade engineering and a product specific façade engineering.

First the case I was going to work on was the Boijmans van Beuningen new museum in Rotterdam. This double curved mirrored building, designed by MVRDV has a very complex façade with lots of opportunities, but due to a difficult juridical process with the municipality of Rotterdam, I was not allowed to proceed with the research on this building.

Therefore MVRDV has another case for me, this is the Tianjin educational centre library, the façade is on first sight less complex but when you look deeper there are some interesting problems. For example a 17 meter high façade and louvres in concrete 400 mm wide. Also the climate inside the building is quite a challenge because placing a complete glass box in a climate where the winter is -10 and the summer +30 needs special attention to the façade, later I will go deeper in the climatical, comfort and location requirements.



Figure 22: Render Parkside source: MVRDV

Architectural vision and starting point

The building concept of the façade from MVRDV is showed in the image below. The design starts with a glass box with louvre of 400x100 in front of it. A cylinder (purple in the image below) is pushed in this box, where this cylinder is going through a louvre this louvre is cut at this point and the part inside the cylinder is removed. The louvres flowing inside this “gap” creating terraces in a big atrium.

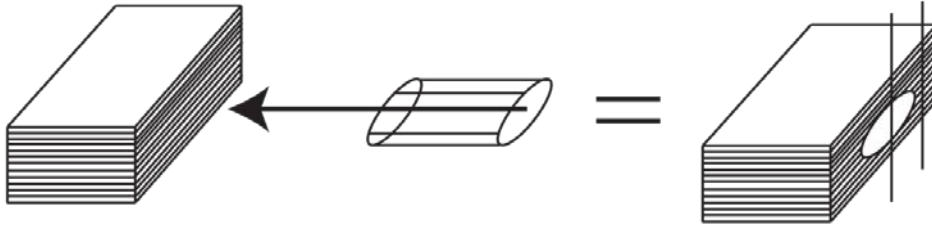


Figure 23: architectural design explained source: Luuk Jansen

The common part in the façade is a complete glass façade (purple in the image below) on some parts concrete louvres are placed in front of it and on some parts not.

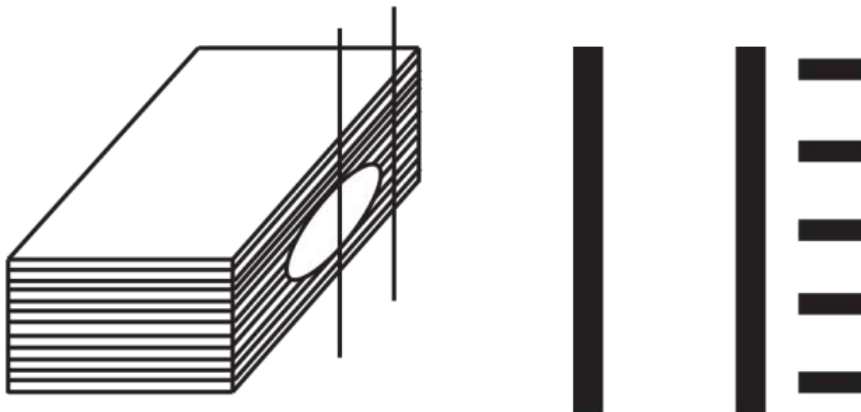


Figure 24: architectural design explained source: Luuk Jansen

Context and climate - Tianjin

Tianjin is a harbor city in the north of China and is one of the five national central cities of China. The city province of Tianjin is next to Hebei and Beijing, in the east it borders on the Bohai sea and the yellow sea.



Figure 25: world map source :Google maps

Tianjin is the biggest coastal city in the northern China and after Shanghai, Beijing and Guangzhou the biggest city of China. Since the 19th century Tianjin forms an excess port to the capital Beijing.

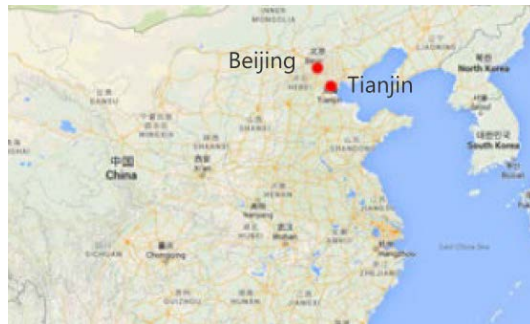


Figure 26: map of China source: Google maps

History

During the Tang Dynastie (618-907) Tianjin was an important commercial town. Till 1858 when the harbor was opened, Tianjin was a garrison town. In 1900 during the boxer rebellion, the city was damaged severely and was rebuild in western style. In 1984 Tianjin became an open city, which means the city was open for foreign investments. (chinatouronline.com)

Climate

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Dec
Average high	1,8	5	11,7	20,5	26,1	30,1	31	30,2	26,3	19,7	10,6	3,9
Average low	-7,5	-4,9	1,3	8,9	14,6	19,7	22,7	21,9	16,4	9,3	1,3	-4,9
percepitation	3,3	4	7,7	20,9	37,7	71,1	170,6	145,7	46,1	22,7	10,4	4,1
humidity	56	54	53	51	56	64	76	77	68	64	63	59
mean monthly sunshine hours	178	176	205	229	265	251	217	223	223	211	173	166

Figure 27: monthly climate Tianjin source: <http://www.city-data.com/forum/weather/2041494-climate-beijing-vs-tianjin.html>

Tianjin is located on the east shore of the European-Asian continent, which is affected by monsoons. Due to this temperate monsoon climate, the area is windy and dry in spring, hot and rainy in summer, cool in the autumn and cold and snowy in winter. The annual rainfall is around 600 mm and the annual average temperature is around 12 degrees.

Spring is short, starting in March and lasting only 50 to 60 days. The average temperature is around 15 degrees Celsius.

Summer starts in June. Because the high temperature and low humidity it is a comfortable climate. The average temperature is around 27 degrees.

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Autumn is only 60 days. From mid-August to mid-October. The weather is cool and there is almost no rain. The average temperature is around 16 degrees.

Winter is over 160 days. With an average temperature of -4 degrees and lot of snowfall.

(chinahighlights.com/Tianjin/weather)

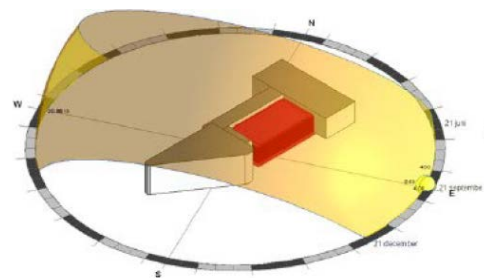
Context and Climate Location

Orientation: The Tianjin educational Centre is located in the center of the city and has a north-west to south east orientation. The complex is situated inside a park.



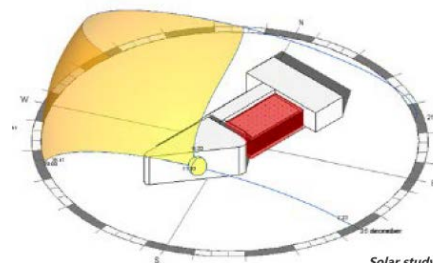
Figure 28: location source: MVRDV

Sun: the concerning façade has a south east orientation. This means that on this location that the morning sun will shine on the façade. According to the solar study below, you can see that on:



21 June the sun will shine on this façade from 4.48 till 11.30, sun goes down at 19.38

21 September the sun will shine on this façade from 6.00 till 11.30, sun goes down at 20.10



21 December sun will shine on the façade from 7.20 till 11.30, sun goes down at 16.46

Wind: The prevailing wind direction is east to south. This means that the wind is not blocked by any buildings, because it comes over the park.

Because Tianjin is a harbor city with a monsoon climate, the wind speed which has to take into account is high, around 13m/s straight on the façade.

Figure 29: solar study source: Luuk Jansen

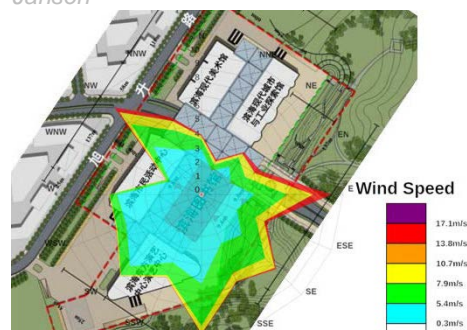


Figure 30: wind study source: <http://www.city-data.com/forum/weather/2041494-climate-beijing-vs-tianjin.html>

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Noise: due to the location of the building inside a park the noise level is a moderate 35 dB. But there is a road going through where 70 dB has to take into account.

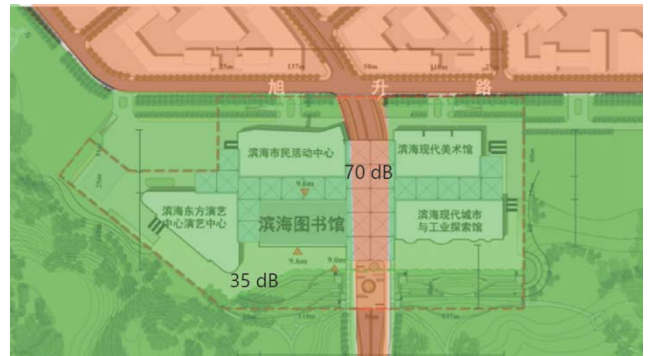


Figure 31: Noise source Luuk Jansen

Legislation and user requirements

Because I cannot read Chinese and I cannot find the Chinese building legislation, I will use the Dutch building Legislation.

Legislation

Insulation

The Dutch building legislation has an insulation requirement. Separated in close parts and in glass parts. (Article 5.3: thermal insulation of the Dutch building legislation)

gebruiksfunctie	leden van toepassing												grenswaarde											
	energieprestatiecoëfficiënt			thermische isolatie								luchtvolumestroom		onverwarmde gebruiksfunctie		verbouw		tijdelijk bouwwerk		energieprestatiecoëfficiënt		thermische isolatie		
artikel	5.2			5.3								5.4		5.5		5.6		5.7		5.2		5.3		
lid	1	2	3	1	2	3	4	5	6	7	8	1	2	*	1	2	3	4	*	1, 2 en 3	1 en 5	2	3 en 4	
	[-]			[m ² .K/W]																				
1 Woonfunctie																								
a woonwag en	1	-	3	1	2	3	4	5	6	7	8	1	2	-	1	2	3	4	*	1,3	2,5	2,5	2,5	
b andere woonfunctie	1	2	3	1	2	3	4	5	6	7	8	1	2	-	1	2	3	4	*	0,4	4,5	6,0	3,5	
2 Bijeenkomstfunctie	1	2	3	1	2	3	4	5	6	7	8	1	2	*	1	-	3	4	*	1,1	4,5	6,0	3,5	
3 Celfunctie																								
a in een cellingebouw	1	2	3	1	2	3	4	5	6	7	8	1	2	-	1	-	3	4	*	1,0	4,5	6,0	3,5	
b andere celfunctie	1	2	3	1	2	3	4	5	6	7	8	1	2	-	1	-	3	4	*	1,0	4,5	6,0	3,5	
4 Gezondheidszorgfunctie																								
a met bedegebied	1	2	3	1	2	3	4	5	6	7	8	1	2	-	1	-	3	4	*	1,8	4,5	6,0	3,5	
b andere gezondheidszorgfunctie	1	2	3	1	2	3	4	5	6	7	8	1	2	-	1	-	3	4	*	0,8	4,5	6,0	3,5	
5 Industriefunctie	-	-	-	1	2	3	4	5	6	7	8	1	2	*	1	-	3	4	*	-	4,5	6,0	3,5	
6 Kantoorfunctie	1	2	3	1	2	3	4	5	6	7	8	1	2	-	1	-	3	4	*	0,8	4,5	6,0	3,5	
7 Logiesfunctie																								
a in een logiesgebouw	1	2	3	1	2	3	4	5	6	7	8	1	2	-	1	-	3	4	*	1,0	4,5	6,0	3,5	
b andere logiesfunctie	1	2	3	1	2	3	4	5	6	7	8	1	2	*	1	-	3	4	*	1,4	4,5	6,0	3,5	
8 Onderwijsfunctie	1	2	3	1	2	3	4	5	6	7	8	1	2	-	1	-	3	4	*	0,7	4,5	6,0	3,5	
9 Sportfunctie	1	2	3	1	2	3	4	5	6	7	8	1	2	*	1	-	3	4	*	0,9	4,5	6,0	3,5	
10 Winkelfunctie	1	2	3	1	2	3	4	5	6	7	8	1	2	*	1	-	3	4	*	1,7	4,5	6,0	3,5	
11 Overige gebruiksfunctie	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
12 Bouwwerk geen gebouw zijnde	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Figure 32: Table out of the Dutch building regulation 5.1 source: bouwbesluitonline.nl

For closed parts the minimal Rc values are:

4.5 M2.K/W for façades.

6.0 M2.K/W for roofs.

3.5 M2.K/W for floors.

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For open parts the rules are:

The u frame should be lower than 1.4. The u frame is a value which is the heat transfer coefficient through the frame of the window.

The u window can be calculated with this U frame. Usually the U_w is calculated for a standard window size of 1.23 to 1.48 meters. When a window gets smaller the percentage frame gets bigger and therefore the U_w gets smaller.

U_g = heat transfer coefficient of the glazing

U_f = heat transfer coefficient of the frame

Ψ_g = linear heat transfer coefficient of the insulated glazing edge seal

A_g = glass area

A_f = frame area

$A_w = A_g + A_f$

l_g = length of inside edge of frame profile (or visible periphery of the glass sheet)
(inoutic.de)

Air flow through construction and separating parts (according to NEN2686)

The air flow of the sum of residential areas, toilet rooms and bathrooms in the building is not higher than 0.2 m³/s.

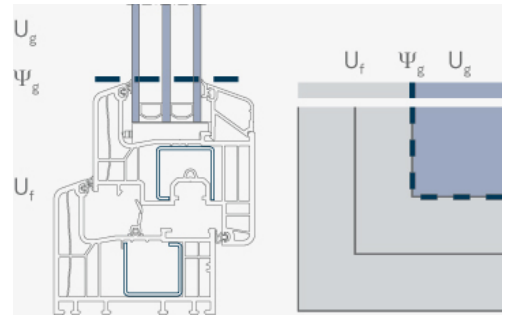


Figure 33: U value explained source: inoutic.de

$$U_w = \frac{(A_g \times U_g + A_f \times U_f + l_g \times \Psi_g)}{(A_g + A_f)}$$

Figure 34: U_w formula source: inoutic.de

Noise level

According to article 3.2 noise from outside of the Dutch building legislation, a minimal of 20 dB of characteristic noise reduction is required of the outer separation structure.

According to article 3.3 industry, road and railway noise the maximum acceptable noise level is 35 dB(a) for industrial noise and 33 dB(a) of railway and road noise.

Absorption and reverberation time

According to article 3.13 geluidsabsorptie and NEN-EN 12354-6 there should be a certain amount of absorption for the given wave lengths. But when you meet this requirement it is still possible that the room acoustics is very bad. Therefore you should consider a typical reverberation time for each typical building function or activity inside a room.

Leslokalen	0,8 - 1,0 s
Muziekleslokalen	0,6 - 0,8 s
Repetitieruimten voor muziek	1,2 - 1,4 s
Ruimte voor een kamerorkest (klein volume)	1,3 - 1,6 s
Concertzaal (groot volume)	1,6 - 2,0 s
Kantoorvertrekken	0,6 - 0,8 s
Vergaderkamers	0,7 - 0,9 s
Bibliotheek / leeszaal	0,6 - 0,8 s
Collegezaal	0,7 - 0,9 s
Gehoorzaal	0,8 - 1,0 s
Schouwburg	0,8 - 1,2 s
Gangen en hallen	1,0 - 1,5 s
Sportzalen / gymzalen	1,0 - 1,5 s
Fabriekshallen	0,5 - 1,5 s

(source: <http://www.greten.nl/zaalenruimteakoestiek>)

Ventilation

To create a healthy climate there should be a certain amount of air circulation to provide the area with fresh air.

Article 3.29 Air displacement rate.

1. According to NEN1087 the capacity should be 0.9 dm³/s per m² floor area of the residential area with a minimum of 7 dm³/s.
2. According to NEN1087 the capacity should be 0.7 dm³/s per m² floor area of the residential rooms with a minimum of 7 dm³/s.
3. For residential area there is a certain amount of air replacement per person, see the table below.
4. If there is a kitchen or such in the room an air replacement of at least 21 dm³/s is required.
5. A toilet room has a minimal air replacement of 7 dm³/s according to NEN1087.
6. A bathroom has a minimal air replacement of 14 dm³/s according to NEN1087.

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gebruiksfunctie	leden van toepassing																											grenswaarden						
	luchtuverissing, verblijfsgebied, verblijfsruimte, toertruimte en badruimte							thermisch comfort			luchtuverissing overige ruimten							plaats van de opening			luchtwaaliteit								verbouw		tijdelijke bouw		capaciteit per persoon	
	3.30							3.31			3.32							3.33			3.34								3.35		3.38		3.29	
artike	1	2	3	4	5	6	7	*	1	2	3	1	2	3	4	5	6	7	1	2	3	1	2	3	4	5	6	7	8	9	1	2	*	3
lid																																		
1 Woonfunctie	1	2	-	4	5	6	7	*	1	2	3	1	2	3	4	-	-	-	1	2	3	1	2	3	4	5	-	7	8	-	1	2	*	3
2 Bijeenkomstfunctie	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	*	3
a voor kinderopvang	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	*	3
b andere bijeenkomstfunctie	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	4
3 Ceïlfunctie	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	4
a cel	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	12
b ander verblijfsgebied	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	6,5
4 Gezondheidszorgfunctie	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	12
a bedgebed	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	6,5
b ander verblijfsgebied	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	6,5
5 Industriefunctie	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	6,5
6 Kantoorfunctie	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	6,5
7 Logiesfunctie	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	2	-	4	5	-	7	8	-	1	2	-	12
a in een logiesgebouw	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	2	-	4	5	-	7	8	-	1	2	-	12
b andere logiesfunctie	-	-	3	4	5	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	2	-	4	5	-	7	8	-	1	2	-	12
8 Ondernijfsfunctie	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	*	8,5
9 Sportfunctie	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	6,5
10 Winkelfunctie	-	-	3	4	-	6	7	*	1	2	3	-	2	3	4	-	-	-	1	2	3	1	-	-	4	5	-	7	8	-	1	2	-	4
11 Overige gebruiksfunctie	-	-	-	-	-	6	7	-	-	-	-	-	2	3	4	5	-	-	-	-	-	-	-	-	4	5	-	7	8	9	1	2	-	-
a voor het stallen van motorvoertuigen	-	-	-	-	-	6	7	-	-	-	-	-	2	3	4	5	-	-	-	-	-	-	-	-	4	5	-	7	8	9	1	2	-	-
b andere overige gebruiksfunctie	-	-	-	-	-	6	7	-	-	-	-	-	2	3	4	5	-	-	-	-	-	-	-	-	4	5	-	7	8	9	1	2	-	-
12 Bouwwerk geen gebouw zijnde	-	-	-	-	-	-	-	-	-	-	-	-	2	4	-	6	7	-	-	-	-	-	-	4	-	6	-	-	-	1	2	-	-	
a wegtunnel met een tunnellengete van meer dan 250 m	-	-	-	-	-	-	-	-	-	-	-	-	2	4	-	6	7	-	-	-	-	-	-	4	-	6	-	-	-	1	2	-	-	
b andere tunnel of tunnelvormig bouwwerk	-	-	-	-	-	-	-	-	-	-	-	-	2	4	-	6	7	-	-	-	-	-	-	4	-	-	-	-	-	1	2	-	-	
c ander bouwwerk geen gebouw zijnde	-	-	-	-	-	-	-	-	-	-	-	-	2	4	-	-	-	-	-	-	-	-	-	4	5	-	-	-	-	1	2	-	-	

Figure 35: Table 3.28 out of the Dutch building regulation source: bouwbesluitonline.nl

Article 3.30 thermal comfort.

According to NEN1087 the maximum air speed of supplied ventilation air is 0.2 m/s

Daylight

According to article 3.75 daylight area. A residential area has a certain daylight area. Which should be higher than the required daylight area according to the table below. To calculate the equivalent daylight area you should consider that the angle of obstruction A should be smaller than 20 degrees. (NEN 2057)

gebruiksfunctie	leden van toepassing									grenswaarden		
	daglic htoppervlakte									verbouw	daglic htoppervlakte	
artikel	3.75									3.76	3.75	
lid	1	2	3	4	5	6	7	8	*	1	2	
										[%]	[m ²]	
1 Woonfunctie	1	2	3	-	-	-	-	-	*	10	0,5	
2 Bijeenkomstfunctie												
a voor kinderopvang	1	2	3	4	5	-	-	-	*	5	0,5	
b andere bijeenkomstfunctie	-	-	-	-	-	-	-	-	-	-	-	
3 Celfunctie	1	2	3	4	-	6	-	-	*	3	0,15	
4 Gezondheidszorgfunctie	1	2	3	4	-	-	7	-	*	5	0,5	
5 Industriefunctie	-	-	-	-	-	-	-	-	-	-	-	
6 Kantoorfunctie	1	2	3	4	-	-	-	-	*	2,5	0,5	
7 Logiefunctie	-	-	-	-	-	-	-	-	-	-	-	
8 Onderwijsfunctie	1	2	3	4	-	-	-	8	*	5	0,5	
9 Sportfunctie	-	-	-	-	-	-	-	-	-	-	-	
10 Winkelfunctie	-	-	-	-	-	-	-	-	-	-	-	
11 Overige gebruiksfunctie	-	-	-	-	-	-	-	-	-	-	-	
12 Bouwwerk geen gebouw zijnde	-	-	-	-	-	-	-	-	-	-	-	

Figure 36: Table 3.7 out of the Dutch building regulation source: bouwbesluitonline.nl

User requirements

Next to some rules from the government there are also some requirements from the intended users to make it comfortable residential area.

In a library the main function is reading, this function has some specific requirements.

1. There should be a good glare protection else it is hard to read.
2. Because people are mostly sitting they have a low metabolism which means during winter a temperature of 19 – 23 degrees is comfortable and during summer a temperature of 21 – 25 degrees is comfortable.
3. Light intensity should be 300 – 400 lux at least to allow for a comfortable reading, next to a proper intensity the contrast between outside and inside should be not too high.

Other factors are:

1. Humidity between 30 and 70%.
2. A daylight factor between 2 and 5%.
3. A comfortable reverberation time in a library is between 0.6 and 0.8 sec.

Analyzing the Design of MVRDV

Acoustics.

To have a comfortable inner climate the reverberation time plays a huge roll. As you can see in the picture on the right, the architectural design consists mainly hard not acoustic absorbent material. There is a stone floor, wooden bookshelves with books in it, wooden roof and a glass façade.



Figure 37: Interior render source: MVRDV

Therefore I did a basic calculation to determine the starting point and to see if there is something which has to be done to reach the reverberation time required. The image below shows this basic calculation. In this calculation I did some assumptions for the bookshelves, in this case I stated that the back of the shelves is covered with absorbent material.

The outcome of this calculation is a reverberation time of 0.775 (or 0.79 without people) this is acceptable and within the requirements stated above.

Note: when the back of the bookshelves is not from absorbent material the reverberation time will not meet this requirement.

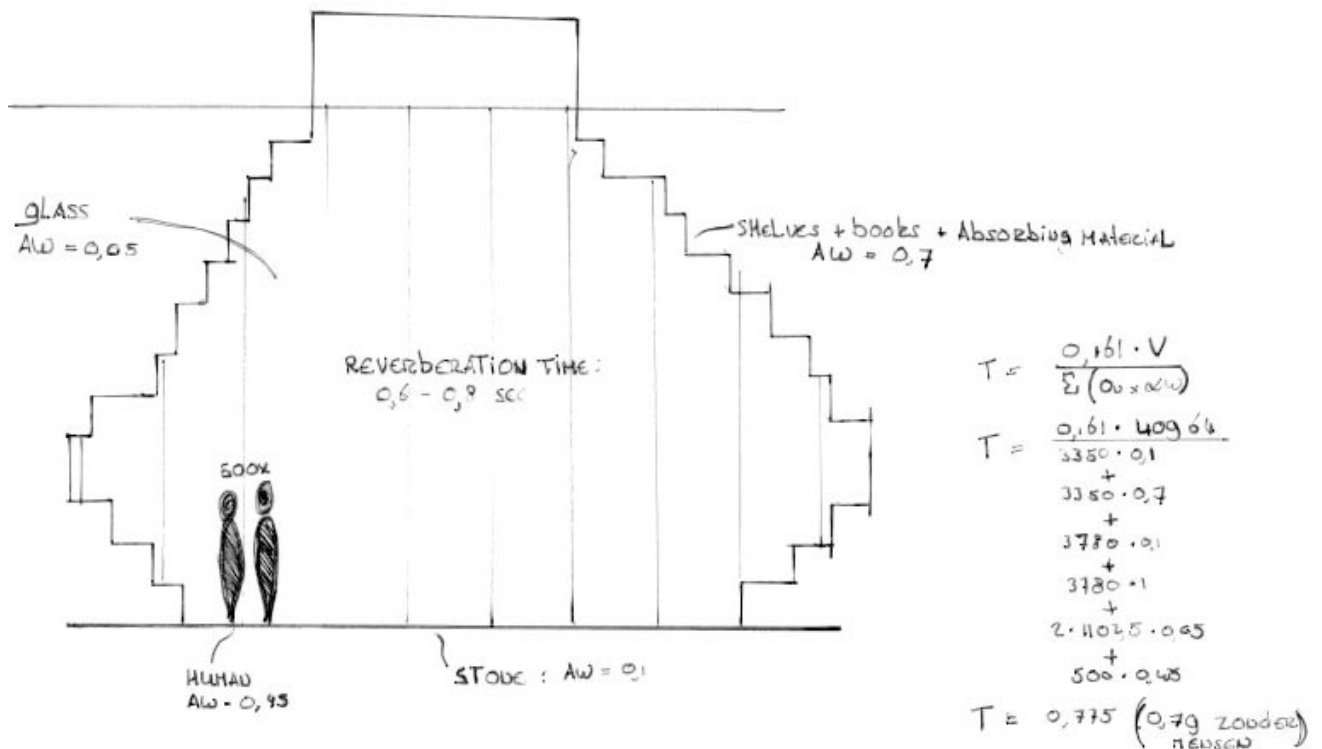


Figure 38: Acoustic starting point calculation source: Luuk Jansen

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Insulation

With a complete glass building it is not hard to reach the insulation requirements stated in the Dutch building legislation, because an u-frame of 1,4 is easily to achieve, but this says nothing about the energy losses through this façade when it is a complete glass façade. Therefore I decided to try to achieve as high as possible insulation for this glass façade.

I found out that with a quadruple glazing (3-12-3-12-3-12-3) in a structural glazed façade systems, with nylon supporting brackets for the louvres a Rc value of 3.4 can be achieved.

This means that when a total average Rc value of 5 has to be reached, the floor and the roof has a required Rc value of 6.11. This value is easily achievable with standard insulation, maybe if there is a limit height for the floor or the roof a more high performance insulation can be used.

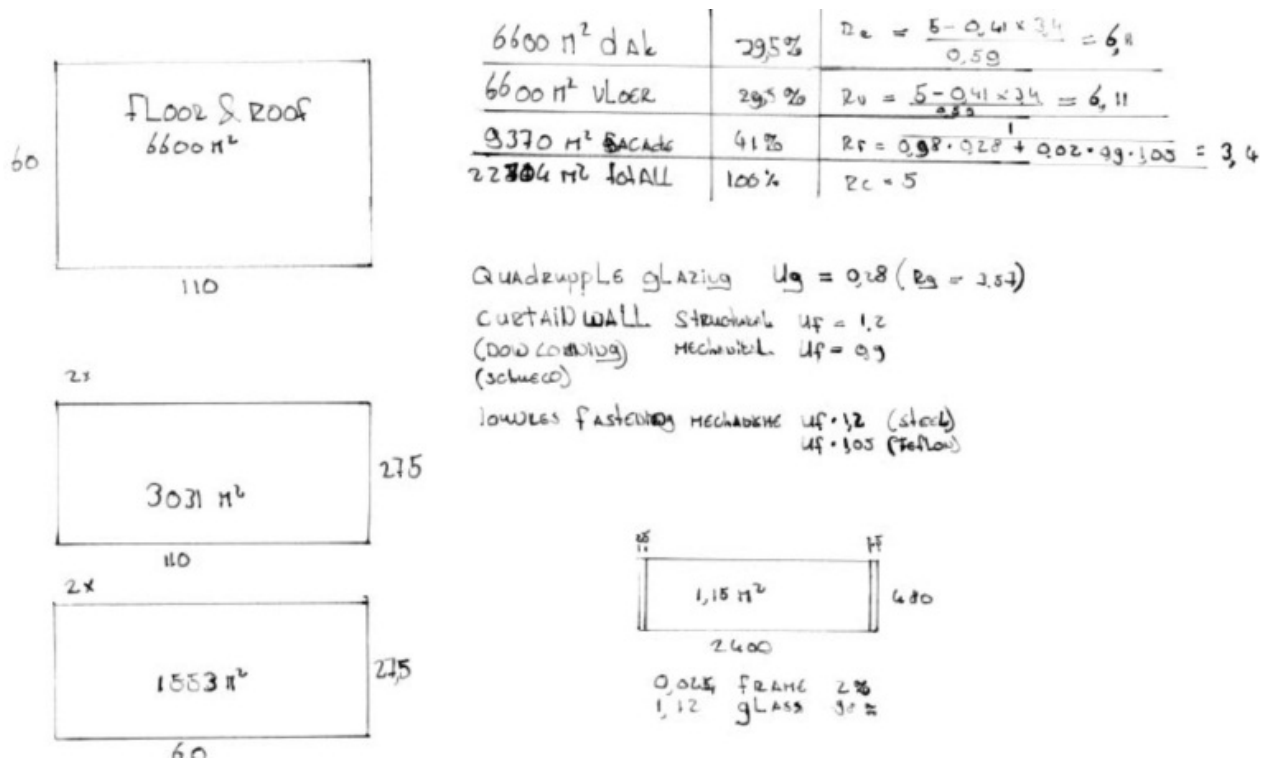


Figure 39: Insulation starting point calculation. Source: Luuk Jansen

Design process finding the most suitable way of constructing this façade.

My design process has several stages/steps. First I focused on just idea finding, therefore I did not look at feasibility. Second I made a comparison between all these different ideas to find the best suitable way to construct the façade for this particular project. Third I refined this chosen first thought to a feasible concept. Fourth I made the actual engineering of every important detail as principle details. Fifth I found out that these principle details can be refined a bit on certain topics. At last I made the actual details.

First thoughts, crazy ideas.

To make a completely project specific design I first start with completely crazy ideas trying to find the most suitable construction system, for this specific architectural vision.

In order to classify the different variants I made 8 objective criteria on what I can objectively test the different variants.

1. Provide solar shading but still have a clear look outside.

An important measurable criteria is solar shading, the amount of daylight entering and the unblocked vision outside. These are important because to read a book in the library you need some glare protection else the sun will blind you.

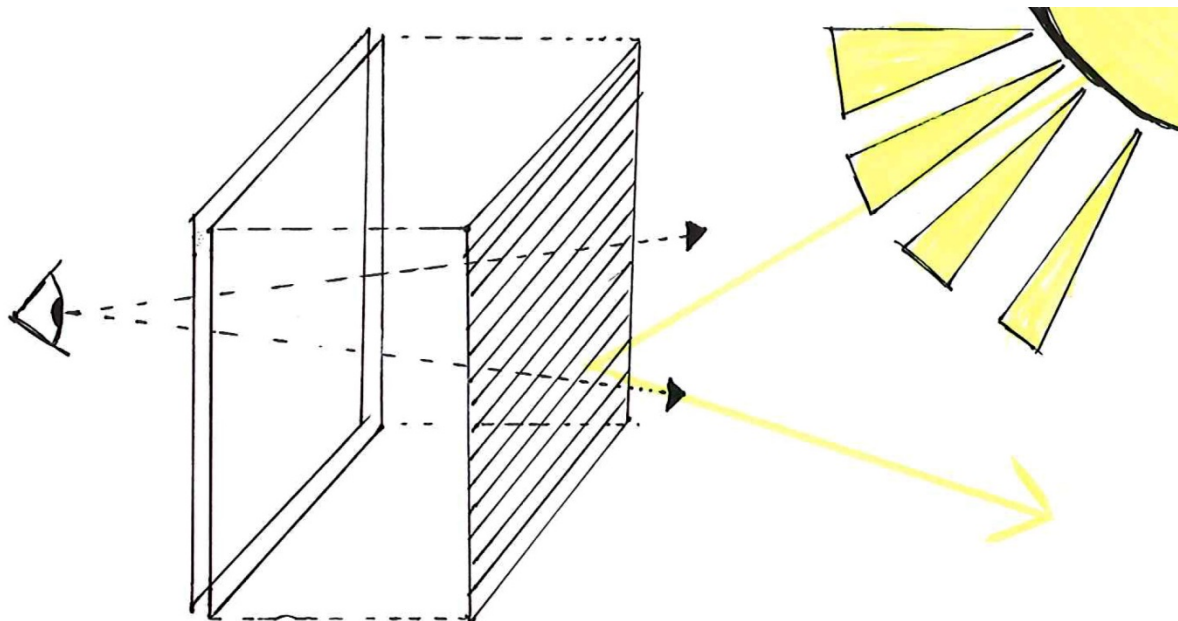


Figure 40: Clear vision outside, but blocking the sunlight source Luuk Jansen

2. No intermediate structure between the two façade systems (with louvres and without louvres)

An important architectural principle is that there is no visible intermediate structure, it should look like one façade not two separate ones which are attached to each other by a third element.

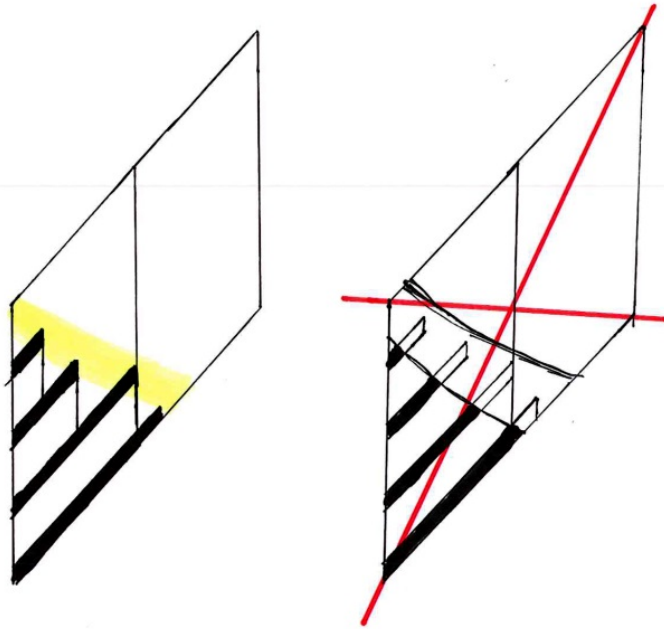


Figure 41: No intermediate structure source: Luuk Jansen

3. Meet the architectural vision.

The main goal in the research is to make a design which cope as much as possible with the architectural requirements and principles

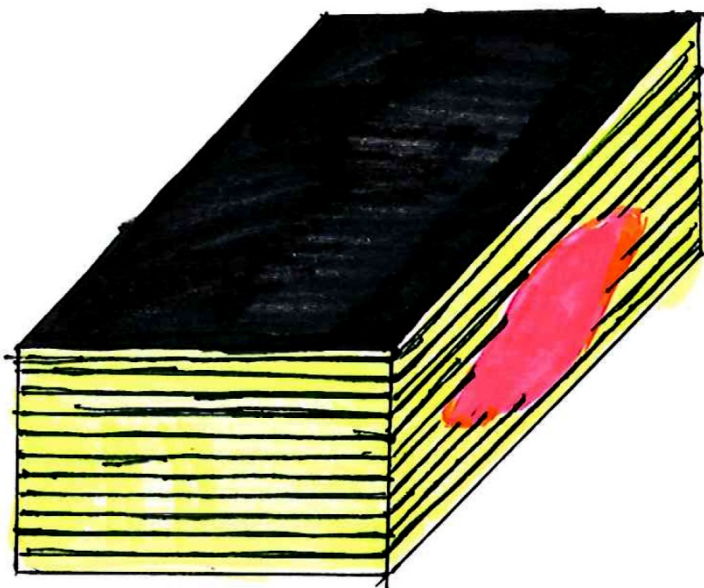


Figure 42: Meet the architectural vision source Luuk Jansen

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4. Making openings in the same façade system.

The façade has to look like one system and therefore openings as doors and windows should be made in one system. With other words, to make openings there should not be a need to add a different construction or system.

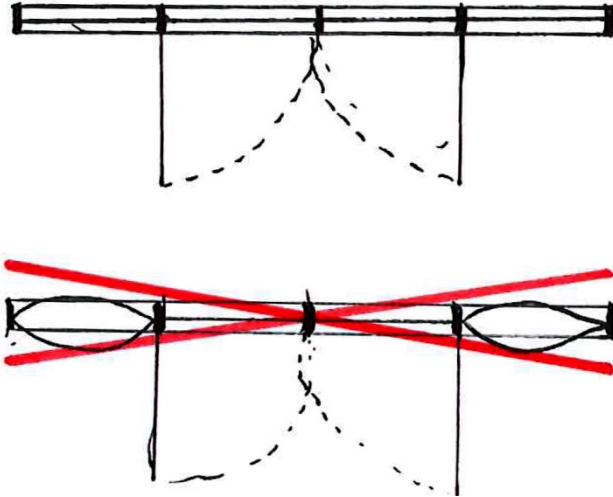


Figure 43: Making openings in the same façade system source Luuk Jansen

5. As less as visible structure

The main elements of the architectural principle are the glass and the horizontal louvres. All added construction will change the look of the façade and therefore the construction has to be as slender and transparent as possible.

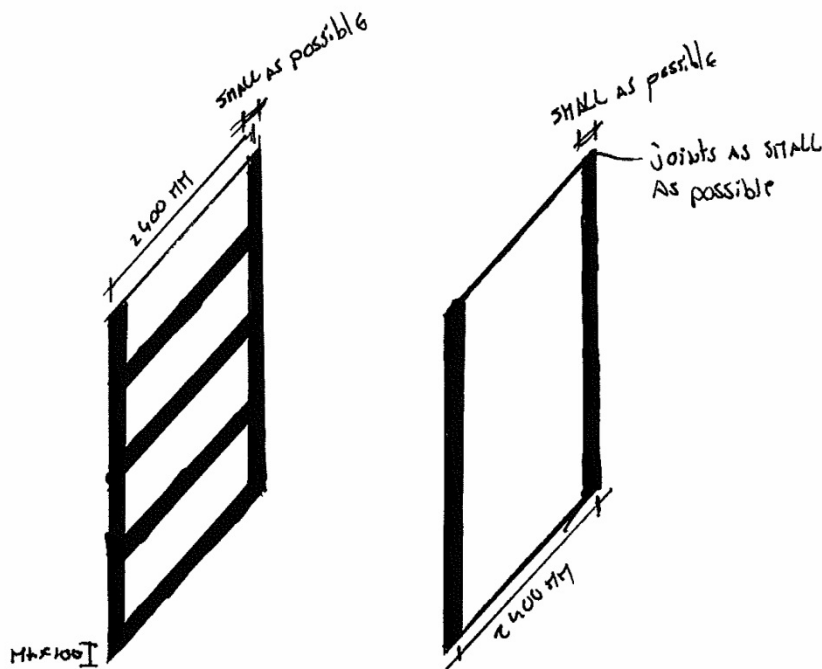


Figure 44: Minimalistic structure source: Luuk Jansen

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6. High Rc-value

To make sure energy costs are not very high a good Rc-value is required.

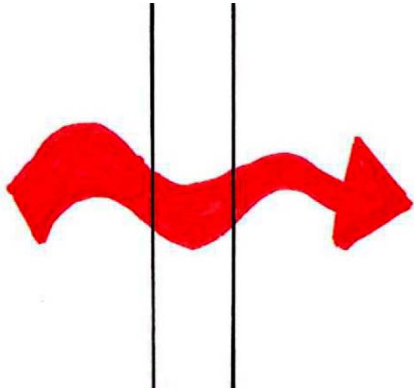


Figure 45: Rc-Value source: Luuk Jansen

7. Lightweight system

To keep the construction light and invisible the façade has to be as light as possible, but still meet all the requirements.

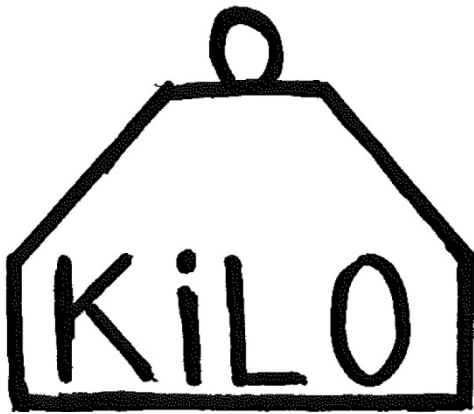


Figure 46: Weight source: Luuk jansen

8. Low cost

As always there is a budget, therefore the façade should have a reasonable price but still has a high quality and meets the architectural principles.

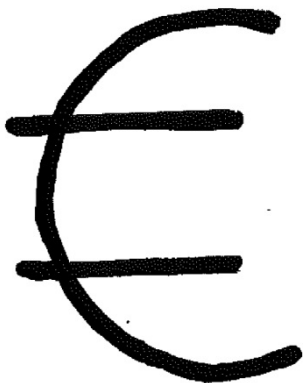


Figure 47: Cost source: Luuk Jansen

1. Story high composite panels, with glass infill.

This system is made out of composite panels, these panels are story high and 2400 mm wide, the construction and the panels are made is one. Inside these panels an aluminum framework is placed with the glass infill. There is a problem to make this façade construction because in the gap where no louvres are there is no construction, therefore another construction is needed there. Another issue is where this transition is, because at that point different panels are needed and to make it look like the architectural vision you have to make complex glass panels.

Good:

- + Represents the architectural vision.
- + Good Rc-value possible.
- + Composite is lightweight.

Bad:

- Lot of framework needed.
- Transition is visible.
- Lot of construction needed.
- Expensive unique molds needed.

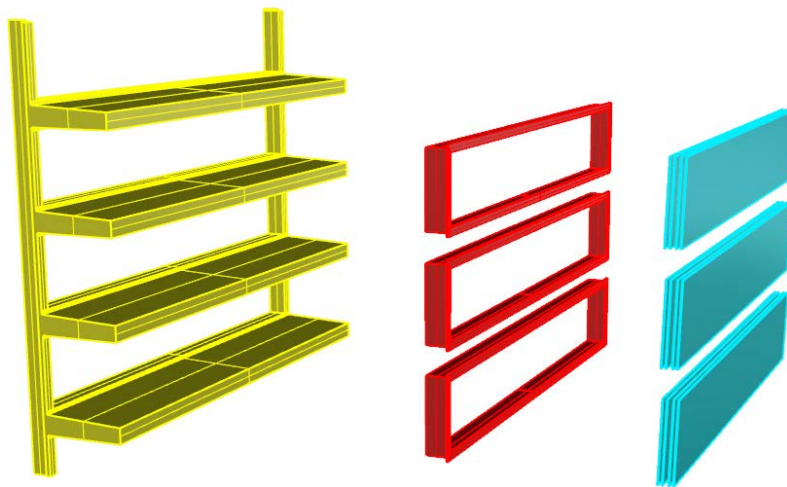


Figure 48: Composite façade elements with glass infill source Luuk Jansen

2. Tension cable façade.

This system is build out of tension cables with clamped glazing hung to this. On some parts louvres are hung to this and on some parts not. The cables are 2400 apart. The main problem with this façade is the high tension required to hold the façade stable, but because of the high monsoon wind load and the height the façade still will displace several decameters.

Good:

- + Lot of light because the very minimal construction.
- + Glass as common system with added louvres (as the architectural concept)
- + Good Rc-value due to the small framework.
- + Lightweight, only glass attached to cables

Bad:

- Large intermediate structure needed with transition to other systems due to the high required tension.
- Added framework needed by doors and window.
- Lot of displacement due to cable structure.

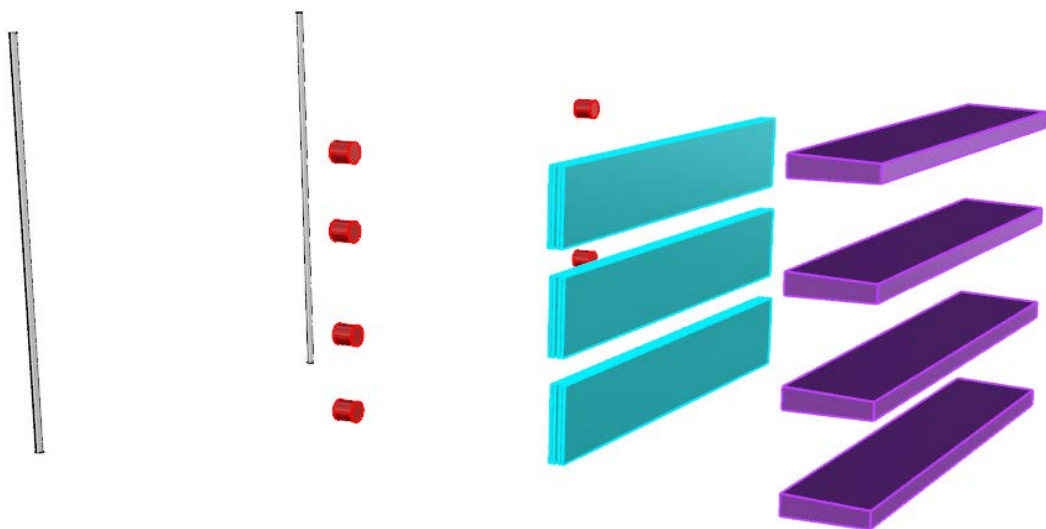


Figure 49: Tension cable façade source Luuk Jansen

3. Louvres on backing structure with glass infill

This system is built out of a regular steel structure. Louvres are attached to this and the glass basically is an infill between the louvres. The main problem with this is that the louvres become the common system, this means on places where no louvres are placed the glass can be attached to something.

Good:

- + Windows and doors can be made in the same system.
- + Medium Rc-value possible.
- + Cheap because it is easily buildable.

Bad:

- Lot of construction needed.
- Heavy.
- Lot of light blocking elements.
- Completely different look as the architect.
- Intermediate construction needed to a system without louvres.

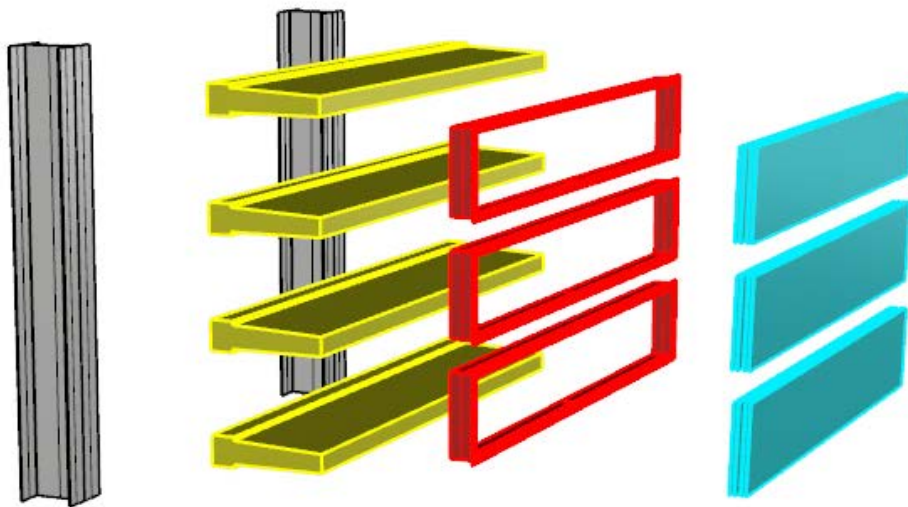


Figure 50: Louvres on backing structure with glass infill source Luuk Jansen

4. Glass façade with louvre construction in front.

This system is basically made out of two systems, one façade system, with the glass infill and one system holding the louvres. The benefit of this system is the separated structures, because the common system is the glass façade and on places where louvres are placed a separate construction is made.

Good:

- + No intermediate structure needed.
- + Openings can be integrated in the system.
- + Good Rc-value because of separated systems.

Bad:

- Lot of light blocking elements.
- Lot of construction needed.
- Looks completely different as the architectural vision.
- Very heavy because of the double construction.
- Expensive because of the double construction a lot of elements are needed.

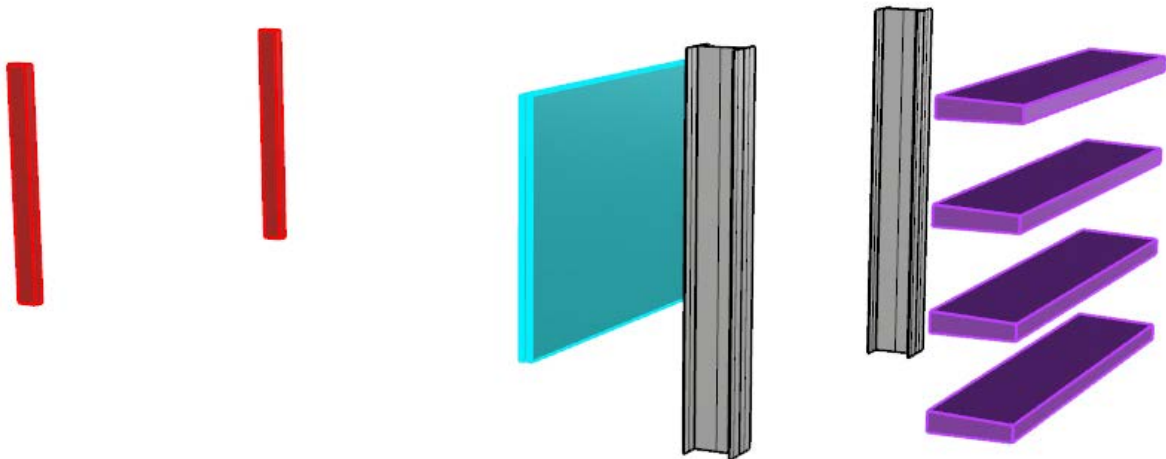


Figure 51: Glass façade with louvres on a separate structure source Luuk Jansen

5. ETFE cushion façade

This system is a façade build out of ETFE cushions on a backing structure. On this backing structure also the louvres are attached. For openings a different façade structure is needed.

Good:

- + Less construction and integrated solar shading possible.
- + No visible intermediate structure.
- + Lightweight

Bad:

- A completely different system and looks as the architect has in mind.
- Different construction needed for openings.
- Low Rc-value due to the ETFE cushions.

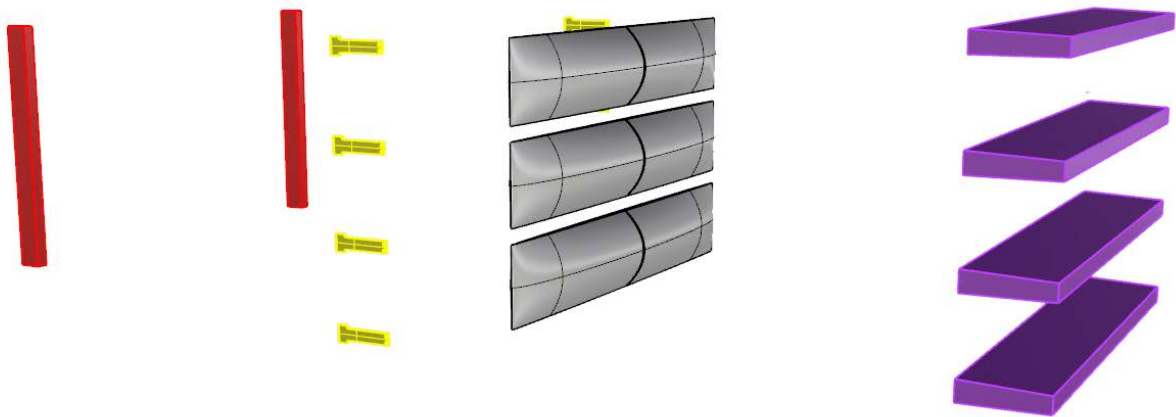


Figure 52: Effe cushion façade mitt louvres in front source: Luuk Jansen

6. ETFE cushion façade on non-louvre part.

This system uses two separated systems, one for the louvre part and one for the open part. Therefore it is possible to optimize both systems. The main problem is that there is no common part as in the architectural principle is. Glass looks namely completely different then etfe.

Good:

- + Less construction and integrated solar shading.
- + Lightweight.

Bad:

- Intermediate structure needed.
- Looks completely different than the architect has in mind.
- Different construction needed for openings.
- Low Rc-value, due to the use of etfe cushions.

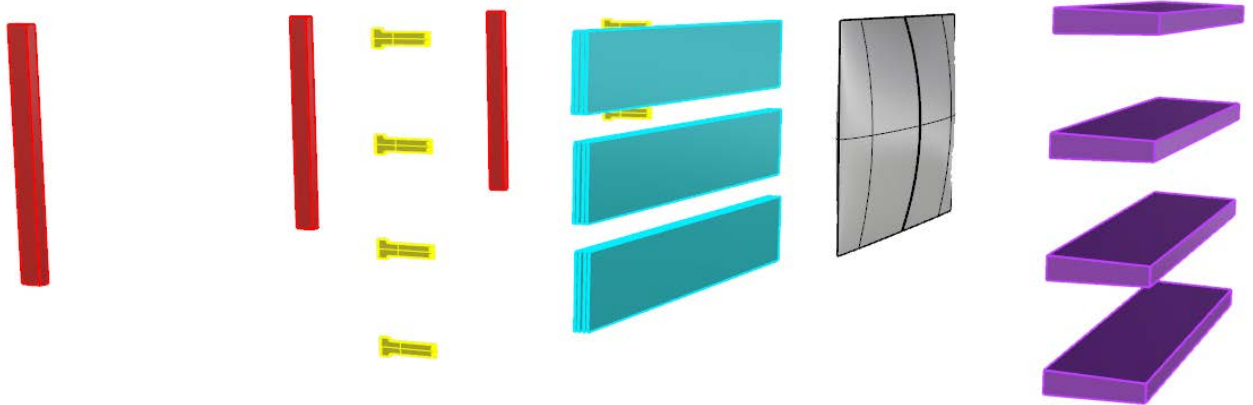


Figure 53: Ete cushion façade on non-louvre part source: Luuk Jansen

7. Glass fin façade

A glass fin façade characterizes itself due to its transparent construction. To these glass fins aluminum brackets are attached which clamp the glass and where the louvres are attached to. The main problem with a glass fin system is the shape of these fins, because the small and deep character they are very sensitive to nod. Therefore you need to couple them horizontally.

Good:

- + Very transparent construction.
- + No intermediate construction needed.
- + Different system but looks the same as the architectural concept.
- + Openings can be made in the same system.
- + Good Rc-value possible due to the absence of a framework.

Bad:

- Heavy.
- Expensive because of the large amount of glass

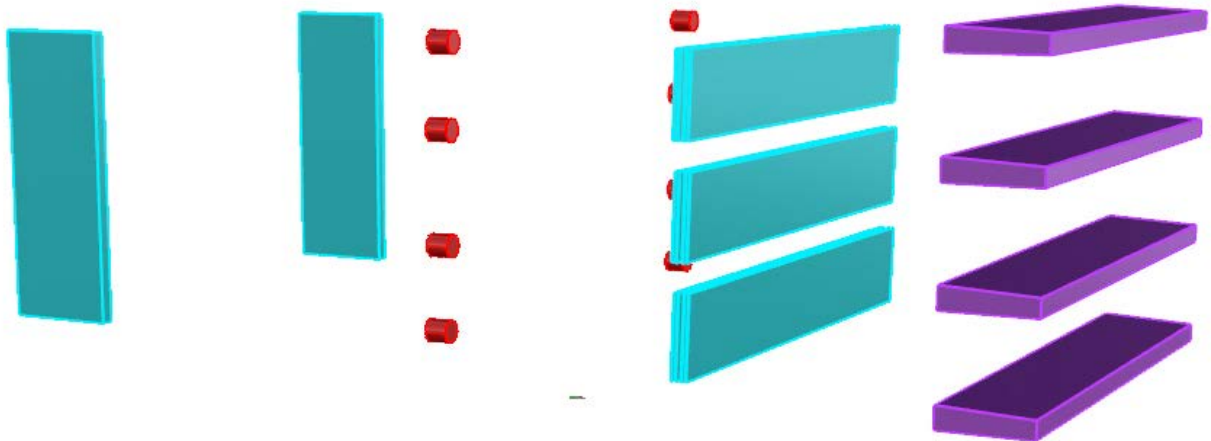


Figure 54: Glass fin façade source: Luuk Jansen

8. Extrusion profile façade.

This system is characterized to its construction, these are lightweight aluminum extrusion profiles. In this case the glass is structural attached, therefore no clamping profile is needed. The louvres are attached through the kit joint to the backing structure, this is a risk due to water tightness. This façades common element is the glass extrusion profile façade, louvres can be attached on every place where needed.

Good:

- + No intermediate structure.
- + Looks like the architectural vision.
- + Openings are part of the same system.
- + Good Rc value possible.
- + Cheap because potential standardized profiles.

Bad:

- Relatively a lot of framework needed.
- A lot of visible construction.
- Heavy due to the large amount of profiles needed.

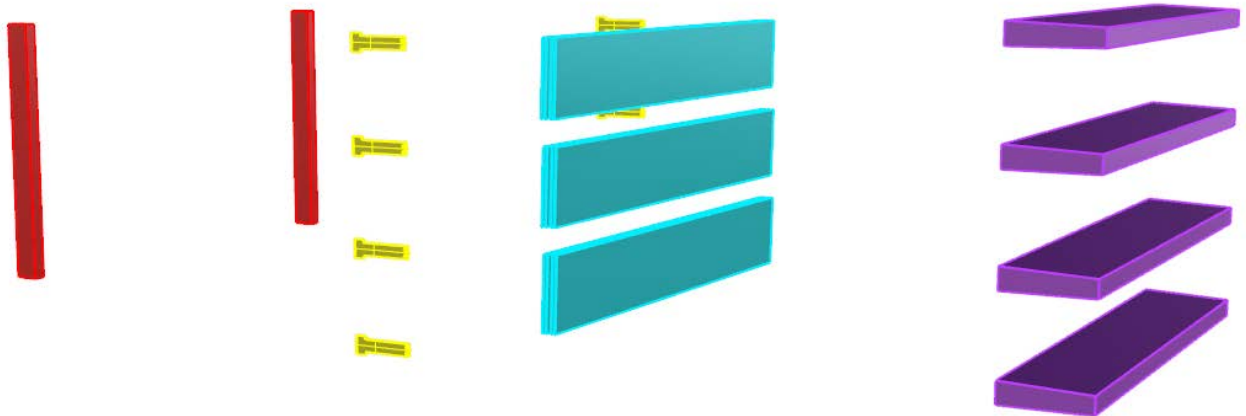


Figure 55: Extrusion profile façade source: Luuk Jansen

Comparison matrix

In this matrix all the 8 systems which are explained above are compared to each other, with five colors there is a value given to the façade in the 8 criteria.

Red --
 Orange -
 Yellow +/-
 Green +
 Dark green ++

	lot of framework needed	transition is visible -- intermediate construction needed	+ represents the architectural vision	+ windows and doors are possible to make in the same system.	- lot of construction needed	+ good rc value is possible	+ composite = lightweight	- moulds are expensive and difficult to make. -- Lot of unique panels.	
	lots of light because the minimal construction that is required	- intermediate construction is needed with the transition of other system.	+ glass as common with added louvers.	- lot of construction needed by doors and windows.	+ standard structure - lot of placement because of the cable system	+ good rc value is possible due to small framework	+ lightweight because it's only glass hanging on a cable	+ cheap because not so many unique parts required.	
	because of construction lot of light is blocked.	- intermediate construction is needed when a different facade system, which can't include louvers.	- glass as common with added louvers.	+ windows and doors are possible to make in the same system.	- lot of construction needed.	+/- standard rc value possible.	- relative heavy.	+ cheap because easily to built	
	lot of construction.	+ intermediate construction	- glass as common with added louvers.	+ openings can be integrated in the system.	- lot of construction needed because of the cable structure	+ good rc value possible because of separated systems.	- heavy because of the cable construction	- expensive because of the construction	
	+/- relative less construction but the light permeability of the foil is less than glass. + integrated solar shading	+ invisible intermediate construction	- glass as common with added louvers.	- different system because of the foil.	+ relative less construction needed	+ low rc value because of the foil.	+ lightweight because the foil weights almost nothing	+/- relative cheap but you need a mechanical pressure balancing system for the cushions.	
	+/- relative less construction but the light permeability of the foil is less than glass. + integrated solar shading	- intermediate construction	- glass as common with added louvers.	- different system because of the foil.	+ relative less construction needed	- low rc value because of the foil.	+ lightweight because the foil weights almost nothing	+/- relative cheap but you need a mechanical pressure balancing system for the cushions.	
	++ very transparent construction	+ intermediate construction	+/- different system but looks the same.	+ openings can be made in the same system.	++ invisible structure	+ good rc value possible because of the absence of a framework.	- heavy	- expensive because of the amount of glass	
	relatively a lot of framework	+ intermediate construction	++ like the architectural vision	+ openings are part of the system.	- lot of construction needed	+/- good rc value possible.	- heavy because of the construction.	+ cheap because standardised profiles can be used.	

Figure 56: Comparison Matrix: source Luuk Jansen

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Choosing the right principle solution for the situation

According to matrix I made two systems pops out. These are design seven: the glass fin façade and eight: extrusion profile façade. I want to use the benefits of both systems to make an even better system.

The first thoughts I had was a glass fin with aluminum profiles clamped to this fin. As you can see on the image below, this was still a difficult system to make and flimsy due to the small profiles required, also the aluminum part is still a bit large which blocks a lot of light and also take away the benefit of the glass fin. Another problem was the poor insulation value and glazing from the inside, making this difficult to do.

In this stage I found out that for the high part (17 meter) the glass should be suspended from the roof. The smaller heights (4 meter) can be clamped between the floor slabs.

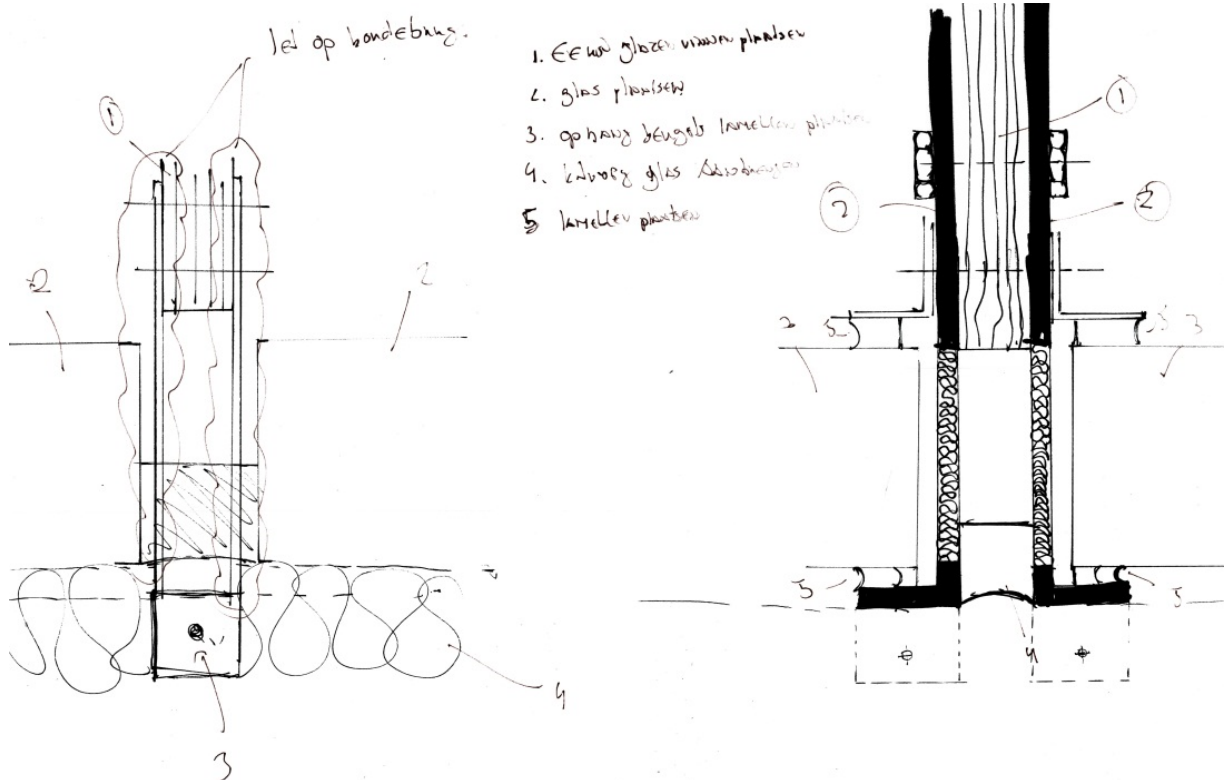


Figure 57: First thoughts combined systems source: Luuk Jansen

Because this principle is not yet the best way to do it, in my opinion a further engineering is needed.

Refining the principle solution

With the idea above I went to Schüco and talked to Tom van Dorp. He gave me a good insight how I can improve the system a bit more to make the aluminum part less and easier placement of the glass.

So I came up with the idea below.

It is a 50x50 extrusion profile with a locally placed fin on the back. (HOH 600) This steel fin is placed insight the therefore suited holes inside the laminated glass, bolted to each other.

The Glass (quadruple 3-12-3-12-3-12-3) is structurally placed from the outside with the suited clips in between the glass plates.

This gap is closed with a flexible wet sealant with a 25 mm width.

Where louvres are placed on a nylon sword which goes through the sealant and is attached to the extrusion profile.

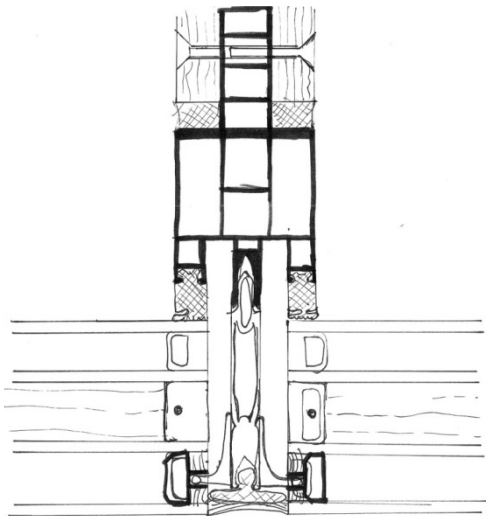


Figure 58: Refined idea source Luuk Jansen

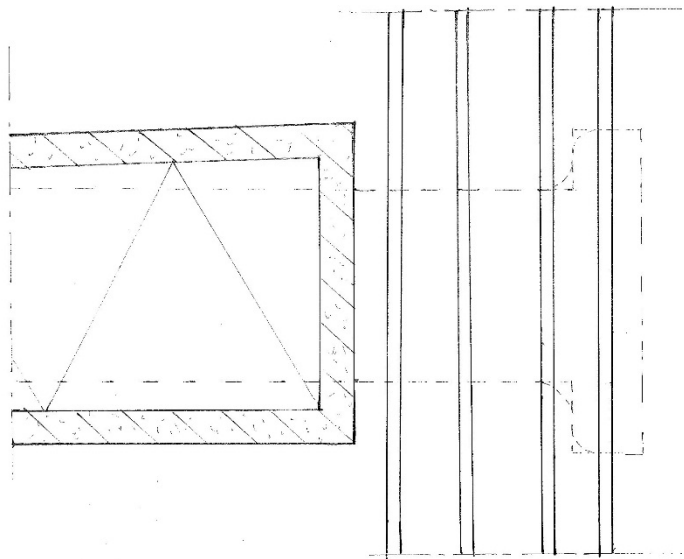


Figure 59: Refined idea 2 source: Luuk Jansen

On the images below the building sequence of the system is showed.

First the glass fins are set into place. They are 2400 mm HOH and 500 mm wide.



Figure 60: Façade principle build-up 1 source: Luuk Jansen

Second the aluminum extrusion profiles are bolted to these glass fins. For the windows and doors but also where a floor edge meets the facade a horizontal mullion is placed. To make sure there is a proper closed detail there.

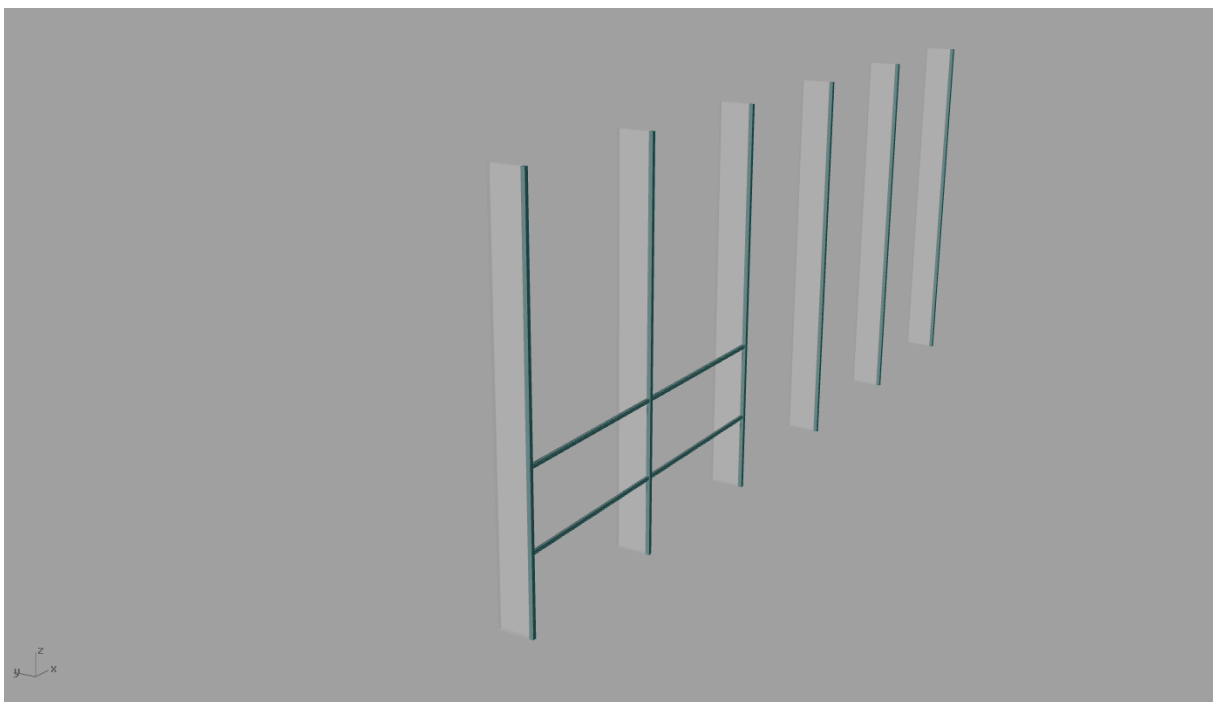


Figure 61: Façade principle build-up 2 source: Luuk Jansen

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Third the quadruple glazing is placed and clamped with little clamps inside the cavity to the mullions.

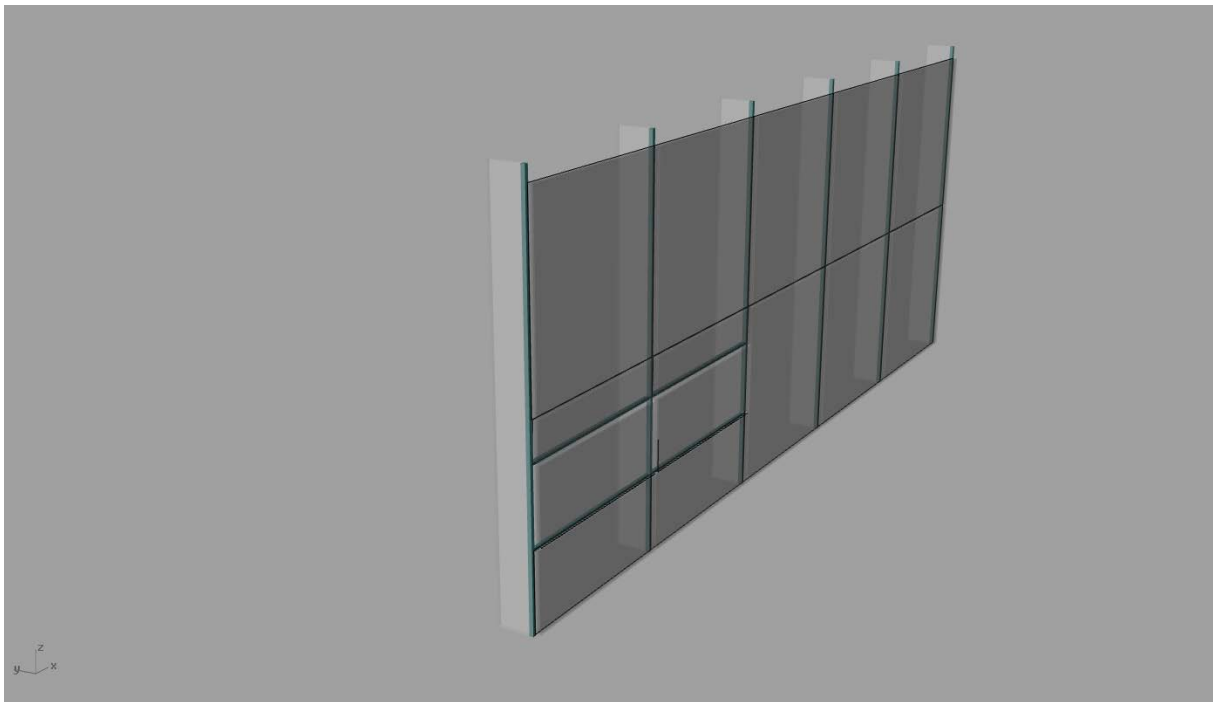


Figure 62: Façade principle build-up 3 source: Luuk Jansen

Fourth the louvres are attached to the swords, where the end of the louvre is not at a seam it is cantilevered.

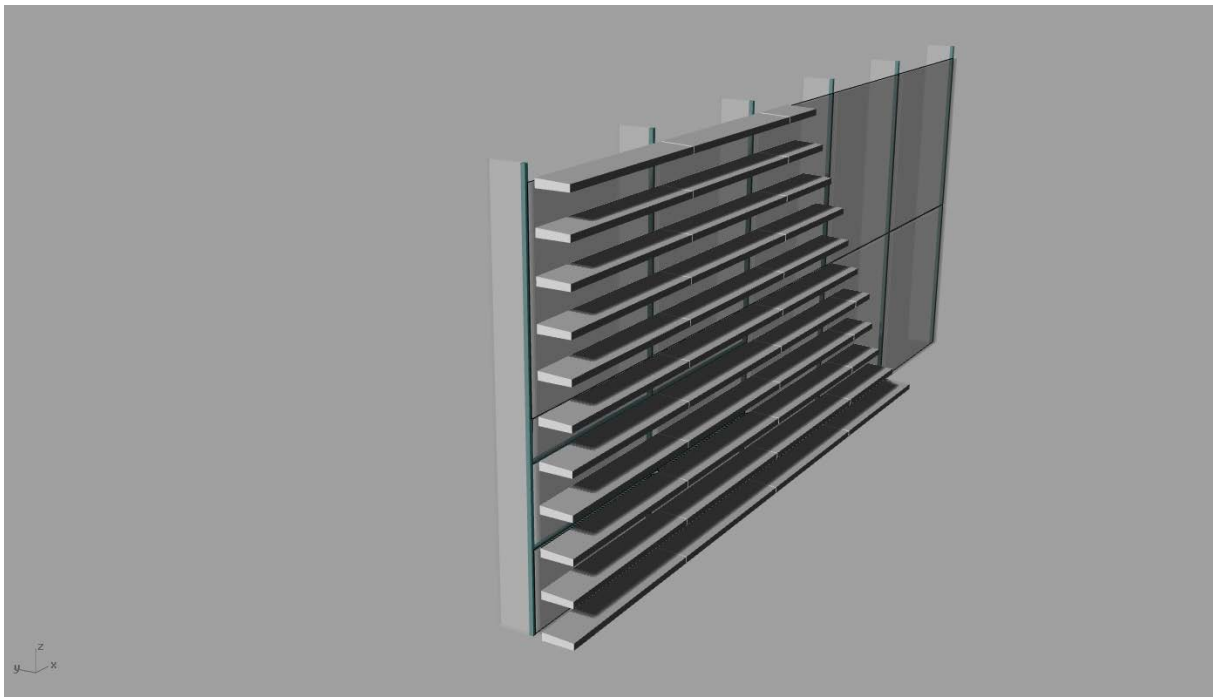


Figure 63: Façade principle build-up 4 source: Luuk Jansen

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Engineering the principle solution

With the decisions I took above I start with the technical elaboration of the façade. This is basically the work ABT does, starting with a concept working it out to a completely buildable façade. To make sure all problems are tackled, a 1:5 detail is made for each connection which needs extra attention.

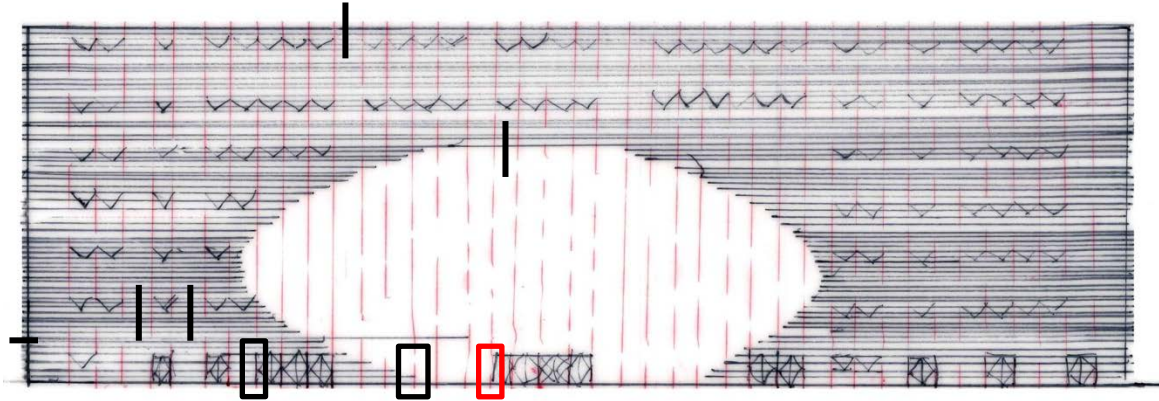


Figure 64: Detail indication source: Luuk Jansen

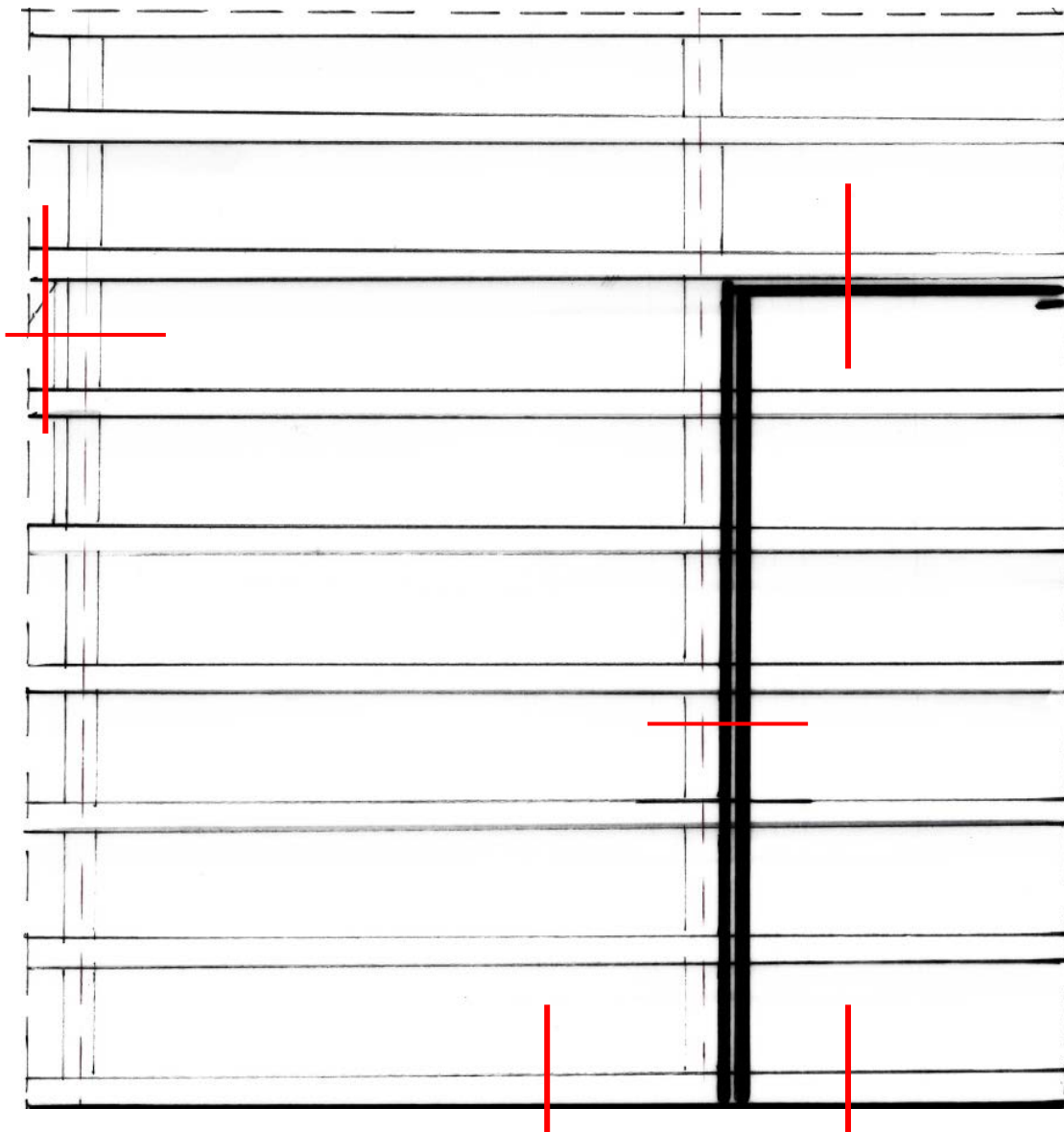
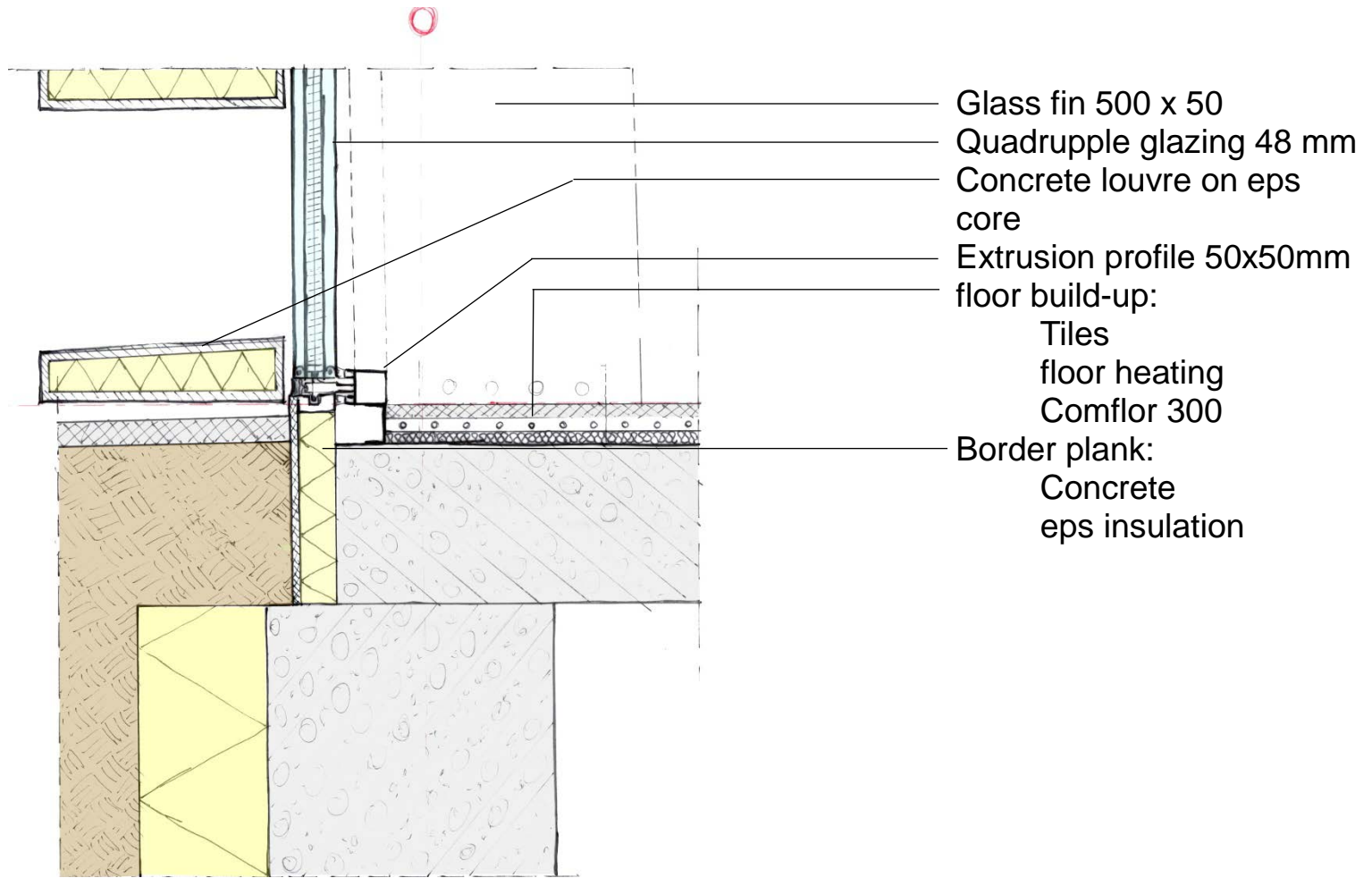
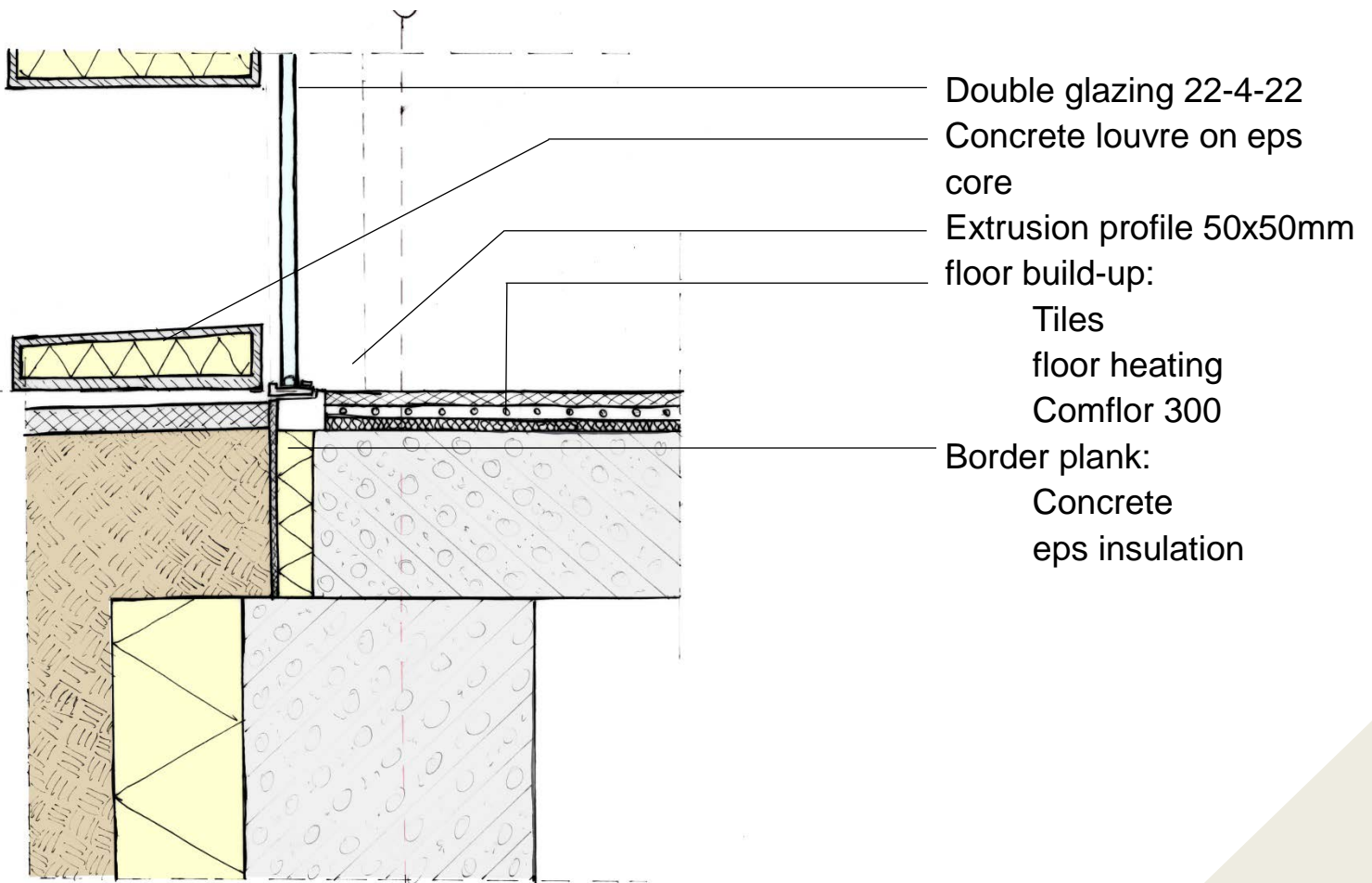


Figure 65: Louvre facade type. And emergency exit Source: Luuk Jansen
Luuk Jansen (4065573): an innovative façade design approach.



- Glass fin 500 x 50
- Quadruple glazing 48 mm
- Concrete louvre on eps core
- Extrusion profile 50x50mm
- floor build-up:
 - Tiles
 - floor heating
 - Comflor 300
- Border plank:
 - Concrete
 - eps insulation

Figure 66: Louvre façade principle ground floor detail source: Luuk Jansen



- Double glazing 22-4-22
- Concrete louvre on eps core
- Extrusion profile 50x50mm
- floor build-up:
 - Tiles
 - floor heating
 - Comflor 300
- Border plank:
 - Concrete
 - eps insulation

Figure 67: Louvre façade emergency exit ground floor detail source: Luuk Jansen

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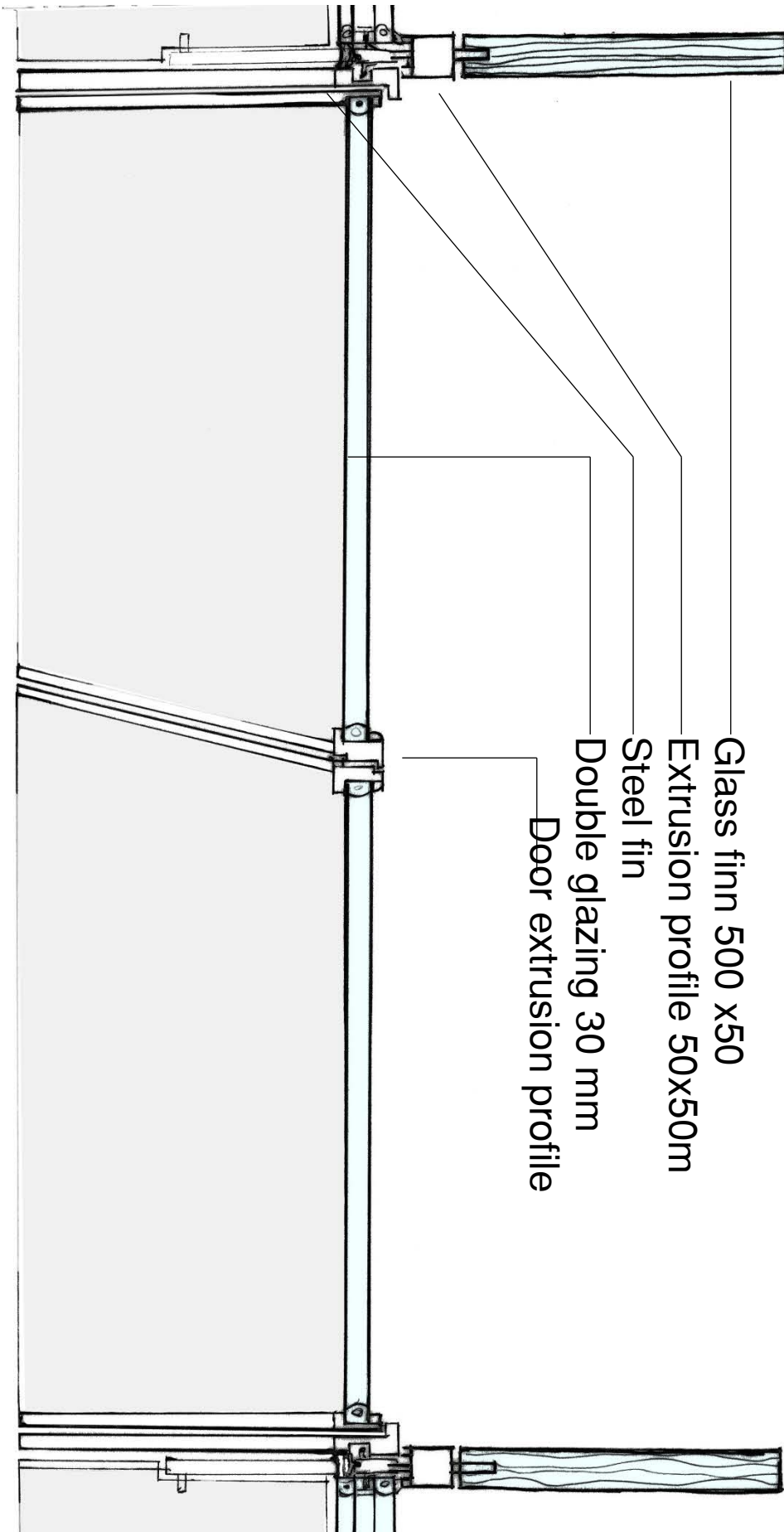


Figure 68: Emergency exit horizontal detail source: Luuk Jansen

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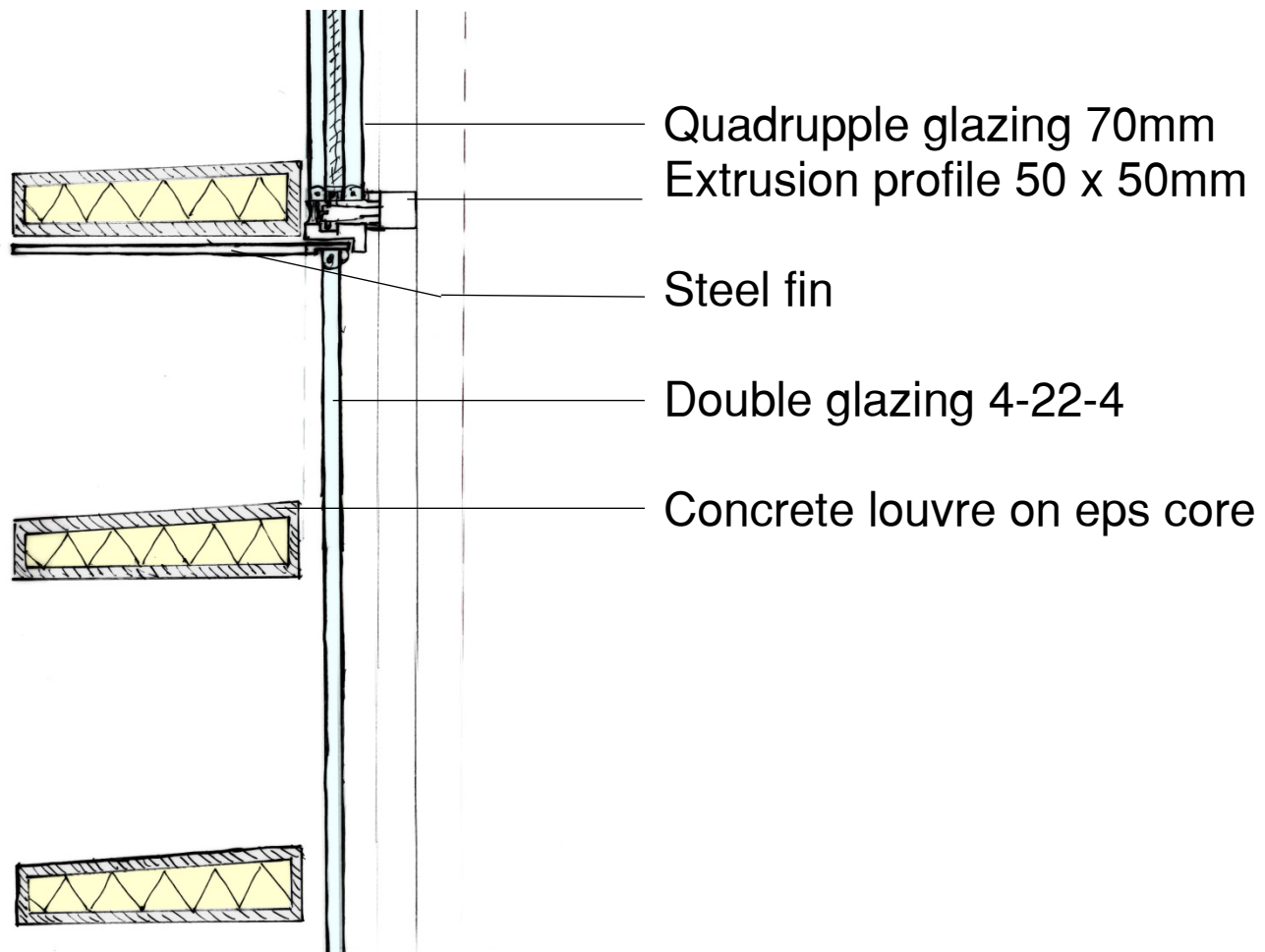
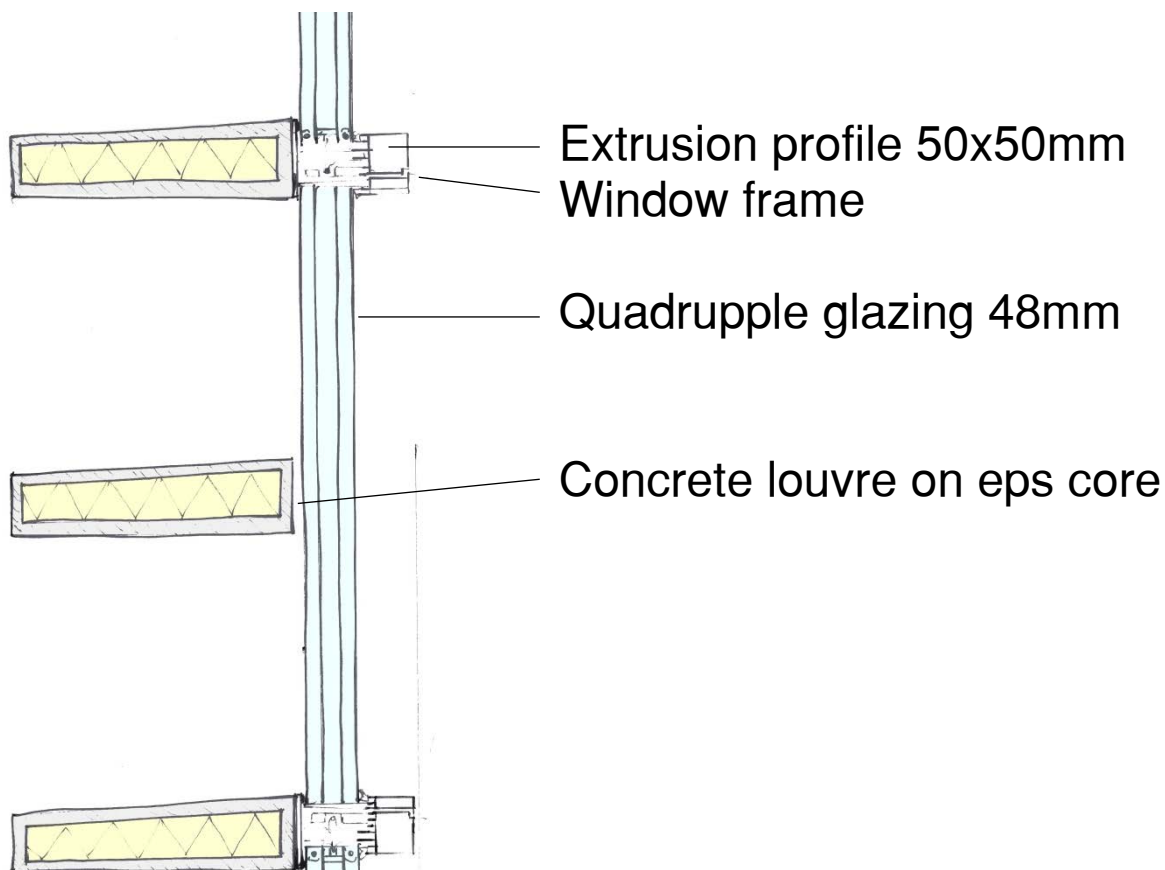


Figure 70: Emergency exit top detail source: Luuk Jansen



Luuk Jansen (4065573): an innovative façade design approach.

Figure 69: vertical window detail source: Luuk Jansen

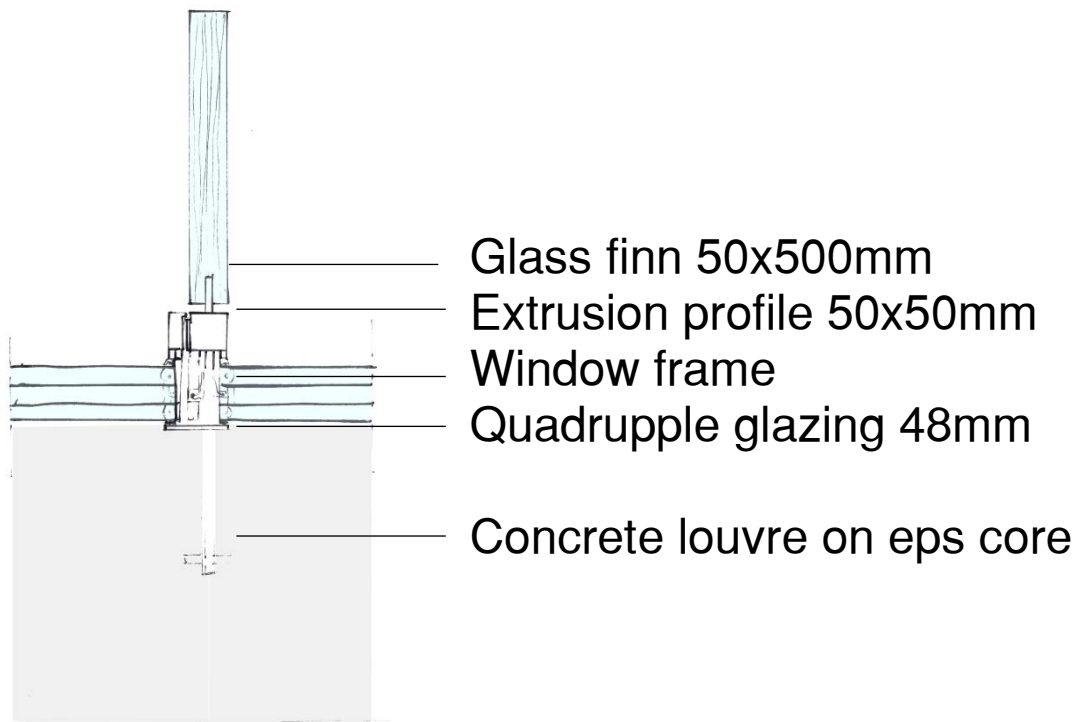


Figure 71: horizontal window detail source: Luuk Jansen

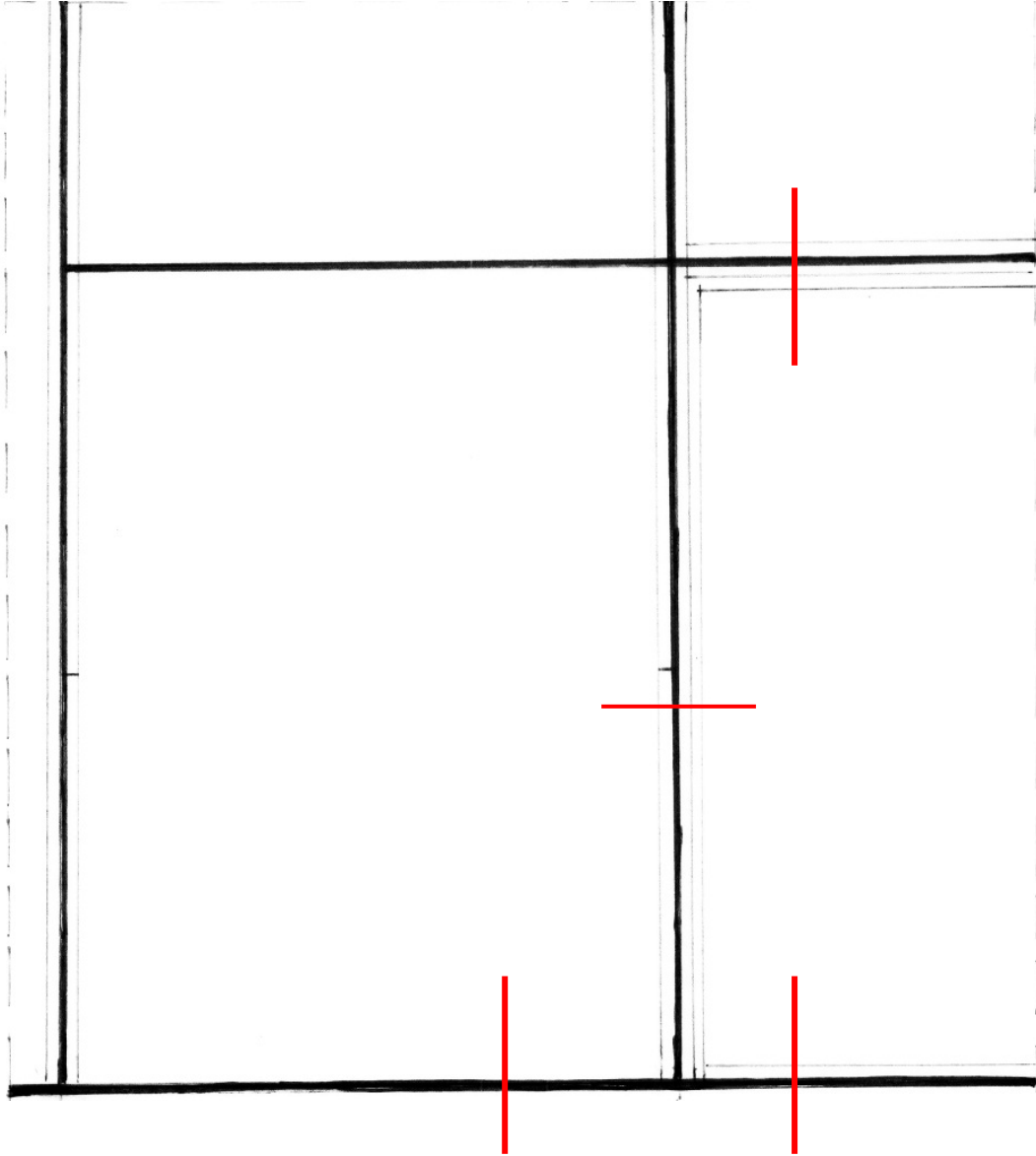
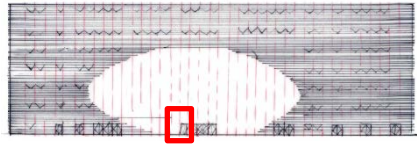
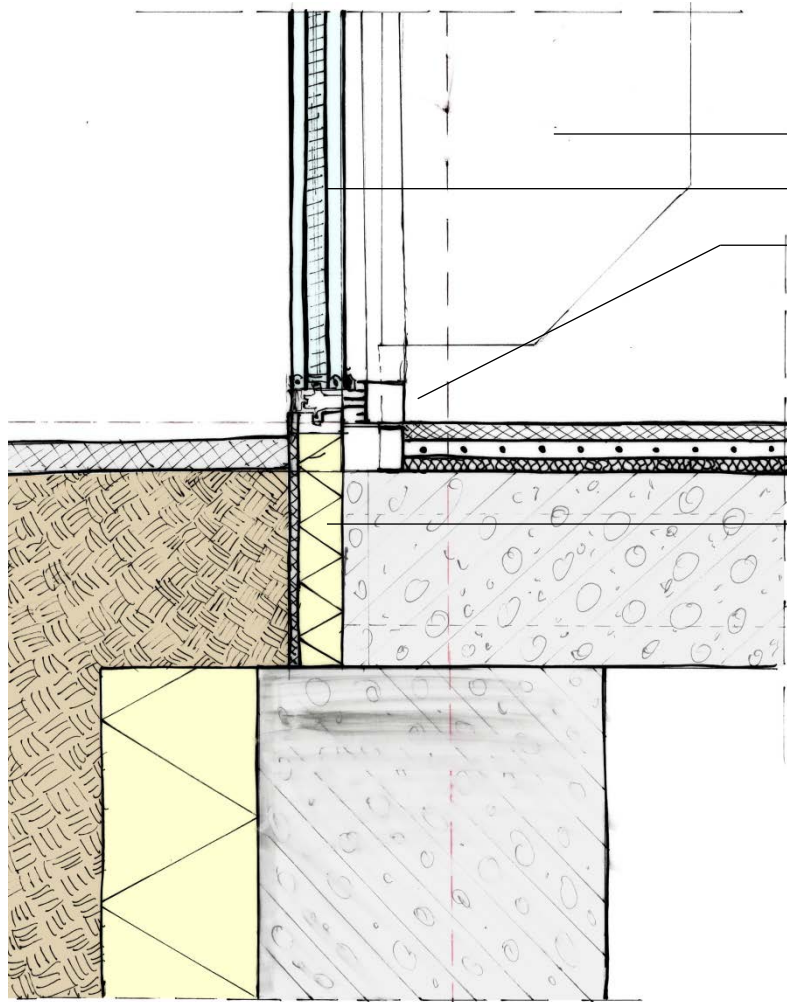


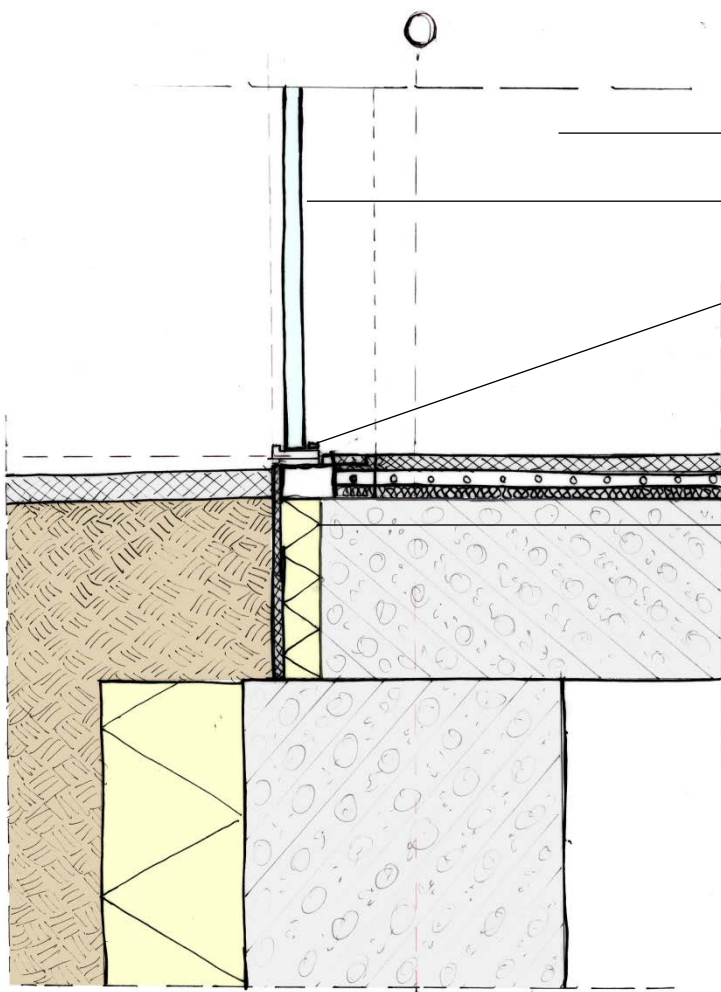
Figure 72: Open façade type source: Luuk Jansen

Luuk Jansen (4065573): an innovative façade design approach.



- Glass fin 500 x 50
- Quadruple glazing 48mm
- Extrusion profile 50x50mm
- floor buildup:
 - Tiles
 - Floor heating comflor 300
- Border plank:
 - Concrete
 - eps insulation

Figure 74: Open façade ground floor detail source: Luuk Jansen



- Glass fin 500 x 50
- Double glazing 4-22-4
- Door profile
- floor buildup:
 - Tiles
 - Floor heating Comflor 300
- Border plank:
 - Concrete
 - eps insulation

Figure 73: Main entrance ground floor detail source: Luuk Jansen

Luuk Jansen (4065573): an innovative façade design approach.

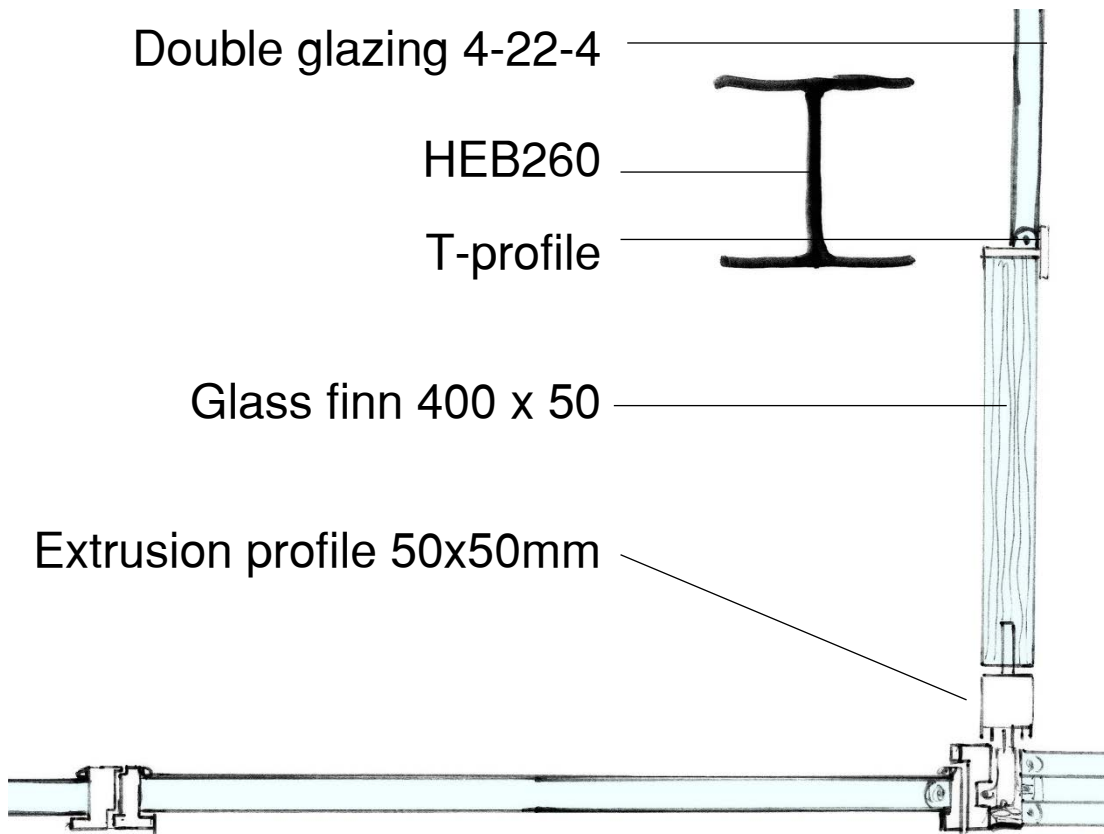


Figure 75: Main entrance horizontal source: Luuk Jansen

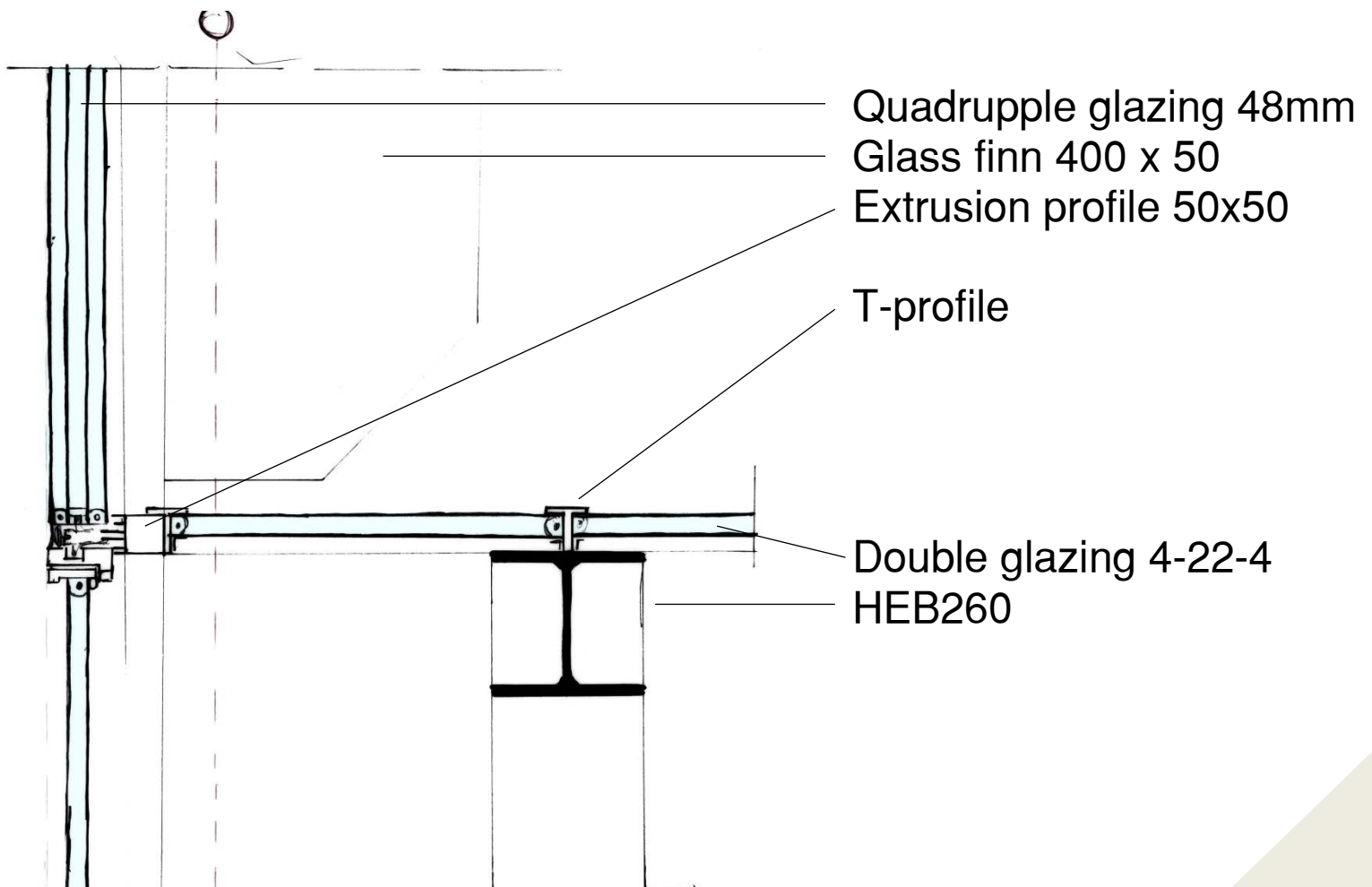


Figure 76: Main entrance top detail source: Luuk Jansen

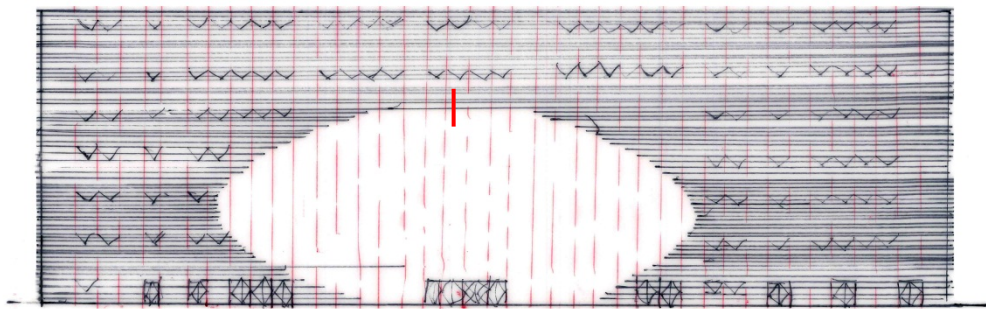
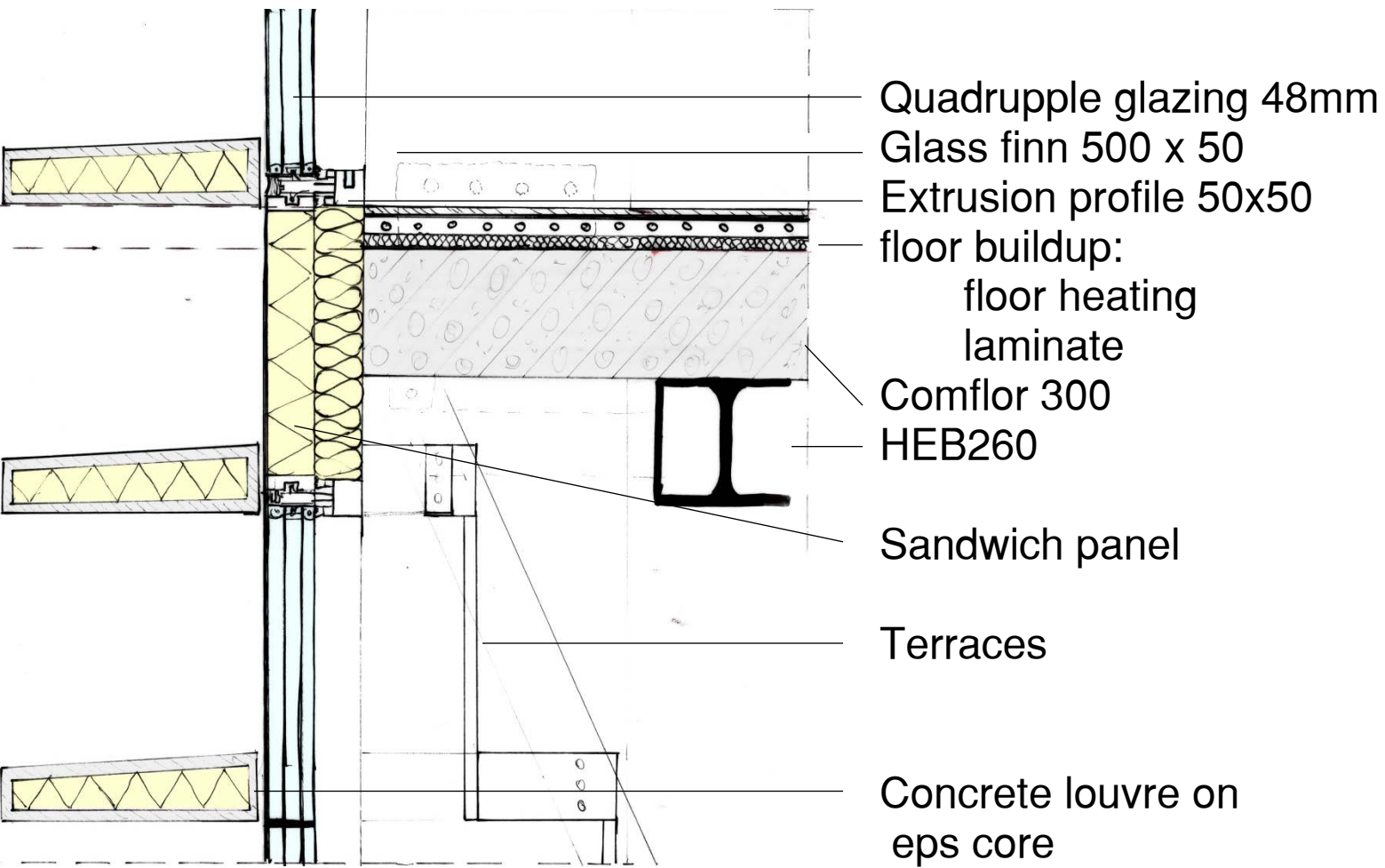


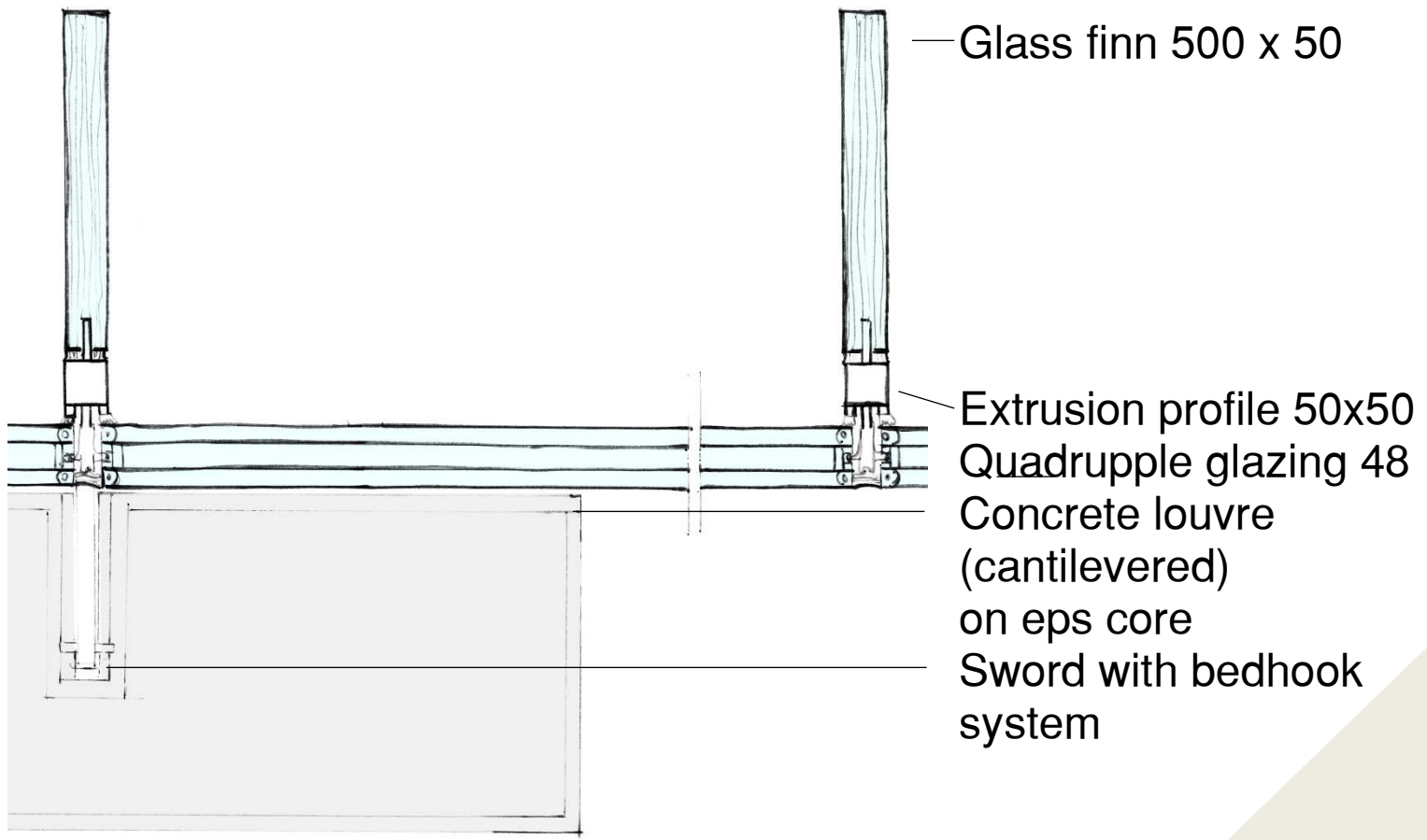
Figure 77: Transition details source: Luuk Jansen

Luuk Jansen (4065573): an innovative façade design approach.



- Quadruple glazing 48mm
- Glass fin 500 x 50
- Extrusion profile 50x50
- floor buildup:
floor heating
laminate
- Comflor 300
HEB260
- Sandwich panel
- Terraces
- Concrete louvre on
eps core

Figure 79: Vertical transition detail source: Luuk Jansen



- Glass fin 500 x 50
- Extrusion profile 50x50
- Quadruple glazing 48
- Concrete louvre
(cantilevered)
on eps core
- Sword with bedhook
system

Figure 78: Horizontal transition detail source: Luuk Jansen

Luuk Jansen (4065573): an innovative façade design approach.

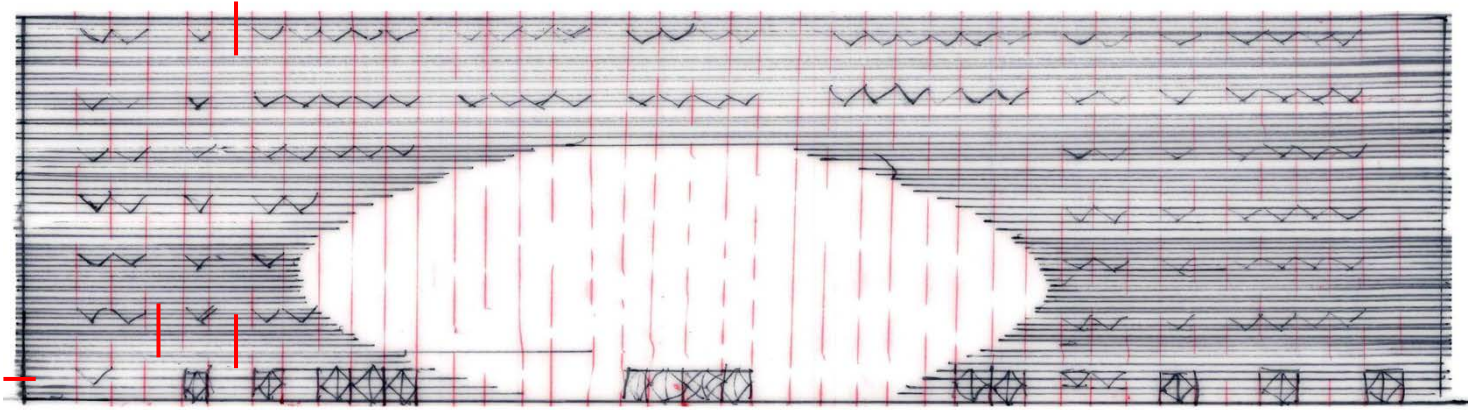


Figure 81: Remaining details source: Luuk Jansen

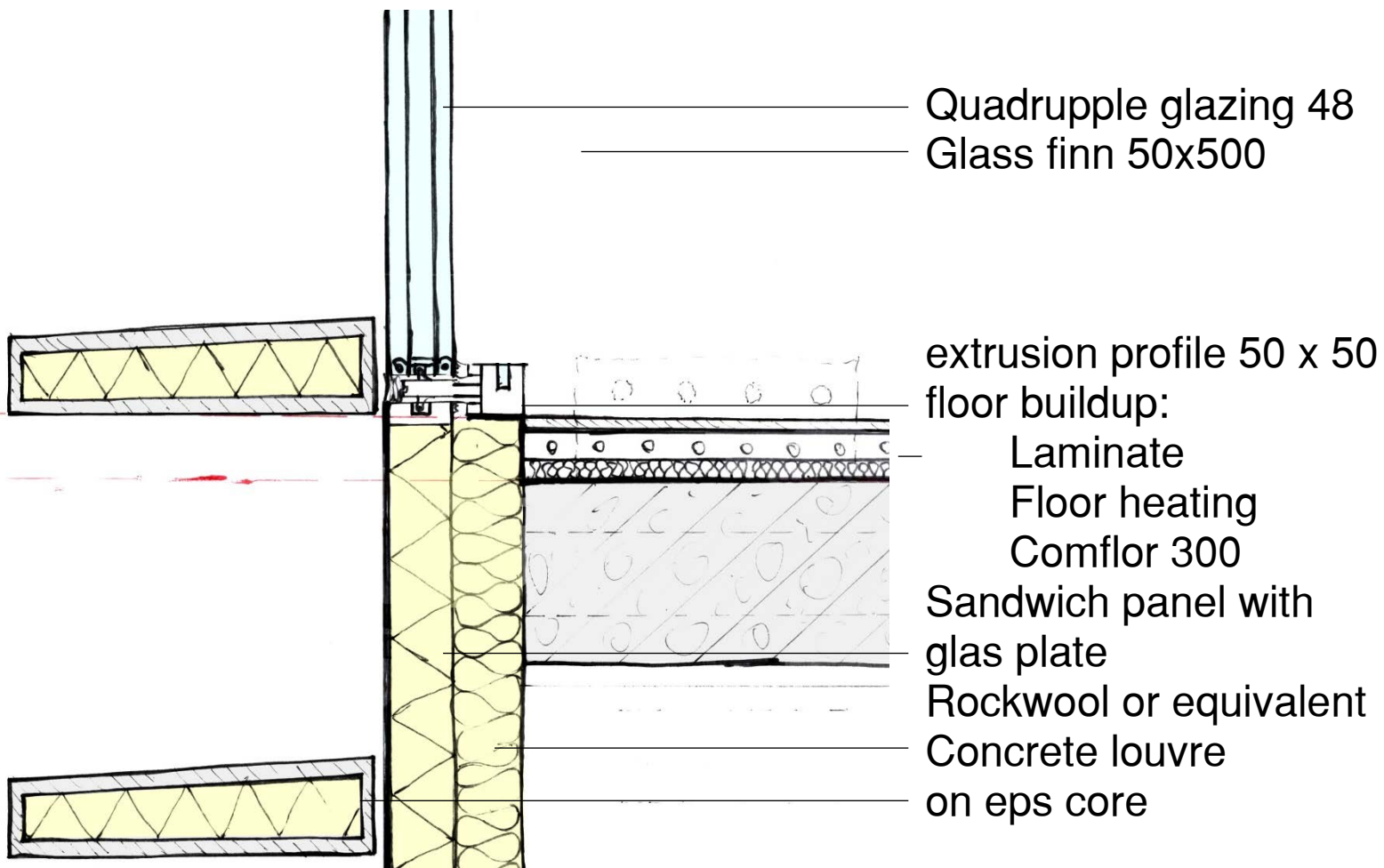


Figure 80: Floor edge detail source: Luuk Jansen

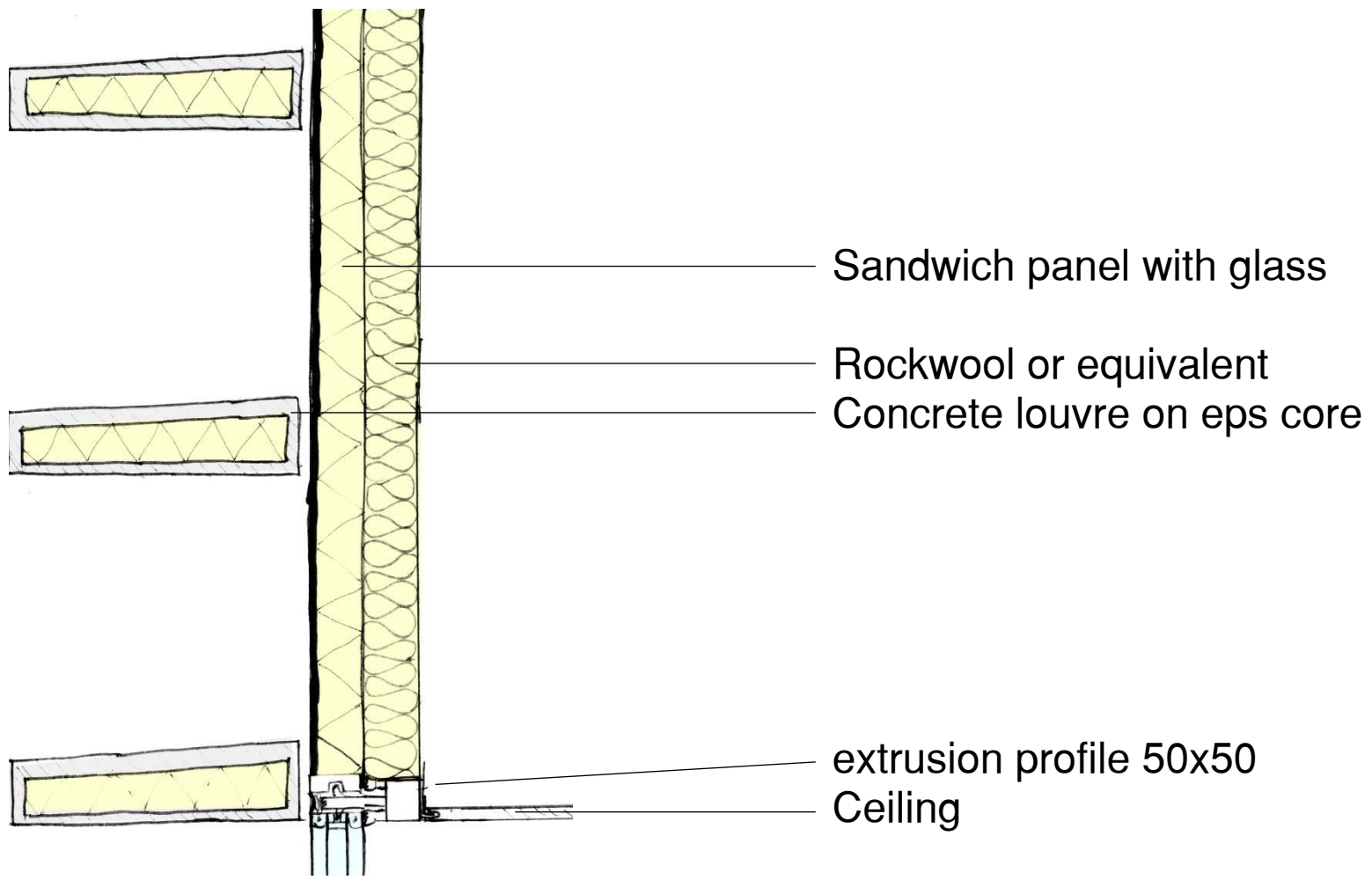


Figure 82: Ceiling detail source: Luuk Jansen

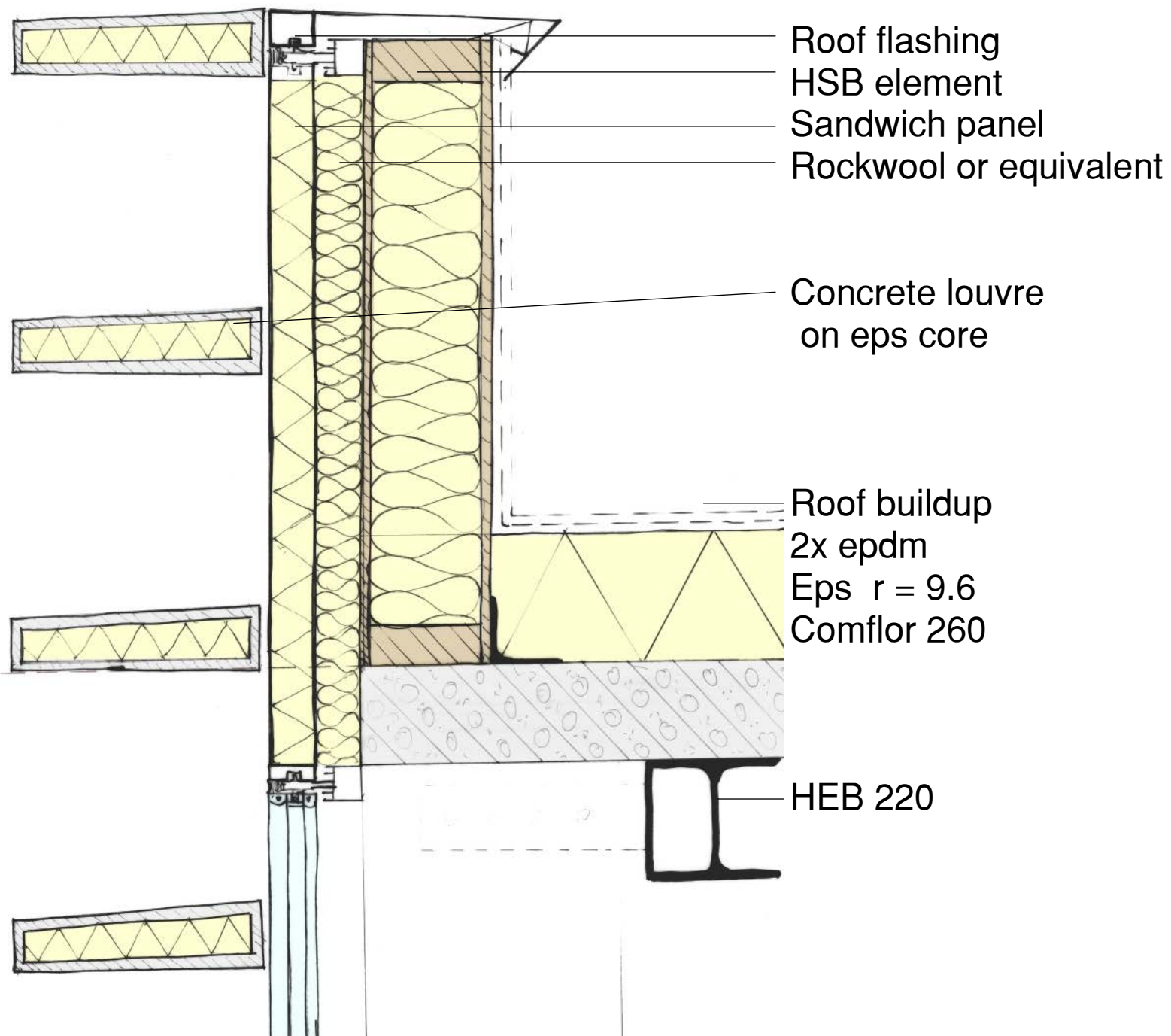


Figure 83: Roof edge detail source: Luuk Jansen

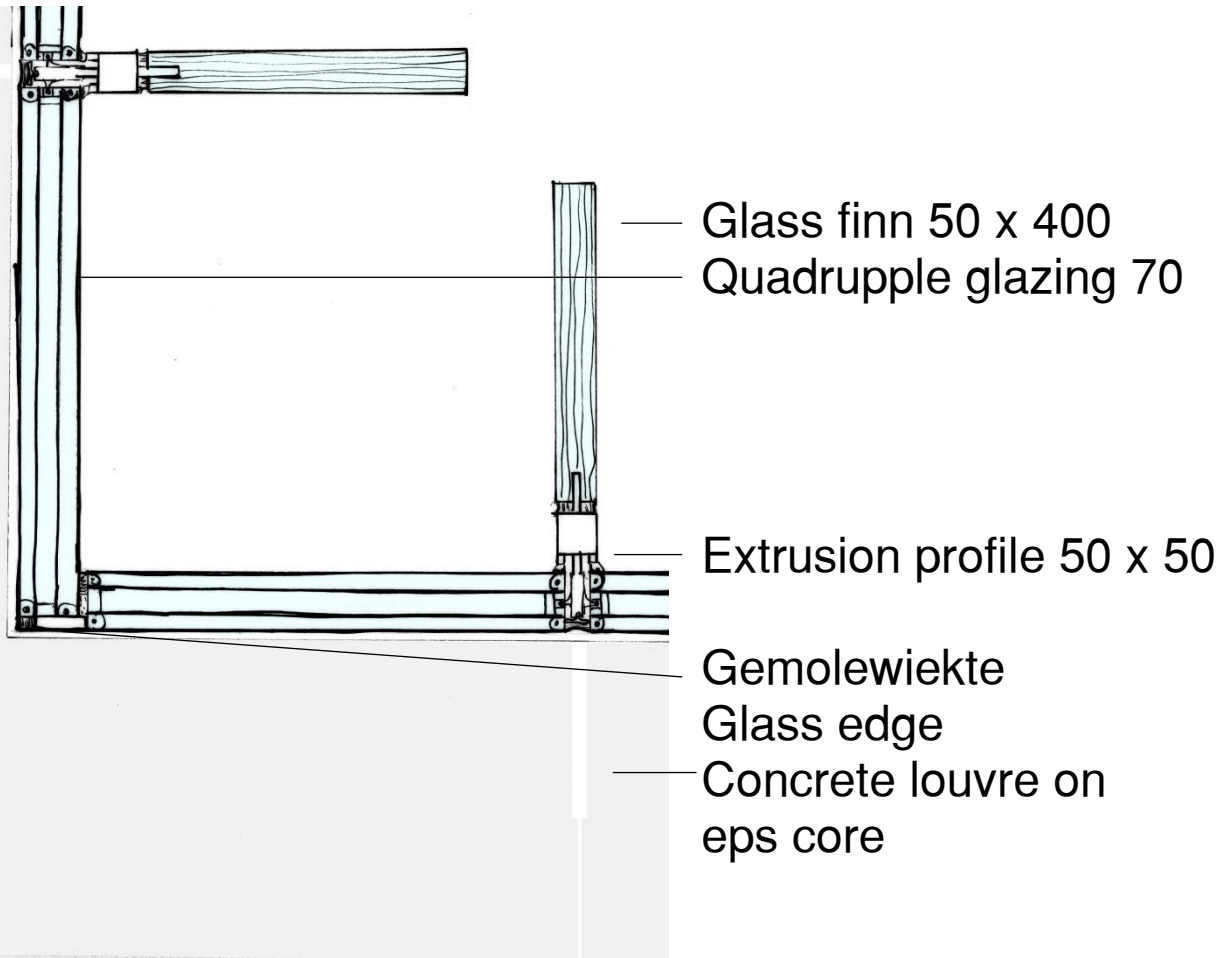


Figure 84: Corner detail source: Luuk Jansen

The details above shows that every exception can be made with the façade principle I came up with. In my opinion I solved most of the difficult problems in the design and did this with no concessions on architectural principles and design.

Finishing the principle solution

With this principle ideas I talked to some lead engineers at ABT and they liked the idea very much only at some points it good be better. So I looked at the design again and try to make this design, which is good in my opinion even better. This led me look to my design on a fresh way. Some parts I did not do research add, I just toke one possibility in the design, so I did some more research into these topics, trying to find out if the solution I opt for is the best or if there is room for improvement. I will show a couple of solutions but the actual choice is up to the architect

Louvre construction:

1. Extruded frc with polystyrene core

The louvre construction I first come up with is a principle often used for kitchen blades. It is a polystyrene foam core with a concrete outer layer.

Good: low weight: 52.9 kg. Easy to make. Is concrete, so the look is good. Very robust and vandalism proof.

Bad: cannot find an outside usage (balsa concrete)

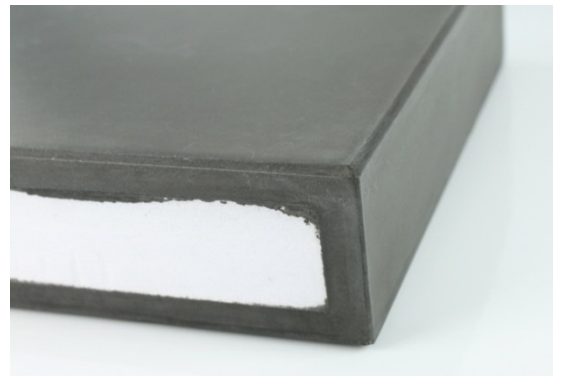


Figure 85: balsa concrete source: <http://retaildesignblog.net/wp-content/uploads/2011/09/BalsaConcrete-by-EVOLVE.jpg>

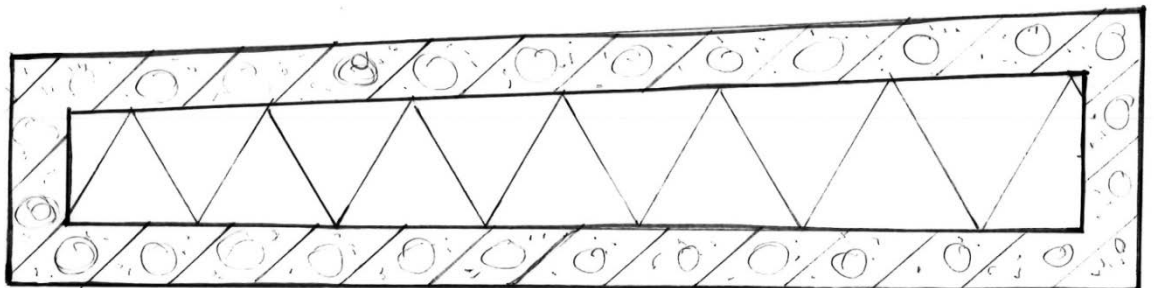


Figure 86: section principle source: Luuk Jansen

2. Aluminum extrusion profiles with concrete look coating:

In theory aluminum extrusions profiles are one of the best solutions because of the low weight, they are easy to produce in the right shape and are cheap, but such thing as a concrete coating does not exist.

Good: low weight: 15.9 kg. Easy to make.

Bad: not exactly looks like concrete because you only can take a color which looks like concrete but never get the proper outer structure.



Figure 87: RAL 7035 source: <http://polyesterwinkel.com/polyester-pigmentpasta-ivoor-ral1015-p40.html>

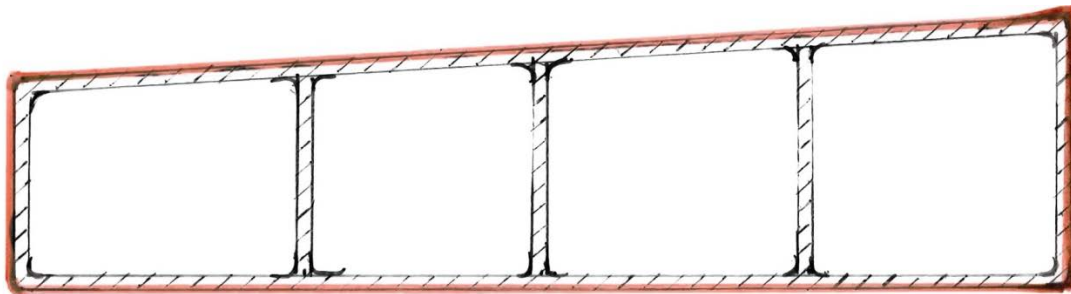


Figure 88: Extruded louvre source: Luuk Jansen

3. Extruded ceramics.

Extruding ceramics is a quick process to produce façade panels, or other different shapes. Ceramics is very easy to make and to clean. But it is also heavy and it does not look like concrete.

Good: easy to make and to clean.

Bad: heavy: 122 kg. Color is not concrete (MBK m7.02.0)



Figure 89: Concrete look ceramic source:

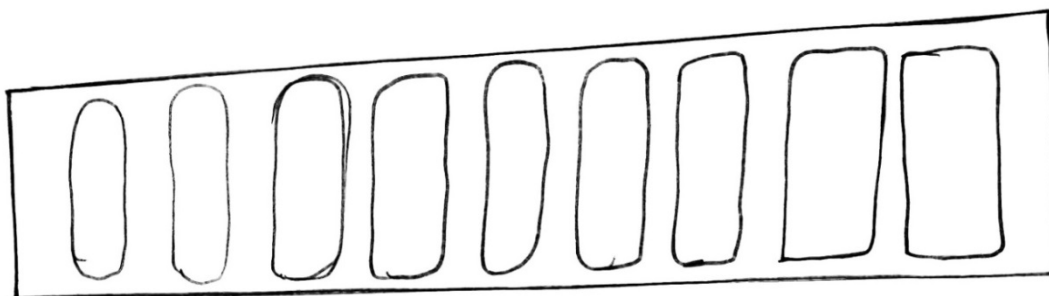


Figure 90: Extruded ceramic louvre source: Luuk Jansen

4. Full concrete louvre

The benchmark of a concrete louvre is of course a full concrete louvre, the looks and rigidity are great but it is a very heavy solution.

Good: easy to make. Looks exactly like a concrete louvre.

Bad: it is very heavy: 212,5 kg.

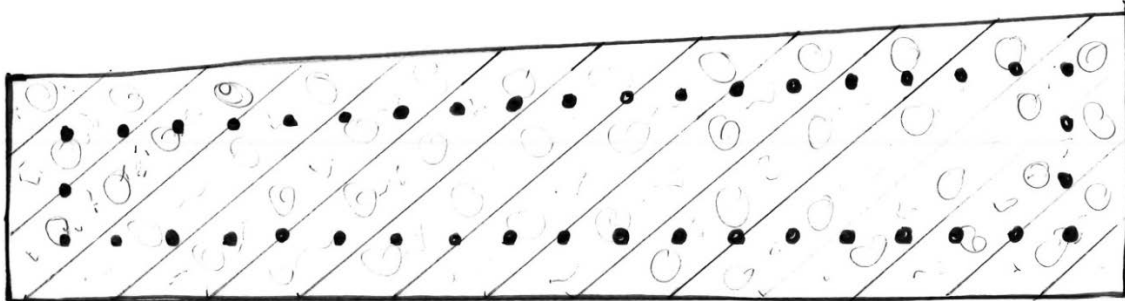


Figure 92: concrete louvre source: Luuk Jansen

5. Concrete stucco on fermacell

This is a very lightweight option which looks exactly like a concrete louvre. But it is in the same time also very flimsy and vulnerable to vandalism.

Good: looks exactly as it should. (verbau betonstuc).

Lightweight: 23,3 kg.

Bad: is costly to make. Very flimsy.



Figure 91: Concrete stucco source: <http://verbauhaus.com/betonstuc/kleurpalet-verbau-betonstuc/>

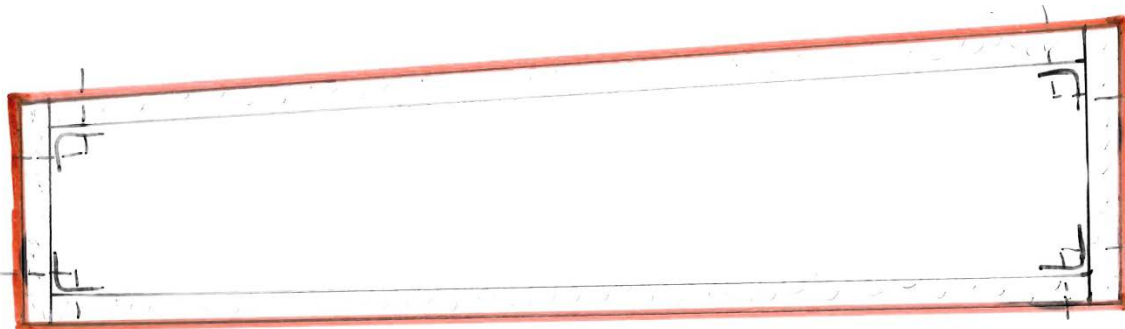


Figure 93: Concrete stucco on fermacell source: Luuk Jansen

Conclusion: I should recommend option 1. Frc on polystyrene core to the architect. In my opinion this is the strongest solution which still is lightweight and not too costly.

Solar shading:

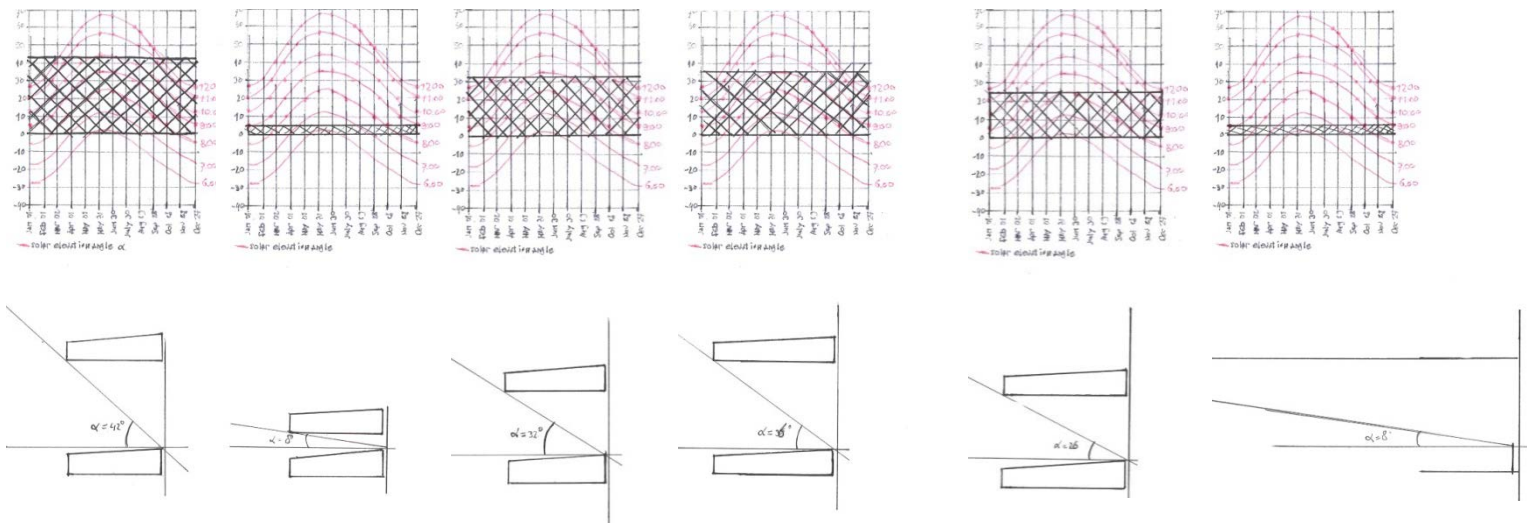


Figure 94: Louvre arrangement solar study source: Luuk Jansen

Out of research came as you can see above that the louvre design the architect made is not good enough to have a proper glare protection inside during the hole day, in practice this means that the sun will enter the building directly till 11.30. In the research above I tried different arrangements, changing length of the louvre and hoh distance of the louvres but none of them brings a suitable solution therefore there should be an added solar shading. I will show a couple of possible solutions but the actual choice is in this case up to the architect.

1. Anti-glare coating

An anti-glare coating blocks direct sunlight, but still 70% of the daylight will get through (3M). This is also the problem with anti-glare coating because it is always on, for example during a cloudy winter day you don't want this coating to be on.

Good: blocks uv and ir rays, 70% of the daylight is getting through, see-through, no cleaning needed.

Bad: always on, meaning no free heat gain during winter. When sun is away it will be quiet dark inside, so there is a lot of interior light needed.



Figure 95: Anti glare coating source: http://solutions.3m nederland.nl/wps/port al/3M/n_L/3MWindowFilm/WindowFilm/Products/Prestige/

2. Solar shading integrated in the glass.

Solar shading can be integrated in the glass, which means it is protected from the outside environment. It is also adaptable to different situations and therefore suitable to have a summer and winter protocol.

Good: no extra heat inside. Clean look. Adaptable to what needed.

Bad: difficult to maintenance, gets dirty due to wear which cannot get out of the system. Extra added, when closed it gets dark inside.



Figure 96: Pilkington screenline source: <http://www.sama.nl/producten-en-diensten/raamdecoratie-zonwering/screenline/>

3. Interior solar shading

Solar shading can also be added inside, on places where glare is an issue, but because this solar shading is inside it will not block the uv and ir rays to come inside, which means extra heat inside, which means more cooling is needed in summer.

Good: easy to maintenance and clean, regulating depending on the needs.

Bad: extra heat load, does not look very clean, extra added, no see through when closed, when closed it gets dark inside.

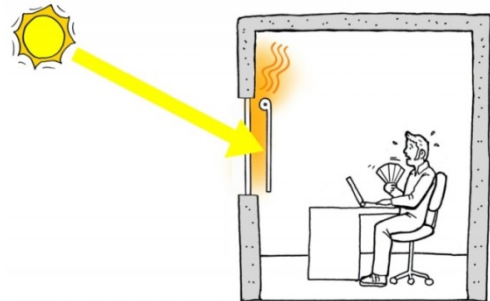


Figure 97: Interior solar shading source: <http://sustainabilityworkshop.autodesk.com/buildings/shading-solar-heat-gain>

4. Outside solar shading

The solar shading also can be placed outside, which means no extra heat in summer but also not in winter. Most of the times it looks cleaner because it can be better integrated in the façade structure.

Good: no extra heat load, easy for maintenance, easy to clean, regulating depending on needs, looks clean when properly detailed.

Bad: extra added, gets extra dirty due to outside environment, blocks vision but is partially see-through, when closed it gets darker inside.

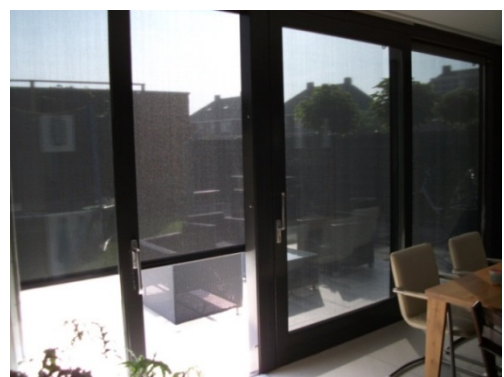


Figure 98: Exterior solar shading source: swela.com

Conclusion: I should recommend 4. Outside solar shading to the architect because this is the best solution esthetic but also for see-through, heating and maintenance. A zip screen is recommended because the high wind load.

Load bearing of the glass:

Glass: 2800 kg/m³

4mm = 11,2 kg/m²

Laminated 4,4mm 11,2 kg/m²

Quadruple glazing (4-16-4-16-4-16-4): 305 kg

(3-12-3-12-3-12-3): 228 kg

Triple glazing: (4-16-4-16-4) 228 kg

Double glazing: (4-22-4) 152 kg

Schüco fw 50+ sg: max 375 kg

Conclusion:

The calculation above shows clearly that the use of quadruple glazing is no issue in a 50x50 façade.

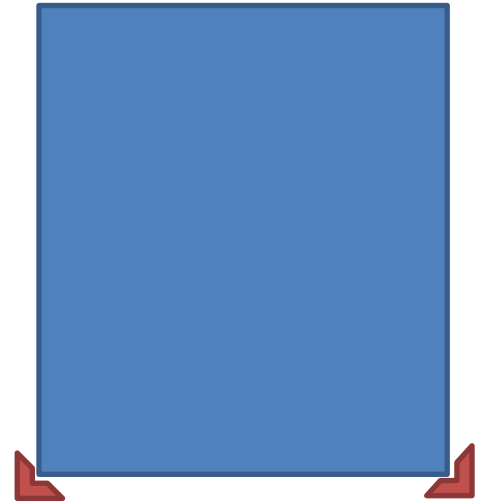


Figure 99: Glass bearing structure source: Luuk Jansen

Insulation of the glass really needed:

Enuiro quarto

Pilkington insulight

saint gobain climaplus

Ug = 0.35

Ug = 0.50

Ug = 1.0

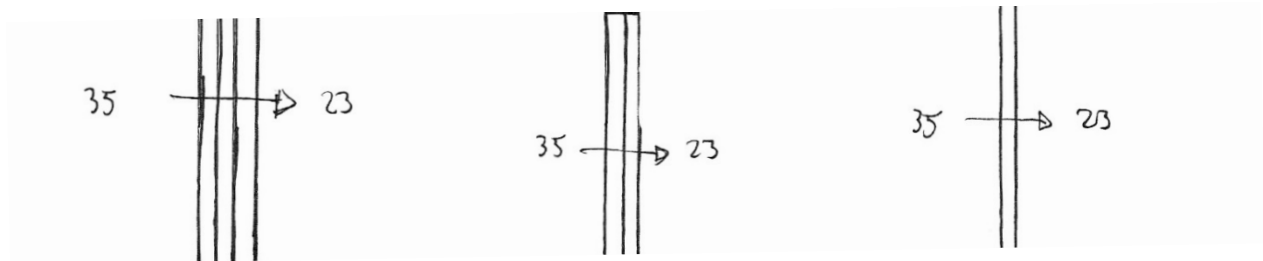


Figure 100: Summer situation source: Luuk Jansen

$\Phi = 69 \text{ W}$

$\Phi = 99 \text{ w}$

$\Phi = 179 \text{ w}$

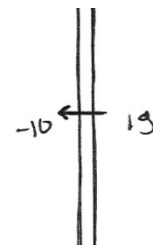
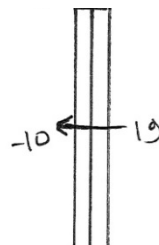
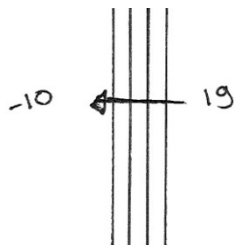


Figure 101: Winter situation source: Luuk Jansen

$\Phi = 28 \text{ w}$

$\Phi = 41 \text{ w}$

$\Phi = 82 \text{ w}$

Quadruple vs double

577 kwh extra usage (per 6,8 m²), 59 m³ gas = 38 euro (Dutch gas price)
59280 euro/year

Quadruple vs triple

201 kwh extra usage (per 6,8 m²), 20 m³ gas = 13 euro (Dutch gas price)
20280 euro/year

Conclusion

As you can see in the calculation above quadruple glazing has a large influence on energy costs. Therefore I decide to use the quadruple glazing, because in my research I go for the best performing façade possible. The calculation above also shows that it feasible to get the extra money spent on quadruple glazing back in a reasonable time.

The fin construction:

Façade load bearing glass fin 17 meter span

The detail on the right shows a glass fin façade in Hoog Catherijne. ABT did the engineering on this façade.

This façade is 19 meter high. They used a glass fin with a depth of 900 mm and a width of 50 mm to support this façade.

A lesson they learned out of other projects is that drilling holes in the glass should at least 50 mm outside the edge of the glass.

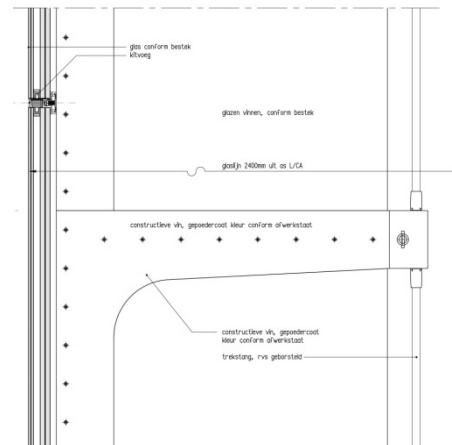


Figure 102: Glass fin facade Hoog Catherijne Source: ABT

Façade load bearing glass fin: 4 meter span

In the example on the right is the Apple store in New York. This cube is 10 by 10 by 10 meters using 3 glass plates per side. The construction which hold up this building are glass fins 480 mm depth and 62,5 mm wide.

The building is engineered by Eckersley O'Callaghan Structural Design



Figure 103: Apple store New York source: <http://architizer.com/projects/apple-store-fifth-avenue/>

Conclusion

The examples above give a better indication on the depth of the glass fin. It also shows that the 500x50 mm I picked in my details is way too small to bear the façade and cope with the wind load.

Therefore the high parts will have a glass fin of 900x75mm and the lower parts a glass fin of 500x60. This should be sufficient to bear the façade and cope with the monsoon wind load. The width will prevent the glass fins from buckling, the other measure to prevent the fins from buckling is to couple the horizontally as done in the Hoog Catherijne building.

Building envelope details

The above research shows that there a couple of points where the principle design can be improved to make the façade more feasible and performance better. This points where the details should be changed are:

Glass fin dimension	decision of the engineer	High: 900x75 low: 500x60
Louvre construction	decision of the architect	As recommended: eps core frc
Solar shading	decision of the architect	As recommended: zip screens
Glass type	decision of the engineer	quadruple (3-12-3-12-3-12-3)

The drawings below are the final details of the project specific approach.

[The most updated details – a cad]

Conclusion Design process

The steps I took during the design process where:

1. The design principles of MVRDV where the starting point of the design process. During the design process I tried to reach those principles.
 - a. First I had two concepts, one for the large open part and one for the louvre part. For the open part I am willing to use a tension cable façade and for the louvre part, storey high composite panels.
2. The next step was to solve the difficult details to see if the concepts are possible. The critical details here where the doors and windows.
3. Improving the conceptual details.
4. Let both façade systems meet each other. For example make the border planks in one line.
5. Make a 3d model of the façade, during this step I already find out some problems, especially where both façade types meet each other, because one of the architectural principles was that there is no intermediate structure needed.
 - a. The tension cable façade should be made stepped to make a connection to the louvre façade, first I was trying to solve this with a stepped cut glass, but then almost every panel is different and therefore expensive.
 - b. Another solution could be to make the complete façade out of a cable mesh, but it is difficult to make openings in such a system and a cable mesh façade will move several decameters and therefore it is not suitable to hang louvres at it.

so I decided to come up with a new concept.

6. After coming from the above I start with a dozen of crazy ideas trying to find what is a possible façade to meet the architectural principles. Before I made these designs I made a matrix what I think is important in the façade to make a sort of objective grading of the different ideas.
7. Out of this matrix came that a glass finn façade combined with a extrusion profile.
8. Optimalisation of the idea above.
9. Making all the principle details of the system to see if it works at all points.

What you can see is that the design process is not a linear one but it goes in circles, sometimes you have to go two steps back to go one step forward. What I have learned during this design process that it is really important to make an objective comparison between ideas, because only then you can make sure you go for the best option and you didn't choose by emotion. It is also important to documentate the steps really well because then it is easy to go a step back, improve it or take another direction.

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Comparison between my solution and MVRDV solution

The main part of the research is the comparison between a product specific façade engineering approach done by MVRDV in cooperation with Schüco and a project specific (an engineering done to come up with an design where the architect does not have to do a lot of concessions, his façade principles are in this case the holy grail) façade engineering approach.

Hypothesis

I think that the outcome of this comparison will be:

1. The project specific approach is more expensive due to the use of non-standardized systems and products.
2. The project specific approach will weight much more.
3. The project specific approach will outperform the product specific approach.
4. The project specific approach will realize the architectural principles stated in the preliminary design better than a product specific approach.
5. The project specific approach will score better overall because it scores better on the architectural categories.

Comparison reference

The images below comes out of the preliminary design book by MVRDV. These are the images to achieve with the design.



Figure 104: Park render source: MVRDV

主题概念

“滨海之眼”和图书馆中庭空间结合，共同为图书馆创造了一个良好的公共空间。“书山”内设置一个外径22.5m的球幕演示厅，形成图书馆的空间核心。通过“书山”空间可以分别进入到首层、二层的阅览空间，“书山”空间将不同的阅览区有机整合，为读者带来丰富的空间体验。

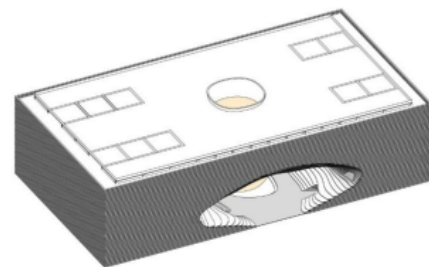
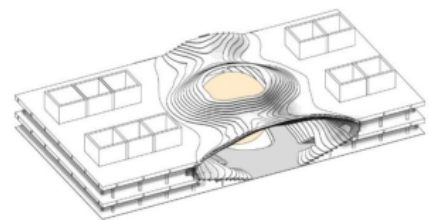
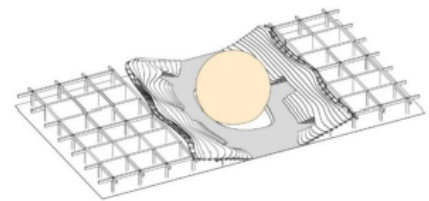
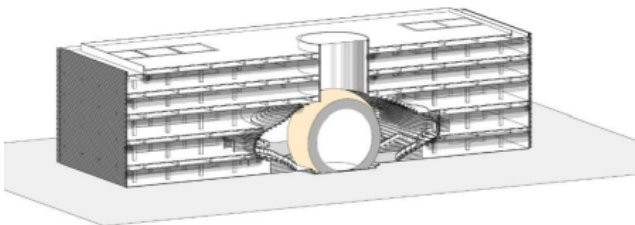


Figure 105: Inner organization principle source: MVRDV

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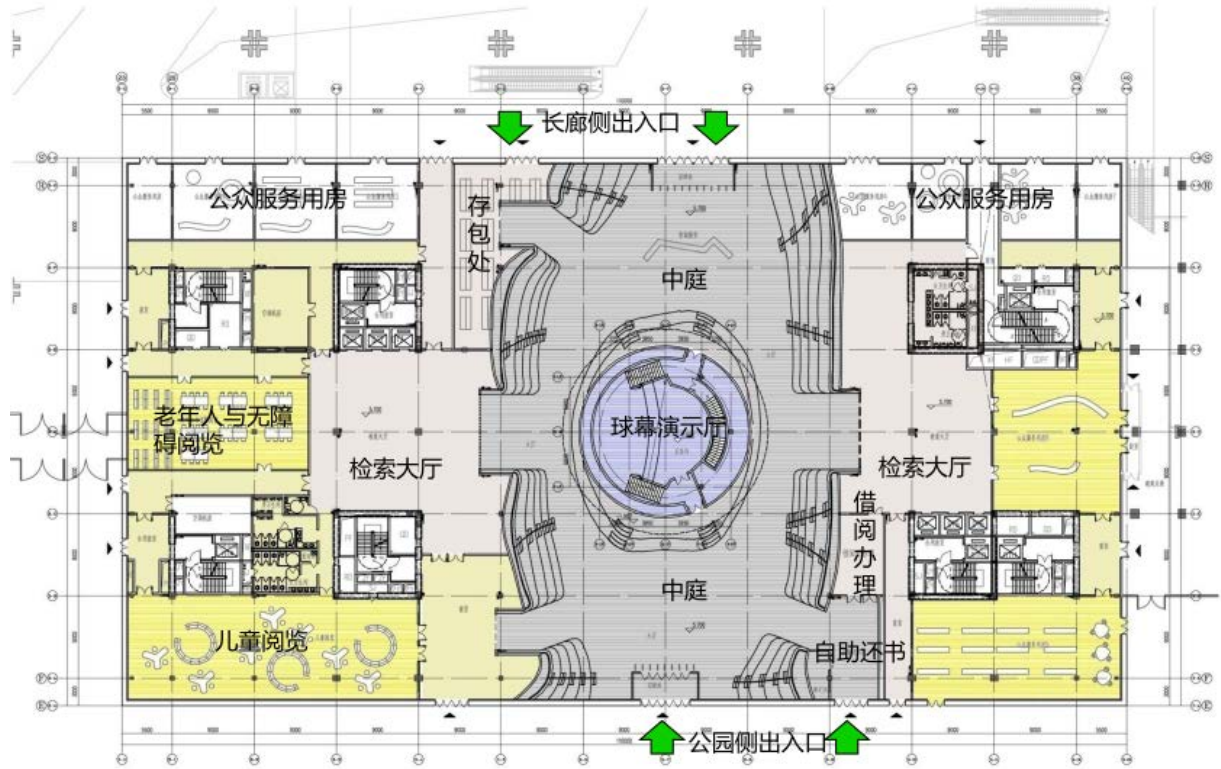


Figure 106: Floor plan 00 source: Luuk Jansen

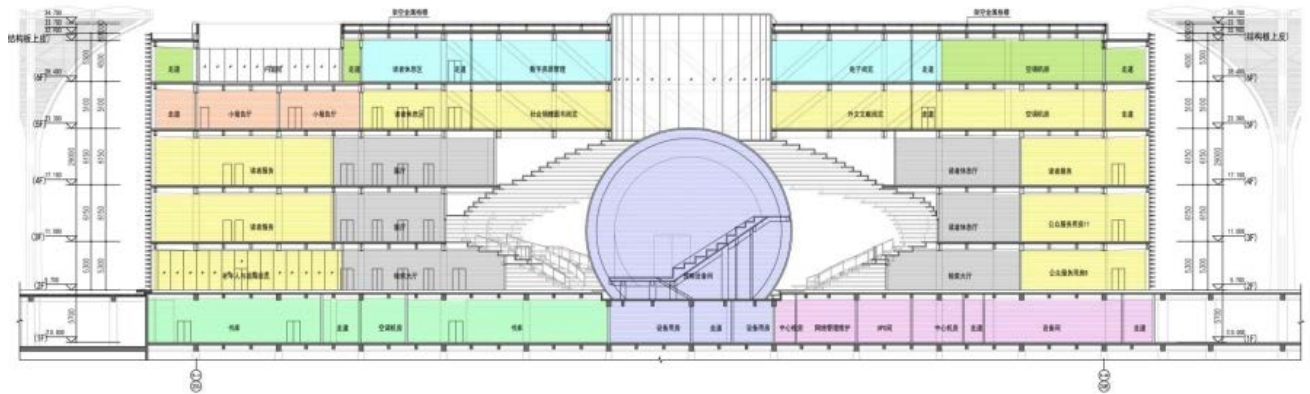


Figure 107: Section AA source: AA

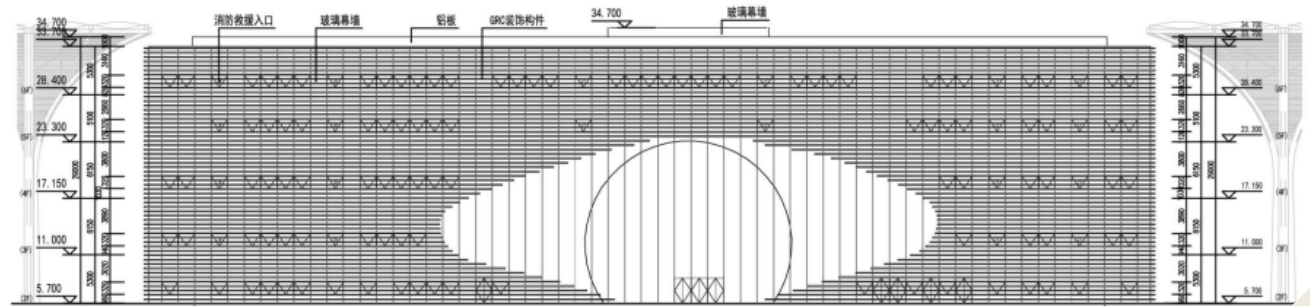


Figure 108: South façade source: MVRDV

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Project specific design by Luuk Jansen

On the images below you can see the project specific engineering I did.

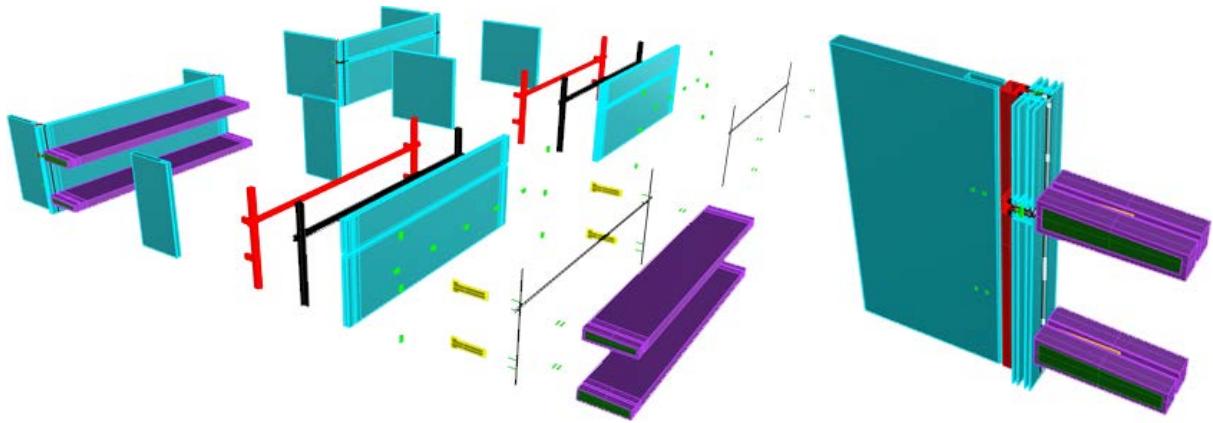


Figure 109: Exploded view source: Luuk Jansen

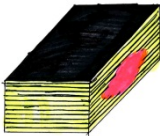
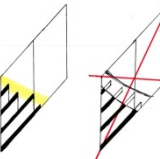
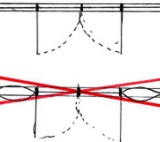
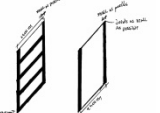
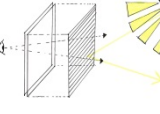
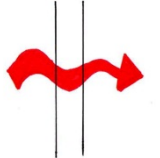
Figure 110: Fragment project specific elaboration source: Luuk Jansen


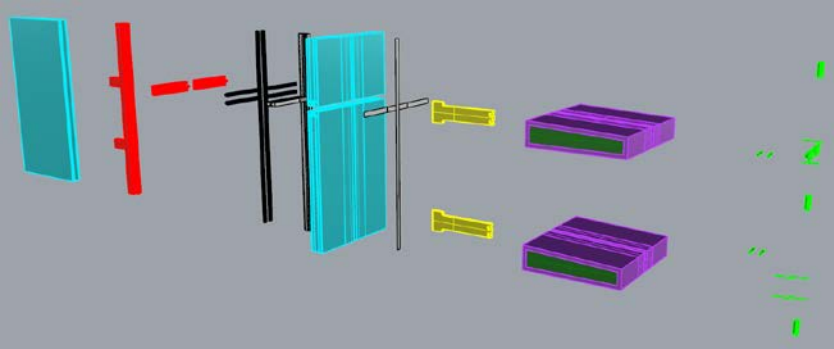



Figure 111: Render source: Luuk Jansen

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Below you can find the rating table. The categories are ordered on importance and relevance. The first four categories are about meeting the architectural principles, the others are about user comfort, climate and costs. The first four categories all will count double, the other four are count standard. This is because then the importance is take into account.

	Category	Research	value
1		When you compare the preliminary design render of MVRDV to the render above you will see that there are almost no visible changes. This means that the project specific engineering looks almost exactly the same as the design proposal by MVRDV. But the construction is a bit more visible and therefore it is not perfect.	8
2		Because the façade has a common system, namely the glass fin façade build up where louvres can placed on every position you like. Therefore there is no intermediate structure needed.	10
3		As you can see in the technical elaboration I did before the openings can be done in the same extruded profile system. But on these places it will look a bit different therefore it is not perfect.	7
4		The only visible view blocking structural elements are extruded profiles 60x60 and 75x60 this means the construction is slender and small.	10
5		By using the louvre layout as designed by MVRDV there is a clear look outside but the sun will still enter the building till 11:30 in the winter. Therefore there should be a glare protection. In my technical elaboration I did some proposals to prevent from glare but it is up to the architect or the end user what the solution will be. Therefore in the current elaboration the sun shading/glare protection is poor.	3
6		Below you see an RC calculation, for the value I decided when the total building average is more than 5 then it is an 6 because this is the minimal requirement according to the Dutch building regulation. above 9 will be a 10 between 7-8 will be a 9 between 6-7 will be a 8 between 5-6 will be a 7 between 4-5 will be a 5 between 3-4 will be a 4 between 2-3 will be a 3 below 2 will be a 1 Calculation: Rfaçade = $1/(0.95*0.35+0.05*1.26) = 2.53$ Rroof = $0.3*0.031 + 0.26*1.03 = 9.85$ Rfloor = $0.3*0.031 + 0.3*1.03 = 9.905$	8

		$R_{\text{totaal}} = 0.295 \cdot 9.905 + 0.295 \cdot 9.85 + 0.41 \cdot 2.53 = 6.87$ (see appendices for further calculation)	
7		<p>To make an equal comparison both fragments are 0,45 m2. According to monico Rossi (http://www.collegepublishing.us/jgb/samples/JGB_V6N2_b02_Rossi.pdf) a façade weights from 90 kilo per m2, so 90 kilo is very good.</p> <p>> 90 10 Between 100 – 150 9 Between 150 – 200 8 Between 200 – 250 7 Between 250 – 300 6 Between 300 – 350 5 Between 350 – 400 4 Between 400 – 450 3 Between 450 – 500 2 500 < 1</p> <p>The total weight of the fragment above is 108.01 kilo per 0.45 m2 -> 240 kilo</p> 	7
8		<p>To make an objective price for a part of the façade, I decided to use only the material costs of the part because for certain parts it is difficult to find the right price for the part as machined etc.</p> <p>For parts like screws etc., I will take some sort of average value.</p> <p>According to bouwkostenkompas the average façade price between 515 to 685 euro/ m2</p> <p>> 515 8 Between 515 – 685 6 685 < 4</p> <p>The price of this façade is 1186,64 euro for material costs</p>	4

Product specific design by MVRDV – Schüco

The images below are the translation I made from the façade principle made by MVRDV and Schüco. The input they gave me in this phase was very little, therefore I decided to do the comparison with these exploded views I made based on the façade principle detail I get from them and on the render.

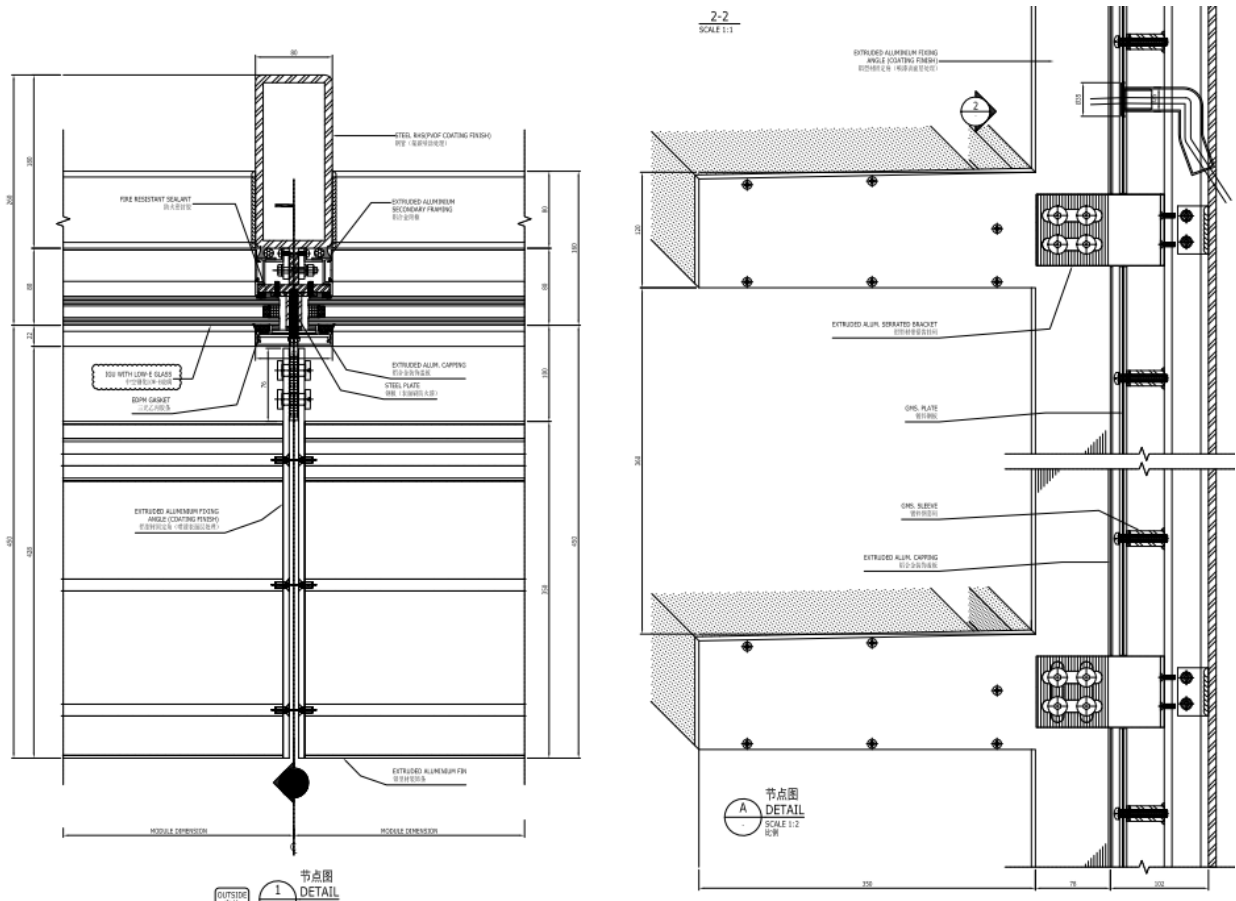


Figure 112: Façade detail source: MVRDV

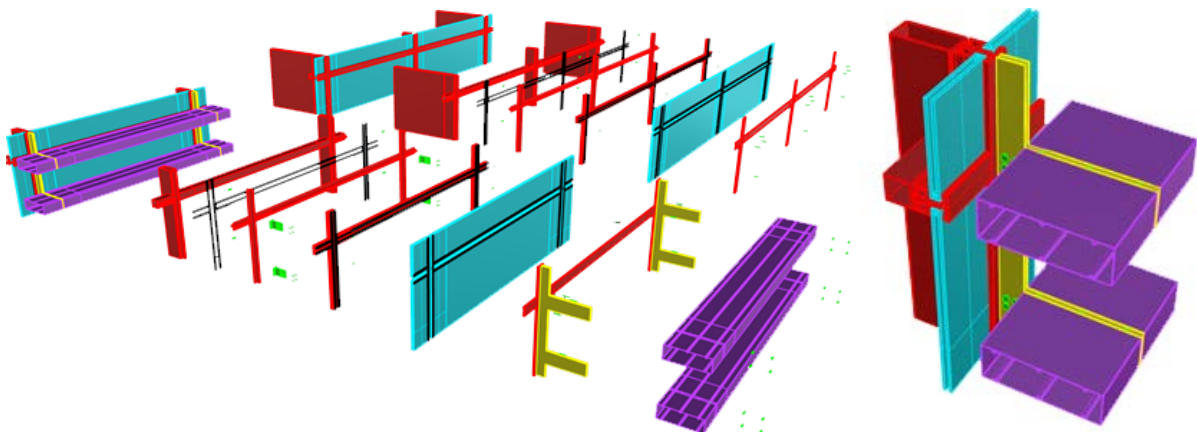


Figure 113: Fragment source: Luuk Jansen

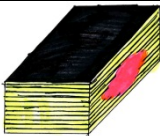
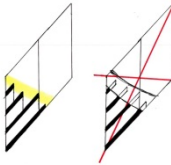
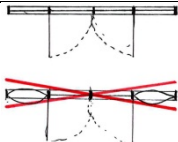
Figure 114: exploded view 2 source: Luuk Jansen

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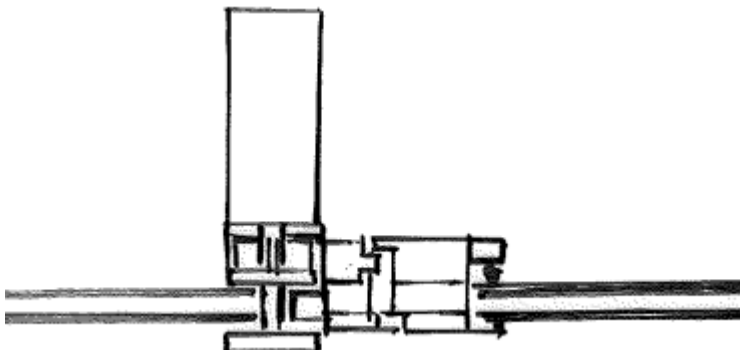
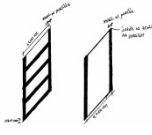
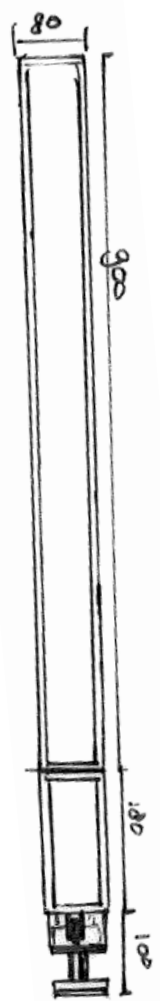
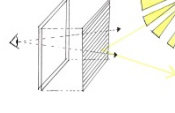


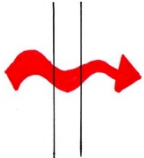

Figure 115: Parkside render source: MVRDV

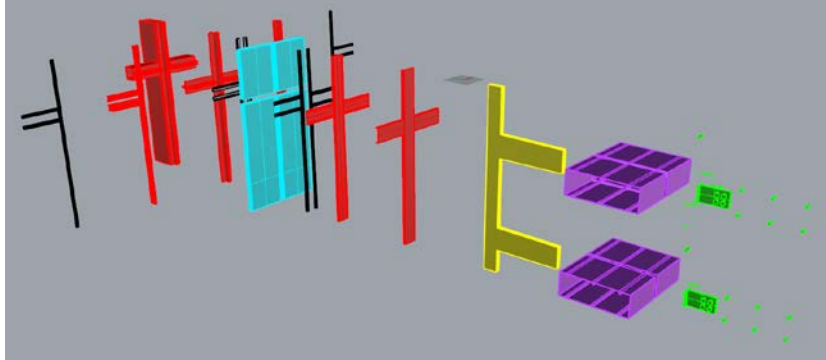
Below you can find the rating table. The categories are ordered on importance and relevance. The first four categories are about meeting the architectural principles, the others are about user comfort, climate and costs. The first four categories all will count double, the other four are count standard. This is because then the importance is take into account.

	Category	Research	value
1		As you compare the render out of the preliminary design and the render above, you can clearly see some differences. The main difference is the presents of the façade structure. Therefore the image they had in mind is not quit visible anymore.	7
2		MVRDV make the façade as a common system namely a curtain wall system, when the curtain wall is higher they use another backing structure then when it is lower, therefore there is no need for an intermediate structure. My only point of interest is how they made the hole in the louvres work, because according to the principle façade detail, it looks like there is a un going steel strip where the louvres are bolted to. Therefore there should be some sort of intermediate structure.	7
3		I haven't seen any door details but when I look at the system they designed, I can imagine that a certain profile has to be added to make doors and windows work. The	6

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		<p>drawing below is a sketch I made. This is how I imagine doors and windows can be made. As you can see this adds a significant extra profile which means it can be considered as different system. Therefore the score is not that good, but still sufficient.</p> 	
4		<p>In the design of MVRDV there is a lot of aluminium which is visible and blocking the view outside. For example. They use a 180mm aluminium column for the lower part and a 900mm + 180mm aluminium columns for the high part.</p> <p>The glazing is non-structural meaning there are clamp plates and clamp plate covers to hold the glass. Which means there is an additional 100 mm added to this structural part, for holding the glass and make a neat detail.</p> <p>This has also an influence on the façade image because a 20 mm wide kit joint is less visible then a 80 mm wide clamp plate.</p> <p>Therefore the minimalist construction is way less than the architect had in mind. But because these elements are purely horizontal and still only 80 mm wide it is still not that worse.</p> 	5
5		<p>As far as I can see in the design of MVRDV they did nothing with the solar shading. Also the louvre layout is not sufficient to protect from glare on certain moments during the day.</p>	3

6		<p>Below you see an RC calculation, for the value I decided when the total building average is more than 5 then it is a 6 because this is the minimal requirement according to the Dutch building regulation.</p> <p>above 9 will be a 10 between 7-8 will be a 9 between 6-7 will be a 8 between 5-6 will be a 7 between 4-5 will be a 5 between 3-4 will be a 4 between 2-3 will be a 3 below 2 will be a 1</p> <p>Calculation: Note: for Roof and Rfaçade I took the minimal required values as in the Dutch building regulations due to absence of this information in the files from MVRDV. Rfaçade = $1/(0.21*1.08+0.79*1.0) = 0.98$ Roof = 6 Rfloor = 3.5 Rtotal = $0.295*6+0.295*3.5+0.41*0.98 = 3.2$ (see appendices for further calculation)</p>	4
7		<p>To make an equal comparison both fragments are 0,45 m2.</p> <p>According to Monico Rossi (http://www.collegepublishing.us/jgb/samples/JGB_V6N2_b02_Rossi.pdf) a façade weights from 90 kilo per m2, so 90 kilo is very good.</p> <p>> 90 10 Between 100 – 150 9 Between 150 – 200 8 Between 200 – 250 7 Between 250 – 300 6 Between 300 – 350 5 Between 350 – 400 4 Between 400 – 450 3 Between 450 – 500 2 500< 1</p> <p>The total weight for the fragment above is 52.58 kilo per 0.45 m2 -> 116 kilo/m2</p>	9

			
8	<p>€</p>	<p>To make an objective price for a part of the façade, I decided to use only the material costs of the part because for certain parts it is difficult to find the right price for it. For parts like screws etc., I will take some sort of average value.</p> <p>According to bouwkostenkompas the average façade price between 515 to 685 euro/ m²</p> <p>> 515 8 Between 515 – 685 6 685 < 4</p> <p>The cost of a square meter of this façade is 276,78 for material costs</p>	8

Conclusion on comparison

Note on Rc value calculation:

The Dutch building regulation says for closed parts

The minimal Rc values are:

4.5 M2.K/W for façades.

6.0 M2.K/W for roofs.

3.5 M2.K/W for floors.

The Dutch building regulation says for open parts the rules are:

The u frame should be lower than 1.4.

This means that the MVRD solution is sufficient according to the Dutch building regulation, and the project specific design is overkill but because the building has a complete glass façade in my opinion the minimal is not good enough because there is still a lot of energy losses.

35 outside in summer, 23 inside in summer

-10 outside in winter, 19 outside in winter

Product specific: $1/3.2 = 0.3125$

$$Q = UxAdT$$

$$Q_{summer} = 0.3125 \times 22570 \times 13 = 91.69 \text{ kW/s}$$

Meaning 264960 Kwh a year

$$Q_{winter} = 0.3125 \times 22570 \times 29 = 204 \text{ kW/s}$$

Meaning 783360 Kwh a year

This means that over a complete year heating and cooling will cost 230630 euros (when using electrical heating based on the Dutch energy prices of 2015/2016 according to <http://www.energiesite.nl/begrippen/kwh-prijs/>)

Project specific: $1/6.87 = 0.1456$

$$Q = UxAdT$$

$$Q_{summer} = 0.1456 \times 22570 \times 13 = 42.7 \text{ kW/s}$$

Meaning 273600 Kwh a year,

$$Q_{winter} = 0.1456 \times 22570 \times 29 = 95 \text{ kW/s}$$

Meaning 364800 Kwh a year

This means that over a complete year heating and cooling will cost 140448 euros (when using electrical heating based on the Dutch energy prices of 2015/2016 according to <http://www.energiesite.nl/begrippen/kwh-prijs/>) This is almost a reduction of 60% meaning that extra building costs are reasonable. Concludes out of this calculation you see that when not take the minimum required but take the average as the required minimum then the building will perform twice as good.

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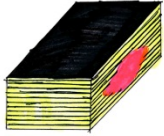
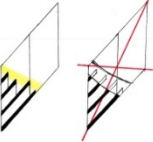
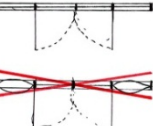
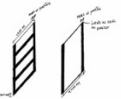
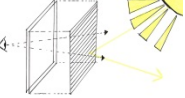
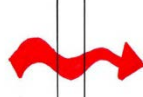


In my opinion for a complete glass building it is better to place a minimal average Rc value requirement in the legislation because else the building maybe meet the requirements but has a poor insulation value and therefore a lot of maintenance and operating costs, as you can see in the example above.

Note for costs

The price of one square meter façade is now based only on material costs but an important thing to consider is the building time of the façade.

When we look at building time the project specific façade is more easily to build, because it has less parts to attach then the product specific. The product specific façade has 5 times more bolts to fasten, it uses more separate parts, like coated flimsy flashings etc, which has to be handled carefully. It also uses more kit joints which has to cure, before you can go on with the building.

Table of Comparison

	Category	Project specific	Product specific
1		8 (16)	7 (14)
2		10 (20)	7 (14)
3		7 (14)	6 (12)
4		10 (20)	5 (10)
5		3	3
6		8	4
7		7	9
8		4	8
Total		92 (70 on architectural 22 on technical)	74 (50 on architectural 24 on technical)

As you can see in the table above, the project specific approach will score much better total than the product specific approach.

The hypotheses I had before are true are, the project specific approach score better on achieving the architectural principles, will achieve a better insulation value. But to achieve this the project specific approach will weigh more, but not that much as I thought before. It also will cost more, this is a significant difference compared to the product specific approach. (4 times more)

The question is: is the client willing to pay this extra money to get a building which performs better and which meets the first architectural sketches better?

Critical note on the comparison

On some points this comparison is not completely accurate. The first thing which could have had influence on the accuracy is the input I get from MVRDV in this stage. This was very little (a render and a façade principle) therefore I need to do lot of assumptions. For this assumptions I took merely known systems which perhaps does not exactly fit in the façade principle MVRDV developed in cooperation with Schüco.

For this comparison and also for the design made, I choose 8 criteria which I think are important but maybe the architect and the client have other important criteria to follow. Therefore it is important for the design process to choose several criteria together with the architect/client to make sure everyone is on the same line.

Generic method

With the input out of the literature, from the design process and the comparison we can come up with a generic method how to come up with an innovative solution for a complex façade design. In this generic method I tried to not generalize all designs, every design is unique therefore with this method you can put your own attention and importance to specific criteria.

The method:

1. The architect comes with a question.
2. Together with the architect a number of scoring criteria are chosen to what the engineering proposals should meet. These criteria are chosen from a given list. These criteria help to make an objective rating of a variant.
3. Every criteria get its own weighing 3 for very important criteria and 1 for criteria which are not meaningless but not that important.
4. Come up with several engineering proposals to solve the problem.
5. Make a matrix to compare all the proposals to see which suits the situation the best.
6. The one with the highest score is the one which is most suitable.
7. Make a further elaboration to make it feasible and buildable.
8. Get the right testimonial and guarantees, because the technical elaboration comes from proven concepts, testimonials and guarantees should easily be given.
9. The façade can be built now including the right certificates and guarantees.

Answering main and sub questions

Sub questions:

1. Which requirements should a façade meet?

In my literature research I found out that there are a lot of requirements, these requirements can be separated in a couple of categories.

1. Requirements coming from the context/climate

The façade protects from the hostile outer environment and forms a barrier between outside and inside. This separation has to take care of, ventilation, light entrance and a visible connection between the interior and the exterior. (Herzog, T., Krippner, R., & Lang, W. 2004)

For façade engineering and design we can assume that the exterior/climate cannot be changed, so these should be considered as primary conditions in a design.

This means when engineering the façade you should consider this context and make sure the façade design is optimised for this specific set of conditions (temperature, wind, sun, etc.) function like a tailored suit for this specific location and conditions.

2. Building legislation requirements

The requirements coming from the building legislation can be separated in 4 categories

1. Insulation

For closed parts the minimal R_c values are: 4.5 $M^2.K/W$ for façades, 6.0 $M^2.K/W$ for roofs, 3.5 $M^2.K/W$ for floors.

For open parts the rules are: $U_{frame} > 1,65$ average, 2,2 for individual parts.

2. Noise level

A minimal of 20 dB of characteristic noise reduction is required of the outer separation structure.

The maximum acceptable noise level is 35 dB(a) for industrial noise and 33 dB(a) of railway and road noise.

3. Ventilation

According to NEN1087 the capacity should be 0.9 dm^3/s per m^2 floor area of the residential area with a minimum of 7 dm^3/s .

If there is a kitchen or such in the room an air replacement of at least 21 dm^3/s is required.

A toilet room has a minimal air replacement of 7 dm^3/s according to NEN1087.

A bathroom has a minimal air replacement of 14 dm^3/s according to NEN1087.

4. Daylight

A residential area has a certain minimal daylight area. To calculate the equivalent daylight area you should consider that the angle of obstruction A should be smaller than 20 degrees. (NEN 2057)

3. User comfort requirements

The user comfort requirements can be separated in three categories:

1. Temperature

Human beings are capable to adapt to the climate they are in, this is called adaptive comfort. This means that the optimal theoretical temperature is 20 to 25 degrees Celsius. But in summer a temperature of 27 degrees Celsius is acceptable, provided that humidity and surface temperature is controlled. In winter 18 degrees is acceptable. The surface temperature is preferable maximal 2 a 3 degrees Celsius more or less then the air temperature. (Schittich, C. 2006)

2. Daylight

To function as a human being there should be a certain amount of daylight in a residential area. An important parameter to be considered is daylightfactor (df). This value state the effectiveness of daylight in relation with artificial light. 2-5% is considered as good, to function.

3. Air/ventilation

To function as a human being it is important to have a certain amount of fresh air, with an average humidity, this amount is around 40-60 m³ to provide on person with fresh air for an hour. For rooms where no people are staying is 0,3 times the room an hour sufficient. With a humidity of 30-70%

2. Which engineering methods successfully transform an architectural concept to a buildable façade?

In the research above I found out that there are a lot of methods to come up with a technical feasible façade concept which represents the architectural vision more or less. Basically we can separate four approaches.

1. The 3d computer model of the architect is the starting point.

Sometimes the design is very complex. With such a complex design the 3d model of the architect can directly been used by the engineers to come up with the construction and the façade cladding. When the architect want to use this way of engineering, then in an early stage the other contractors should play a role determine which information should be in the architectural model and how.

2. Pre rationalization in an early design stage.

Sometimes the architect goes crazy on a certain shape, which he likes as a mass but when windows and other façade elements has to be drawn the architect rationalize the shape to buildable elements and such.

3. Construction follows form.
Sometimes the architect will search a partner how can construct engineer and build the building in such way that the outer shell looks exactly as the architect has in mind, what's is happening underneath this shell is not his concern.
4. Starting with the material.
Sometimes the architect has a certain interest in a construction type or materializing. If the client shares this interest the architect then can make sure this façade construction of this certain material works with the design.

3. Which steps have to be taken using standardized products to transform the architectural concept to a buildable façade?

Out of the research above, especially talking to the companies a certain strategy can be found in which way a façade is engineered with standardized products, a product specific façade engineering process.

1. The architect comes with a certain question or a design, sometimes they made a decision in this design which façade system it should be or how it should look like.
2. Look if the proposal of the architect is feasible with standardised systems, considering the architectural vision with this façade. Sometimes the systems needs to be altered seeking it's extremes to cope with the architectural idea.
3. Make a proposal to the architect with the engineered system, if they like it look for a façade builder which can make it this way, and help them with the further engineering.

4. Which steps have to be taken starting from scratch to transform the architectural concept to a buildable façade?

Out of the research above, especially talking to the companies and my own design process a certain strategy can be found in which way a façade is engineered in a project specific custom way.

1. The architect comes with a definitive design to an engineering office like ABT.
2. Try to find the deeper thought behind the system, what are the architectural decisions took to come up with this system. What does the architect want to achieve with this façade.

This depends on the architect, some architects comes with a set of assumptions, ABT is then in the lead to define the system. (for example Neutelings Riedijk) Other architects come with a solution (OMA for example) then you have to come to the core of the design, what do they want to achieve with the façade and is the system they choose really what they want.

3. Make a set of proposals to find the best suitable solution mostly done with a matrix with an objective set of criteria. This can be done very abstract, only on basic principles and on defining elements.

4. Choose the best proposal and talk to the architect if they liked it, when the matrix comparison was properly done the architect should agree with it because it should completely follow the architectural façade principles. The only downside can be the cost.
5. When the architect agree on it the further engineering can take place, making buildable details.

Main question

My main question is: Does a technical elaboration of the façade without looking at standardized systems in an early state lead to a better approximation of the façade principles by the architect relative to a technical elaboration where in an early state a standardized product, material or engineering company is chosen and changed to meet the requirements of the architect?

After the research I did above there is a clear answer on this main question, namely Yes.

What I have seen in the research is that when not focusing on one system in an early stage of the façade engineering the outcome will much more cope with the early architectural design then when in an early stage already is decided which product has to be used or which company should make it, with this approach the architect has to do a lot more concessions.

When you look at the comparison between the project specific elaboration for the Tianjin library with the design MVRDV made in cooperation with Schüco is that the project specific design represents much better the preliminary design façade principles.

But there is also a downside with a project specific approach, most of the times it will cost a lot more then choosing a product specific approach. Therefore you should consider to make a project specific design but based on existing products or the extra added value should be worth it to pay extra for this solution.

I think there should come a new mind set designing facades, the architect should only make the principles or the image they want to achieve with the façade. Then an engineer can start with a blank sheet trying to achieve this image. With a set of wild ideas, he can come up with the best façade approach suited for the climate, context, user requirements, legislation and architectural concepts. There is also a new mindset needed from the clients, no longer all the certification and guarantees can be given. The certification process should maybe change from a certificate for each specific system to a certificate for the basic principle of systems.

What you can say: the product specific façade design approach is a suit from the Primark or when it is a high value building it is a bit more expensive suit. It is suitable for the situation but not a perfect fit, but with a given price and some concessions on how it looks it is suitable.

The project specific façade design is a tailored suit, custom made for the specific situation. But it will cost a bit more then you on forehand suspects, but if you are willing to invest in this it will pay you back.

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Reflection

When looking back on my design I think I succeeded in achieving the goals I set to myself.

In the beginning it was a struggle to get the right theme for my research, during the P2 I was heading in a more theoretical real estate and housing topic, but what I wanted was a research by design.

After my P2 I changed my main question in a more design direction but a comparison between two different approaches still was a very important part of my graduation. The literature research I presented during the P2 was still valuable because it was more about facades and façade engineering processes in general.

During my p3 I presented the design I made on basis of a preliminary design by MVRDV for the Tianjin library, I succeeded in making a technical feasible design principle but some parts were not solved yet, there are also some choices the architect should make, these choices are not very big concessions but more ways to make sure the building will perform better.

After my p3 I made the comparison between my elaboration and the elaboration Schüco and MVRDV did.

The input on this stage from MVRDV was very little therefore I had to make some assumptions to make a good comparison. For this comparison I choose the options which are the minimum according to legislation or the most standard solution. This made the comparison less accurate because I had to guess some variables, but I think the comparison is still valuable, because the information I had shown there ambition level.

The research confirmed my hypothesis but was also interesting that the difference on certain topics was smaller than expected.

How and why of the research reflected

The goal of my research was to find out if there is a need to come up with a new façade engineering approach. One forehand I separated two ways to make a façade engineering, the first one is a more product specific approach and the second a project specific approach.

In my research and daily business as building engineer at ABT, I found out that often the architect has to do a lot of concessions to their first thoughts to get the façade to work. So in my graduation I look to find out how the current way of engineering a façade take place and seek for a new approach where the architectural principles are the starting point and eventually the architect don't have to do any concessions or just little concessions.

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I went to MVRDV with the question if they have a complex project where they do an engineering and where I was allowed to do the same engineering but then on a different way.

I was lucky that they were working on a library in China where they engineer the façade in cooperation with Schüco, so on a more product specific system. On the moment I was there they just finishing the definitive design.

So this was a perfect moment to start with a more project specific design because all the design requirements where there.

After I finishing the project specific design I theoretically was able to make an objective comparison between both approaches, but I didn't get all the required information I needed to do this comparison.

First I have to translate the facade detail principle MVRDV come up with to a three dimensional model to make sure I can compare this properly to the same fragment out of my own three dimensional model.

When I finished these models the comparison was a success. I confirmed my hypotheses but I also found out that some of the negative hypotheses weren't so negative.

Aspect 1: the relationship between research and design.

My research is design focused because I want to make a comparison between a product specific approach of a certain project and for the same project a project specific approach. Therefore I have to made a project specific design for a case where another company do a product specific design.

To learn more about the basic principles of the façade I read several books. (As you can see in the literature study above) In these books I came across several requirements a façade has to cope with. For example climate, user comfort and building legislation

With these theoretical knowledge I was able to make a suitable design for this situation, coping with all the requirements from the legislation.

So in this case I first did the theoretical research which forms part of the engineering guide line.

After the design I did some research in weight, material cost and climate to make a proper evaluation of the design proposals.

What you can see in my graduation is that research and design follow up on each other, first I did some theoretical research to find out where the design has to cope with. Then I use this design to do a deeper research in façade design approaches.

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Aspect 4: The relationship between the project and the wider social context.

What you see is when complexity grows in the façade design, the more concessions the architect has to do.

I talked to several architects and they do not like this way of dealing with projects, because they want to make a beautiful complex design which actually can be built on time and in the budget they get from the client.

To achieve this I think there should be a different way of engineering these complex façade designs, where we not take standardized products but make products or an assembly of several products specific for this design.

This has a social impact on the architectural business because the engineer should be involved earlier in the process, to help the architect make an feasible design for the façade in an early stage. The classic roles will shift.

Then the influence is bigger and also they can help to tempt the client to spend more money on the façade to get a better design and performance.

What you also can see is if you think out of the box the performance is much better. Therefore there is less impact on the environment.

The other social aspect is on rules, legislation and certificating. These aspects has to change in order to make innovative façade designs and engineering possible.

Recommendations

1. To help innovative façade design processes the mindset of both the client as the architect has to change. The client should not only focus on money but also on quality and saved cost during the usage of the building. What I found out in the research above is that when you looking for quality and performance you can save a lot of money each year on heating and cooling.
2. The legislation can be more demanding and therefore make sure the durability of the building is good. Because when you know go for the minimum the building performance is poor, when making an all glass building.
3. Architects should look more into principles then in systems. If they do so they have to do less concessions.
4. Rules on certification and guarantee has to change to make it possible to innovate.

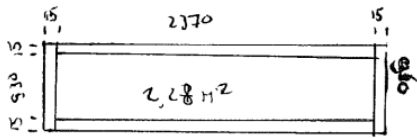
Appendices

Calculations on behalf of comparison

Rc- value project specific

$f_{w,ext} : u_g = 0,35$
 $u_f = 1,2 \times 1,05 = 1,26$

$6600 \text{ m}^2 \text{ roof } 29,8\%$
 $6600 \text{ m}^2 \text{ floor } 29,5\%$
 $9370 \text{ m}^2 \text{ facade } 41\%$



0ϕ FRAME 5%
 $2,28 \text{ m}^2$ GLASS 95%

$U_w = 0,35 \times 0,35 + 0,05 \times 1,26$
 $= 0,336$

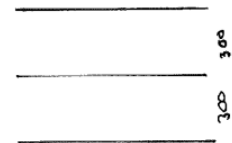
$R = \frac{1}{u} = \frac{1}{0,335} = 2,53$

slab

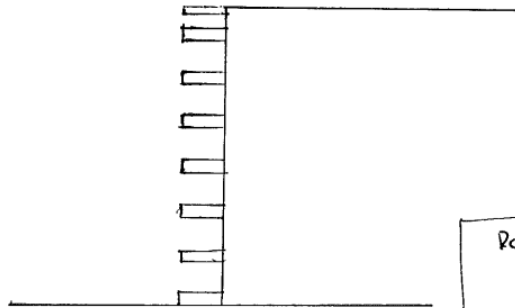


$0,300 \times 0,031 = 0,0093$
 $0,260 \times 1,05 = 0,273$
 $R_c = 0,85$

Vloer



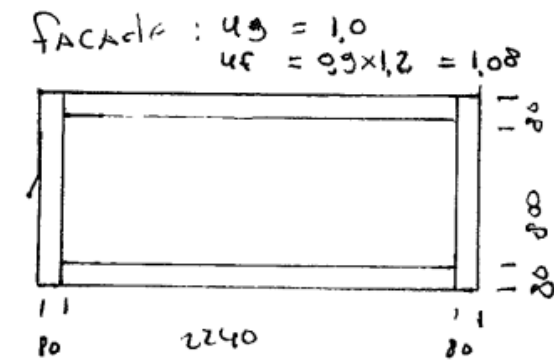
$0,3 \times 1,03 = 0,309$
 $0,3 \times 0,031 = 0,0093$
 $R_c = 0,909$



$R_{c, \text{total}} = 0,295 \times 0,909 +$
 $0,295 \times 0,85 +$
 $0,41 \times 2,53$
 $= 6,87$

Figure 116: Rc calculation project specific source: Luuk Jansen

Rc – value product specific



0,5 FRAME 21%

1,79 GLASS 79%

$$U_w = 0,21 \times 1,08 + 0,79 \times 1,0$$

$$= 1,01$$

$$R = \frac{1}{U} = \frac{1}{1,01} = 0,98$$

Roof

$$R_c = 6,0$$

Floor

$$R_c = 3,5$$

$$R_c \text{ total} = 0,033 \times 6 +$$

$$0,295 \times 3,5 +$$

$$0,41 \times 0,98$$

$$= 3,2$$

Figure 117: Rc value calculation product specific Source: Luuk Jansen

Weight info and calculations

Aluminium:

Density aluminium 2,755 g/cm³ (<http://www.soortelijkgewicht.com/vaste-stoffen/aluminium>)

Mullions:

Product specific: load bearing: vertical mullion: 4036 cm³ -> 11.1 kilo
Horizontal mullion: 2x377 cm³ -> 2.1 kilo

Glass bearing: vertical 1168 cm³ -> 3.2 kilo
Horizontal 490 cm³ -> 1.35 kilo

Project specific: Vertical mullions: 859 cm³ -> 2.3 kilo
Horizontal mullions: 238 cm³ -> 0.6 kilo

Flashings: 665 cm³ -> 1.83 kilo

Clamp plate: 383 cm³ -> 1.1 kilo

Clamp cover plate: 291 cm³ -> 0.8 kilo

Aluminium Louvre: 2016 cm³ -> 5.5 kilo

Louvre bearing structure: 1876 cm³ -> 5.1 kilo

Glass:

Density float glass: 2,5 g/cm³ (<http://www.soortelijkgewicht.com/vaste-stoffen>)

Double glass: 6638 cm³ -> 16.5 kilo

Quadruple glass: 6873 cm³ (4mm glass) -> 17.1 kilo

Glass fin: 21201 cm³ -> 53 kilo

Nylon:

Density nylon 1.15 g/cm³ (<https://en.wikipedia.org/wiki/Nylon>)

Brackets: 564 cm³ -> 0.6 kilo

Bolts:

M8 bolt – length: 40mm (is average more or less): 20.3 gram

Product specific: (50x) 1 kilo

Project specific: (10x) 0.2 kilo

Steel:

Density steel: 7,8 g/cm³ (<http://www.soortelijkgewicht.com/vaste-stoffen>)

Clamps:

Project specific, louvre clamps: 180 cm³ -> 1.4 kilo

Product specific, glass clamps: 75 cm³ -> 0.5 kilo

FRC louvre: 30.7 kilo

Polystyrene 1.05 g/cm³ (<http://www.icis.com/chemicals/polystyrene/?tab=tbc-tab2>)

Frc 1.473 g/cm³ (<http://www.hindawi.com/journals/ace/2010/549642/>)

Table 5: Properties of fiber lightweight concrete (no surfactant).

Fiber	Fiber volume (%)	Unit weight (kg/m ³)	Compressive strength (MPa)	Axial strain at peak (mm/mm)	Modulus of elasticity (GPa)	Toughness index
Polypropylene	0	1473.7	32.8	0.0037	10.8	1
	1	1457.7	31.5	0.0044	6.6	1.03
	2	1489.7	34.7	0.0044	11.2	1.26
	3	1473.7	38.3	0.0040	11.0	1.29
	4	1473.7	33.2	0.0034	12.0	1.33
Carbon	0	1473.7	32.8	0.0037	10.8	1
	1	1425.6	34.7	0.0039	10.3	1.05
	2	1141.7	29.9	0.0043	9.7	1.38
	3	1505.7	39.4	0.0046	10.4	1.22
	4	1457.7	22.2	0.0043	8.2	1.74

Figure 118: Mechanical Properties of Fiber Reinforced Lightweight Concrete Containing Surfactant source: *Advances in Civil Engineering*, Volume 2010 (2010) retrieved: <http://www.hindawi.com/journals/ace/2010/549642/>

13254 cm³ frc = 13.9 kilo

16000 cm³ polystyrene = 16.8 kilo

Rubber:

Density rubber: 1.1 g/cm³ (http://www.engineeringtoolbox.com/density-solids-d_1265.html)

Project specific: 689 cm³ -> 0.75 kilo

Product specific: 1424 cm³ -> 1.6 kilo

Kit joints:

Density silicon kit 1.5 g/cm³ (<http://www.azom.com/properties.aspx?ArticleID=920>)

Product specific: 601 cm³ -> 0.9 kilo

Project specific: 309 cm³ -> 0.46 kilo

Pricing info and calculations

Aluminium:

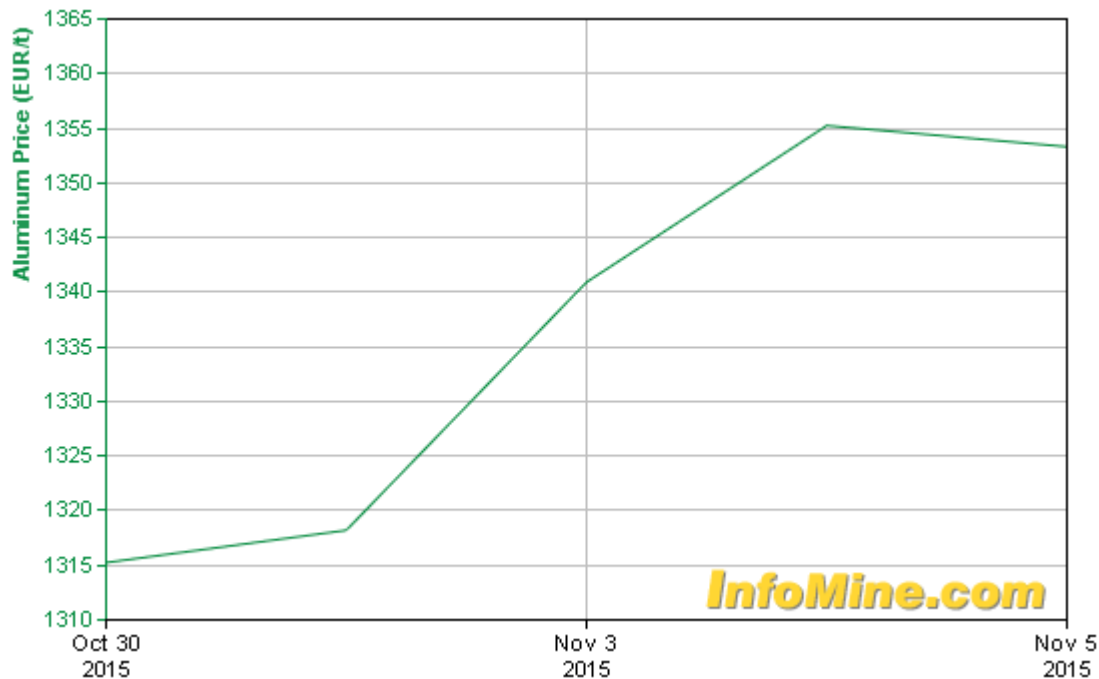


Figure 119: Aluminium stock price Source: infomine.com

The aluminium price is 1371.57 euro/ ton this means 1,371 euro per kilo

Mullions:

Product specific:

load bearing: vertical mullion: 4036 cm³ -> 11.1 kilo = 15,22 euro

Horizontal mullion: 2x377 cm³ -> 2.1 kilo = 2,88 euro

Glass bearing:

vertical 1168 cm³ -> 3.2 kilo = 4,39 euro

Horizontal 490 cm³ -> 1.35 kilo = 1,85 euro

Project specific:

Vertical mullions: 859 cm³ -> 2.3 kilo = 3,15 euro

Horizontal mullions: 238 cm² -> 0.6 kilo = 0.82 euro

flashings: 665 cm³ -> 1.83 kilo = 2,51 euro

Clamp plate: 383 cm³ -> 1.1 kilo = 1,51 euro

Clamp cover plate: 291 cm³ -> 0.8 kilo = 1,10 euro

Aluminium Louvre: 2016 cm³ -> 5.5 kilo = 7,54 euro

Louvre bearing structure: 1876 cm³ -> 5.1 kilo = 6,99 euro

Glass:

Price is 45 euro/m² for double hr glass and 125 euro/m² triple glazing and 205 euro/m² for quadruple glass. Cost for a project with more than 1000m² glass surface, price is an average of three market sources, February 2009.

http://media.except.nl/media/uploaded_files/asset_files/Energie_en_Kostenanalyse_dubbel_en_driedubbel_glas.pdf

Double glass: 6638 cm³ -> 16.5 kilo (0,41 m²) = 18,45 euro

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Quadruple glass: 6873 cm³ (4mm glass) -> 17.1 kilo (0,41 m²) = 84,05
 Price 112 euro/m² 10mm thickness -> 60mm = 672 euro/m², 75mm = 840 euro/m²
<http://www.expresstoughening.com/content/order-bespoke-glass>

Glass fin: 21201 cm³ -> 53 kilo (0,46 m²) 309,12 euro

Nylon:

Price is 2.40 – 2.65 euro/kg

<http://www.icis.com/resources/news/2012/03/27/9545343/europe-nylon-6-march-prices-up-0-05-0-15-kg-on-margin-recovery/>

Brackets: 564 cm³ -> 0.6 kilo = 1,59 euro

Bolts:

Price is 0.84 euro/st <http://breur.isero.nl/bevestigingsmiddelen/bouten-moeren-en-ringen-rvs/inbusbouten-rvs/365741/inbusbout-rvs-a2-cilinderkop-m8x40mm/>

Product specific: 50x = 42 euro

Project specific: 10x = 8,4 euro

Steel:

Price is 1560 euro/ton p -> 1.56 euro/kilo

<https://www.quandl.com/collections/markets/industrial-metals>

Clamps:

Project specific, louvre clamps: 180 cm³ -> 1.4 kilo = 2,18 euro

Product specific, glass clamps: 75 cm³ -> 0.5 kilo = 0,78 euro

FRC louvre: 30.7 kilo

Polystyrene 1.05 g/cm³ <http://www.icis.com/chemicals/polystyrene/?tab=tbc-tab2>

Frc 1.473 g/cm³ <http://www.hindawi.com/journals/ace/2010/549642/>

Fiber	Fiber volume (%)	Unit weight (kg/m ³)	Compressive strength (MPa)	Axial strain at peak (mm/mm)	Modulus of elasticity (GPa)	Toughness index
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	1	1457.7	31.5	0.0044	6.6	1.03
	2	1489.7	34.7	0.0044	11.2	1.26
	3	1473.7	38.3	0.0040	11.0	1.29
	4	1473.7	33.2	0.0034	12.0	1.33
Carbon	0	1473.7	32.8	0.0037	10.8	1
	1	1425.6	34.7	0.0039	10.3	1.05
	2	1141.7	29.9	0.0043	9.7	1.38
	3	1505.7	39.4	0.0046	10.4	1.22
	4	1457.7	22.2	0.0043	8.2	1.74

Figure 120: Mechanical Properties of Fiber Reinforced Lightweight Concrete Containing Surfactant source: *Advances in Civil Engineering*, Volume 2010 (2010) retrieved: <http://www.hindawi.com/journals/ace/2010/549642/>

13254 cm³ frc = 13.9 kilo

Concrete 232 euro/m³ <http://www.eurekaconcrete.com.au/pricing>

glass fibers 30g/m² 5,93 euro/m² <http://www.carbonwinkel.nl/nl/glasvezel/217-glasmat-30-g-m-127-cm-breed.html>

96% concrete = 12723,84 cm³ = 0.012 m³ = 2.95 euro

4% fibers = 530 cm³ = 0.55 kilo = 18 m² = 108 euro

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16000 cm³ polystyrene = 16.8 kilo

0.144 m³ is 6,47 euro

(http://www.insulationwarehouse.co.uk/polystyrene_insulation.htm) therefore 16000 cm³ = 0.71 euro So the price for the louvre will be 111.66 euro

Rubber:

Price is 1.17 euro/kg

(<http://www.indexmundi.com/commodities/?commodity=rubber¤cy=eur>)

Project specific: 689 cm³ -> 0.75 kilo = 0,87 euro

Product specific: 1424 cm³ -> 1.6 kilo = 1.87 euro

Kit joints:

Black 310 ml/0.25 kilo price is 5.37 euro -> 21.48 euro/kilo

Product specific: 601 cm³ -> 0.9 kilo = 19.33 euro

Project specific: 309 cm³ -> 0.46 kilo = 9,88 euro

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