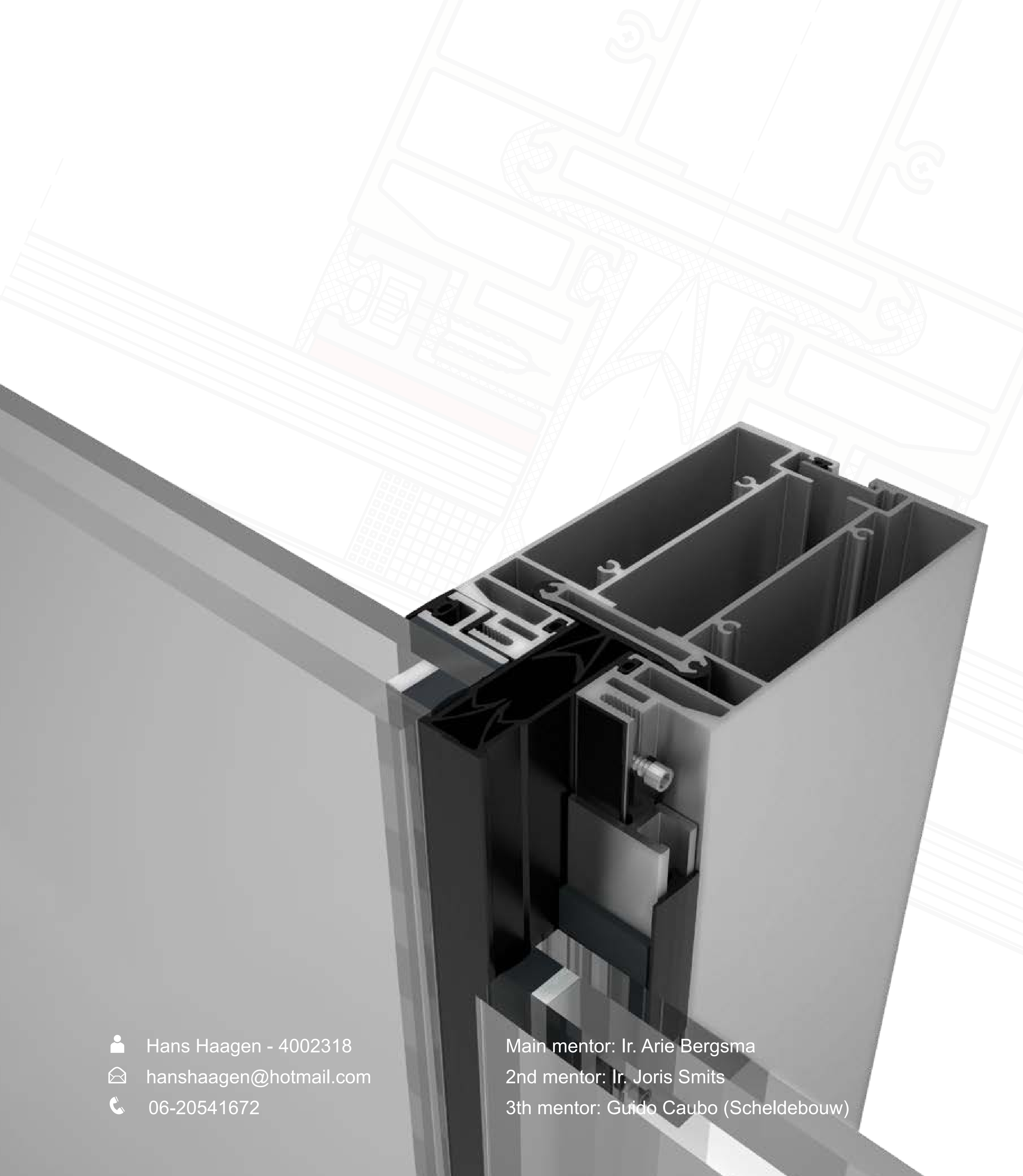
Graduation report

Hans Haagen 4002318 - 4 July 2014

A research on the optimization of the process: structural bonding of glazing in unitized curtain wall façades.

In coöperation with SCHELDEBOUW



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Main mentor: Ir. Arie Bergsma

2nd mentor: Ir. Joris Smits

3th mentor: Guido Caubo (Scheldebouw)

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Acknowledgement

Foremost, I would like to thank my mentors: Ir. Arie Bergsma and Ir. Joris Smits. Arie Bergsma has been the initiator of this coöperation with Scheldebouw and I want to thank him for that. This gave me the opportunity to work on this interesting research, together with a renowned company. Both mentors gave me valuable input and feedback on this research, from their own points of view.

Then I would like to thank my mentor and supervisor at Scheldebouw: Guido Caubo. On the one hand he left a high degree of freedom in the research, where I had to start from zero and find my own way in what would be interesting to focus on. On the other hand he provided me with supporting feedback, valuable sources of information, and brought me in contact with the right persons throughout the company in different stages of the project. These contacts have been highly valuable because of their expertise in specific fields.

Therefore, I would like to thank all others at Scheldebouw where I have been in contact with. I have been able to talk and discuss with a lot of different people at Scheldebouw, situated at tender, engineering, concept design, sales, quality control and management, service and maintenance, logistics and production. All showed their interest and support in this research, which provided me with a lot of information, feedback and motivation.

Especially, I would like to thank Rene Koster and Ruud Bongers, both quality inspectors, for providing me with a desk in their office. This has been a pleasant environment to work in and their critical view provided me with a lot of valuable feedback and food for thought. Also they helped me to find my way around in the production facility and to other sources of information.

Martin Breemer, Technical Service Engineer at 3M, has provided me with a lot of information and material on the VHB tapes. Also he was willing to come to Heerlen and demonstrate the VHB tape bonding process by building some prototypes together.

Other companies I would like to mention and thank are Terberg Specials and Carglass Nederland for providing me with knowledge and information on structural bonding in the automotive industry. They where able to give me a clear insight in the process and procedures in this industry. Additionaly, I would like to thank Saint-Gobain glasssolutions for providing me with a free custom size glass sample for the mock-up.

Finally, I would like to thank my parents for their financial and psychological support throughout my studies.

Table of content

1.0 Introduction

This graduation project has started with my interest in working with a renowned company, to gain experience in practical work and working with professionals in my field of interest. My personal interest lays in technical aspects and knowledge of new and innovative technologies in architectural and urban design, combined with a focus on sustainable design. This can be in detail, but also on macro scale concepts.

The choice to work with Scheldebouw, came from their interest in a specific subject, namely a graduation research on the structural bonding of glazing in unitized curtain wall façades.
This would give me the possibility to work on a specific part in building technology. A specific subject means a more in depth research which I preferred. This to gain experience in mastering a specific subject in a practical environment.
The subject of adhesives and sealants is an interesting subject, where the right detail might not be the most important aspect. More important aspects with structural bonding might be the right process, procedures and in that way the assurance of quality. This is accompanied by concerns like time, money and image, which are practical aspects that are currently generally missing in the education program.

Goal of this thesis is to perform a research on how the structural bonding process at Scheldebouw could be improved.

This thesis will result in different approaches to improve this process, which will be evaluated on the different aspects that appear to be from influence on the process of structural bonding.

One of the approaches will be the development of a new structural bonding concept.

At first the research will form an understanding of the structural glazing principle and its abilities, disabilities, advantages and disadvantages.
The different approaches in improvement will be based on these conclusions.

This thesis will provide a design concept by which the structural bonding process can be improved. This design will not be an exclusive result, but by evaluation of this design, possible improvement by design will become apparent.
It also evaluates the principles where this design is based on. These can be used in future development.

2.0 Preliminary research

Prelimenary research contains the information that was needed, prior to the start of the actual analysis in chapter 4.

Information in this chapter can be seen as the background information, needed to understand the further course of this research.

2.1 Design with structural bonding

2.1.1 Definition of structural bonding

Structural bonding is the making of a bond that joins basic load-bearing parts of an assembly, by using a structural sealant / adhesive.

2.1.2 Why structural bonding

The main reason for structural bonding comes from architect demands. The flush detail, possible by structural bonding, is a much sought appearance in modern achitecture.

This research focuses on the structural bonding of glazing in curtain wall facades, also known as structural glazing (abbrevation: SG). This way of cladding is mainly popular in commercial buildings and especially in multistory buildings.

Structural glazing gives the architect a facade with maximum transparency and a flush outer layer of the facade.

For Scheldebouw it is currently only possible to achieve this appearance by the use of structural bonding. Another option for this appearance is toggle glazing (figure 2.1.2), but combining this system with a unitized curtain wall system appears to encounter difficulties.

Research on the combination of toggle glazing with a unitized curtain wall system is conducted, is conducted parallel to this reserach on how to improve the current process of structural bonding at Scheldebouw.

2.1.3 Types of structural glazing

Schematically, you can distinguish four types of structural glazing. These are based on examples from a guideline for european technical approval of Structural Sealant Glazing Kits (ETAG 002).

Figure 2.1.1 shows the four schematic examples, type I to type IV, which are described in the table.

Devices to reduce danger in the event of bond failure, like in type I and III, may be required by national regulations. Therefore, in some cases the choice for these types are obligatory. In other situations this might be a voluntary choice of the client and/or producer to reduce risk.

According to this guideline types III and IV are only applicable to single glass units. For insulating glass units or laminated glass, each pane of glass needs to be supported.

Self-weight support makes a different in loads and so in calculation of the structural sealant joint. Dynamic loads, like windloads, are present in all situations. In unsupported situations, also a dead load calculation determines the joint size.

Variants within these types include different types of retaining devices and variants with for example spiders in stead of frames. For example, retaining devices can be designed like a toggle (figure 2.1.3).

Type I:	Mechanical transfer of the self-weight of the infill to the sealant support frame and from there to the structure. The structural seal transfers all other actions. Devices are used to reduce danger in the event of a bond failure
Type II:	Mechanical transfer of the self-weight of the infill to the sealant support frame and from there to the structure. The structural seal transfers all other actions, and no devices are used to reduce danger in the event of bond failure.
Type III:	The structural seal transfers all actions including the self-weight of the infill to the sealant support frame, and from there to the structure. Devices are used to reduce danger in the event of a bond failure.
Type IV:	The structural seal transfers all actions, including the self-weight of the infill, to the sealant support frame and from there to the structure. No devices are used to reduce danger in the event of bond failure.

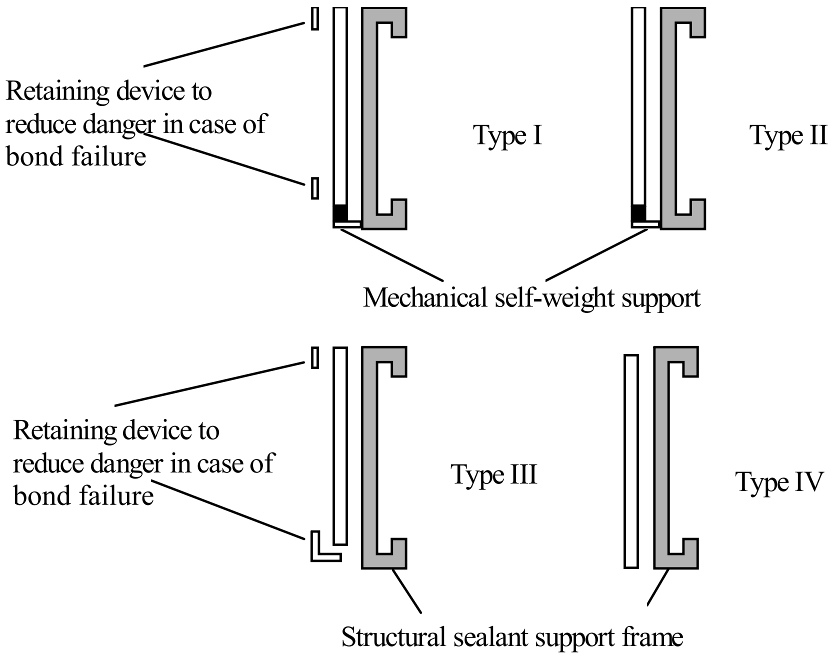


Figure 2.1.1 - Schematic examples of the different types of SSGK. (ETAG 002, 2012)

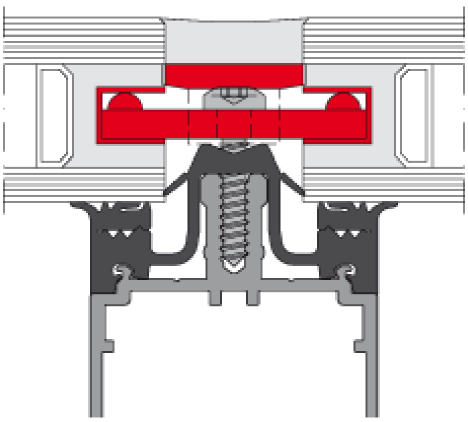


Figure 2.1.2 - Toggle glazing. (Raico, 2014)

Figure 2.1.3 - Slot in a double glass panel for a retaining device. (Own ill.)

2.1.4 **Performance**

Besides the aesthetic reasons to choose for a structural glazed facade, a designer should also look at other properties of this kind of facade.

The best way to look at these properties is by comparing them with other typical curtainwall glazing systems.

In association with Dow Corning, Lawrence D. Carbary (2007) did a comparison on the ***U value and energy consumption*** of typical curtainwall glazing systems used in commercial buildings. Results of this are shown in figure 2.1.x. This research showed best results where achieved by the structural glazed facades. Yet, there are much better performing mechanically fastened systems with U-values up to 0,8 W/m^{2}K, but they are very complex systems that prevent thermal bridging with breaks. Structural glazing does not have thermal bridges in its nature.

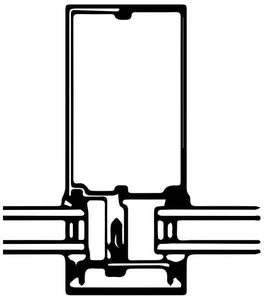
The same is true for ***acoustic properties***. Structural glazing has a maximum amount of glass, which normally has good sound insulating properties compared to the framing.

The absence of an outer profile for the purpose of mechanically fastening provides a ***lower weight*** of the system. This is both a material saving and will provide lower costs. It can not be said what kind of system is cheaper, because this differs per project.

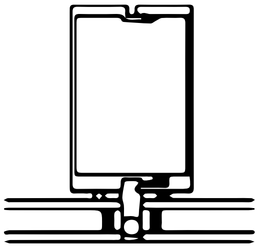
According to Wolf (2013), a structural silicone glazed facade also offers several enhancements in sustainable renovation projects. These enhancements show the following positive ***sustainable properties*** of a structural glazed facade:

- Energy savings: Improved thermal and air-tightness performance of the curtain wall (reduced H VAC requirements), natural lighting (reduced AI lighting requirements)
- Increase of comfort: Natural lighting, exterior noise reduction (improved acoustic performance of curtain wall)
- Healthy working environment: Low volatile organic content (VOC) of silicone sealants and adhesives
- Extension of building life cycle: Increased longevity of curtain wall
- Economized exploitation: Lower life cycle cost
- Environmental protection: Reduced carbon footprint (versus conventional curtain wall) due to lower operational energy requirements.

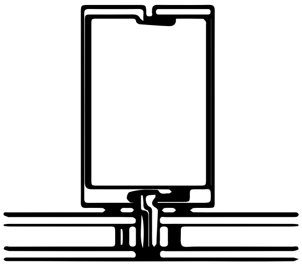
Mechanically
fastened system



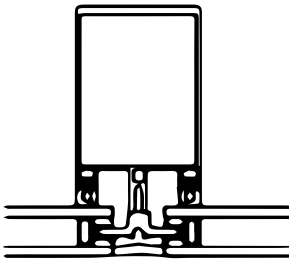
Structural glazed
wet weatherseal



Structural glazed
with gasket seal



Hybrid toggle
glazing



Type of glazing system	U value Frame W/m^{2}°K	IG spacer design	Interior profile temp °C	Interior glass temp °C	U value* façade W/m^{2}°K	Overall Rating **
Mechanically fixed new	3.652	Aluminum	15.91	11.19	2.05	12
	3.652	Stainless Steel	15.83	11.74	2.02	8***
	3.652	Warm Edge Silicone Foam	16.35	13.55	1.88	4
Mechanically fixed aged	3.711	Aluminum	13.45	11.60	3.39	14
	3.711	Stainless Steel	13.56	11.86	2.37	13
	3.711	Warm Edge Silicone Foam	14.05	13.19	2.35	9***
Structural Silicone with wet weatherseals	1.126	Aluminum	17.19	13.09	1.90	6
	1.126	Stainless Steel	17.32	13.27	1.87	3
	1.126	Warm Edge Silicone Foam	18.17	14.68	1.66	1
Structural Silicone with gasket weatherseal	1.639	Aluminum	16.88	13.09	1.96	7
	1.639	Stainless Steel	17.00	13.29	1.93	5
	1.639	Warm Edge Silicone Foam	17.94	14.67	1.70	2
Hybrid Toggle system continuous polyamide toggle	2.371	Aluminum	16.2	8.12	1.99	10***
Hybrid Toggle system, toggle omitted	2.371	Aluminum	16.2	8.35	2.02	11***

* Calculation done based on EN10077 -2 using a 1m x 2m glazing panel with the U value of 1.393 W/m^{2}°K and a low e coating of 4 % emissivity on the #3 surface
**The overall rating is determined by ranking each property, profile temp, glass temp, and facade U value, in order from 1-14. These three rankings are then averaged and the average ranking is assigned. For instance the structural silicone glazed system with wet weatherseals had a #1 ranking on profile temp, #1 ranking on glass temperature, and a # 1 ranking on the façade U value. This resulted in an average of 1 [(1+1+1)/3] for the top ranking.
*** The average rankings of systems 8-11 were all essentially equivalent using this ranking system.

Figure 2.1.4 - comparison on the U value and energy consumption of typical curtainwall glazing systems. (Carbary, 2007)

2.1.5 **Concerns in the use of adhesives**

When using adhesives for structural bonding, there are several concerns that need to be taken into account.

According to vereniging FME-CWM (2008), three links can be distinguished in a structural bond. These links are:

- The adhesion strength between the cured glue layer and the first adhesive surface
- The cohesive strength of the cured adhesive layer itself
- The adhesion strength between the cured glue layer and the second bonding surface

The difference in adhesive and cohesive failure is visualised in figure 2.1.7. In case of an adhesive failure, the surface was not compatible with the adhesive. In some cases this could have been prevented by a correct pre-treatment.

Pre-treatment can happen in different ways, dependent on the surface material and the type of adhesive. When bonding aluminium with glass, the aluminium is pre-treated with an activator fluid and the glass is only cleaned with specified product from the supplier of structural sealant (figure 2.1.6).

The adhesion strength of the adhesive on the both surfaces is the result of:

- The properties of the adhesive material in the mounting state, for example, the viscosity.
- The condition of the surfaces, for example all or not contaminated or oxidized, at the moment of application of the adhesive.

The cohesive strength of the cured adhesive layer is dependent on from :

- The adhesive in the mounting state, e.g. for with regard to the mixing ratio
- The curing parameters, such as temperature , pressure and curing time.

The strength of the adhesive connection depends in its entirety from :

- The quality of the workpiece material;
- The state of the workpiece in terms of the materials for treatment ,such as degreasing, sanding, blasting, etching, etc.
- The manner of implementation of the gluing process, such as pressure, curing time and temperature
- The used adhesive
- The condition of the glue , such as the mixing ratio, the time in which the adhesive is to be applied , etc.
- The treatment
- The seam form , among other things, the gap width and the overlap
- The load situation
- The design

In detailing the joint there are some concerns, regarding the use of adhesives. In figure 2.1.5 you can see three different load situations on a joint. Most favourable situation for an adhesive joint is a load in axial direction (shear load). In this situation the load can be divided over the total glued area. It is dependent on the stiffness of the adhesives how evenly divided this load will be.

An eccentric load situation could cause an effect like figure 2.1.8, caused by a shear load. Though, this situation is not common when glueing aluminium and glass because of the relatively high stiffness of these elements.

Figure 2.1.9 shows different load situations. When an adhesive bond is exposed to a static load (e.g. dead weight), this can cause an increasing deformation. Hereby, a bond can succumb without reaching its maximum tension. This can be prevented by using a dead weight support.

Finally, a concern is the quality assurance of an adhesive bond. This will be further discussed in chapter 2.2.

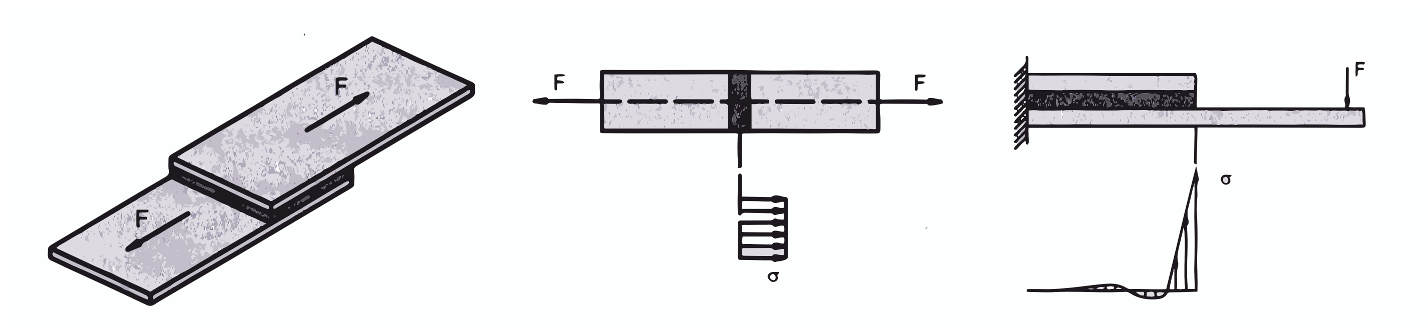


Figure 2.1.5 - Different load situations, from left to right: shear load, tensile load, peel load.
(Belis, 2011)

Figure 2.1.6 - Pre-treatment fluids.
(Own ill.)

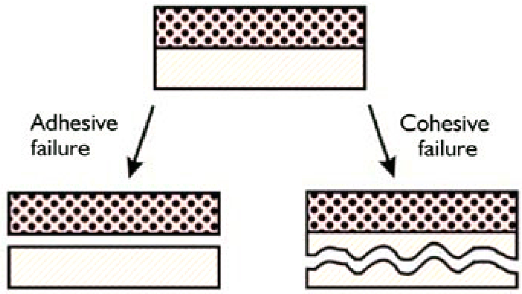


Figure 2.1.7 - Adhesive/Cohesive failure.
(Belis, 2011)

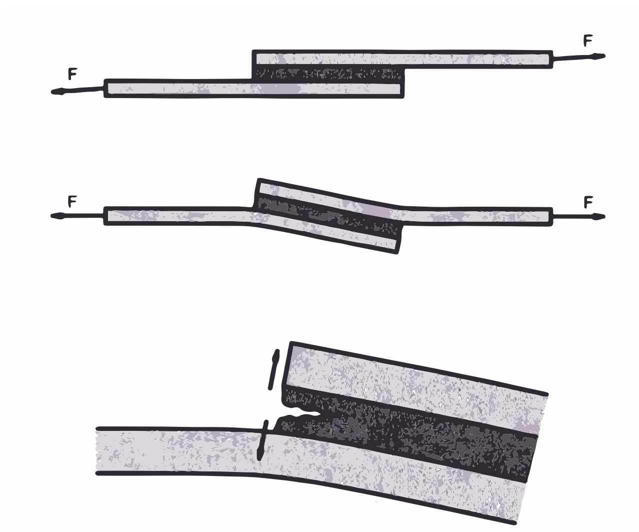


Figure 2.1.8 - Eccentric shear load.
(Belis, 2011)

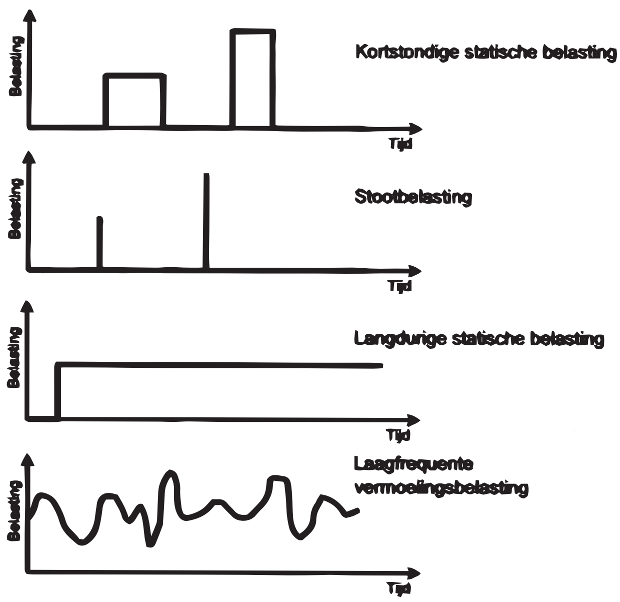


Figure 2.1.9 - Different load situations.
(Belis, 2011)

2.2 Quality assurance and guidelines

2.2.1 Quality assurance

As can be red in paragraph 2.1.4, there are some concerns in designing with structural bonds. There are several steps in the process that are critical to the final result.

The main concern with quality assurance is the risk. When you are using adhesives, there are several moments in the process that are critical for the end result.

According to Knottnerus (2012), it is still not possible to measure the integrity of an adhesive bond without damaging this connection. This despite extensive research conducted around the development of NDT (Non Destructive Testing) methods.

In non destructive testing there can be distinguished:

- Visual inspection
- Leak test
- Acoustic emission
- Beat Test
- Fokker bond tester
- Ultrasonic examination
- X-rays
- Shearography
- IR thermography
- NMR (Nuclear Magnetic Resonance)

All of these techniques are aimed to find. Defects in the adhesive layer but even though there are no measurable defects, it does not mean that the bond (with 100% certainty) is good.

For this reason, normally with structural bonding, there is no final inspection on the quality of the bond. In stead of this there is a quality assurance of the entire production process. The product is produced in such a way the quality is assured to comply with the requirements. This can be achieved by using a procedure that describes every step in the process.

Normally, a manufacturer/supplier of adhesives can only give a guarantee on its product. The supplier can guarantee the adhesive complies to the technical specifications they claim to have. Yet, as can be red in paragraph 2.1.4, the structural bond is not only a product of the adhesive, but also is dependant on the surfaces which are bonded.

Vereniging FME-CWM (2008), states the quality of a bonded product is determined by:

- The suitability of the materials used
- The appropriateness of the means of production
- Efficiency of the processes and controls
- The competence of personnel

For structural bonding, each of the above is critical for the end-result. A not suitable material surface, production environment with wrong conditions, no checks of the sealant and mixer, no or inadequate pre-treatment, will all result in an insufficient bond.

Problem with this is that all those steps will not be directly visible and noticed if they are not properly executed. In comparison to a screw connection, it will be visible if the screw is in the element and the applier will notice if the screw holds/grabs. The strength of the screw and other elements is specified by the producer and they are not dependent on processing in the production facility.

These factors describe the risks in structural bonding and the need for an extensive procedure to assure adequate quality.


QUALITY CONTROL
APPROVED

2.2.2 **Standards, guidelines and contracts**

Standards, guidelines and contracts are documents which are present in every project. It depends on the kind of project and design which documents are applicable.

The documents that are related to Scheldebouw, specifically for structural glazing projects, are:

- ETAG 002, Part 1, Part 2 and Part 3
- Cahier 3488 (France) Pass-Vec certification by CSTB
- EN and ASTM standards
- Permasteelisa Sika 'Umbrella Supply Contract' d.d. 22-12-2005
- Permasteelisa Sika Procurement Contract including appendices
- 'General Guidelines Structural Silicone Glazing with Sikasil® SG Adhesives'

The ETAG is a guideline for European technical approval of Structural Sealant Glazing Kits. It describes several properties of sealants and production circumstances which need to be sufficient to get a European approval.

Cahier 3488 certification is a French certification which is based on the ETAG. This certification is needed on projects, mostly dependant on the location. For example countries like Germany are more demanding in this. This certification mainly focusses on the production.

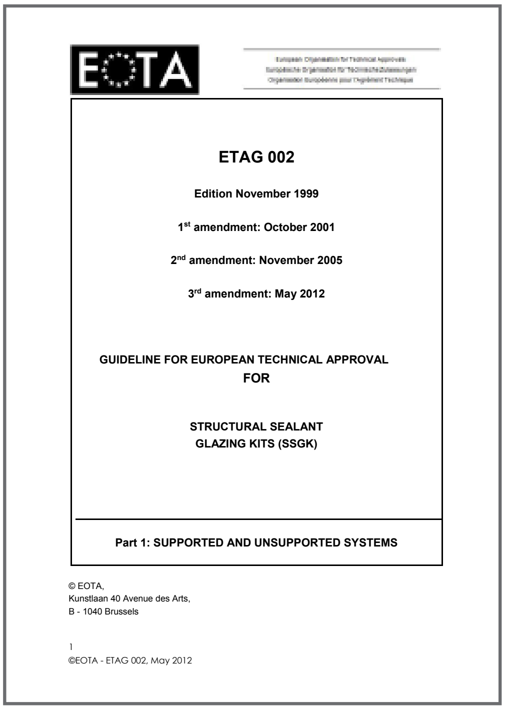
EN and ASTM are standards. A standard is a document with agreements, specifications or criteria about a product, a service or a method. Standards can be established within a company or organization within a consortium of organizations or by recognized standards bodies. EN are European standards.

ASTM is the American Society for Testing and Materials, which provides standards for the United States. Yet, all standards can be used voluntarily or obligatory by client demands.

The Permasteelisa Sika 'Umbrella Supply Contract' is the contract also discussed in paragraph 2.3.2. This umbrella contract has financial benefits. For example, as a group they can get a discount if they purchase more than a certain amount of these products. Besides these financial benefits it was also possible for the Permasteelisa Group to work on a procedure, together with Sika, to be able to get warranty on the total structural bond and not only on the sealant itself.

The 'General Guidelines Structural Silicone Glazing with Sikasil® SG Adhesives' are the guidelines provided by Sika, that should be followed to assure a quality process and product. This document describes the different steps and product that should be used in the process.

These documents are processed into a procedure by Scheldebouw, which is further explained in chapter 4.3.3. This procedure describes the steps in process which are needed to comply to these documents.


European Organisation for Technical Approvals
Europäische Organisation für Technische Zulassungen
Organisation Européenne pour l'Agrément Technique

ETAG 002

Edition November 1999

1st amendment: October 2001

2nd amendment: November 2005

3rd amendment: May 2012

GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL
FOR

STRUCTURAL SEALANT
GLAZING KITS (SSGK)

Part 1: SUPPORTED AND UNSUPPORTED SYSTEMS

© EOTA,
Kunstlaan 40 Avenue des Arts,
B - 1040 Brussels

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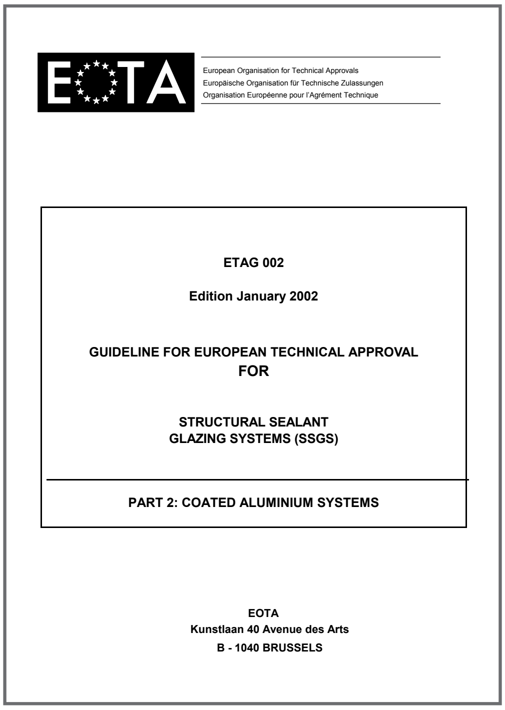
©EOTA - ETAG 002, May 2012


European Organisation for Technical Approvals
Europäische Organisation für Technische Zulassungen
Organisation Européenne pour l'Agrément Technique

ETAG 002

Edition January 2002

GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL
FOR

STRUCTURAL SEALANT
GLAZING SYSTEMS (SSGS)

PART 2: COATED ALUMINIUM SYSTEMS

EOTA
Kunstlaan 40 Avenue des Arts
B - 1040 BRUSSELS


CSTB

22 JUIN 2010

SSG PASS

testifying to the conformity
of the factory production control

n° PASS0218

Limit date of validity: June 1, 2015

Issued in Champs sur Marne, on June 1, 2010

Charles BALOCHE
Technical Director of CSTB

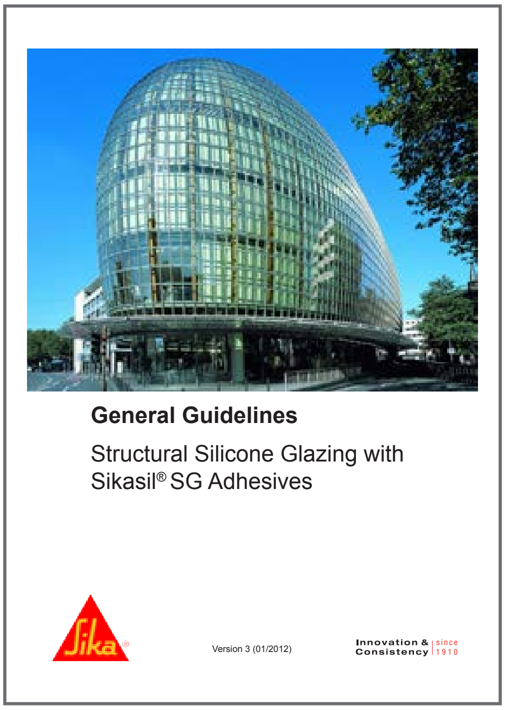


Figure 2.2.1 - Some of the documents related to Scheldebouw SG projects. (Various, 2014)

2.3 Research on types of adhesives

2.3.1 Critical properties

The ETAG, which is a guideline for European technical approval of Structural Sealant Glazing Kits, describes several properties of sealants and production circumstances which need to be sufficient to get a European approval. It is possible for manufacturers of sealants to get this ETAG approval, whereby they can enter this industry.

It is not always prohibited to use a non approved sealant for structural glazing, but often the client and/or local authority asks for compliance to the ETAG. In this case an ETAG approved sealant should be used. If compliance to the ETAG is not needed, the ETAG is still a usefull document, because this will help you selecting a sealant with the right properties.

Critical properties for sealants for structural glazing are: bond strength, shear strain, durability, UV resitance, thermal stability, moisture and solvent resistance, curing time, processability and its appearance.

2.3.2 At Scheldebouw

Scheldebouw is part of the Permasteelisa Group, which is a worldwide leading Contractor in the engineering, project management, manufacturing and installation of architectural envelopes and interior systems. This group has over 50 companies in more than 30 countries and 11 production plants.

As a group, it was possible for Permesteelisa to get an 'Umbrella Contract' with Sika. Sika is a supplier of chemical construction product. For the structural glazing facade industry they supply 'Sikasil SG' which is a group of products, specifically for this industry.

This umbrella contract has financial benefits. For example, as a group they can get a discount if they purchase more than a certain amount of these products.

Besides these financial benefits it was also possible for the Permasteelisa Group to work on a procedure, together with Sika, to be able to get warranty on the total structural bond and not only on the sealant itself. This means an extended warranty, where more than only the structual sealant will be remunerated in case of failure by the cause of Sika.

The Sikasil SG products mainly used by Scheldebouw are:

Sikasil SG-20 | 1-part Silicone SG Adhesive with extremely high mechanical strength, long elongation at break; globally approved for SG, e.g. ETA. Cures by humidification by air, which causes a much longer curing time and the limitation of the joint size. Joints deeper than 15 mm should be avoided. Deeper joints will not cure completely. This variant is rarely used on this moment.

Sikasil SG-500 | 2-part Silicone SG Adhesive globally approved for SG, e.g. ETA. The two parts are a base compound and a catalyst paste, which are mixed in the production facility of Scheldebouw.

Sikasil SG-550 | This product is a high-strength version of Sikasil SG-500. Downside of this product is i.a. its tougher processability. Though, this product can provide in minimised joint dimensions. For the same element sizes the joint bite can be up to 30% smaller with this sealant. Vice versa, bigger glass sizes can be approved with this sealant.

Figure 2.3.1 - 2-component mixer at Scheldebouw. (Own ill.)

Figure 2.3.2 - Untooled Sikasil SG-500 joint. (Own ill.)

Figure 2.3.3 - Sikasil SG-500 for on-site replacement. (Own ill.)

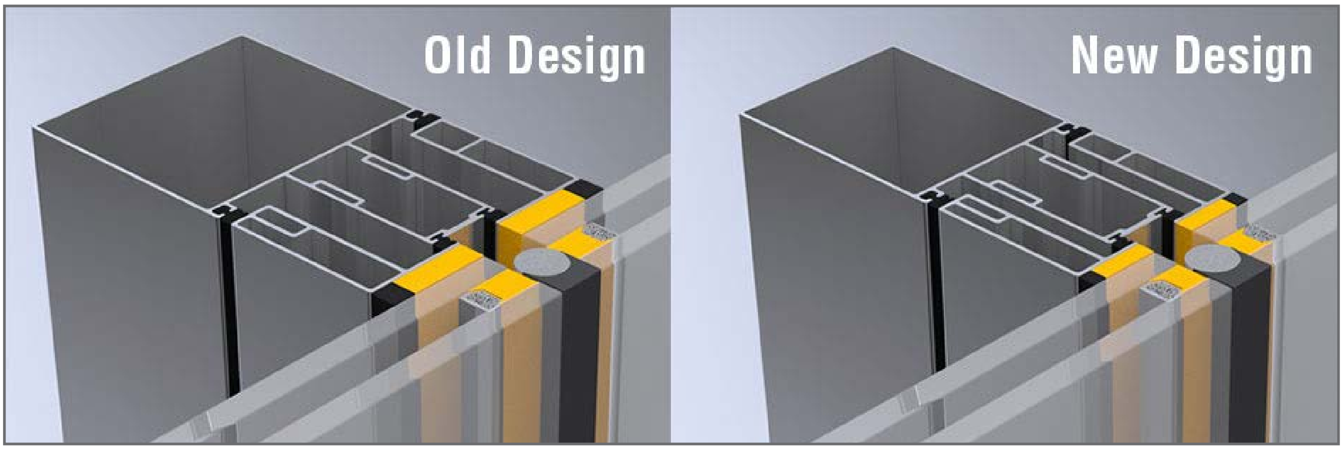


Figure 2.3.4 - Standard SG-500 vs high strength SG-550. (Sika Facade System Specification Guide, 2012)

2.3.3 **Other types of adhesives**

As can be red in paragraph 2.3.1, adhesives should comply to several critical properties. These propeties are:

- Bond strength
- Shear strain
- Durability
- UV resistance
- Thermal stability
- Moisture and solvent resistance
- Curing time (put-through)
- Processability
- Appearance

According to the ETAG the structural bond is to be silicone, in the form of a linear bead. Yet, this document also states: In due course, further parts of the Guideline may be issued to reduce these restrictions. In other words, they say it might be allowed to use another kind of adhesive.

Research on other types of adhesives resulted in a look up at companies, well known for their adhesives, like: Dow Corning, Sika, 3M and GE.

For once, it migh be unrealistic to convince Permasteelisa/Scheldebouw to migrate to another supplier of adhesive/sealant. The reason for this is the Umbrella contract they have at this moment, which gives them financial and warranty benefits.

Yet, if a product is found that gives a significant amount of benefits, this might be a possibility.

One of these reasons could be a significant improvement in the structural bonding process, which is the scope of this thesis.

Other reasons could be:

- Financially
- Environmentally
- Less risk

In the end, three kind of products can be distinguished that are suitable for structural glazing projects: 1-part silicone, 2-part silicone and an acrylic foam tape.

1-part silicone has a relatively long curing time, which can hinder the wished for put-through time in production. Also 1-part silicone had a limited joint depth. Because the curing type of this sealant, which is by air humidity, the joint depth is limited to around 15 mm. For some projects a bigger joint is needed.

2-part silicone is a good performing adhesive in structural glazing. Yet, this kind of adhesive brings an extra risk factor which is the combining of the two components in the production facility. This needs an investment in an expensive mixer and a lot of attention in maintenance, inspection, samples and tests to assure the correct mixture of these two components.

Acrylic foam tape is fast curing and does bring less risk factors, in comparison to the 2-part silicone sealant. This tape possibly also has other benefits in process, because of easier application.

Possibilities, benefits and problems with these types will be further discussed and researched in this thesis. In chapter 5 a process improvement will be discussed by using a 1-part silicone in stead of a 2-part silicone. This is only possible if a longer curing time is allowed for the specific project and the joint depth does not exceed 15mm.

In chapter 6 the acrylic foam tape will be further researched and will be processed into a design variant. According to this variant the benefits and problems will be exposed.

Figure 2.3.5 - Suppliers of SG adhesives. (Var., 2014)

Figure 2.3.6 - 1-part Sikasil SG-500. (Sika, 2014)

Figure 2.3.7 - 2-part Sikasil SG-500. (Sika, 2014)

Figure 2.3.8 - Acrylic foam tape. (3M, 2014)

2.4 Research on other industries

2.4.1 Automotive industry

(Carglass interview is scheduled)

Research on the automotive industry could be on the automatized mass production factories of big car manufacturers, but the decision has been made to contact a specialized company.

This company is Terberg Specials Belgium, where I had contact with John de Jong, which is the Quality Manager at this company. He explained how the quality typically is assured in the automotive industry.

Terberg Specials transforms existing road legal vehicles into customized vehicles. These vehicles need a new legal approval to be road legal and to be able to be assured.

Statuary body for this in the Netherlands is the RDW (Rijksdienst wegverkeer). This institution is engaged in the legal admission of vehicles and components of these vehicles.

When a new type of vehicle is build you need a type approval. Legal approval for this type of vehicle can be national or European. This means one vehicle out of the series is checked and others are build in the same way, with the same products, to obtain approval. This approval is achieved by visual inspection and for some elements destructive testing is used to approve these elements.

Glued windshield are not tested, but get their approval based on the used sealant and their way of appliance.

The approval of this sealant is obtained from the RDW based on its specifications and way of appliance (work instructions).

In other words, as long as you use a sealant which is approved by the RDW and do this according to the work instructions, the bond will be approved. This shows a trust in the sealant and the way of appliance, because there is no obligatory testing in the process.

What Terberg Specials does, is performing a waterproofing test on 1 in 10 vehicles. This is just done by spraying water on the windshield and checking for leakage on the inside.

In the past, Terberg was also working with Sika, but has now switched to Henkel. The decision for this was made after they invited multiple suppliers and asked them how they could assist them in the building process.

Henkel showed much more support and advise then Sika. According to de Jong, Sika had good performing products, but Henkel was able to provide Terberg with better application specific solutions. For example, they advised them to use a specific kind of sealant that did not need any primer. This primer was incorporated in this kind of sealant.

In the automotive industry it is not only the windshield they glue, but they also have other applications. For this, Henkel was better able to provide Terberg with all the products they needed.

Differences, compared to the facade industry are in a shorter period of warranty (5 years), lower demands on durability, lower demands on bonding strength and less involved risk.

The way of structural bonding and possible lessons from the process in this industry are further analysed in chapter 4.3.5.

Figure 2.4.1- Automotive industry. (ÚAMT, 2014)

Figure 2.4.2 - The appliance of structural sealant for a windshield. (Own ill)

2.4.2 **Aviation industry**

Higgins (2000) describes the most common applications in aircraft structures. In the aerospace industry, adhesive bonding is used for both structural and non-structural applications. In the aerospace market, a distinction is made between primary and secondary structural applications. Joint failure in a primary structure will result in the loss of the aircraft, whereas failure in a secondary structure will result in only local damage. Structural adhesives are used in both applications.

Figure 2.4.3 illustrates the degree to which adhesive bonding is used in modern aircraft. Structural adhesives such as epoxy and epoxy hybrids are used for manufacturing lightweight honey-comb sheets and for creating high- stress joints for purposes such as stiffening, creating of sandwich structures and bonding laminates.

One thing that makes adhesives in the aircraft industry more advanced is the use of adhesive films. Films are the most prevalent form of adhesives used in aircraft. The aerospace industry has led in the development and utilization of these advanced adhesive systems.

Films offer several advantages over liquid systems:

- Ease of handling and application, especially with regard to large structures
- Elimination of metering and mixing and associated reduction in waste
- Uniformity of composition
- Uniformity and control of thickness

This might also be interesting for the facade industry.

When looking at the quality assurance in the aerospace industry it is a totally different story in comparison to the facade/building industry.

Where the Dutch automotive market has the RDW and its mandatory ‘APK‘, the aviation industry has the EASA. This is short for: European Aviation Safety Agency. This agency creates regulation on common rules in the field of civil aviation and other matters regarding aviation.

Airlines and other commercial operators of large or turbine-powered aircraft follow a continuous inspection program approved by the EASA. This includes both routine checks and detailed inspections. There are different checks, which are all done in a specified amount of time (Franken, 2013):

> **A Check |** This is performed approximately every 500 - 800 flight hours or 200 - 400 flights. The construction is checked on eventual corrosion or missing parts. Other checks are on the pressure of the oxygen system, emergency lighting, lubrication of landing gear, brake accumulator and built-in tests of the plane. This test takes around 20 to 100 man-hours.
>
> **B Check |** This is performed approximately every 4 - 6 months. This is an elaborate version of the A Check. It takes around 150 man-hours.
>
> *Where A and B check are primarily intended to ensure the airworthiness of the aircraft, a complete inspection of the entire aircraft with the C and D check.*
>
> **C Check |** This is performed approximately every 12–18 months. C-check take 3 to 5 days and can cost up to 6,000 man hours. During the C-check individual systems are tested. Personnel of the highest level and special tools are needed for this. Parts of the plane are also disassembled for control and even individual bolts are checked.
>
> **D Check |** This is the most comprehensive check for an airplane. This check occurs approximately every 4–5 years. This is the check that, more or less, takes the entire airplane apart for inspection. The D-check can take up to 40,000 man hours and 2 months. During the D-Check there are a huge number of specialists working to inspect the aircraft to the smallest detail. Most aircraft undergo 2 to 3 D-checks before they retire from service. On this moment a D-check is not profitable anymore.

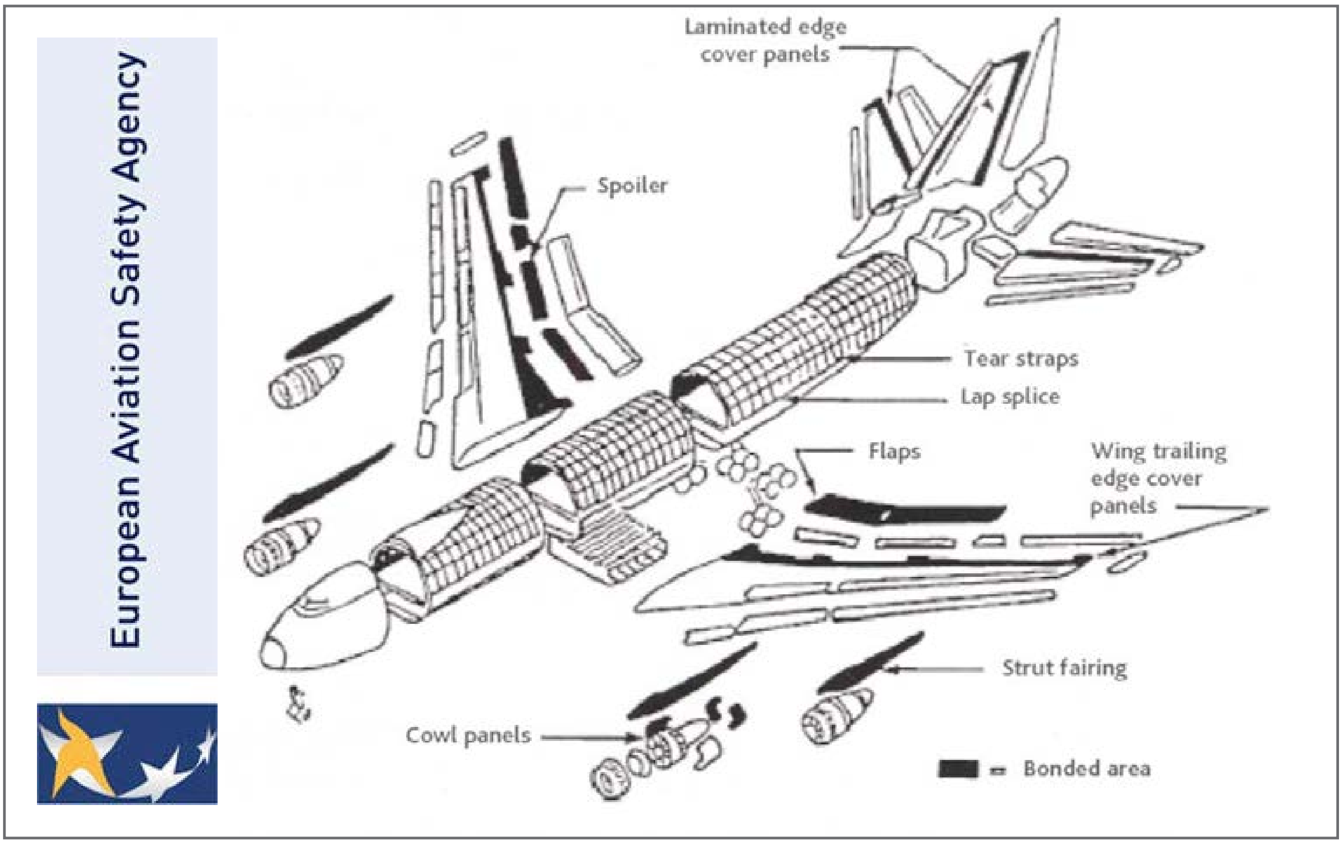


Figure 2.4.3 - Bonded areas in modern aircraft. (Higgins, 2000)

Especially in the C and D check, where total parts are disassembled, different glued elements are visually inspected and by using thermographic and ultrasonic techniques.

In relation to the facade/building industry, a similar program would never be feasible. Costs will be too high and other options without these extensive checks will be prefered.

The reason this program is feasible for the aviation industry is the higher risk involved in this business.

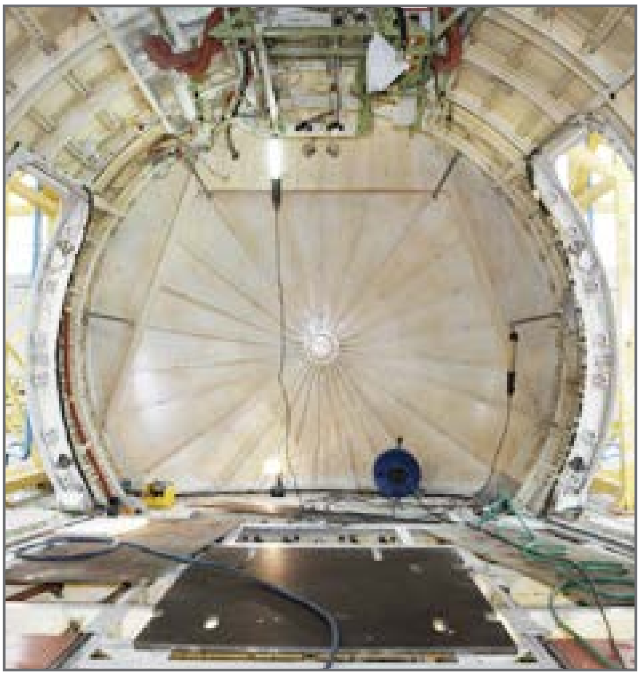


Figure 2.4.4 - Airplane during a D-check. (Franken, 2013)

3.0 Topic Definition

3.1 Problem statement

As can be red in the preliminary research, structural glazing is a quite complicated process, due to procedures for safety and quality regulations and their compliance. Though, the design in detail on its own is one of the most simple you can find.

This simplicity mainly comes from the fact that it is a minimalistic detail, consisting of a frame, a sealant and a glass pane that is fixated directly on this frame. Except from some rubber gaskets there is not a lot more in this detail. This detail has a good performance when compared to dry glazing. There are no thermal bridges, where in dry glazing complicated detailing is needed to prevent thermal bridges. Also the fixation doubles as the weather sealant, which keeps it simple.

In discussions with engineers, designers and professionals, structural glazing seems a performing way of glazing, which is highly demanded. Though, when looked at this with a critical view it becomes clear that there are also flaws in this way of building. Does this way of structural glazing still meet the standards and is it the way to go?

Flaws in this way of structural glazing are primarily in compliance to guidelines and procedures, difficulties in production and replacement.

Because of the simplicity of the detail and cost driven nature, possible improvements could be disregarded because of a more complicated system and higher costs.

3.2 Aim of research

Goal of this thesis is to research how the structural bonding process at Scheldebouw could be improved. Different directions for this can be:

- The current design could still be a good design, but be improved by process improvement.
- An other option is to develop or improve the current design on process level.
- Last option is to improve by implementing a new system, based on the conclusions of this research.

Research will result in different approaches to improve this process. These approaches need to be evaluated. For this it is necessary to perform research on the reasons an improvement will be feasible or infeasible.

Therefore, these reasons need to become apparent from research by:

- Analysis of the current situation to be able to improve on this situation.
- The creation of an overview of all stakeholders in the process and their particular interests. By this it will become clear which improvements benefit what stakeholder.

One of the approaches will be the development of a new structural bonding system/detail. After evaluation of this detail it will become clear if this approach is feasible and should be the way to improve this process.

3.3 Research question / subquestions

?

How can the process of structural bonding of glazing in unitized curtain wall facade systems be improved?

This research question can be divided in several sub-questions:

- How and to what extend can the process be improved, merely on process level?

- How and to what extend can the process be improved by implementing a new system and what should these improvements be?

- How should the detailing of such an improvement be?

- What reasons are there to change, or to not change, the current process? In other words: What benefits are needed to make a proposed improvement feasible?

3.4 Research contribution

The research will contribute to the general knowledge about structural bonding:

- At first the research will form an understandment of the structural glazing principle and its abilities, disabilities, advantages and disadvantages. The different approaches in improvement will be based on these conclusions.

- It will provide a design concept by which the structural bonding process can be improved. This design will not be an exclusive result, but by evaluating this design, possible improvement by design can be evaluated. It also provides and evaluates the principles where this design is based on. These can be used in future development.

- It will provide a guideline towards the direction that should be followed for further development in this topic.

3.5 Methodology of research

The research will be done in different steps:

1 - Step one will be the ***preliminary research***. This will consist out of a literature study, which will focus on three aspects: design with structural bonding, quality assurance and guidelines, other types of adhesives and other industries. By this a general knowledge regarding these aspects will be achieved. Mainly, the aim of this is to understand the process, application and characteristics of structural glazing and its elements.

This literature study will later be used for the design of a new design concept for the improvement of the process of structural bonding.

2 - The second step will focus on an ***analysis of the current process and use in structural glazing***. This will consist out of an analysis of the current step by step process at Scheldebouw, a stakeholder analysis and an analysis of the current basic structural bonding detail at Scheldebouw.

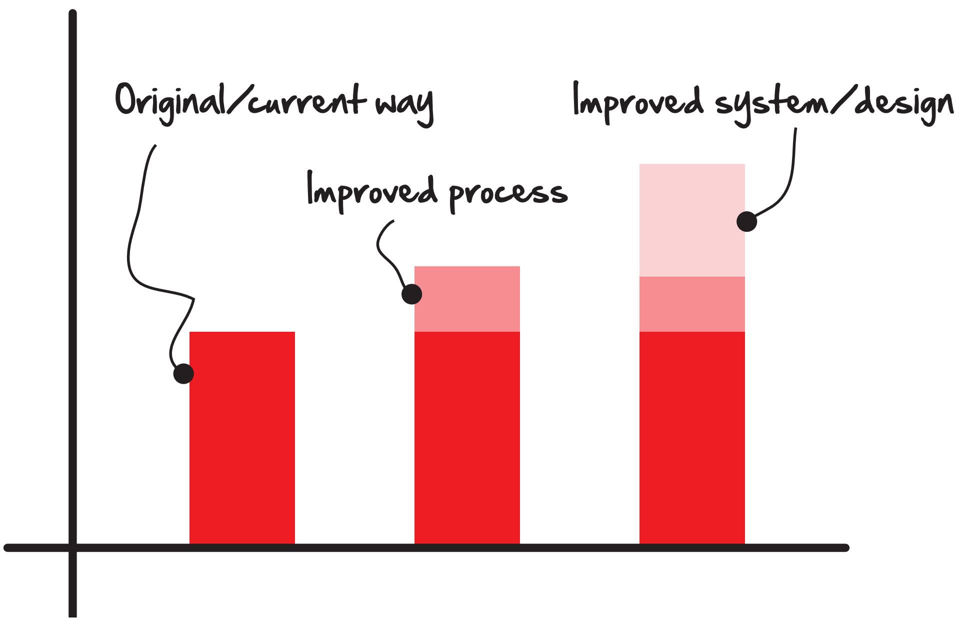
By this, on the one hand principles can be generated on how to improve this process. On the other hand, an overview can be made on what interest every stakeholder has in this process. By this, a redesign can be evaluated to all stakeholders. This could result in a design that is more expensive to produce, but also has more value in other ways, which could make it a feasible design.

3 - Third step will be the description of different possible **approaches**, where one of these approaches is a **new design concept**.

These will be based on the knowledge, collected in step one and two.

4 - Fourth step is the ***evaluation of the design and approaches.*** This will be done accordingly to the findings in step two. The evaluation will be done in comparison to the original/current way of structural glazing at Scheldbouw. Both qualitative and quantitative evaluation will be used for this. The evaluation will be to aspects, generated in step three. The use of a case study can strengthen this evaluation.

5 - Last step will be the ***conclusion on the final designs,*** which will come out of the evaluation of the designs, according to the criteria and conditions, stated in the research of step three. This will be an answer to the research question of this thesis.



4.0 Research

4.1 Plan of approach

This research is started with an interview with employees of Scheldebouw, that are chosen to represent the different disciplines, with different points of view on the structural bonding process.

An overview of these different disciplines is showed in figure 4.1.1. These interviews will give more understanding of the process and design in practice and will give general knowledge of visions on structural glazing throughout the company.

After this the process is researched to understand the current procedures and the motivation and reasons behind these.

A stakeholder analysis will be conducted to bring out an overview in different inerests of the different stakeholders involved in this process.

Also the current design will be evaluated in the last paragraph of this chapter.

By this, the current situation will become clear.

With this information it will be possible to define the further approach in process and design.

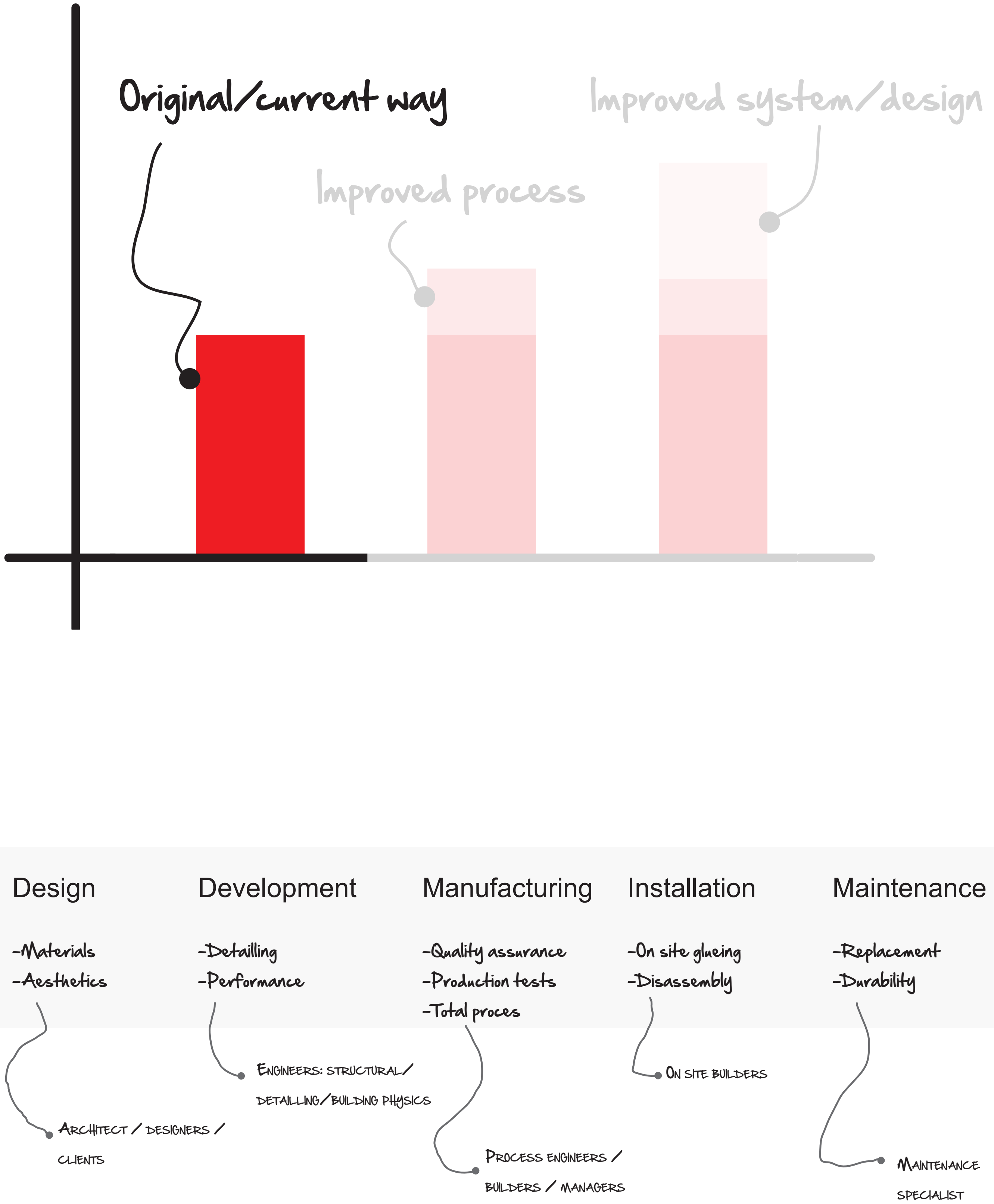


Figure 4.1.1 - Process overview. (own ill.)

4.2 Interviews

4.2.1 Goal

This chapter is an description and elaboration of the interviews, conducted to create an overview of the views on structural glazing along different disciplines at Scheldebouw.

The employees are chosen in a way that different disciplines, with different points of view are interviewed.

These interviews will give more understanding of the process and design in practice and will give general knowledge of visions on structural glazing throughout the company.

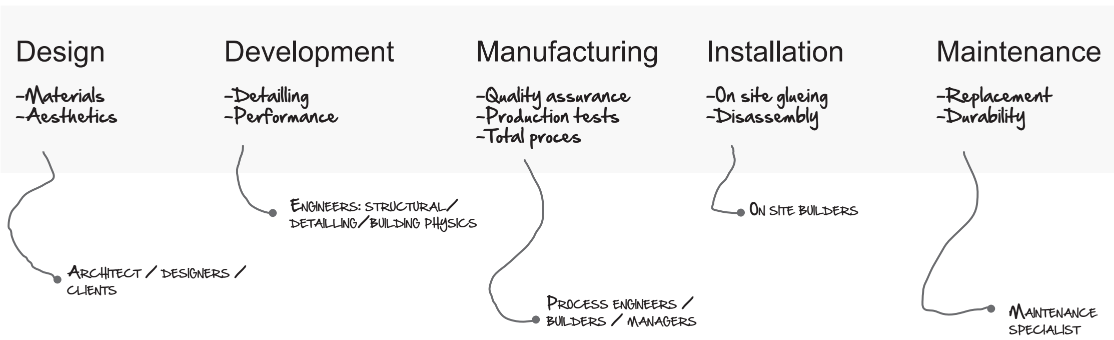
Also these interviews might give hints on flaws in process and design, where improvement might be possible.

Orientation Interview at Scheldebouw - Structural Glazing

Hans Haagen - 13, 14 and 18 February 2014

Introduction

This interview is conducted in order to get an overview of the total process in engineering a structural glazing facade at Scheldebouw. This process can be divided in different fields, that each have their specialists at Scheldbouw. By interviewing experts on these fields, an overview can be generated that shows where there are opportunities for further research.



Name:

Questions

1. What is your role within the company?

2. Project experience with structural glazing?

3. What where the reasons to use structural glazing?

4. What problems with structural glazing did you encounter during the process(es)?

5. Most important reason for using structural glazing?

6. Most important reason not to use structural glazing?

7. Do you think the current structural glazing systems are up to date to the latest market requests?

8. Where do you see possibilities for improvement in structural glazing?

Further discussion ...

PERMASTEELISA GROUP SCHELDEBOUW TUDelft

Figure 4.2.1 - Interview questions. (Own ill.)

4.2.2 **Questions**

The questions are arranged to time: past, present and future. Questions are used as a guideline to cover all possible subjects to discuss, but because of the different disciplines every person will have different focal points on these questions. The interview will not be strictly held conform these questions, but function as a start up of discussion on these topics.

Individual interviews and conclusions on the interviews can be found in appendix 1.

4.2.3 **Collective conclusion on the interviews**

In total, eight people from the company have been interviewed. Of these eight people, four where clearly pro structural glazing. One person clearly had their doubts, and three had a more neutral position. Based on all the interviews and further discussion, also outside the interviews, it can be said that there is no uni-vocal idea about structural glazing inside the company. Also outside the company this is noticeable, for example in the governments in London where in one street structural glazing is allowed, and in the next street structural glazing is only allowed with a mechanical fixation for safety issues.

Remarkable to see is the fact that there is a discrepancy in views on structural glazing inside the same company. This can be because of lack of knowledge, or experiences that some have in their field of work and others don't. By sharing these experiences the reasons to use, or not to use, structural glazing will become clearer. In this case, I see it as my task to collect these views, compare them, and see if this gives possibilities for improvement.

The keywords that are given to the interviews can be ordered in three parts: personal ideas and experience about SG, design/detailing and research.

Personal ideas about structural glazing are more or less feelings or confidence about structural glazing. For example, some will always prefer a mechanical fixing, because of safety issues. Others are fully convinced and don't see the need for a (double) safety system. The discrepancy in this is the lack in data, for example about costs and defaults. If data for this would be available it would be possible to see if there is a reason to use a double system. This could be for safety reasons, but also for financial reasons.

Design and detailing aspects differed for engineers and other professions inside Scheldebouw. Where engineers focused mostly on the simplicity and good performance of a structural glazing detail, for example quality managers focussed more on other aspects. These aspects are for example edge protection, replacement and traceability.

Research aspect, or ideas and suggestions on research, mainly came from quality managers, or people who are close connected to this and the ETAG (for example Eric Vliege).

This suggests that the possibilties are primarily in quality assurance and procedures. Possible improvement in detailling/engineering should also originate from conclussions from research on quality assurance and procedures.

4.2.4 **Output**

Output for these interviews are more understanding of the process and design in practice, general knowledge of visions on SG inside the company and hints on flaws in process and design.

Aspects that need further research are:

Stakeholder / cost - benefits
An analysis on the different stakeholders in a building project with structural glazing. Every stakeholder has different interests in a building project. Not every design solution will be evenly profitable for each stakeholder. With a cost-benefit analysis it will be possible to show which stakeholders have which interests, how an intervention will benefit them and for who there will be more costs.

In this way it is possible to see if an intervention is worth the costs and for who it is profitable.

For structural glazing, an important aspect is risk. For example there is the risk of a broken glass pane. This will cost money (independent on if these costs are for the client or Scheldebouw), but it will also cost image-wise.

- Aesthetics for the architect
- Risk for the client
- Reliability/image of Scheldebouw
- Producability for the production facility
- Workability for the installation
- Replacement for the maintenance
- ...

These interests should be accounted and valuated. Design proposals can then be tested to these results, or in other way around: this analysis could show where design proposals might be feasible.

Competitive position
The stakeholder analysis could come up with conclusions on how to improve certain aspects for specific stakeholders. This will result in a competitive position. A competitive position is needed to have an improvement. A redesign or improvement in process is not useful if it does not give you an advantage over current types of cladding. Therefore, this is an important aspect for this research.

Different situations
The variations in types of facade mainly come from the occurrence of different situations. These situations are external factors like local governments, costs and environmental issues. These cause the basic principle to change in a variant.

These external factors need to be taken into account to see if a more general approach is possible.

ETAG
The ETAG needs to be looked on in a critical way. Why is there a discrepancy in the ETAG and in practice, while stating that the ETAG is followed.

Replacement
The ETAG states: *due to the difficulty of quality control during on site repair, a factory-glazed replacement frame must be installed. Therefore, it is necessary to make an assessment and to comment on the ease of future replacement.*

On this moment, not all designs are possible to repair with a factory-glazed replacement. There are possibilities for this, but statistically the amount of replacements is so low that a possibility for factory-glazed replacement is relatively expensive.

Traceability
On this moment it is not completely possible to follow the procedure, because of the fact that it is just not possible to trace all parts in the production. This might be improved by re-thinking the process.

Automotive industry
This aspect is interesting because of the relevance with the automotive industry. In this industry there is also the bonding of glass with a frame/body. Research should be on the types of sealants used, the way of quality assurance and possible automation of the bonding process.

Shift in risks
A last aspect is if a shift in risk is wished for. It might be possible to come up with a detail where not Scheldebouw but the glass producer executes structural bonding. In this case, Scheldebouw does not have to work with these procedures, but there will still be risk involved. This risk might even be higher because they don't have a direct supervision and have to trust on this producer.

4.3 Process analysis

4.3.1 Goal

In this paragraph the current process at Scheldebouw will be analysed. Goal is to achieve knowledge of the current process, gain experience for my own with the process, experience problems/ bottlenecks and other points of attention in the process.

In the end this will lead to ideas and suggestions for improvement of this process.

4.3.2 Contractual demands

The first input for a new project is always the contractual requirements and architectural design drawings. Contractual requirements can be guideliness, certificates and other demands by the client.

A very common guideline in structural glazing is the ETAG 002. This guideline is already discussed in the prelimenary research in chapter 2, but in this paragraph there will be remarks on this guideline.

A client will demand compliance with guidelines and certification systems to get a certain degree of quality.

The ETAG is a guideline for european technical approval. A lot of projects demand compliance to this guideline, but others also ask for compliance with other systems, like the PassVec. This PassVec is mainly based on the ETAG, but with additional demands.

Analysis of the ETAG guideline consisted out of critical reading of this guideline and reflecting this to practice and the Scheldebouw procedure. This resulted in the remarks at the end of this paragraph.

Besides the possible contractual demands like the ETAG and PassVec, Scheldebouw also has a contractual relationship with Sika.

This relationship is set up in a way to obtain warranty from Sika for the structural bond. Normally Sika can only give a warranty on the structural sealant itself. Though, correct pre-treatment and a suitable material as a surface are just as important for a correct structural bond. These factors are excluded in the Sika contract by describing certain steps in the process.

Remarks:

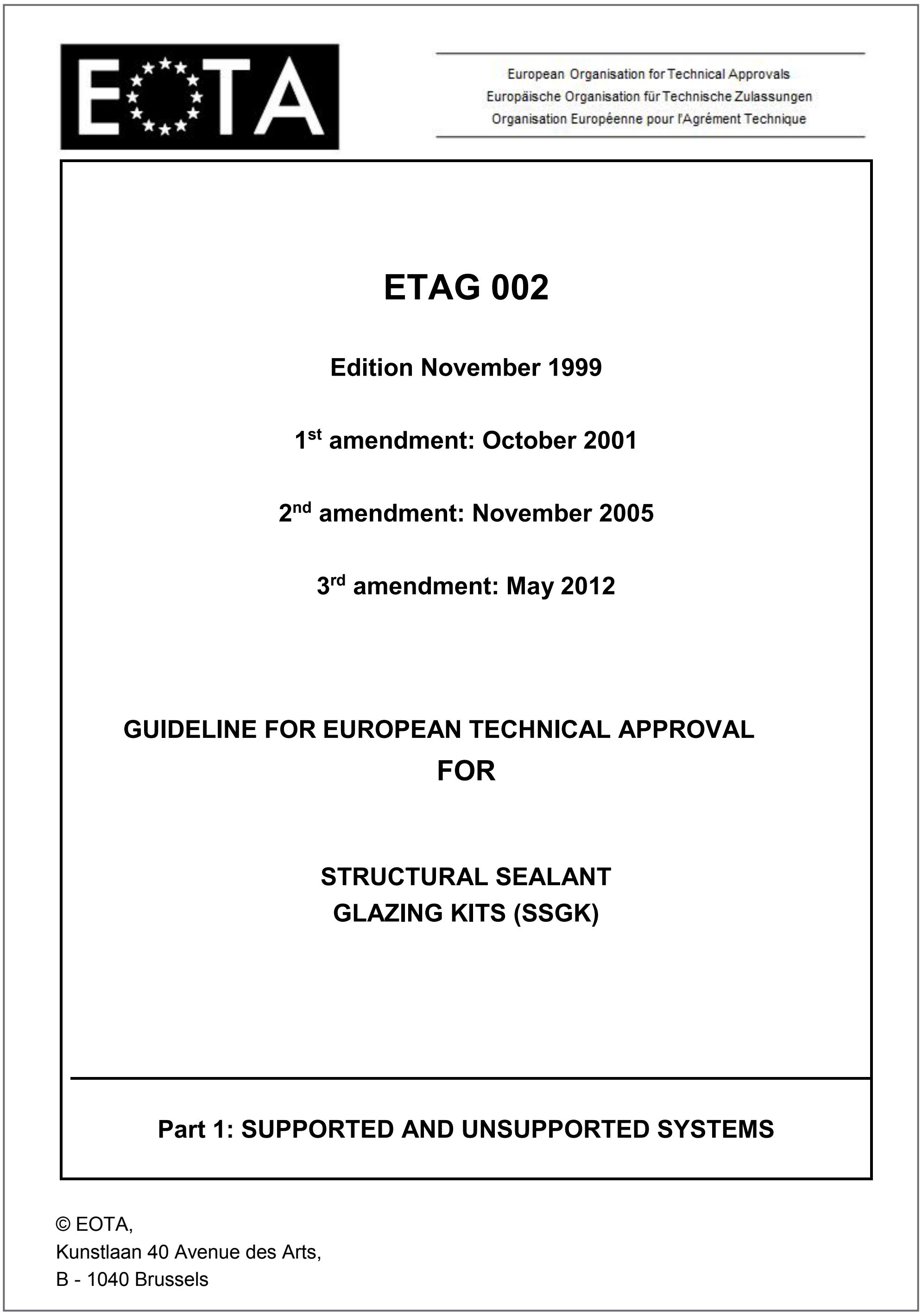
The contractual demands, are demands partly provided by the client. For the other part they are demanded by the supplier of the sealant.

For a significant change to be possible, the needs to be allowed by the contractual demands.

For example, demands by Sika can not be changed without losing the possibility for obtaining their warranty.

With other words, the current way of working originates for a big part from contractual demands, that are outside of Scheldbouw's control.

Innovation and experimenting is difficult because of these demands. Best option might be to work on innovation, within the guideliness, together with Sika.



EOTA

European Organisation for Technical Approvals
Europäische Organisation für Technische Zulassungen
Organisation Européenne pour l'Agrément Technique

ETAG 002

Edition November 1999

1st amendment: October 2001

2nd amendment: November 2005

3rd amendment: May 2012

GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL FOR

STRUCTURAL SEALANT GLAZING KITS (SSGK)

Part 1: SUPPORTED AND UNSUPPORTED SYSTEMS

© EOTA,
Kunstlaan 40 Avenue des Arts,
B - 1040 Brussels

Figure 4.3.1 - Process flow. (EOTA, 2012)

BUILDING TRUST

Sika®

Figure 4.3.2 - Sika, structural sealant supplier. (Sika, 2014)

4.3.3 **Scheldebouw procedure**

The Scheldebouw procedure: Managing and applying structural bonding is a document, implemented by the quality manager.

The purpose of this procedure is to establish a default process for managing and applying structural bonding in compliance to the ETAG, Sika, EN standards, ASTM and Cahier 3488 (France) requirements. Therefore, this procedure is a product of the stated norms, guidelines, contractual regulations and standards.

This procedure covers all structural bonding activities in the factories and on the installation sites.

In addition the procedure covers all structural bonding works subcontracted to other parties.

It is the responsibility of the managers of the involved departments to guarantee that the procedures are strictly followed. In case of sub-contracted works, the Project Manager is responsible for instructions about and respecting of the procedure.

In figure 4.3.3 you can see the process flow, which visualises the different phases and their associated activities.

The procedure will be described concisely by phase.

First phase is **engineering/design**: For this phase, the input are the contractual requirements and architectural design drawings. A desing will be made and joint dimensions are calculated. This design is announced as project to SIKA to get approval. Sika Industry will advise the minimum joint dimensions and secondary seal for each technical detail. With this information the final design will be finished.

After this all material specifications can be defined. For these materials there are specific requirements to comply with the ETAG and other norms. These requirements for every material type are also collected in this procedure.

Second phase is **logistic**. Input for this, are the material data sheets. These are used to prepare samples to sent to Sika for a compatibility test. This concerns materials that are in contact with the silicon joint and the different PVB layers. The purchaser is informed to take special care by following the instruction to purchasing material for structural bonding. For this a special instruction is written to add to the suppliers' contract.

Sika will perform adhesion and compatibility tests and inform Scheldebouw by submitting reports. This information needs to be processed. To ensure a correct and complete information flow from the engineering and logistics phase to the production and installation, a 'Project Manual Structural Bounding' is made. The manual contents the following information:

- Detail sections per façade type and technical situation
- Additional instructions indicated in the sections
- Instructions for pre-treatment of surfaces
- Instructions for deglazing and reglazing
- Sika response on technical file per façade type
- Sika Laboratory Reports Adhesion
- Sika Compatibility Test Reports

Delivered materials need to be checked and approved and handled in a correct way regarding traceability of batches and expiration dates.

All <u>anodised or powder coated profiles</u> suitable for structural bonding <u>should be packed per batch</u>. On each package is the corresponding batch number listed. The batch number is corresponding to the "Sika report for adhesion".

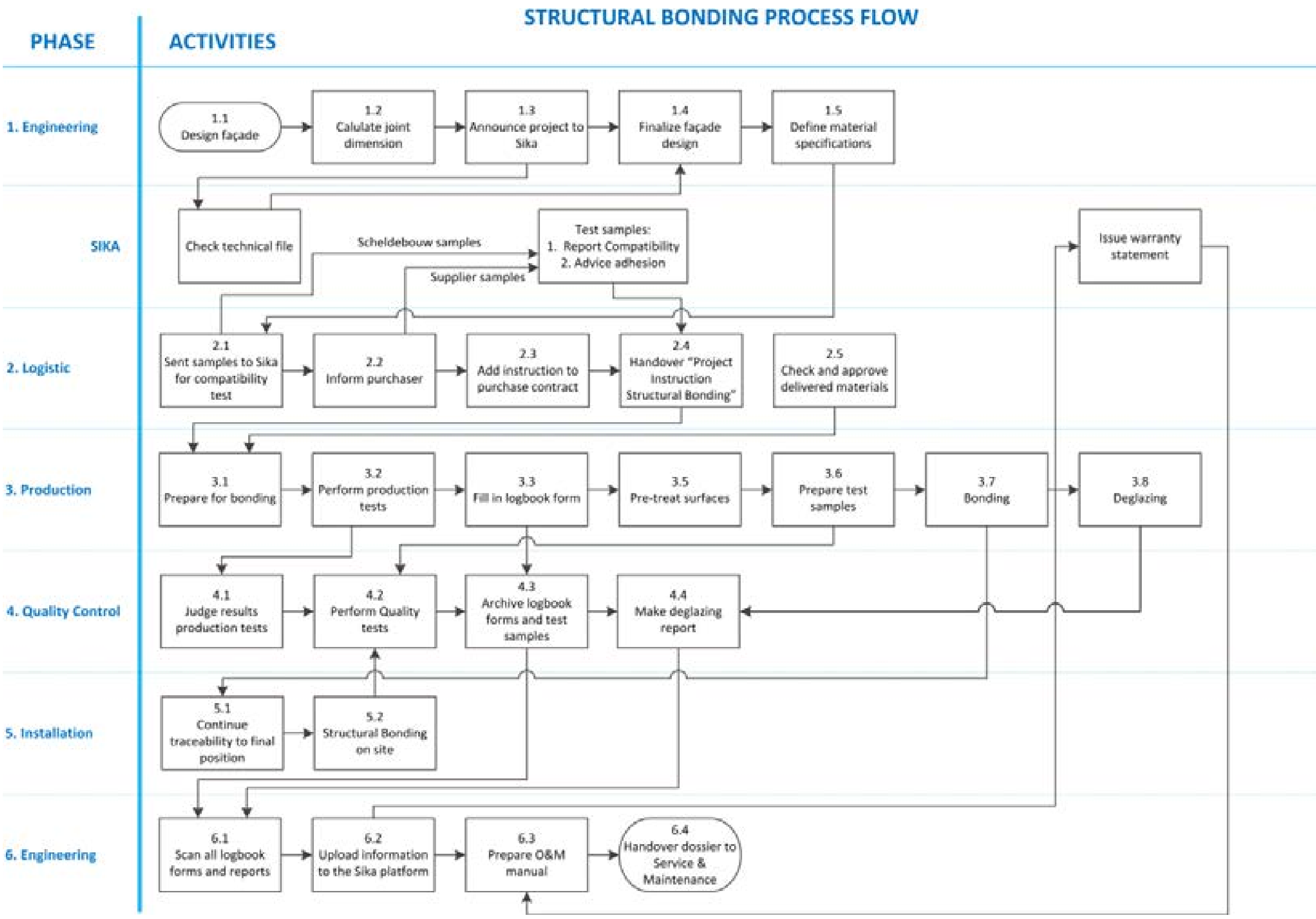


Figure 4.3.3 - Process flow. (Scheldebouw, 2013)

Third phase is **production.** Input for this is the Project Manual Structural Bonding. Prior to the bonding the following regulations need to be checked and respected: the temperature in workshop, temperature of the materials and the correct labeling of each element. Concerning temperatures it is important that all materials are stored for 24 hours in the workshop prior to processing.

To check the correct working of the application device, and a correct mixing and curing of the silicone, initial tests must be carried out. All tests must have succeeded before the real application can start. All below mentioned production test must be performed before the start or re-start of the device and each time base or catalyst are changed. All test results have to be registered at the logbook sheet. Production tests, which are also displayed in figure 4.4.5 - 4.4.7 are:

- Mixing ratio text, a measurement of the correct ratio between the two components.
- Butterfly test, a visually inspection of the sealant on uniformity in color and air inclusion.
- Snap time test, a measurement for the curing time.

The logbook needs to be completed for each production day, project and glass type. This logbook can be found in appendix 2 of this report. It contains general project information, material specific information, information about circumstances and observations and remarks.

After this, pre-treatment can start. The project specific pre-treatment instructions are listed in the 'Project Manual Structural Bonding'. This manual indicates per project and per material type (per glass type, per batch of profiles, etc.), which products must be used for pre-treatment.

Before the application of the structural sealant, two kinds of samples shall be made by production for testing. These are a H-sample and a peel sample, which are displayed in figure 4.3.10 and 4.3.11.

Now the bonding can start. Al information regarding the structural bonding joint is listed in the 'Project Manual Structural Bonding'. All foremen and applicators of cleaners and sealants have to read the manual.

For production, also movement regulations are included. These state that horizontal movement is directly possible, when loads on joint are prevented. Vertical storage is possible after 24 hour. Transportation is allowed after 48 hours and installation after 72 hours. Of course, this is only the case if Sikasil 500 or 550 is used, but this is the bonding material used at Scheldebouw.

To check the correct application of the structural sealant, a certain amount of panels will be deglazed. Deglazing is a Sika requirement for obtaining warranty for a period longer than 12 years. For the first 50 bonded modules there is one deglazing. Ater this there is one for every 200.

The Quality Inspector will make a report of the deglazing, supplemented with pictures. This report contains the following information:

- Date of deglazing and serial number of the module
- Control of the silicone joint bite
- Control of the joint width
- Joint filling
- Presence of air bubbles, etc.
- Adhesion on the frame
- Adhesion on the glass
- Uniform vulcanization (Shore A hardness)
- Other observations

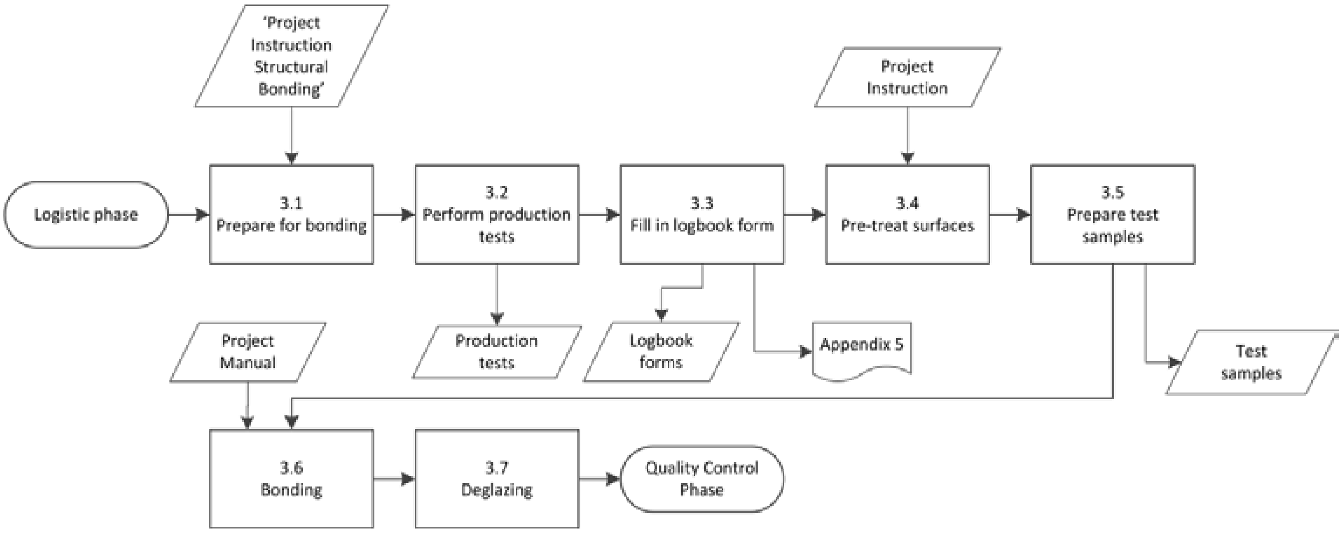


Figure 4.3.4 - Process flow production. (Scheldebouw, 2013)

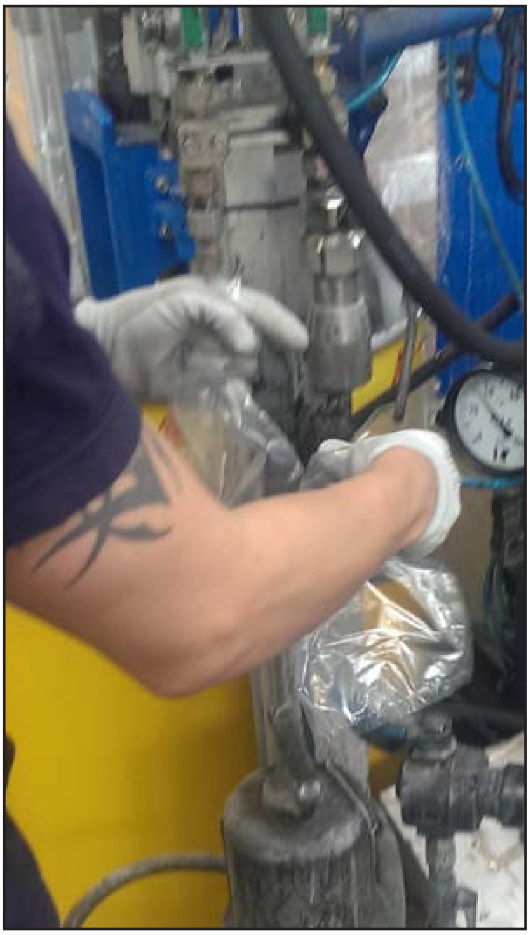
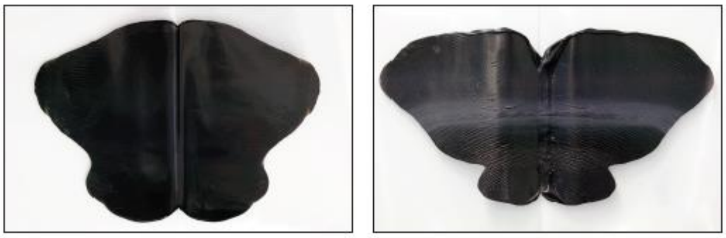


Figure 4.3.5
Taking mixing ratio sample from mixer. (Own ill.)



uniform black the mix **is good** **white streaks** the mix is **NOT good**.

Figure 4.3.6 - Butterfly test. (Scheldebouw, 2013)

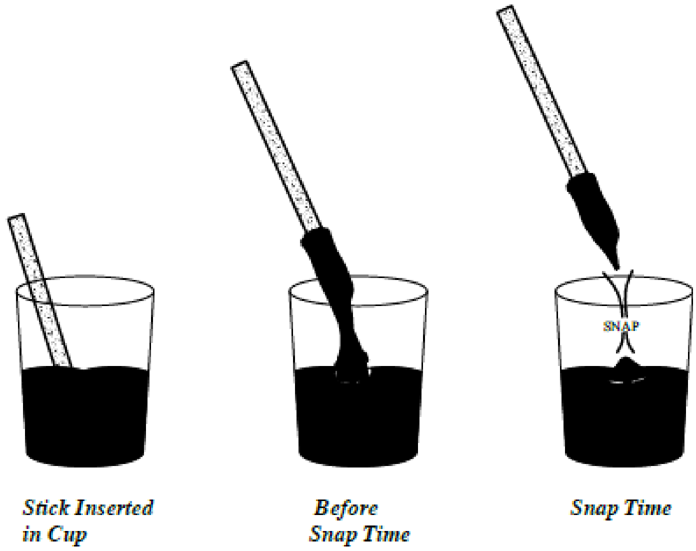


Figure 4.3.7 - Snap time test. (Scheldebouw, 2013)

Fourth phase is **quality control.** Input are the logbook forms, production tests and test samples. The Quality Control phase of the process is the phase in in which the Quality Checks are performed. It is therefore important that the panels remain until the tests are done and conclusions can be made.

The Quality Inspector checks if production test are correctly interpreted and if the results comply with the Sika requirements. In addition the Quality Inspector checks if logbook forms are correctly completed with the correct information.

In figure 4.3.9 you can see the timescale for the execution of the tests. The Quality Inspector is responsible for a timely execution of the required tests. I have also performed these tests myself during my time in Heerlen. The results are documented on the logbook sheet. In case any deviation is found, all the panels in that batch will be immediately separated till additional test has proven that the bonding is correct.

After this the quality manager is responsible for the storage of the H samples and logbook results. This needs to be stored for at least the warranty period of 12 years.

During the production phase Sika will have access to audit the Scheldebouw production and quality control. The number of audits necessary has to be agreed upon between Scheldebouw and Sika and will be in function of the project size. For each visit the Sika representative will make an official audit report.

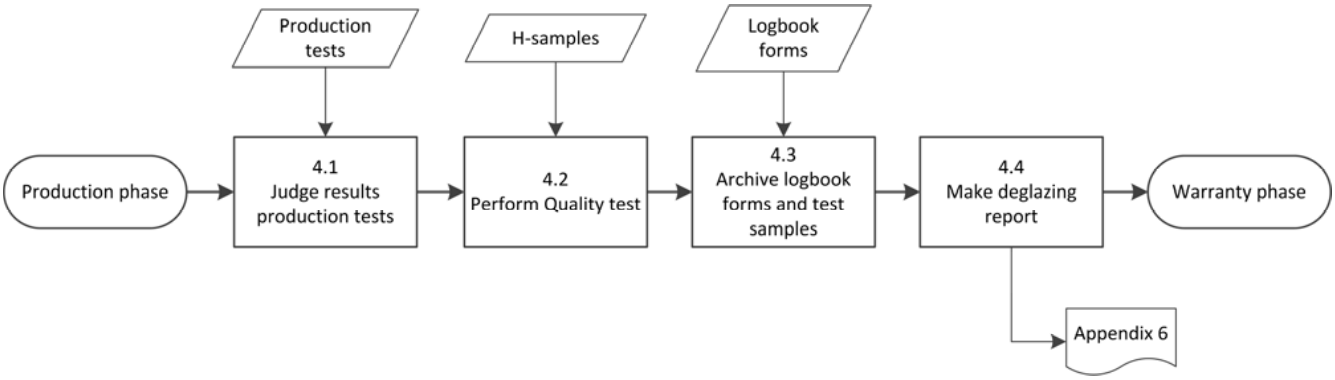


Figure 4.3.8 - Process flow quality control. (Scheldebouw, 2013)

QC-test:	Sample:	Timescale:	Criteria:
Tensile adhesion test	H-sample	48 hours	≥ 0,7 MPa and 100% cohesive failure
Hardness test	Peel sample	24 hours	≥ 30 Shore A
1st Peel test	Peel sample	24 hours	100% cohesive failure
2nd Peel test	Peel sample	7 days in water	100% cohesive failure

Figure 4.3.9 - Timescale for execution of tests. (Scheldebouw, 2013)

Figure 4.3.10 - Execution of H-sample test. (Own ill.)

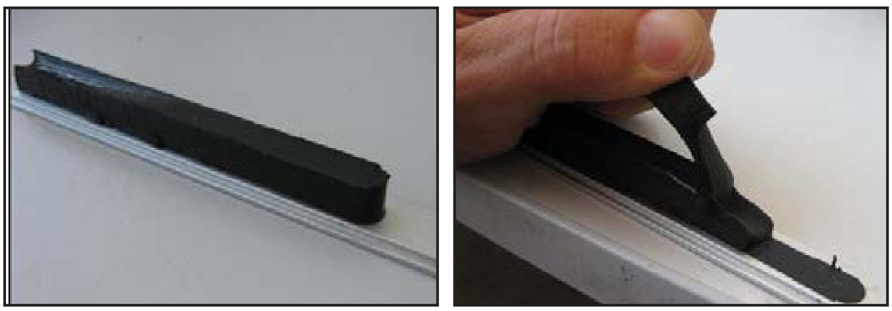


Figure 4.3.11 - Peel sample test. (Scheldebouw, 2013)

Fifth phase is **installation**. Input for this phase are unique numbered panels and the project instruction for structural bonding.

In this phase it is important to register the unique numbers of the panels on their actual position on site, to continue traceability to the final position.

Structural bonding on site is also included in the procedure. If a re-glazing is needed, there is a step by step instruction, accompanied by conditions that need to be met to be allowed to do a re-glazing. More on this is in paragraph 4.5.2.

The sixth and last phase is **warranty**. Input for this are the Scheldebouw file with all drawings and documents, Sika approvals and advices, logbook forms and deglazing and audit reports.

This phase is all about the collection of documents, the send of these documents to Sika, to obtain warranty.

Also an operations and maintenance manual is prepared and handed over to the client. The requirements and recommendations from Sika concerning cleaning and visual inspection of a structural bonded façade are incorporated into this manual.

Finally, there is a handover of the complete Structural bonding file to Service & Maintenance.

This file contains:
- Drawings
- Calculations
- Sika forms
- Warranty statement

The real procedure is more extensive, with in detail descriptions of who is responsible for each step and how these steps should be executed. The description in this chapter is to get a general overview and idea of the content of the procedure. The procedure has been studied and detail and following remarks and conclusions came forth from this:

Remarks

As said in the previous paragraph, the contractual demands, are demands partly provided by the client. For the other part they are demanded by the supplier of the sealant.

This procedure is a product of the stated norms, guidelines, contractual regulations and standards. Therefore, it is not possible to change this procedure in its principles, without changing the parts of its product.

Minor improvements might be possible but these will be mainly in the practical approach of steps in the procedure. These will be further elaborated in chapter 5.

For the sake of traceability, all anodised or powder coated profiles suitable for structural bonding should be packed per batch. These batch numbers need to be traced to the final element wherein this profile is installed. In this way, in case of a problem with a profile from this batch, all elements that contain profiles from this batch can be checked.

Yet, the question is if this is wished for. In this way in case of a problem you will obligate yourself to check all other elements containing this batch, while the defect is more probably by human error. This will be further discussed in chapter 5.4.

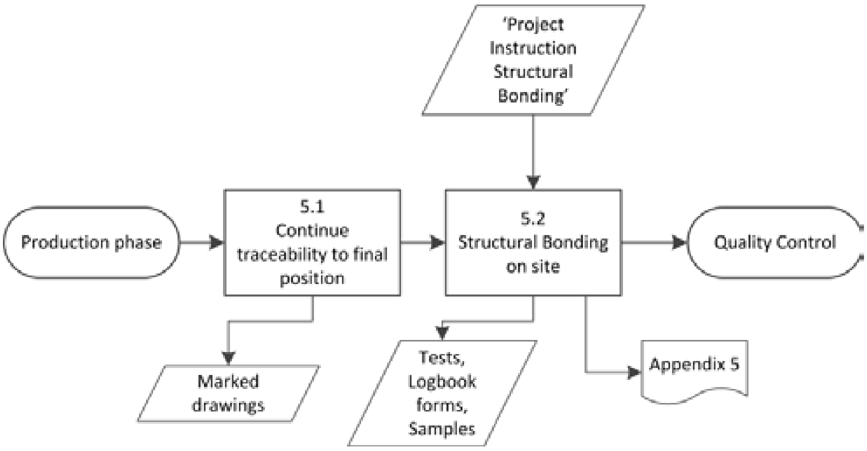


Figure 4.3.12 - Process flow installation. (Scheldebouw, 2013)

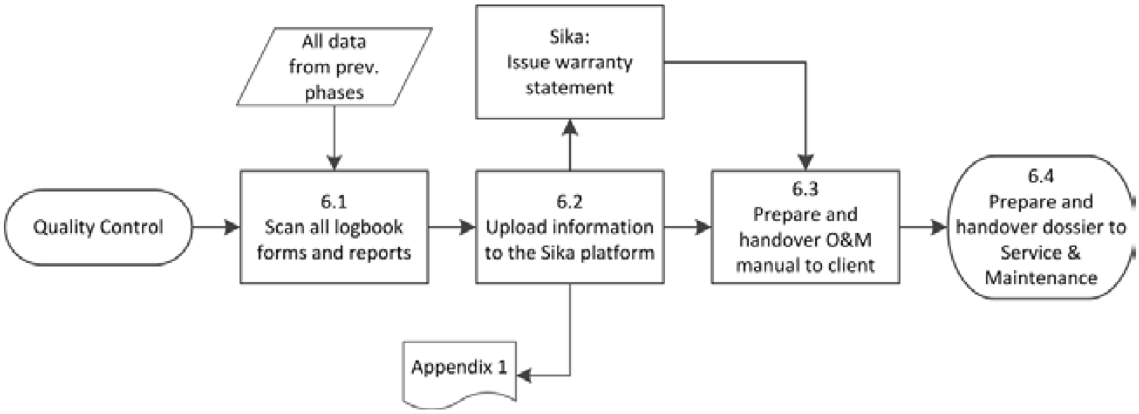


Figure 4.3.13 - Process flow quality warranty. (Scheldebouw, 2013)

4.3.4 **A day in production**

To achieve knowledge of the current process and gain experience for my own with the process I joined for several days in the production and quality management. After studying and discussing the process and reading the procedure it was important to see and experience the different steps in production for my own.

This paragraph will be a description of work and findings of the days in production.

I spend one week at Scheldebouw Heerlen and got a desk at the quality department. On this desk I could work and arrange meetings, but also discuss with René Koster and Ruud Bongers, which are both quality managers. They have a very critical point of view, which makes them interesting to discuss with.

In this week I joined a structural glazing production line for two days for two different projects, namely Stadskantoor Rotterdam and One Tower Bridge in London. In this special attention has been on the procedure and the different steps like the test samples that have to be made during production.

On the quality department I did also perform tests on these samples to experience this.

In figure 4.3.14 you can see various pictures taken during these days. First picture is of the mixer that is combining the two parts sealant components: component A (base compound) and component B (catalyst paste). The correct functioning of this machine is very important. If the mixture is not correct or there is air included, this will make for a sealant that does not meet the requirements. Therefore this machine is regulary checked with production tests.

Another property of this machine is that it can only be idle for around six minutes. After this time an alarm sounds and the applier must open the nozzle and let the sealant flow throught the machine and tubing, into the trash bin. This is to prevent clogging in the machine. When the production line is not working optimally, or appliance of the sealant on the element requires a lot of preparation, quite some sealant is wasted.

On the bottom left picture you see finished elements, which are vertically stored, prior to transport to the location. These specific elements are for stadskantoor Rotterdam.

Top right picture is the preparation of H-samples for testing by the quality inspector. In this case this is not done according to the procedure. You can see all 4 samples, two for the morning and two for the afternoon are prepared on the same moment.

In the last two pictures you can see the appliance of the sealant. In this pictures the sealant is not yet tooled. This will be done with a spatula, While removing the excess silicone, simultaneously the excess silicone is lightly pressed into the joint as much as possible. This ensures excellent contact of the silicone with the adhesive surfaces.

While performing tests on the quality department, I encountered several samples that failed the tests. Examples of these are shown in figure 4.3.15. When a failure is encountered, the quality inspector has to decide for next steps. In this case this was the analysis of the sample to determine the cause of failure. For both samples this was an incorrect way of preparation of the sample. This causes an amount of system elements without a positive tested sample. Though, by visual inspection of the sample on other particularities they can still decide to continue the process without further intervention.

After these days, the following remarks have been made, which can be found on the next page.

Figure 4.3.14 - A day in production: [1] Mixer, [2] finished elements, [3] preparation of H-samples, [4] application of sealant and [4] applicated sealant before tooling. (Own ill.)

Remarks:

Despite of the procedure, there will always be moments where common sense and experience from the quality managers is needed to make decisions for quality and safety.

One of the reasons for this is test irregularity. While every step is described in the procedure, it is possible that the preparation of a test sample is not done in the correct way. Examples of this are in figure 4.3.15. Picture 3 and 4 show examples of test samples that failed the test. This is not because of an incorrect consistence and mixture of the sealant, but because of incorrect preparation. For figure 3 there was an air inclusion. This was not a result of the mixer, but because of an incorrect application.

In this cases, the test itself will not prove quality, but the evaluation of the test and sample by the quality controller will.

After these days in quality control it becomes clear that the safety and quality does not primarily come from this procedure.

It is the people in production who are the most important factor in the process. The people in quality control and the foreman in production are there to make sure all steps are conducted according to the procedure, but also when they are not there workers need to take their responsibility.

The quality and safety is enlarged by raising awareness of the employees, of the importance of the different steps in process. By obliging them to perform the named tests they will stay focussed on the quality of the sealant, surface and the final bond.

Yet, there can always be human error and/or conscious choices in doing and preparing tests and following the checklist.

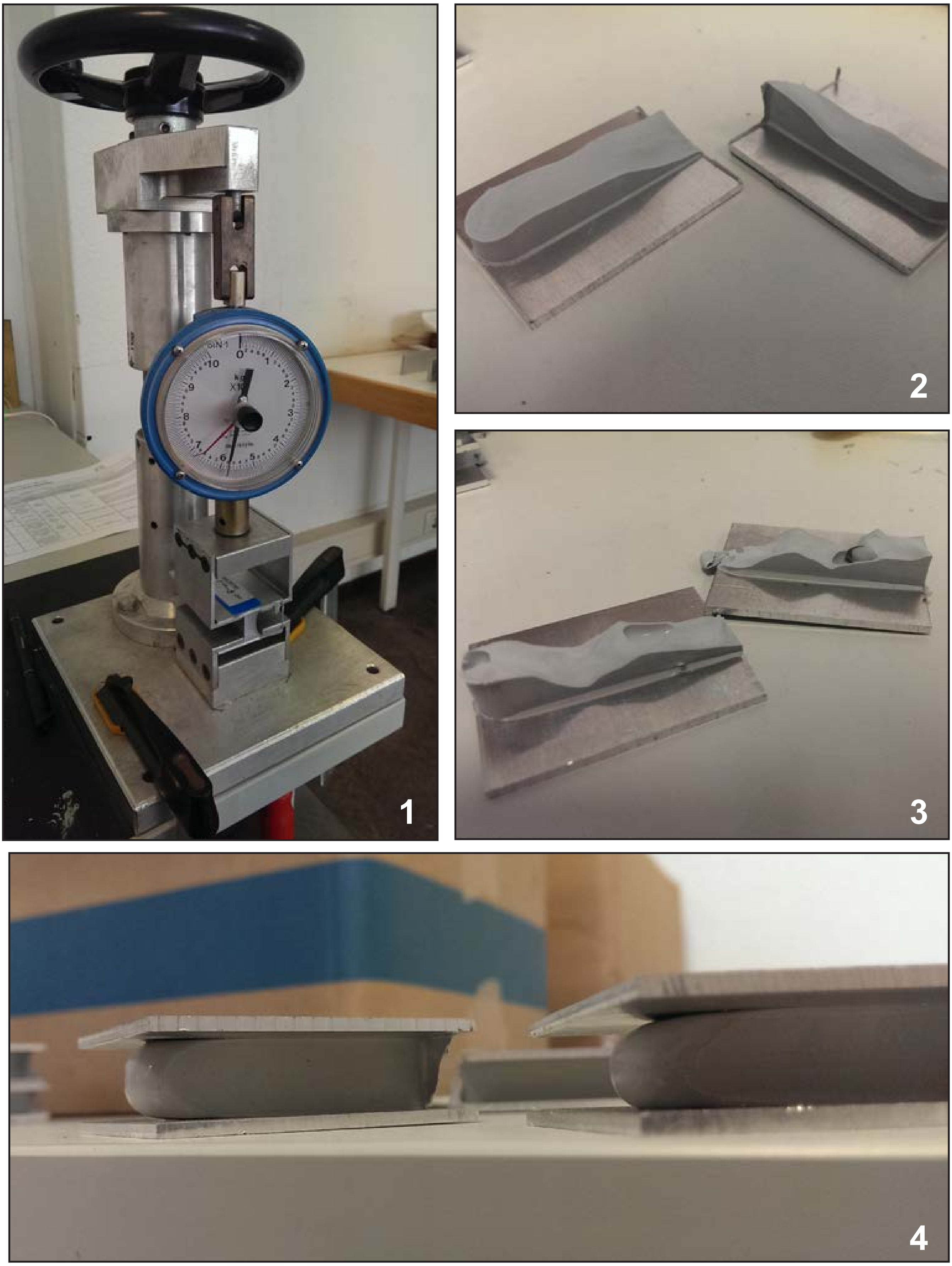


Figure 4.3.15 - A day in production: [1] test device, [2] succesfull test, [3] failed test because of air inclusion, [4] not usefull test because of incorrect preparation (Own ill.)

4.3.5 **Process steps comparison**

A comparison of the process steps in the automotive industry and at Scheldebouw/Sika is made to find differences in these processes. This might result in usable input for a new process approach for Scheldebouw.

Automotive

- Selection of application specific sealant
- Establish requirements and test
- Test results meet the requirements
- Get an approval from the RDW. This is the approval for this kind of sealant for this specific task.
- Appliance of the sealant according to workplace instructions.
- A specified amount of windshields is checked on waterproofing.

Scheldebouw

- Select an ETAG approved sealant
- Establish project specific requirements. These are tested at Sika.
- Get an approval from Sika. This is the approval for this kind of sealant for this specific design.
- Appliance of the sealant according to workplace instructions.
- Samples and tests are prepared to assure a good bonding.

Description of the differences in automotive industry and Scheldebouw:

- Application specific vs. project specific
- Automotive doesn't have warranty by the supplier of sealant, but has trust in the product by testing.
- Less risk involved in the automotive industry
- Shorter period of warranty in the automotive industry
- Less risk because of the use of single component sealant. Therefore less tests are needed.

Conclusion:

Lessons that can be learned from the automotive industry are the application specific testing and approval in stead of the project specific testing. This can be explained by the use of different materials per project in the facade projects. Maybe this could be unitized.

The automotive industry shows more trust in the selected sealant, based on tests. Though, there is also less risk and money involved if one fails. Other reasons for this are the shorter period of warranty and the use of a single component, which is a consistent product.

4.3.6 **Output**

Remarks of this paragraph are used and further discussed in chapter 5 to come to a new approach in process.

Some general output from the paragraphs combined:

- The total procedure is a product of the guidelines and contractual relation with Sika. This makes the procedure applicable for this specific situation, but for significiant improvement in process this will need to change.

- Test are mainly there for the documented evidence of a correct mixture of the 2 component silicone sealant. This is a risk factor that is critical to the final product. Therefore, tests must be prepared and executed, expensive mixers are purchased and sealant is wasted in idle time to prevent clogging.

  These could all be reasons not to use a two component silicone sealant, if there is another option available that meets the requirements.

- Tracing

- Replacement according to ETAG

4.4 Stakeholders analysis

4.4.1 Goal

This chapter will provide an understanding of the stakeholders, involved with structural glazing. Construction management is a complex world where all stakeholders have different interests. For example: architect and the insurance company have completely different interests. By having a complete overview of all stakeholders and their interests it is possible to evaluate a change in the design or process for all stakeholders.

By this, an overview can be made on what interest every stakeholder has in this process. A redesign can be evaluated to this overview of stakeholders. This could result in a design that is more expensive to produce, but also has more value in other ways, which will make it a feasible design.

4.4.2 Stakeholders

The definition of stakeholder can be stated as: an entity that can be affected by the results of that in which they are said to be stakeholders, i.e. that in which they have a stake.

For stakeholders there are contractual relations and non-contractural relations. An example of a contractural releation model is shown in figure 4.4.1. This is a traditional model. In practice there are a lot of variants on this. This is also the case for Scheldebouw. Scheldebouw often takes on multiple functions in the process. They can have an advising role, as well as the role of subcontractor. For Scheldebouw the client often consists out of multiple stakeholders, which they are all in contact with.

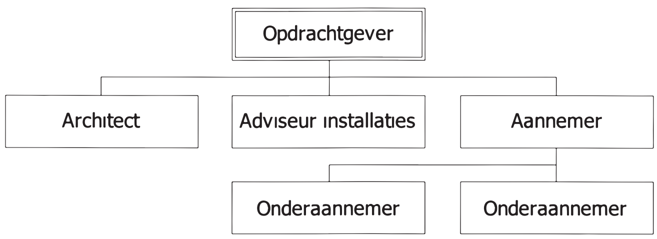


Figure 4.4.1 - Process overview. (Wamelink, 2009)

The client for Scheldebouw can consist out of the architect, funder, other advisors, future users, but also government agencies which they are all in contact with. By this they can decrease the risk there will be any misunderstandings by lack of communication between these stakeholders.

In the cladding industry there are multiple professions, that all have to work and communicate with each other. These are all important stakeholders for Scheldebouw.
An overview of stakeholders in the cladding industry is given in figure 4.4.2. These are all stakeholders which are involved in the design and building process of a cladding. There are also stakeholders that are not directly involved in this process, but have influences from an external point. These will be discussed later on.

Stakeholders which are directly involved in the design and building process all have their own goals and interests in this process. These will be discussed. Stakeholders which are directly involved in this process are:

The architect, cladding company, consultant, supplier of building materials and main contractor.

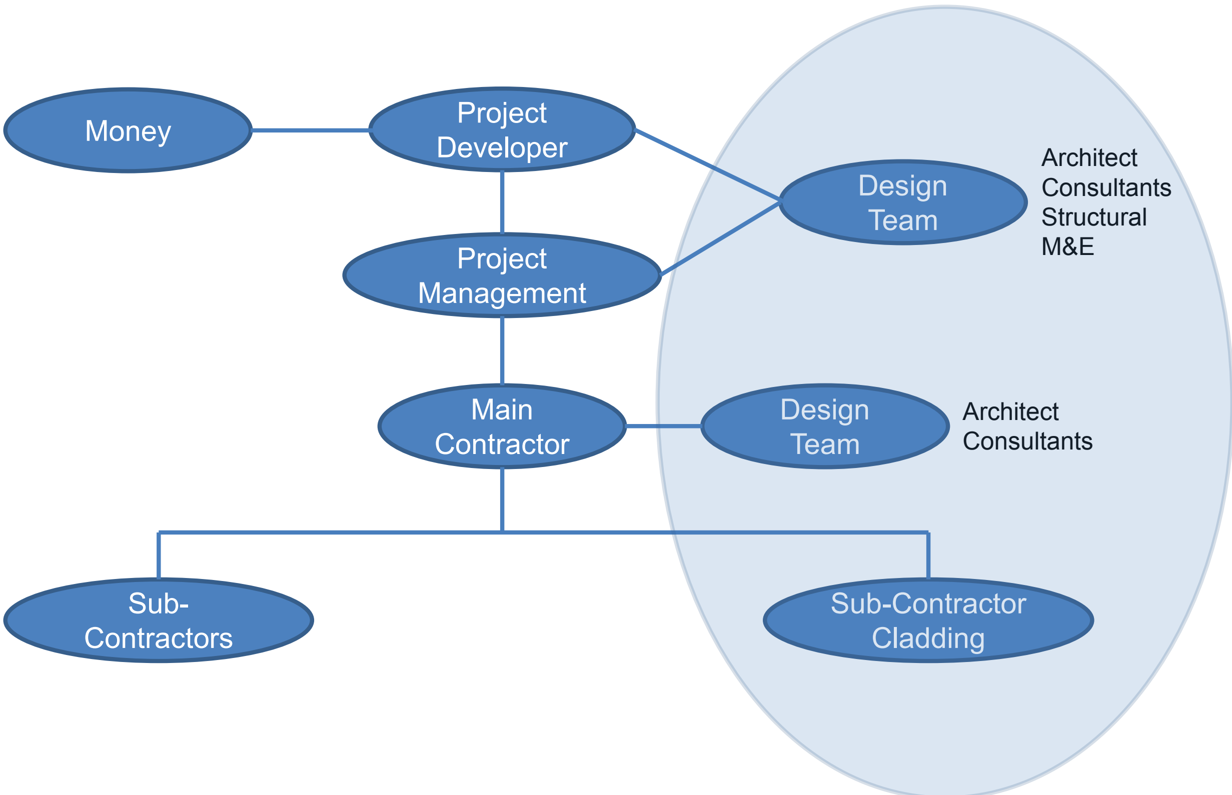


Figure 4.4.2 - Project structure. (Kock, 2014)

Intern at Scheldebouw, which is referred to as the *Cladding Company/ Supplier/ Manufacturer,* more distinction can be made in the functions. Figure 4.4.3 gives an overview of the different functions in Scheldebouw. Functions are:

Project manager, cost controller, project quality manager, project planner, project production manager, project site manager and project design manager.

Project design manager leads the project design team which consists out of:

Test engineer, structural engineer, building physics engineer, system design, detail design and production design.

These different functions also have their own specific points of interest and concern in the process. For a complete and in depth overview a distinction will be made in these different functions inside the stakeholder *'Cladding company'*.

There are also stakeholders which are indirectly involved in the cladding industry, but have important influences. These stakeholders are:

The user, insurance company, municipality, other governments.

All of the named stakeholders are collected and visually represented in an overview on the next pages. This overview shows the presence and activity of all the stakeholders in time. In the next paragraph these stakeholders will be individually discussed and their interests will be described. Costs and benefits which apply to the stakeholder will be discussed.

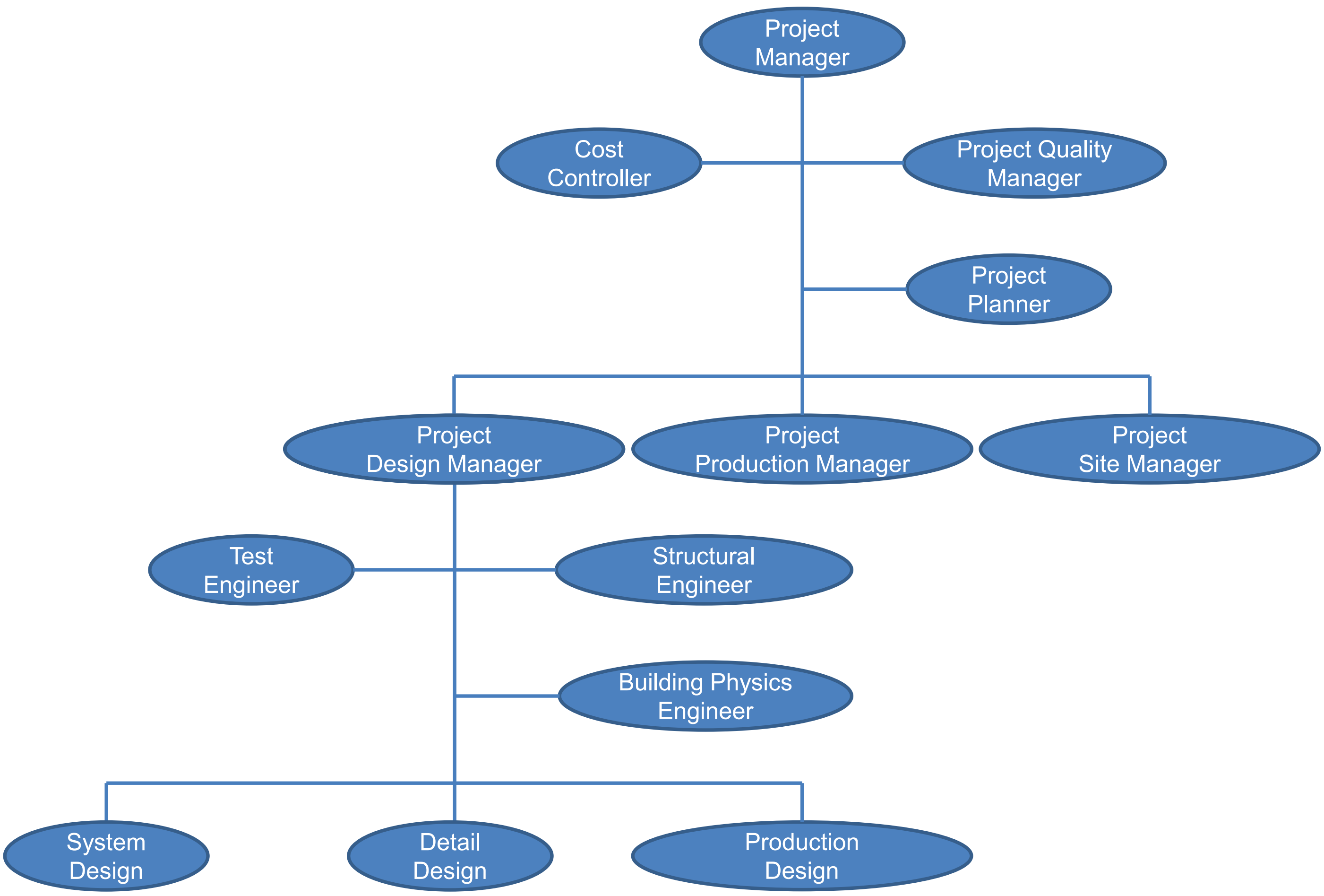


Figure 4.4.3 - Project structure intern at Scheldebouw. (Kock, 2014)


Stakeholders
Initiate
Prepare
Project definition
Tender phase
Engineering / design
Cladding industry
The architect
Cladding company
Consultant
Supplier of building materials
SIKA (supplier of sealants)
Main contractor
Scheldebouw
Project manager
Quality manager
Production manager
Design manager
Logistic manager
Service and maintenance
Indirectly
Funder
The user
Insurance company
Municipality
Other governments

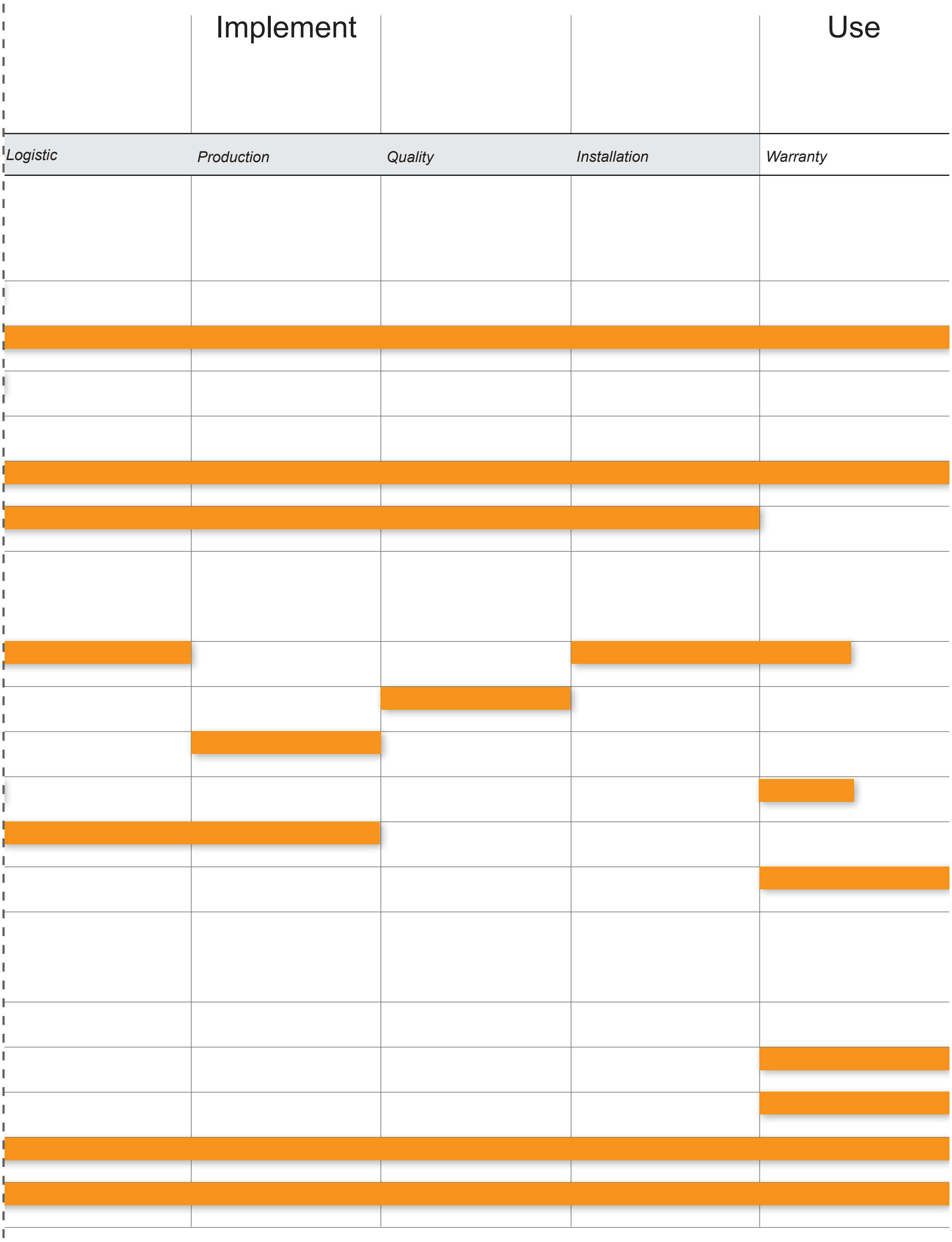


Figure 4.4.4 - Stakeholder overview. (Own ill.)

4.4.3 **Interests**

Directly involved stakeholders:

Architect

A good collaboration with the architect, or an architect that already has enough knowledge of cladding will result in a more integral design. The right cladding design immediately results in better internal climate where less cooling/heating is needed.

Important considerations for the architect are his interests:

Interests

- *Aesthetics*
- *Thickness of the cladding package*
- *Thermal insulation*
- *Acoustic properties*

Cladding Company/ Supplier/ Manufacturer

SCHELDEBOUW

In this specific case, Scheldebouw covers these functions. For this they need knowledge on building physics like thermal, structural and acoustics. Also material knowledge is needed. Overall, knowledge of standards is needed in relation to: the use of a building, calculation methods, material specification, safety and quality certification.

Moreover, knowledge is needed in manufacturing, process, logistics, but also about the interfacing trades, like construction.

Other aspects that they are in contact with are installation knowledge, safety aspects in this and methods of installation.

Quality assurance and quality control are also important aspects in a company with big projects like Scheldebouw.

Special departments in Scheldebouw are R&D and maintenance, which are not directly in contact with everyday projects, but serve as a preparation on projects and after-care. Though, maintenance is an important aspect that should already be incorporated in the design.

Main aspect for Scheldebouw is compliance with the agreements they make. These are agreements with the client, but also with suppliers.

Interests

- *Compliance*
- *Production process*
- *Cost*

- *Intensity of procedures*
- *Quality assurance*
- *Warranty*

Consultant

Often this is a general cladding consultant for the architect, main contractor or both. Scheldebouw can also cover this function, but there can also be an external consultant.

These can be specialized consultants in subjects like materials, thermal properties, acoustics and sustainability. Also they can focus on building regulations and other authorities that need to be taken into account for approval.

Consultants can also be involved in testing or organise independent testing.

Also there can be contact with R&D if there is the need for a new development in building material.

Interests

- *Clear specifications*
- *Trust in the used technology*

Supplier of building materials

The connection with suppliers of building materials can be very basic, by just ordering what the builder needs, but in case of very specific projects the technical department of these suppliers are often consulted. For specific designs, specific properties are needed and they need to be adapted between supplier and consumer.

Also there can be contact with R&D if there is the need for a new development in building material.

The documentation shall make it clear that the incoming material corresponds to that listed in the ETA.

If incoming material or components are manufactured and tested by the supplier in accordance with agreed methods, further testing by the SSG kit manufacturer usually is not necessary. If the supplier does not conduct such tests, the kit manufacturer shall conduct appropriate checks/tests before acceptance.

Interests

- *Clear specifications*
- *Communication*

Sika (Supplier of sealants)

As a supplier of sealants, Sika has an umbrella contract with the Permasteelisa group. She is also a supplier of building materials, but one with a special relationship with Scheldebouw. Together with Sika, Scheldebouw has made a procedure to be able to obtain warranty from Sika on the bond. Without this, Scheldebouw would take more risk in a structural bonding project.

Compliance

Interests

- *Purchases by Scheldebouw*
- *Correct procedures*

Main Contractor

A main contractor is a contractor who oversees all aspects of the project from designing, planning, project managing and cost control. He/she is also responsible for providing labour, materials, equipment and services that are necessary for the project. Often Scheldebouw is the main contractor in relation to the facade, but they are dependent on the contractor for structural work.

Interests

- *Planning*
- *Flexibility*
- *Installation*

Intern at Scheldebouw:

Project manager

Interests

- Communication throughout the project team

Design manager

Project design manager leads the project design team which consists out of:

Test engineer, structural engineer, building physics engineer, system design, detail design and production design.

Interests

- Reliability
- Performance
- Producability

Quality manager

Interests

- Controllable process, with or without the use of procedures
- Reduction of risks

Production manager

Interests

- Manufacturability
- Proper detailing (e.g. space for application device)

Logistic manager

Interests

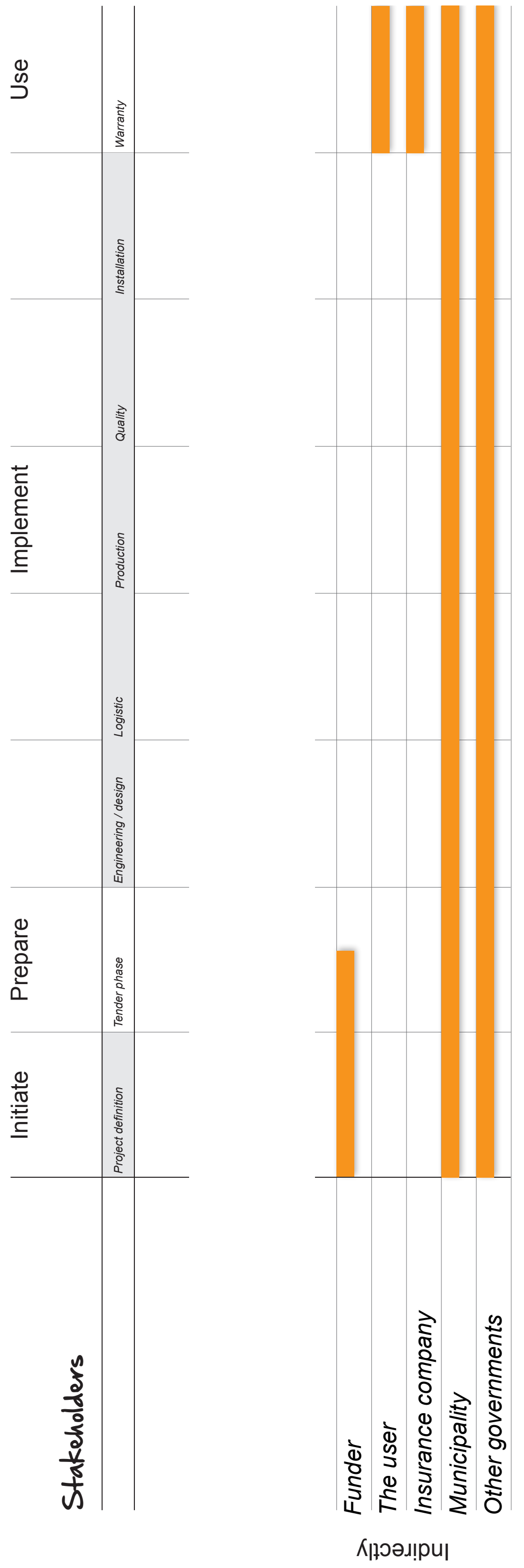
- Clear material specifications
- Traceability

Service and maintenance

Interests

- Clear instructions for replacement
- Easy maintenance (accessibility)

Indirectly involved stakeholders:



Funder

The funder is an individual or organization financing a part or all of a project's cost, mostly as an investment. Their interests and the risk on the total project. Expectations for their investment have to be fulfilled.

Compliance

Interests

- *Costs*
- *Low risk*

The user

The user is a special stakeholder, which is the only one that is in contact with the building and its cladding in everyday use of the building.

In the end the user will be the one that benefits most from a high end facade, but also has to cope with the flaws. Other stakeholders will have a financial loss because of a flaw, but the user is the one with the practical disadvantage.

Interests

- *Comfort (acoustic/thermal/visual)*
- *Timely replacement of damaged elements*

Insurance company

Has to have confidence in the used systems to be able to insure them

Compliance

Interests

- *Proof of functioning*
- *Trust in the used technology*

Governments

Governments use building regulations and guidelines to influence the building market.

Compliance

Interests

- *Safety of the society*
- *Trust in the used technology*

4.4.4 **Output**

For each stakeholder discussed and described what are their interests.

For a new concept it is important to evaluate this to all stakeholders. A design could not be feasible if it benefits all stakeholders, except for one. In some cases this could be corrected by financial compensation but this should not be necessary.

Research for this paragraph gave an overall view and understandment of all different stakeholders. In this way, a new concept can be evaluated from all angles.

This results will be used for later evaluation of the proposal.

4.5 Design analysis

4.5.1 Goal

Goal of this paragraph is to do research on the current detail that is often used in structural glazing. Results should be to know the strengths, weaknesses, opportunities and threats for this detail. By this it should be possible to improve on this detail, based on this knowledge and the knowledge collected by the preliminary research, interviews, stakeholder analysis and process analysis.

4.5.2 Detail description

The detail is visualised with technical drawings on the next pages. In figure 4.5.1 you can see the typical location for the given details. In this, type A is a transparent part, where type B is a closed part. Both have a glass pane, but for type B a non-transparent element is added on the back.

The system is a half-frame system, where two elements connected to each other visually form one mullion. In other words: the outer mullion on each system element is a half mullion, which when joined form a whole.

This way of installation asks for flexible tolerances and measures to accommodate movement. This is achieved by using rubbers and overlapping parts.

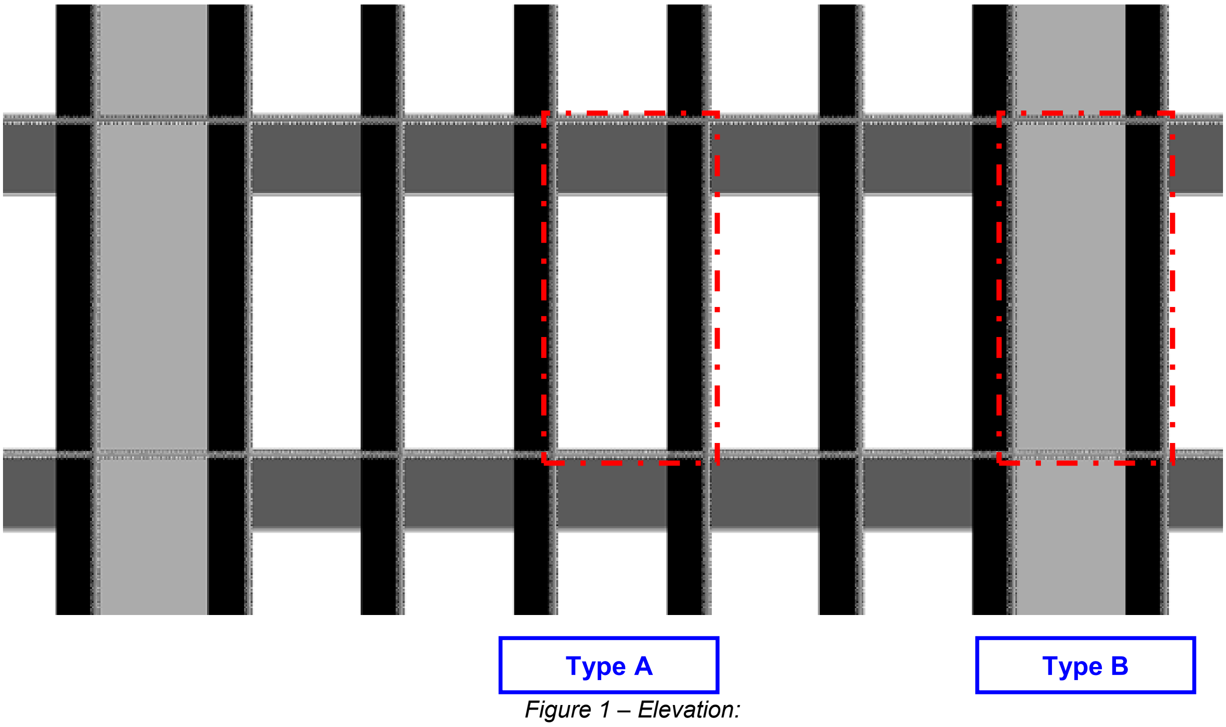


Figure 4.5.1 - Elevation. (Scheldebouw, 2013)

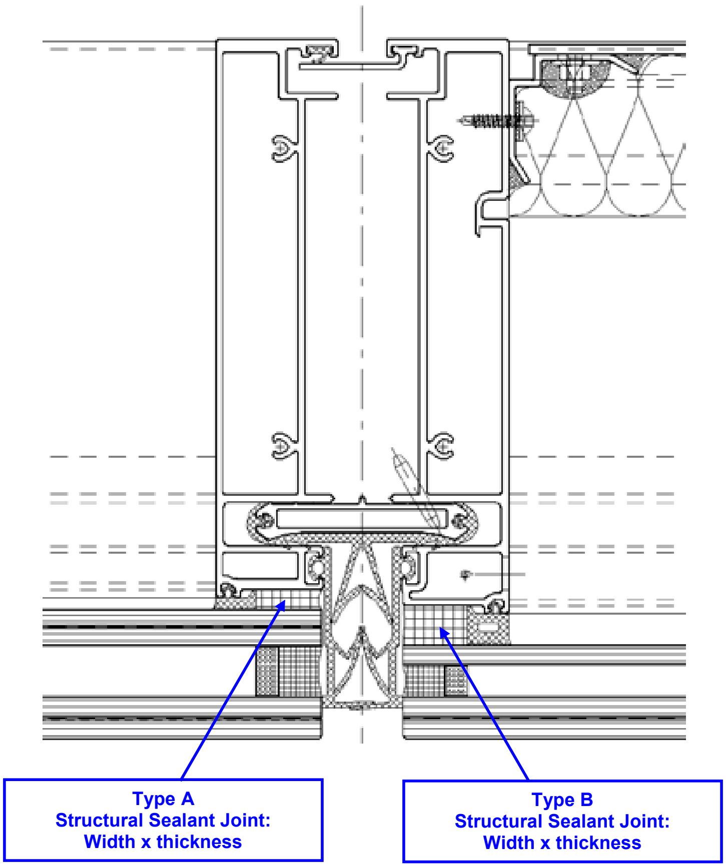


Figure 4.5.2 - Type A Mullion. (Scheldebouw, 2013)

In figure 4.5.3 you can see the horizontal section of a mullion with type A on the left and type B on the right. In this, type A is a transparent part, where type B is a closed part. Both have a glass pane, but for type B a non-transparent element is added on the back. In this figure, the location of the applied sealant is shown. Sikasil SG-500 is the two component structural sealant. Sikasil IG-25 HM Plus is a sealant with high modulus for air and gas filled insulating glass panes. This IG-25 HM Plus sealant can also be from another type, depending on the glass manufacturer.

The dimensioning of the structural sealant joint is dependent on three or four different factors:

- The dynamic load (wind load)
- The differential movement
- The allowable shear strain of the sealant
- The static load in case of no dead weight support

The dynamic load and/or static load determine the width of the joint, also named the ‘bite‘.
The differential movement, together with the allowable shear strain of the sealant, determines the thickness of the joint.

The rubbers next to the structural sealant, between the glass pane and the frame, are there to facilitate and limit the amount of structural sealant. In production, the aluminium frame is placed horizontally, with these rubbers already installed. After this the glass plane is placed on top and the space between the glass pane and frame is filled with structural sealant.

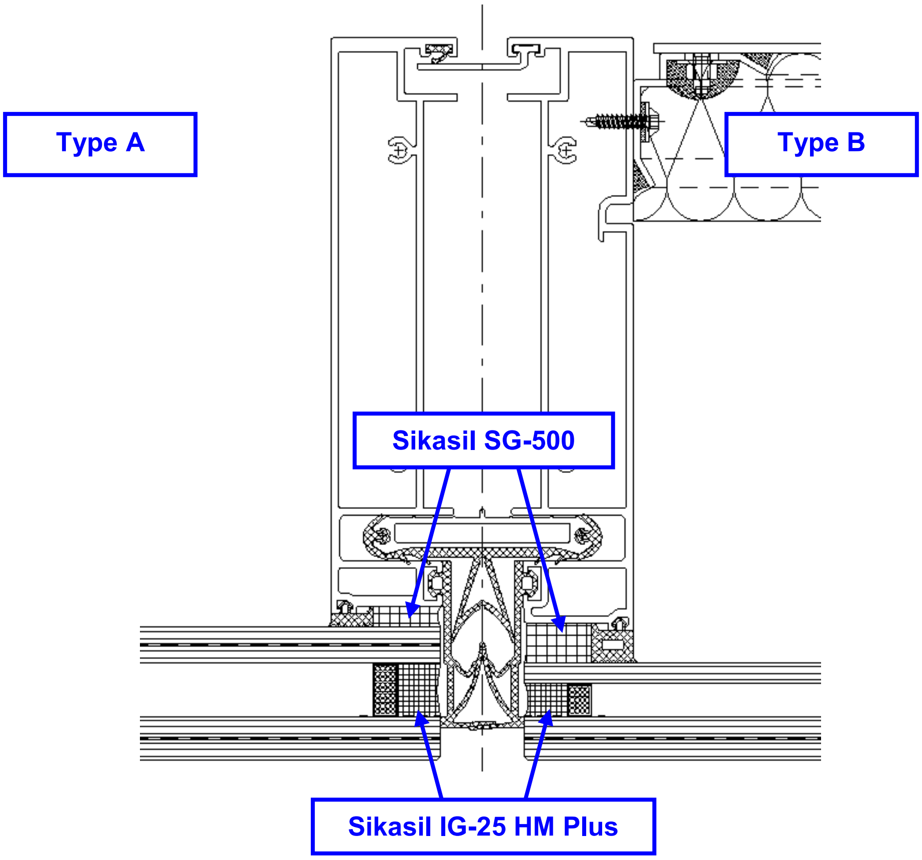


Figure 4.5.3 - Mullion at connection Type A - Type B. (Scheldebouw, 2013)

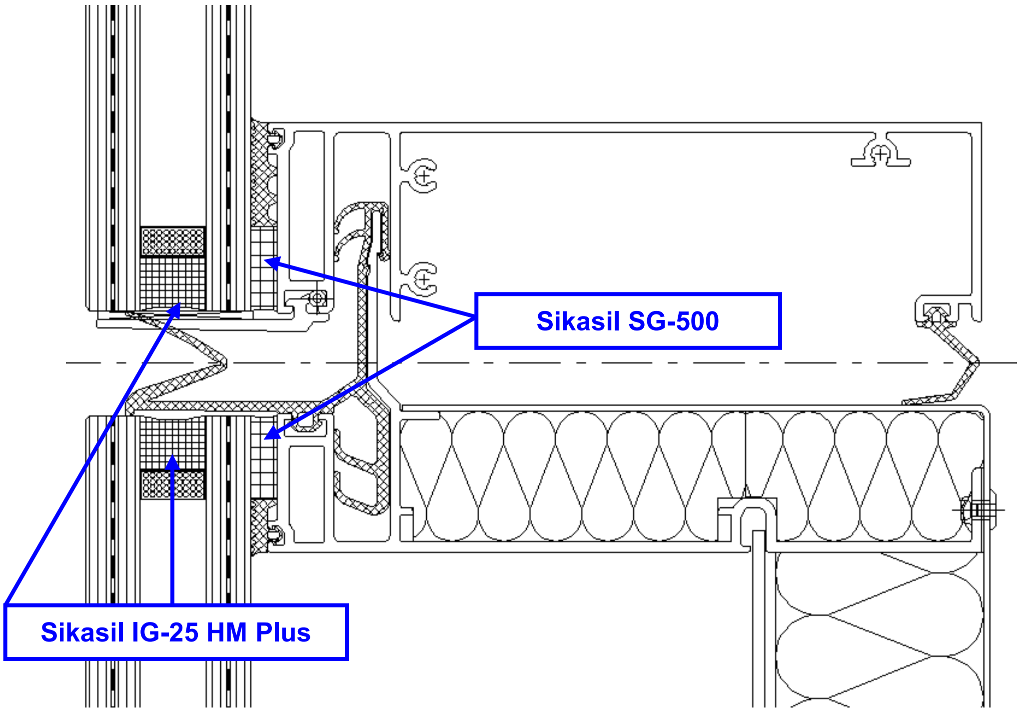


Figure 4.5.4 - Type A Mullion transom (vertical). (Scheldebouw, 2013)

In production, special instructions are given for pretreatment of the frame and glass. These instructions are also shown in the figures 4.5.5 and 4.5.6, which are also present in the Scheldebouw procedure.

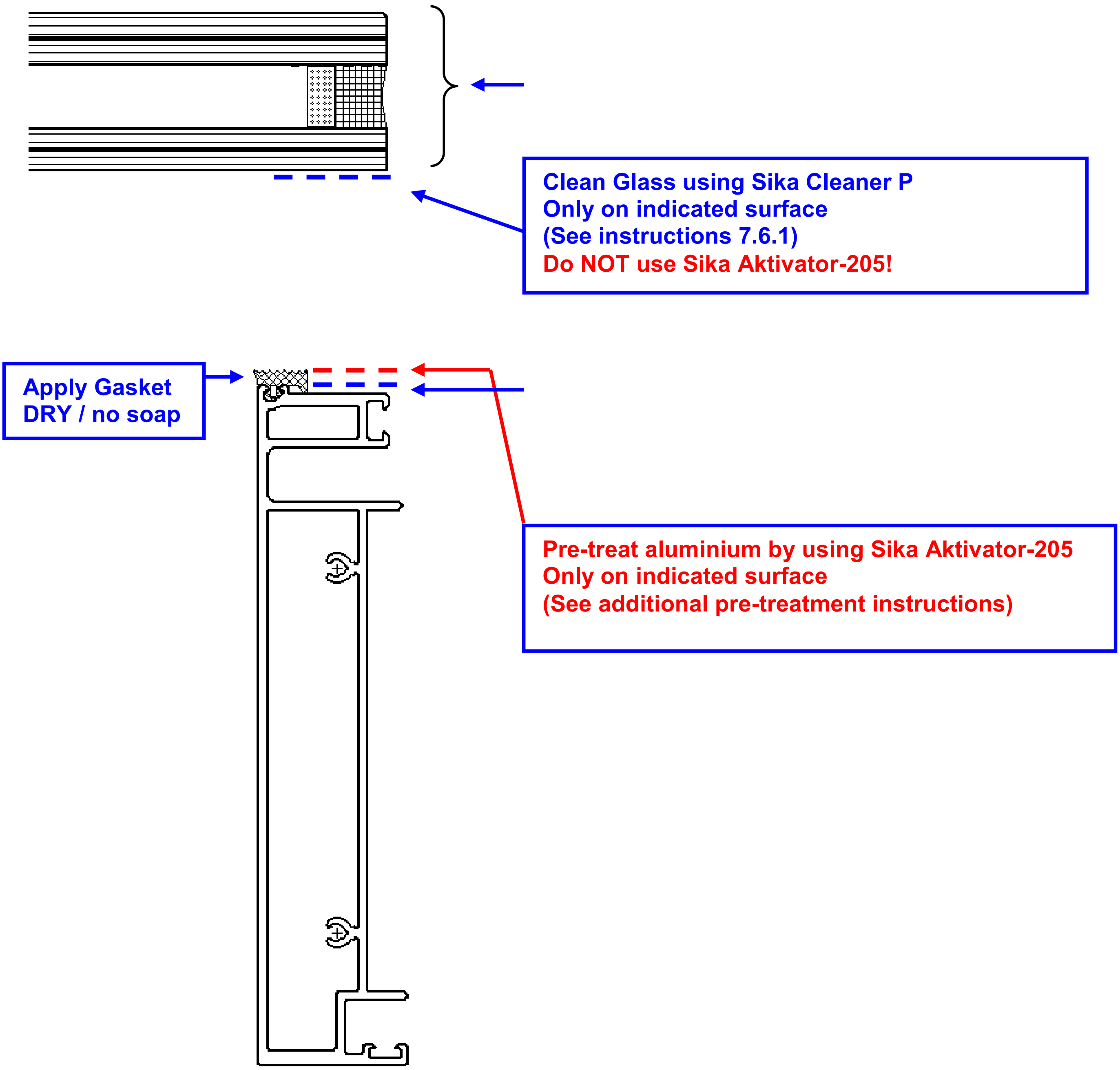


Figure 4.5.5 - Type A Mullion. (Scheldebouw, 2013)

Figure 4.5.6 shows again where the structural sealant is applied. When this sealant has cured for more than 24 hours the gasket can be applied and the element is finished.

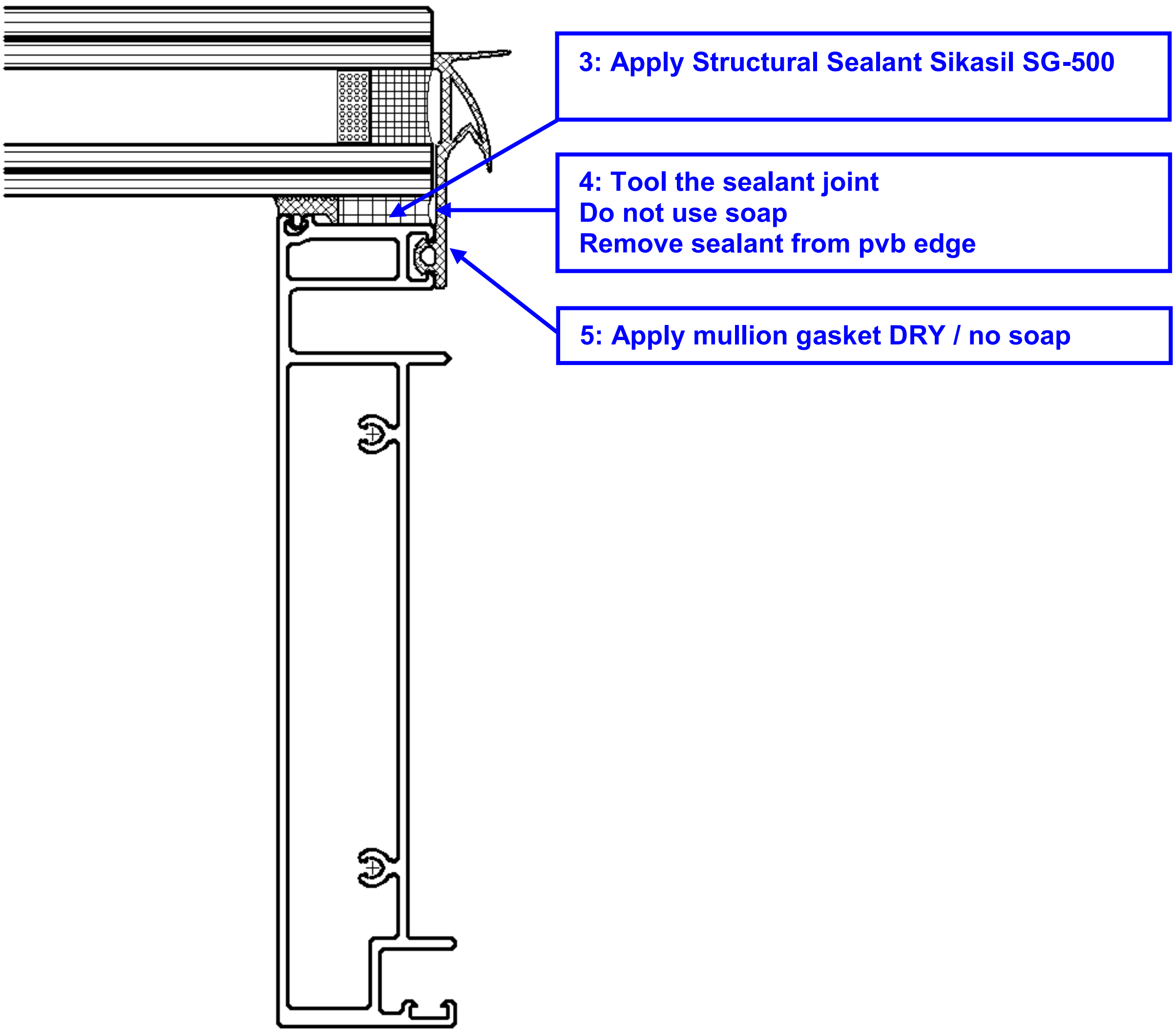


Figure 4.5.6 - Type A Mullion with rubber. (Scheldebouw, 2013)

4.5.3 **Replacement**

There are two methods for exchange of broken structural bonded glass panes on site:

1. Factory-glazed replacement frame (quaternario system)
2. Structural bonding on site.

For both ways, first the damaged glass pane needs to be removed. the glass needs to be cut out, if possible from the inside. This happens with a special ‘saw‘ which is a metal wire. This wire is inserted between the glass pane and the frame and used as a saw to completely cut the structural joint.

After this the glass needs to be disposed and the structural joint needs to be removed completely.

When this is done, the structural bonding on site can begin, by (again) following the procedure. This procedure describes this as a very critical process. In the procedure, also the steps for a re-glazing are described. It containts the same pre-treatment, tests and documentation as in the factory production. For an onsite re-glazing, the following weather conditions are needed:

- Structural Bonding on a rainy day is not allowed.
- Structural Bonding with morning dew is not allowed.
- Structural Bonding only at a dry surface.
- Minimum surface temperature of + 5 degrees.
- Substrate humidity Dry.
- Optimum gunning temperatures are between +15 and +30 degrees.
- Relative humidity of 40% to 95%.

Replacement with a factory glazed replacement frame is easier and does not ask for an on-site procedure. Also there are less problems with weather conditions, except for wind.

Note, the ETAG states:

Due to the difficulty of quality control during on site repair, a factory-glazed replacement frame must be installed. Therefore, it is necessary to make an assessment and to comment on the ease of future replacement.

A common system for factory glazed replacement is the Quaternario system. This system is shown in figurge 4.5.8. This replacement frame consists out of an stepped insulated glass pane, where the outer pane protrudes.

This stepped glass pane provides space for the Quaternario profile, which is a profile that is factory bonded to the glass pane. This profile accomodates mechanical fixation by screwing through this profile, into the mullion.

Yet, most of the time, replacement takes place by on-site structural bonding. This is in contradiction with the ETAG and should also be prevented by means of Scheldebouw’s own quality assurance.

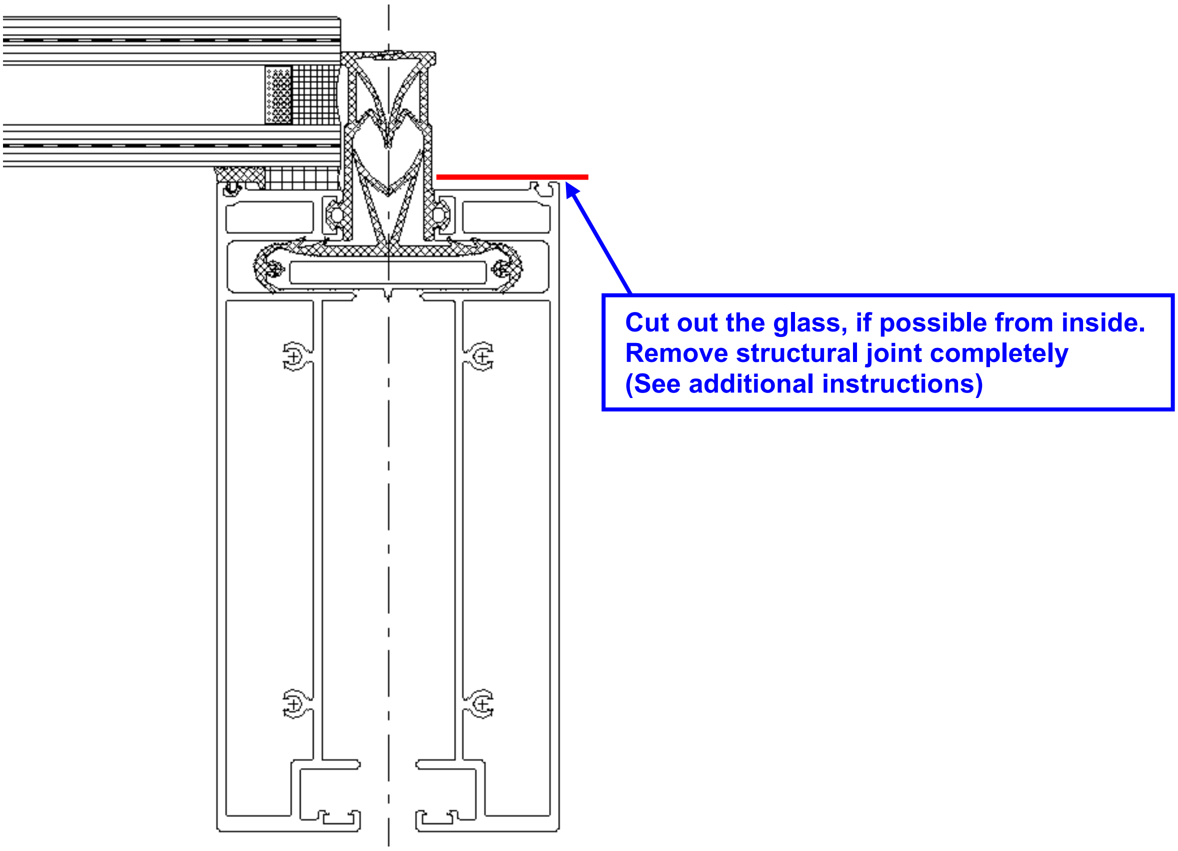


Figure 4.5.7 - Type A Mullion with rubber. (Scheldebouw, 2013)

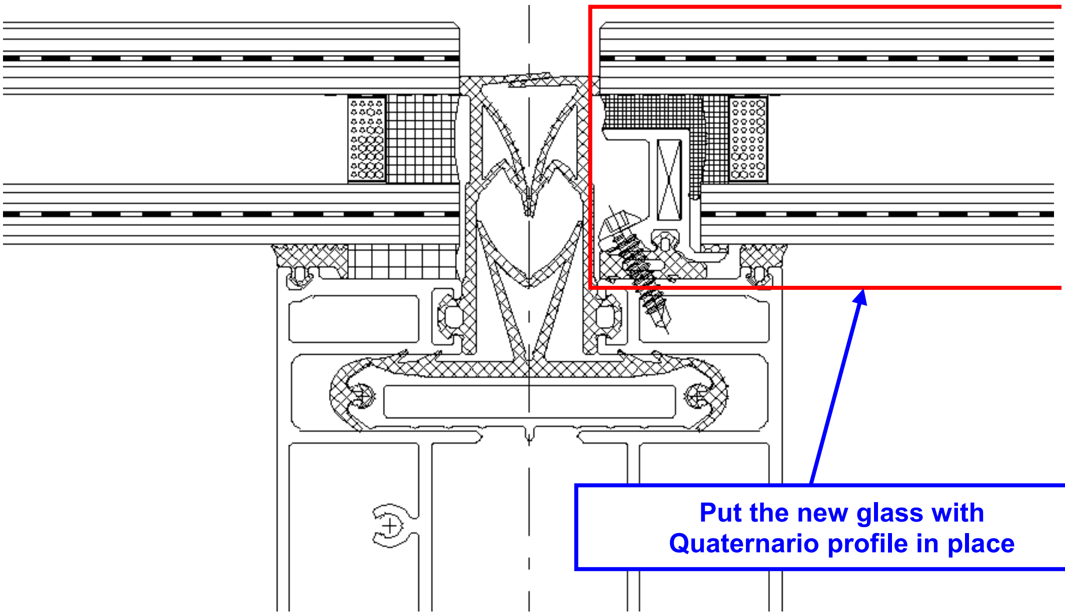


Figure 4.5.8 - Type A Mullion with rubber. (Scheldebouw, 2013)

4.5.4 **SWOT analysis**

After this review of the detail a SWOT analysis can be made to create an overview of the strengths, weaknesses, opportunities and threads for this detail.

Strengths
Flush exterior surface, which is an aesthetic feature that is highly demanded by architects. High performance, both acoustic and thermal. Simple detail that is easy to produce, except from the appliance of sealant, which can be demanding. Also this type of facade has good performance for blast resistance.

Weaknesses
The replacement is a weakness, because the ETAG describes only factory bonded frames should be used. In case of the Quaternario profile the performance of the element decreases thermical and acoustically.

Other weaknesses are possible in detailing, where exposed edges of a glass pane are vulnerable, whereas in framed glazing these edges are always covered. Also the PVB foil in laminated glazing is vulnerable for the chemicals in the sealant. Extra care is needed to prevent complications.

Another weakness for this system is not really in detail, but in the process and procedure that this kind of system needs to be able to assure quality. This procedure causes a more complicated process than for other kind of facades.

Opportunities
This system offers competing properties in terms of aesthetics and performance. These properties can be strengthened even more to improve this position.

Threats
Raising awareness in sustainability might cause a threat because the permanent properties of the way the glazing is connected to the frame. This complicates after use segregation for recycling purposes. Also the chemical properties of the sealant might raise environmental concerns.

Dissimilar (local) regulations and other external factors like local governments, costs and environmental issues. Cause this system, which can be seen as the basic principle to change in a variant. This is a threat to the simplicity and cost of this system.

Another threat is the long term quality assurance. As stated in the ETAG and in compliance with SIKA there is a guidline for a guarantee of 25 years. This is only half the time of the usual 50 years for a building.

4.5.5 **Output**

Goal of this paragraph was to conclude on what are the strengths, weaknesses, opportunities and threats for this type of detail. Hereby, a conclusion can be made on what should be improved.

This will not only be concluded by this design analysis, but also by the preliminary research, interviews, stakeholder analysis and process analysis.

Output from this specific analysis are the SWOT analysis on the previous pages. These properties should be taken into account and improved and/or maintained on the same or a better level.

Strengths

- Flush exterior surface (aesthetic)
- Minimal cold bridge
- Acoustic properties
- Simple detail (minimal amount of components)
- Easy to produce (except for adhesives)
- Blast resistant

Weaknesses

- Replacement (without quaternario)
- Vulnerable exposed edges
- PVB foil impacted by adhesive
- Intensive quality assurance

Opportunities

- Competing properties
- Popular aesthetic properties

Threats

- Raising awareness in sustainability
- Dissimilar (local) regulations
- Long term quality assurance

Figure 4.5.9 - SWOT analysis. (Own ill.)

5.0 Process approach

5.1 Introduction

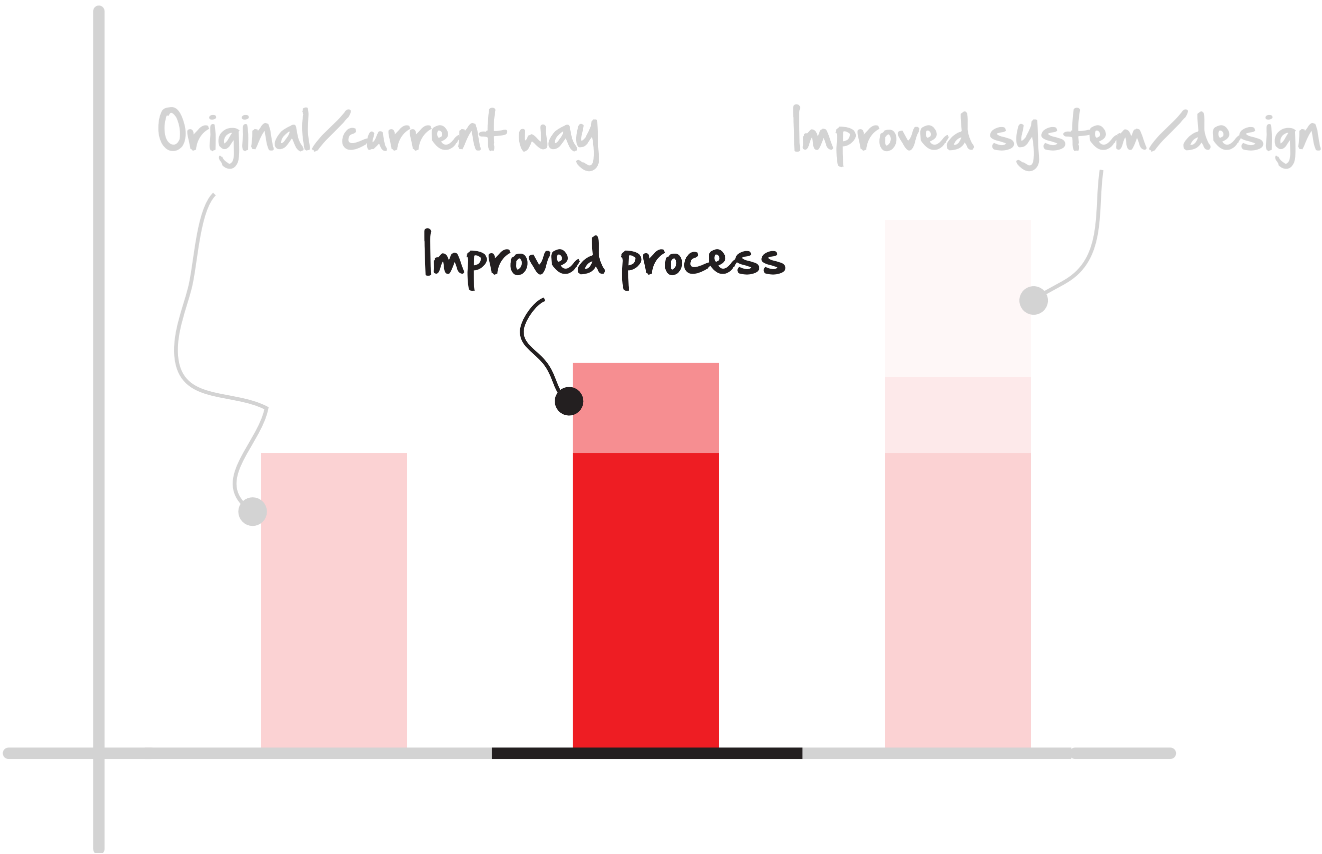
Based on the preliminary research and process analysis, a new approach for the process will be discussed.

This part focusses only on improvements in process. Improvements that ask for a change in system and/or detail are excluded from this chapter and discussed in chapter 6.

The improvements are divided into three different parts:

- When current contractual relations are respected.
- When the current procedure, based on guidelines and Sika is disregarded.
- When the current provider of sealant (Sika) is disregarded or influenced.

Last two are fictional on this moment, because it would not be possible for Scheldebouw to provide a structural glazed facade without the guidelines like the ETAG and the warranty of Sika on this moment. This could change if there is reason for this, but this will take a lot of effort and time.


Original/current way
Improved system/design
Improved process

5.2 Different approaches

[1] **When current contractual relations and guidelines are respected.**

These variants are based on the current way of working. With improvements, the same contractual relations can be respected and also the guidelines are still met.

Limitations:
- No/little experimentation or innovation because of limitations by the contractual relations and guidelines.
- Tests and procedure imposed by ETAG
- Tests and procedure imposed by Sika
- Only SG-500/550 and SG-20 by Sika are the products to use.

Possible improvements:
- Digitalisation of documentation
- Practical aspects in production like the proximity of hygrometer and thermometer
- Traceability
- Create a basic work flow, in accordance with SIKA. This based on a standard glueing surface, also used for traceability
- Outsourcing
- Easier traceability
- Solution for no on-site bonding
- The use of 1-part silicone when possible

Variants:
- Slider profile
- Partial framing
- Quaternario

The outsourcing and traceability will be discussed in next paragraphs. On-site bonding is discussed in paragraph 4.5.2. An effective solution for this could be an improvement.

Like in the automotive industry, the process could be improved by creating a basic work flow. For this, the way of structural bonding and the bonding surfaces should be consistent. In that way, no project specific adhesion testing, recommendations and procedures are needed. This will ease the process, where it only requires the checks on joint dimensioning.

For projects where the joint dimension does not exceed 15 millimetres and there is no time pressure, a 1-part silicone could be used. This will have the advantages of easier appliance and no need for production tests.

Remarks:
Least intrusive measures. Procedure and contractual relations can be kept, and process is still improved.

[2] **When the current procedure, based on guidelines and Sika is disregarded.**

By disregarding the current procedure it becomes possible to begin with a blank page. Yet, for this variant the same sealant is used. In essence, for Scheldebouw it is important to have trust in the product they deliver. They need to assure the quality for the client and themselves in a way they can give a warranty to this client.

Limitations:
- Only sikasil SG-500/550 and SG-20 by Sika are the products to use.
- Contractual demands by client. They might ask for compliance with the ETAG and/or other guideliness.
- No guidance, needs own development of a system for quality assurance and trust by client.

Improvements:
- Other ways of testing, e.g. non-destructive testing in stead of the other tests.
- Own quality assurance system.

Remarks:
Still procedures need to be followed to assure the quality of the product. When using a 2-part silicone it is important to assure the correct mixing. Also the application is very delicate, because e.g. the pre-treatment. Therefore, this will not improve a lot.

[3] **When the current provider of sealant (Sika) is disregarded or influenced.**

By disregarding the established relation with Sika, there are more possibilities in improving the process. On this moment, possibilities are limited to the use of the SG-20, SG-500 and SG-550 Sikasil sealants.

By disregarding this, more options become available.

Also the currently used two component structural sealant has relatively many risk factors. (Mixture/machine)

Limitations:
- Obtaining warranty from the supplier, if working with sealants, or take risks.

Improvements:
- Other types of fixation
- Other types of tests

Variants:
- Structural tape
- Toggle glazing

Remarks:
Requires a whole new warranty system with new contractual relationships with new suppliers or an ‘automotive‘ like system where the product for fixation is trusted by tests. In that case no extensive warranty system would be required. Yet, this might still be a too big risk to take.

5.3 Outsourcing

Outsourcing of the structural bonding could be an option if a sub-frame is used. This could be in the form of a Quaternario profile or another design. Yet, outsourcing will have its advantages and disadvantages. According to Lemmens (2008), these are:

Advantages:

- Optimal use of knowledge, equipment and experience of others. For example a glass producer has the knowledge, equipment and experience of structural bonding. They also bond thermal glazing, and could also perform the bonding of a profile on/in the glass.
- Improvement of the flexibility.
- Outsourcing leads to a clear primary process in the company.

Disadvantages:

- Greater dependence on suppliers.
- A supplier can not comply with the agreements made, for example by a bankruptcy.
- Continuous monitoring of subcontracting costs.
- Outsourcing does not mean that the outsourcing organization usually has no work: cost control, quality control, supplier management.
- Chance of communication and organizational problems in transferring of work.
- Chance of social and legal problems.

5.4 Traceability

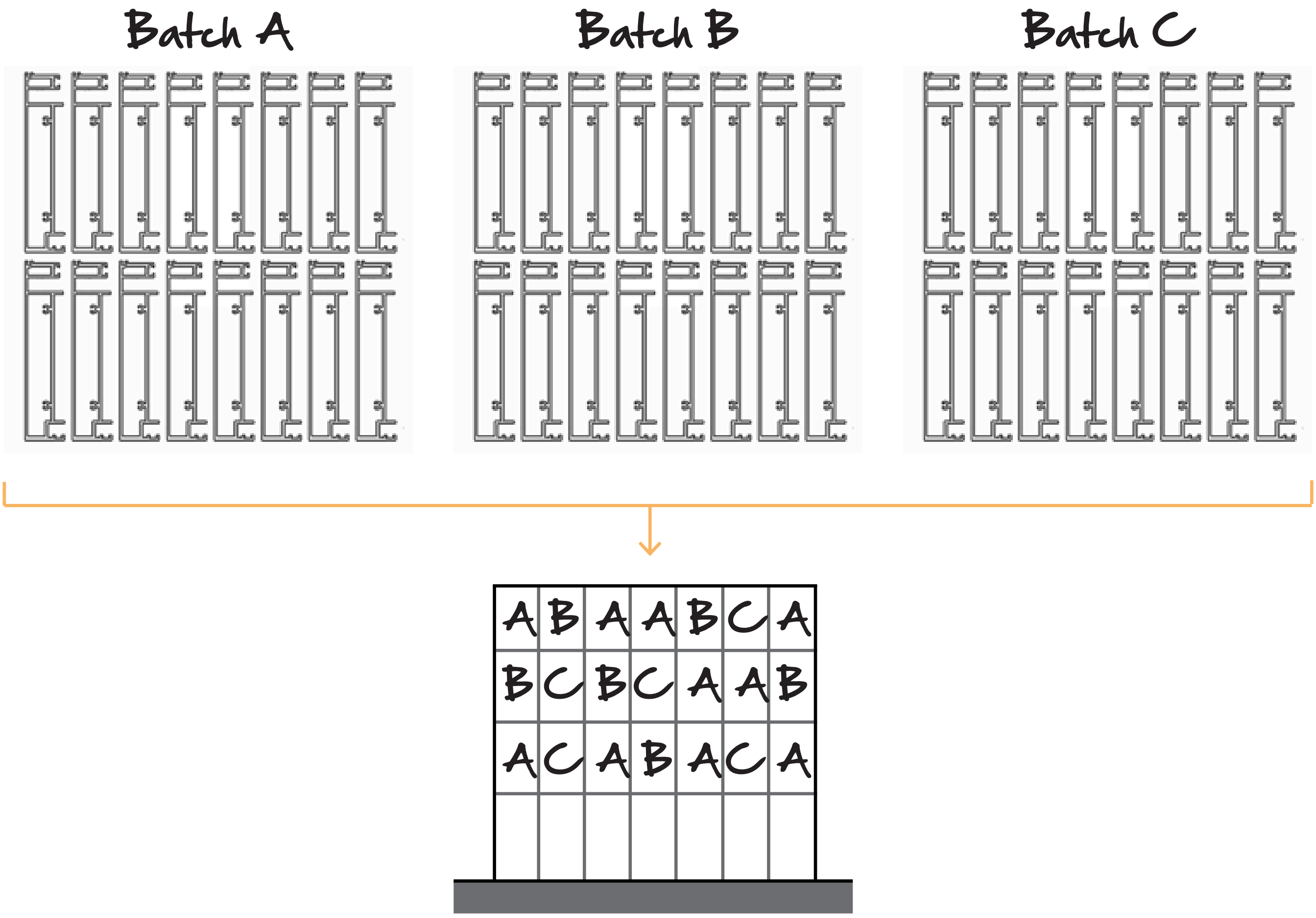
The ETAG states tests should be done on each batch of anodised aluminium (e.g. group of aluminium profiles anodised in the same bath at the same time for one day maximum).

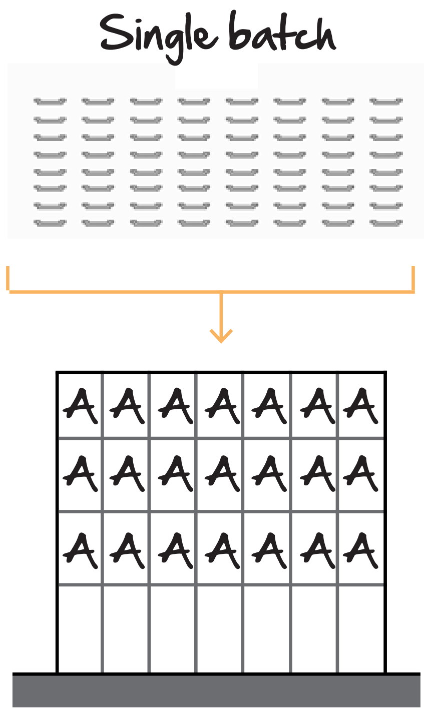
These batches are individually registered and need to be traced to the final element wherein each profile of the batch is installed. In this way, in case of a problem with a profile from this batch, all elements that contain profiles from this batch can be checked.

With big profiles, you will get a lot of batches, because of the limited size of the anodisation bath. This causes the difficulty of tracing, but this is possible by using the right procedures and forms during production. Yet, this also causes a difficulty in case of a failure. With multiple batches you force yourself to check on all of the elements that include a profile out of the same batch as the profile that was in the failed element.

This issue, combined with the need for tracing in the procedure, can be improved by using a smaller element for the bonding surface which is inserted or added to the main profile. This inserts can be produced in large quantities and in one batch. Therefore, no tracing of the profiles is needed.

Another advantage of this is the unitisation of projects. The bonding surface can always be the same because of these inserts.


Batch A
Batch B
Batch C
A B A A B C A
B C B C A A B
A C A B A C A


Single batch
A A A A A A A
A A A A A A A
A A A A A A A

5.5 Conclusion

Different gradations in improvements are given. The choice is dependent on the motivation of Scheldebouw. This can be because of quality increase and/or cost reduction. Improvements are possible from minor improvements to drastic changes in the use of systems and/or products, but for significant improvement an improved system is needed.

The first approach is least intrusive and gives improvements which enhance the process and its compliance to the current guidelines.

Second approach gives the possibility for other ways of testing and quality assurance. Yet, numerous steps in the current process are still needed to assure the correct functioning of the mixer and so the compound of the two component adhesive. To improve this approach, another way of assuring the correct functioning of the mixer is needed. Yet, this will always be an extra factor of uncertainty in comparison with a single component or another way of fixation.

The third approach gives the possibility for other products and/or fixations, which can have less factors of uncertainty.

Outsourcing is an option that could be useful. There will be an optimal use of knowledge, equipment and experience of the glass producer and Scheldebouw could have a a lot more clear primary process. Still there will be the need for quality control, but this will be the responsibility of the glass supplier.

Yet, there will be downsides to this. Primarily this is the cost control. The outsourcing of this process will probably mean higher cost and a higher dependency.

Process wise, outsourcing would be an improvement. Yet, the outsourcing should give the same quality, warranty and not significant higher costs to be feasible.

As can be red in paragraph 5.4, a solution for the traceability issue could also be an improvement in the process.

The choice for a specific approach will be influenced by different factors. These can be reasons to change or not to change current procedure / product / system. These factors are:

- Aesthetics
- Performance
- Production process
- Sustainability
- Cost

- Intensity of procedures
- Quality assurance
- Warranty

These factors are evaluated in chapter 7, on the final design.

6.0 Design approach

Based on conclusions from the previous chapter, directions for a new design approach will be described in this chapter.

In this chapter there will be given multiple concepts for a new design approach. These concepts will be discussed and evaluated, also based on the previous chapters.

In this evaluation the concepts with most potential will be chosen to further elaborate into a new concept/system. A competitive position is needed to have an improvement. A redesign or improvement in process is not useful if it does not give you an advantage over current types of cladding.

6.1 Requirements and preconditions

Requirements for a variant are:

- Flush appearance
- Same or better performance
- Easy to install curtain wall system (á la Scheldebouw)
- ‘standard parameters‘ like producable, waterproof etc.
- A competitive element

The concerning topics for design of structural glazing need to be taken into account:

- Finish of base material
- Space for application device
- Visibility of joint for inspection
- Replacement of glass

Improvements, based on the research, should be in:

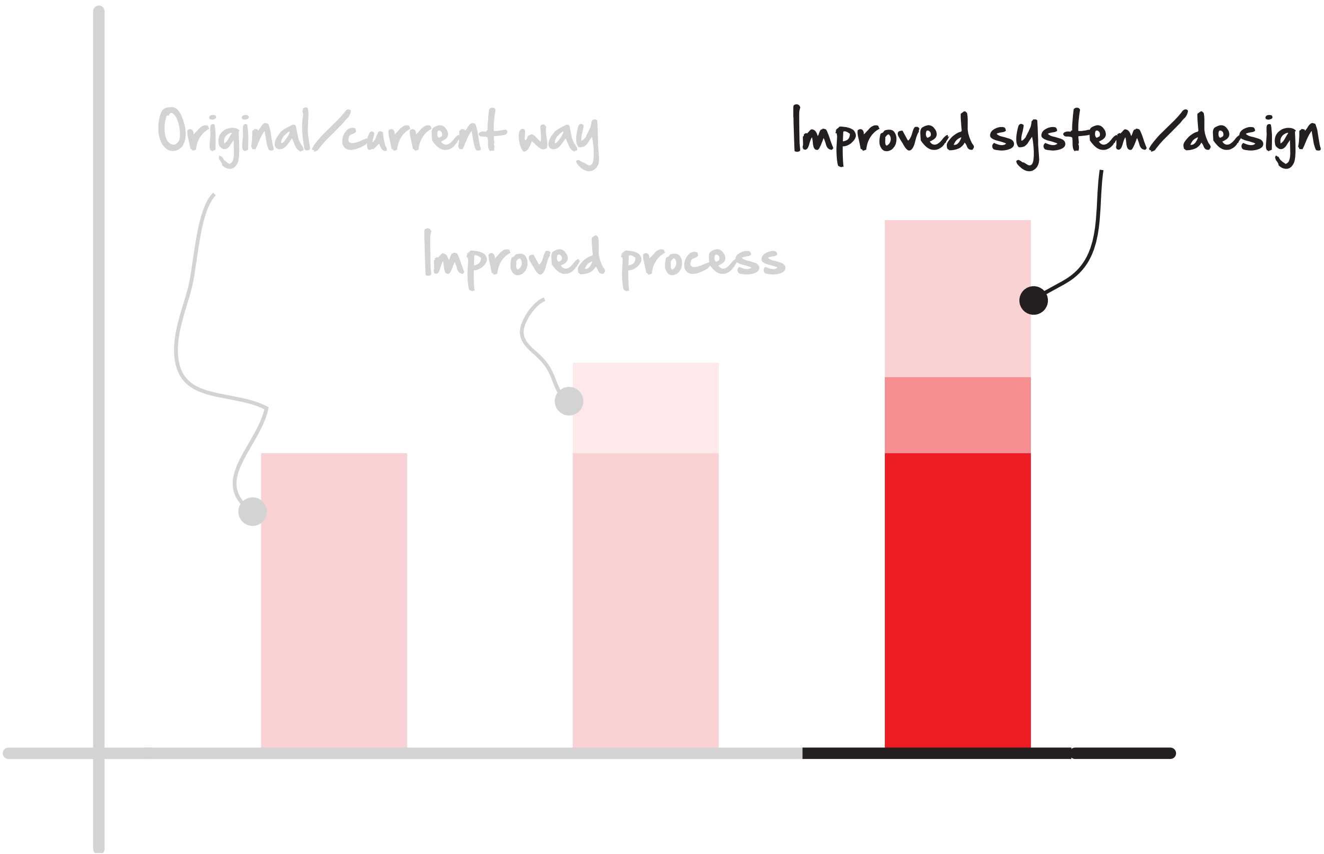
- Traceability
- Replacement
- Overall process

According to chapter 5.4, the traceability should be not required anymore, by using an integrated smaller element, which accomodates large batches. In this way, the used surface for bonding will always have the same constant properties.

Replacement is an issue, where the ETAG states: *due to the difficulty of quality control during on site repair, a factory-glazed replacement frame must be installed. Therefore, it is necessary to make an assessment and to comment on the ease of future replacement.*

Also local authorities sometimes demand factory-glazed replacement. For the overal quality it would be better to implement this replacement in the design.

The overall process can be improved by design, by designing for another type of adhesive and/or easier manufacturing.


Original/current way
Improved process
Improved system/design

6.2 Concept variants

In chapter 5 about the process improvement, three different approaches are discussed. The improvements were divided into three different parts:

[1] When current contractual relations are respected.
[2] When the current procedure, based on guidelines and Sika is disregarded.
[3] When the current provider of sealant (Sika) is excluded.

For this chapter, the second is excluded, because designwise every design for the first approach is also possible in the second. This is because the second part mainly has influence on the way the system is tested and can be given a warranty. These are process based improvements.

Therefore the variants are split in variants 1.x and 2.x where variants 1.x are based on the current contractual relations and where for 2.x the current provider of sealant (Sika) is excluded.

Variants 1.x can be seen as an identification of concepts, possible for the solution of certain problems. This can be used for the development of a new concept.

For all some variants there is a possibility for outsourcing, but this is not always wished for, as discussed in paragraph 5.3.

Variants are theoretically, and sizes in actual projects can differ. These sizes are dependent on too many factors than can not be incorporate in this chapter, like frame size and architectual wishes. Also the choice of glass will change de adhesive joints.

Starting point - basic system

Description:

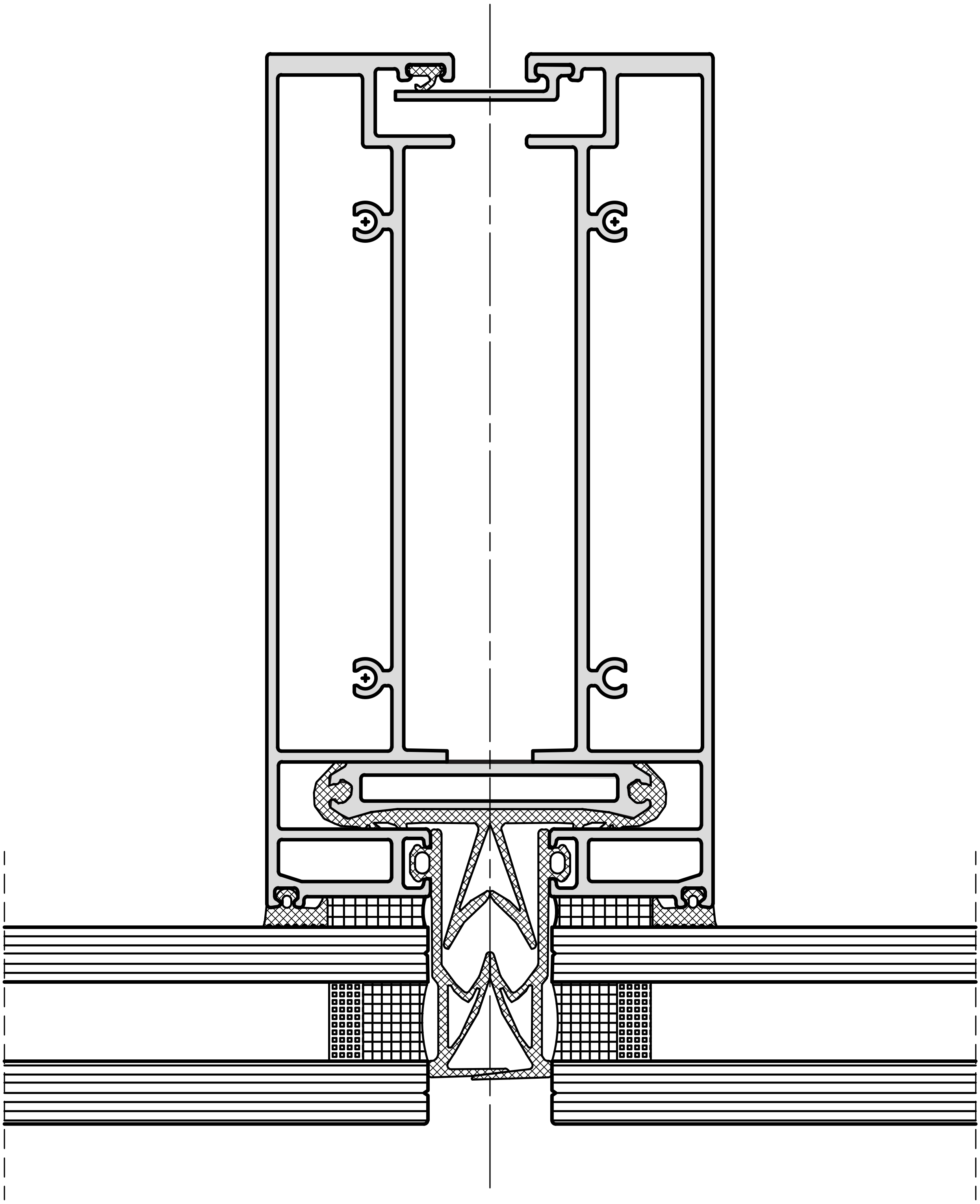
This is the most basic structural sealant system which is used at Scheldebouw. This one is also discussed in chapter 4.5. An analysis is made in this chapter. Advantages, challenges and disadvantages are appointed here again for the sake of completeness.

Advantages:

- Simple detail with minimum amount of components
- Minimal thermal bridging

Challenges and disadvantages:

- Factory replacement is not possible
- Multiple profile batches in a project, caused by the size of this profile. Batches need to be traced throughout the project
- Application and processing of the wet 2-part silicone sealant



Basic structural sealant system – Vertical mullion detail
(bottom is outside)

Variant 1.1 - Slider profile

Description:

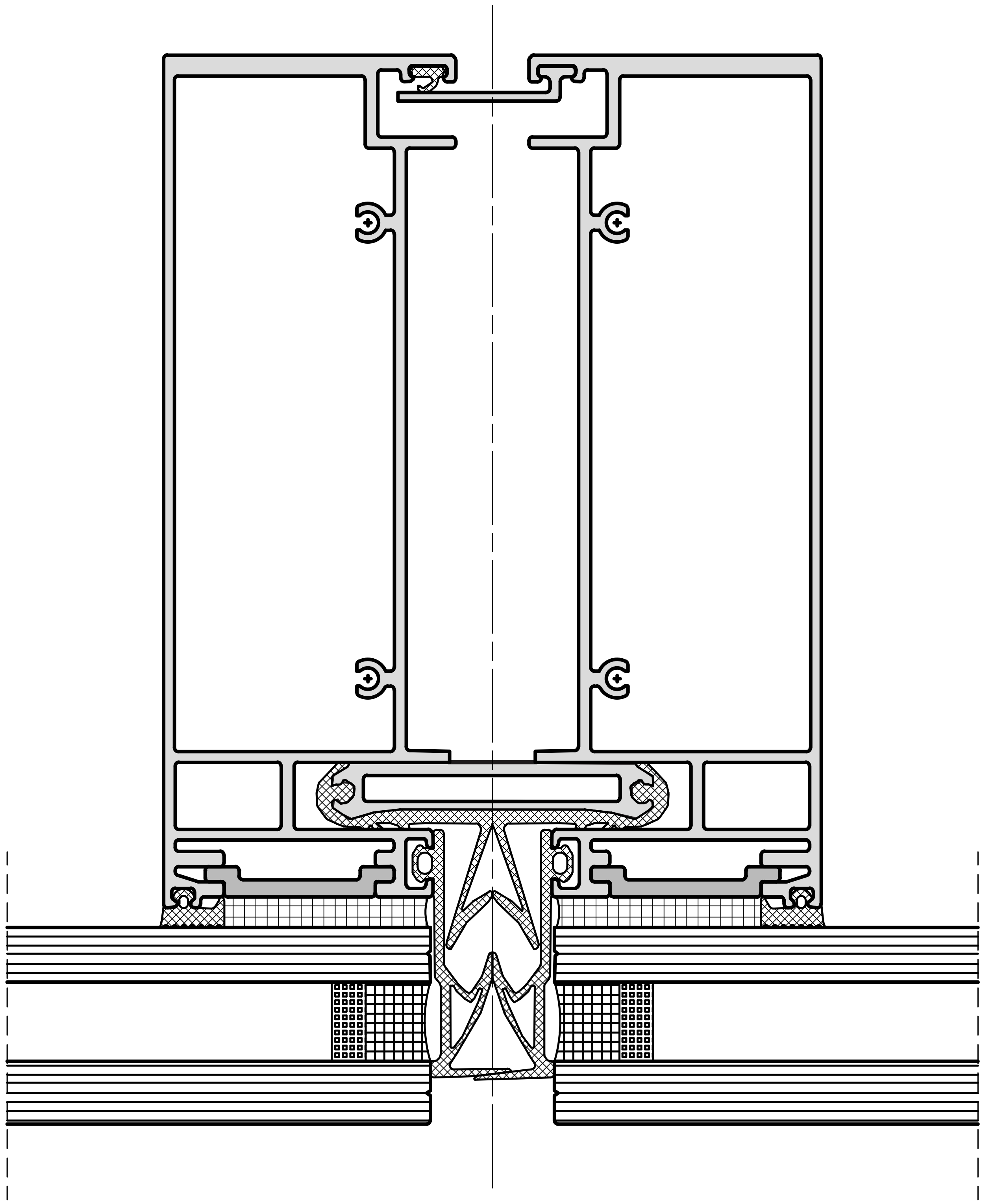
This is currently used at Scheldebouw to solve the traceability issue. It is a variant on the basic system where a slider profile is used. This is a small insert at the outer side of the profile. In this way the structural sealant is in contact with this slider profile, which can always be the same material. This slider element is very small, which ensures large batch sizes can be anodized at the same time. This ensures a constant quality, where no tracing of different batches is needed.

Advantages:

- Simple detail with minimum amount of components
- Minimal thermal bridging
- One batch in a project is possible because of the small insert. Therefore, this does not have to be traced throughout the project.

Challenges and disadvantages:

- Factory replacement is not possible
- Application and processing of the wet 2-part silicone sealant
- Extra component will bring extra costs in material and labour.



Slider profile variant – Vertical mullion detail
(bottom is outside)

Variant 1.2 - Partial framing

Description:

This variant contains a seperate frame where the glass is bonded to. This has several advantages: the glass can be replaced by a factory bonded glass pane with the sub frame. Also this element is smaller and so, a batch can contain more of these profiles.

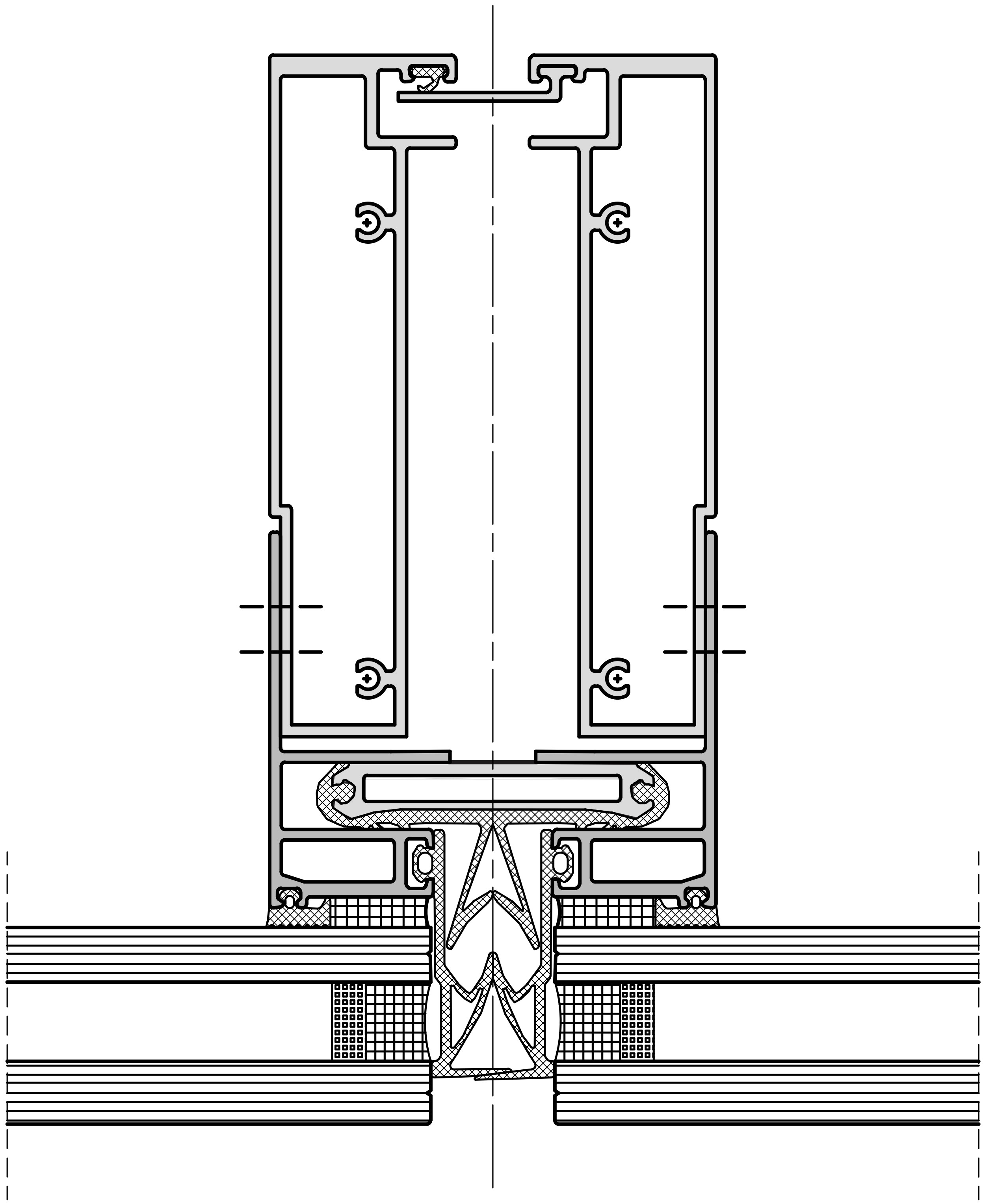
Yet, this sub frame is still fairly large and the connection of this frame to the supporting frame is a visible connection. A flush bolt could be used for this, but this will probably still find disapproval from the architect and/or client.

Advantages:

- Minimal thermal bridging
- Large batch in a project is possible. Yet, This is a bigger and more complicated insert than the slider profile
- Replaceable

Challenges and disadvantages:

- Double work: mechanical fixation *and a* structural bond
- Tolerances with replacement of an element
- Visible connection on the inside. Probable architectural disapproval



Partial framing variant – Vertical mullion detail
(bottom is outside)

Variant 1.3 - Quaternario

Description:

Quaternario is the name which is given to the profile which is used in this system. The Quaternario system is currently used to provide in a structural bonded replacement. Original elements can be directly produced with or without this Quaternario profile.

The replacement has some disadvantages: the replacement glass needs special operation for installing the quateernario profile, this glass is more expensive, it has less good thermal properties and the visual appearance on the outside differs from the original panel.

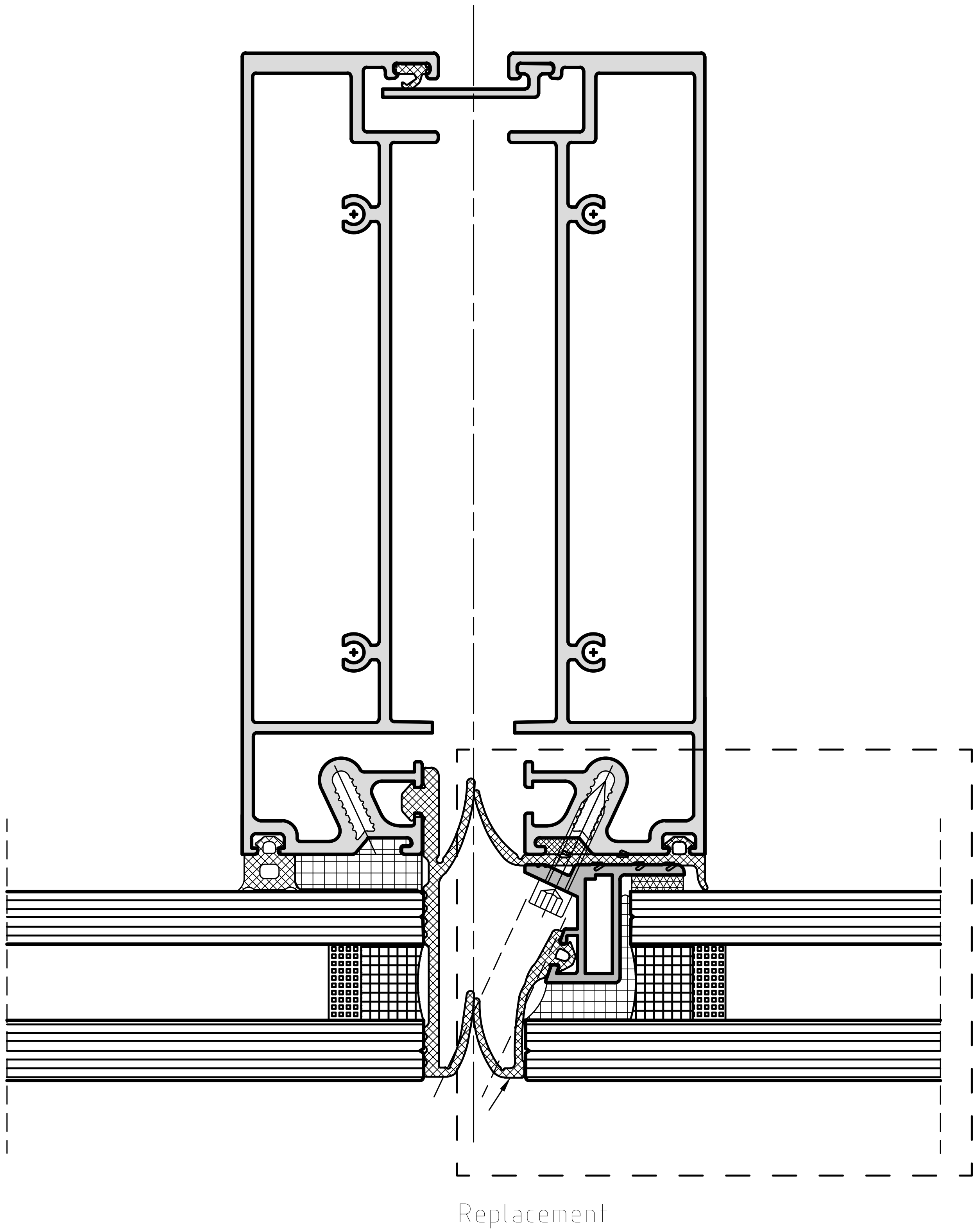
Though, in this variant, in the original design no extra parts or elements have to be used, which will not bring extra costs. Yet, this system is factory-bonded replaceable, without extra costs in the first place.

Advantages:

- Factory bonded replacement is possible
- No extra parts/cost in the first place

Challenges and disadvantages:

- In first instance it is not a solution for the tracing issue
- Stepped glass is needed for replacement which is significantly more expensive. Yet, only a little amount is replaced.
- For replacement, special glass needs to be ordered that requires special operation
- Wider non-transparent border when replaced. Visual difference with the other panels
- Less thermal insulation when replaced



Quaternario system – Vertical mullion detail
(bottom is outside)

Variant 2.1 - VHB tape

Description:

The search for another type of sealant than a two component structural sealant, resulted in research on VHB tape (Very High Bond tape).

VHB tape could bring a process improvement because of the following advantages:

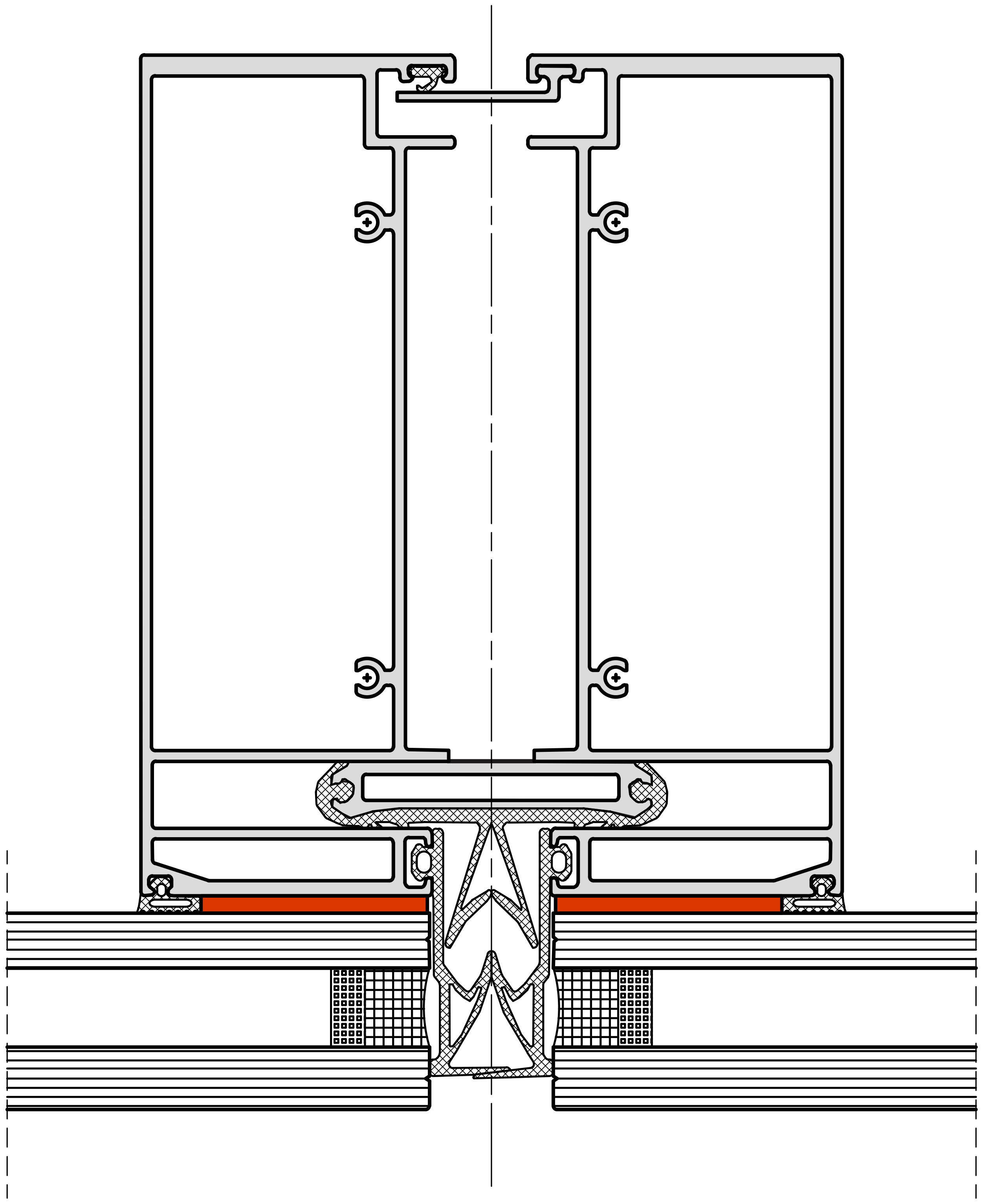
Advantages:

- *Simple detail*
- *Immediate handling strength (no cure time, faster through-put and delivery)*
- *Simplified process – no mixing or curing of liquid adhesives in the factory*
- *No tooling of structural sealant*
- *Reduced process variables/less risk*
- *Less waste*
- *No silicone testing is needed*
- *Cost reduction on the inspection and maintenance of the 2 component mixer*

Discussion at Scheldebouw learned that they used a similar tape on a project. In this project they had bad experiences with this tape.

Challenges and disadvantages:

- Tolerances are smaller because of the absence of sealant
- The appliance of pressure on the bond, which is a practical challenge (production)
- Replacement issue is not solved with this detail



Basic system with VHB tape – Vertical mullion detail
(bottom is outside)

Variant 2.2 - Toggle glazing

Description:

Toggle glazing is a variant with exclusion of the structural bond. The only option for fixing a glass panel with without sealant is by mechanically fixing it. For a flush appearance this fixation can not be on the outside. On the inside is also no possibility because you will need structural bonding for that. The only option is by securing the glass on its inner sheet.

Advantages:

- *No structural bonding, which means less procedures for safeguarding the quality*
- *Easily replaceable*

Challenges and disadvantages:

- The implementation in a half-frame system is difficult, where a connection in the centre is not possible because of tolerances, needed for installation.
- Extra parts and more complex assembly
- Glass needs an extra operation, which is more expensive
- Point loads
- A bigger seal inside the glazing is needed because only the inner sheet is mechanically fixed

Note: this variant is not an option to improve the process of structural bonding: it is the exclusion of it. Therefore, this option will not be an answer to this research. Yet, this option should be further researched in other research, because it might be a better option if the implementation in a half-frame system is found to be a feasible option.

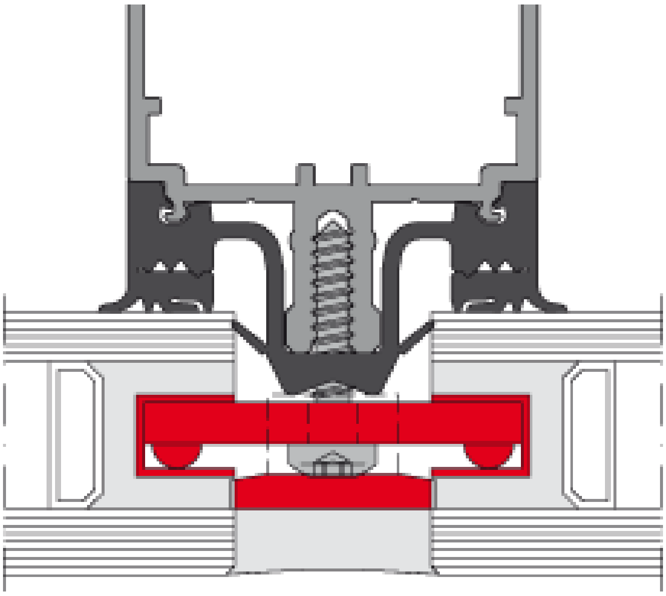
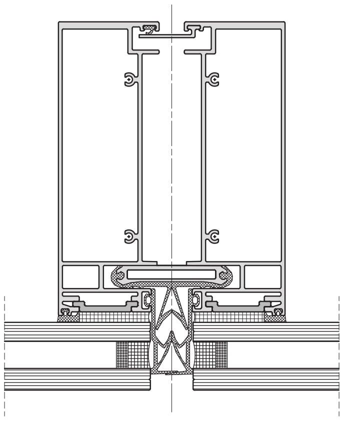


Figure 6.2.1 - Toggle glazing. (Raico, 2014)

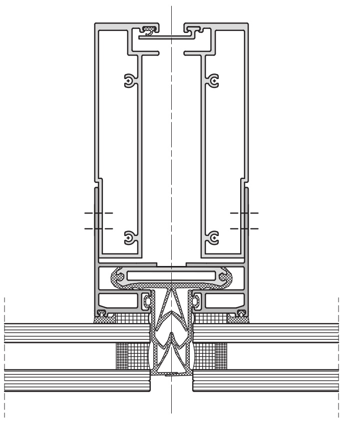
6.3 Evaluation of variants

In this paragraph the variants are evaluated and the direction for the elaboration of the new concept is chosen.



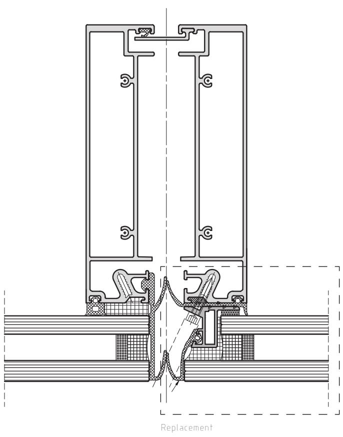
Variant 1.1 - Slider profile

Factory-bonded replacement:	✗	-
Traceability:	✓	By the use of the small slider profile, everything can be fixated on the same batch
Process improvement:	+/−	Only the extra application of the small slider profile
Cost:	+/−	Only the small slider profile: extra material
Additional comment:		Very good option, except for the replacement issue



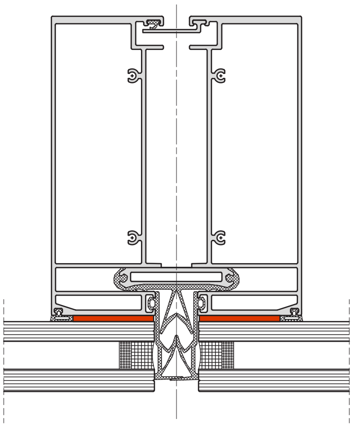
Variant 1.2 - Partial framing

Factory-bonded replacement:	✓	Possible with the partial framing. Project specific problems with this detail might occur. (Aesthetic/practical)
Traceability:	✓	Smaller profile ensures less batches. Yet, this profile might not be small enough for mass processing
Process improvement:	−	Extra labour because of the partial frame
Cost:	−	Cost will be higher because of the partial frame, extra material and labour
Additional comment:		Not a very good option, but is a variant that improves both on factory bonded replacement and the tracing.



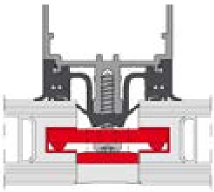
Variant 1.1 - Quaternario profile

Factory-bonded replacement:	✓	A very good option for replacement. Initially this variant does not bring extra cost.
Traceability:	✗	-
Process improvement:	+/−	Process stays the same. Only for replacement this changes. Not per se an improvement in the process of replacement.
Cost:	+/−	Initially this variant does not bring extra cost.
Additional comment:		Is a good and option for replacement. Yet, it does not solve the traceability issue and the replaced glass has some downsides like differing look and less thermal insulation. Though, the amount of replacements is not that big that it will influence the overall look or performance.



Variant 2.1 - VHB Tape

Factory-bonded replacement:	×	-
Traceability:	×	-
Process improvement:	+	Multiple improvements in the process. Less risk, easier appliance, no toolint, less waste, etc.
Cost:	+	Less waste and faster processing results in lower cost.
Additional comment:		A lot of advantages in different areas



Variant 2.2 - Toggle glazing

Process improvement:	+/−	Procedures and the application of sealant is not needed. Yet, the production process might be complicated, dependent on the design.
Cost:	?	Dependent on the actual design that needs to be developed for implementation in a half frame system. Yet, the excl. of structural sealant is beneficial because of high costs.
Additional comment:		This variant is not an option to improve the process of structural bonding: it is the exclusion of it. Therefore, this option will not be an answer to this research.

An option like the slider profile might be feasible because of the easy appliance on the main profile in the first place. This does not cost a lot of extra money or labour.

Therefore, the elaboration should be on a concept with a tracing profile that is small, cheap, and easy to apply. In combination with replacement this profile should be removable, which provides the opportunity of factory bonded replacement.

This, combined with a tape in stead of the 2-part silicone sealant might be an answer to this research. This is further evaluated in chapter 7.0.

6.4 Elaboration of the new concept

6.4.1 Development

This detail is come to development after research on the preceding variants. As concluded, each variant had its own advantages and disadvantages.

This ended in the conclusion that a solution should be found in the combination of the slider profile variant with the possibility of replacement. Therefore, the sub element should be cheap and easy to apply and it needs to allow for a factory bonded replacement.

In appendix 4 an additional presentation drawing is included. This is a three dimensional exploded view.

Traceability
This is wished for, where it eases the process of tracing and quality assurance. It should be facilitated by a small element that can be mass processed. This can also result in a same small element that is used in all projects. This would be a unitisation of the structural bonding process.

Replacement
Design for replacement is valuable, because the amount of replacements is not significantly to the overall project. Therefore, if you design a replacement frame in each element, a lot of these frames will never be used and therefore not cost efficient. Yet, if this could be combined with a solution for the traceability issue these extra costs are more substantiated.

Of course all design should be kept as less costly as possible. A tracer profile like the slider profile is not so costly because of the little material and easy appliance, but to allow for replacement it should be demountable.

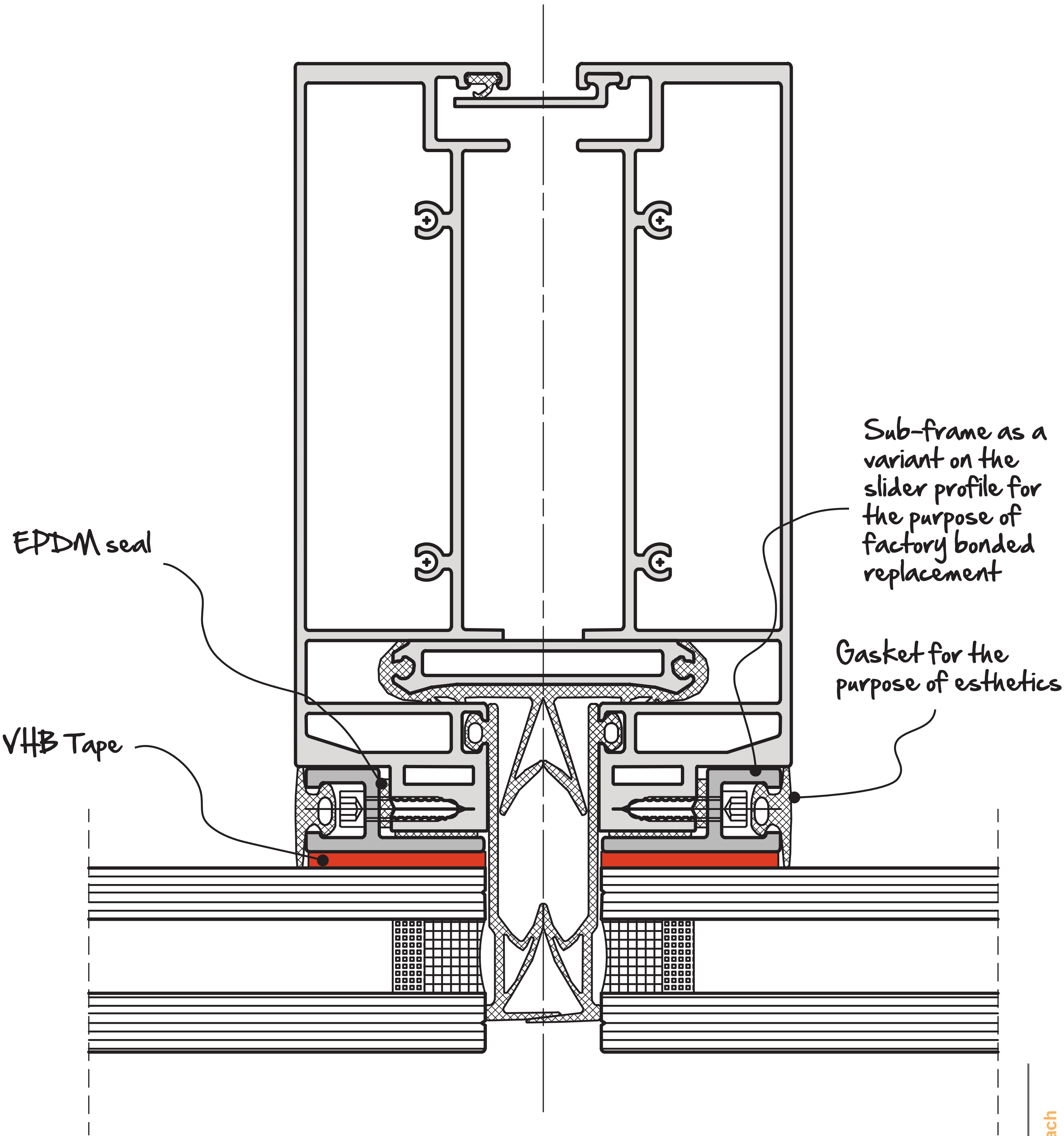
The Quaternario variant shows a possibility where the original element is demountable by using a wire saw to remove the damaged glazing. Now, for the replacement a factory bonded frame is needed. This frame needs to be in a place that does not interfere with the rest of the element. In the quaternario variant this is solved by placing the frame in the glass perimeter.

For the new concept it is chosen to place this replacement frame in the frame perimeter. This does not influence the thermal performance and the costs of the glazing. Additional effect is that this frame now can be used as a variant on the slider profile for the traceability.

The combined with a tape in stead of the 2-part silicone sealant, which is further discussed in the next paragraph, gave options for a new way of montage. An option like the Quaternario profile fixated from the outside in an angle through the joint. Therefore the stepped glazing is needed because otherwise the angle will be to shallow and fixation will not be possible without increasing the joint width.

Because of the lower thickness of the tape, a fixation can be created on the inside and covered by a gasket. This will result in only a little wider gasket than before with the 2-part silicone sealant. The gasket doubles as a cover of the tape edge, which else could suffer from visible dust/dirt accumulation because of its sticky character.

This is a solution for all stated challenges. The solution will be further substantiated in the following paragraphs. In chapter 7, a complete evaluation of this concept will follow.



Production: Easy attachment of the sub-frame to the element. Apply tape and position the glass pane.

Replacement: Easy remove of the glass pane with the sub-frame. Replace with factory-bonded glass/sub frame.

6.4.2 **VHB Tape**

Following from this research, 3M VHB Tape might be an interesting option to improve the structural bonding process. By using a tape in stead of a 2-part silicone sealant you exclude the risk factor of the mixing in the production facility. This needs extensive testing, maintenance and inspection on the mixers. Also during the process multiple tests have to be prepared.

Except for this reduction in risk there are more advantages to this tape:

- *Simple detail*
- *Immediate handling strength (no cure time, faster through-put and delivery)*
- *Simplified process – no mixing or curing of liquid adhesives in the factory*
- *No tooling of structural sealant*
- *Less waste*
- *Cost reduction on the inspection and maintenance of the 2 component mixer*

These advantages will be further evaluated in chapter 7.

3M VHB Structural Glazing Tapes have been granted a European Technical Approval (ETA) through independent testing according to the current European Technical Approval Guideline for structural glazing: ETAG 002. This assures taht the product has the right characteristics to be used in structural glazing projects.

Yet, costs, dimensioning and processing might differ, which are also important factors in the structural bonding process.

3M™ VHB™ Structural Glazing Tape is a closed cell, double-sided acrylic foam tape that has the capability to develop Very High Bond (VHB) strength and excellent long term holding power when bonded to glass and metal framework. It was actually developed to replace structural silicone sealants in structurally glazed curtain wall systems and commercial window units.

For joint dimensioning there are two specifications: the bite and the thickness. This is visualised in figure 6.4.1. For supported systems (no dead load), which is obligatory for double glazed systems, the bite is dimensioned by a dynamic load calculation. This includes the wind load.

The thickness is specified by the shear load or strain. This can be in a unsupported situation, or by a change in length, caused by for example thermal expansion. As can be seen in figure 6.4.3 the allowable shear strain for the VHB tape is significantly higher. This is also the reason this tape can be thinner.

Technical properties, regarding the joint dimensioning, are shown in figure 6.4.3. This figure learns that the design tensile strength, used for dynamic load calculations, is higher for the silicone sealant. This will result in a wider bite for the VHB tape. Yet, no gasket is needed for the retaining of the fluid sealant, which results in less necessary width. Exact dimensions will be calculated in a comparison in chapter 7.

A typical detail for structural glazing with the tape is shown in figure 6.4.2. This detail might have a problem with dirt accumulation in the inside corner, where the tape will always be sticky. Also this detail is not a solution for the known issues with tracing and factory bonded replacement.

In chapter 7 the new concept will be evaluated in a comparison. The comparison will be on an identical panel on an identical location, but with the 2-part silicone sealant SG-500 vs. the 3M VHB Tape. For this, calculations will be made, to find the exact differences in dimensioning. Also the properties: advantages and disadvantages on different topics, will be evaluated in this comparison.

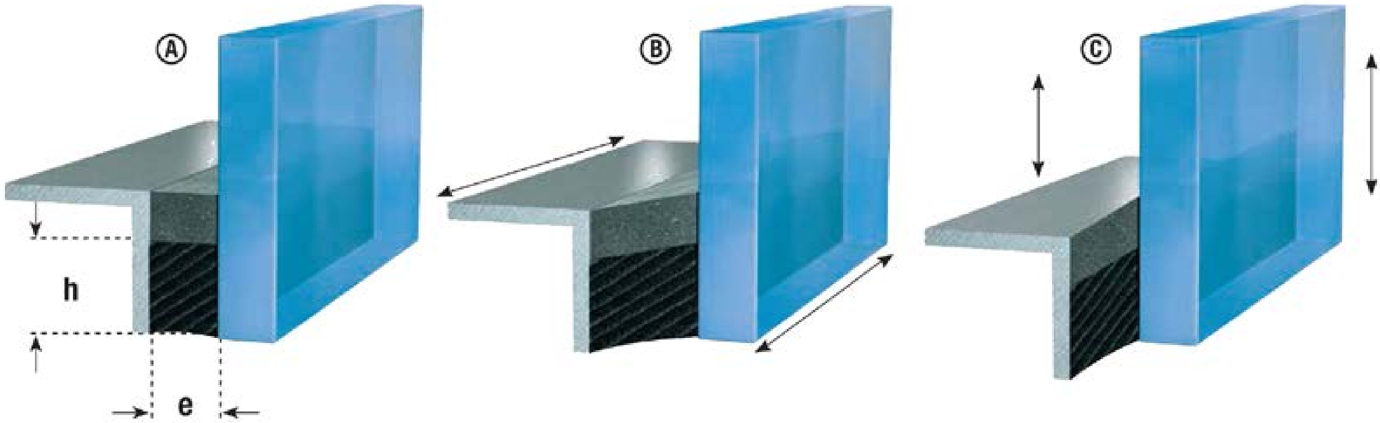


Figure 6.4.1 - Joint: h = bite and e = thickness. (Sika Facade Systems Specifications, 2013)

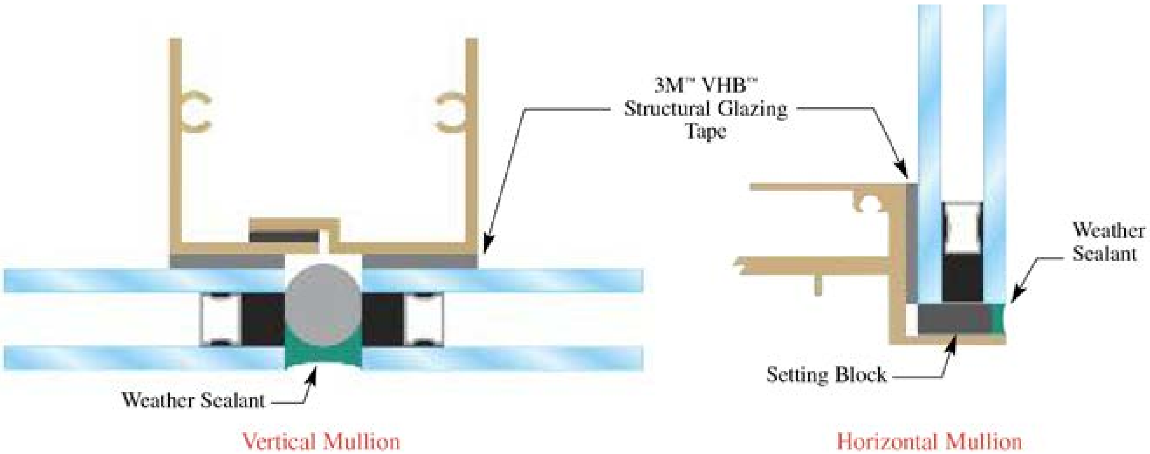


Figure 6.4.2 - Typical structural glazing detail with 3M VHB Tape. (3M Technical Guide, 2010)

	ETAG			
	σ_{dyn}	τ_{dyn}	τ_{stat}	Allowable shear strain
SG-500	0.14 MPa	0.105 MPa	0.0105 MPa	x 125 %
3M™ VHB™ Tape	0.085 MPa	N/A	N/A	x 300 %

Figure 6.4.3 - Design strength properties (Own ill.)

6.5 Remarks

There are some remarks on this concept which need to be figured out before implementation is possible. The first issue is glass allignment. The glass needs to be accurately positioned in one go. If else, the glass will be directly bonded to this tape in a wrong position. Measures need to be taken for this, like the use of temporary spacers for maintaining **glass alignment**.

Second remark, is that the Technical Guide for 3M VHB Tape states that a neutral-curing (non-acidic) silicone sealant should be applied around the entire perimeter of the glass once it's bonded to the structural glazing frame. This would act as a **weather sealant** and help to protect the 3M™ VHB™ Structural Glazing Tape from potentially aggressive glass cleaning agents and should be done while the glazed units are still in the shop if possible. Yet, it would be inconsequently to disregard the sealant for tape and still have the need to use a wet sealant.

The Sika Technical Guide for structural glazing also states that the structural bond should be protected by a weather sealant, but in both cases this is merely an advise. By using a gasket to protect the inner layer with the tape and describing the kind of cleaners there should be used in the maintenance this should be sufficient. This has to be agreed upon by the 3M Technical Deparment.

Last remark is a **warranty issue**. As a group, Permasteelisa has an 'umbrella' contract with Sika. This umbrella contract has financial benefits. For example, as a group they can get a discount if they purchase more than a certain amount of these products.

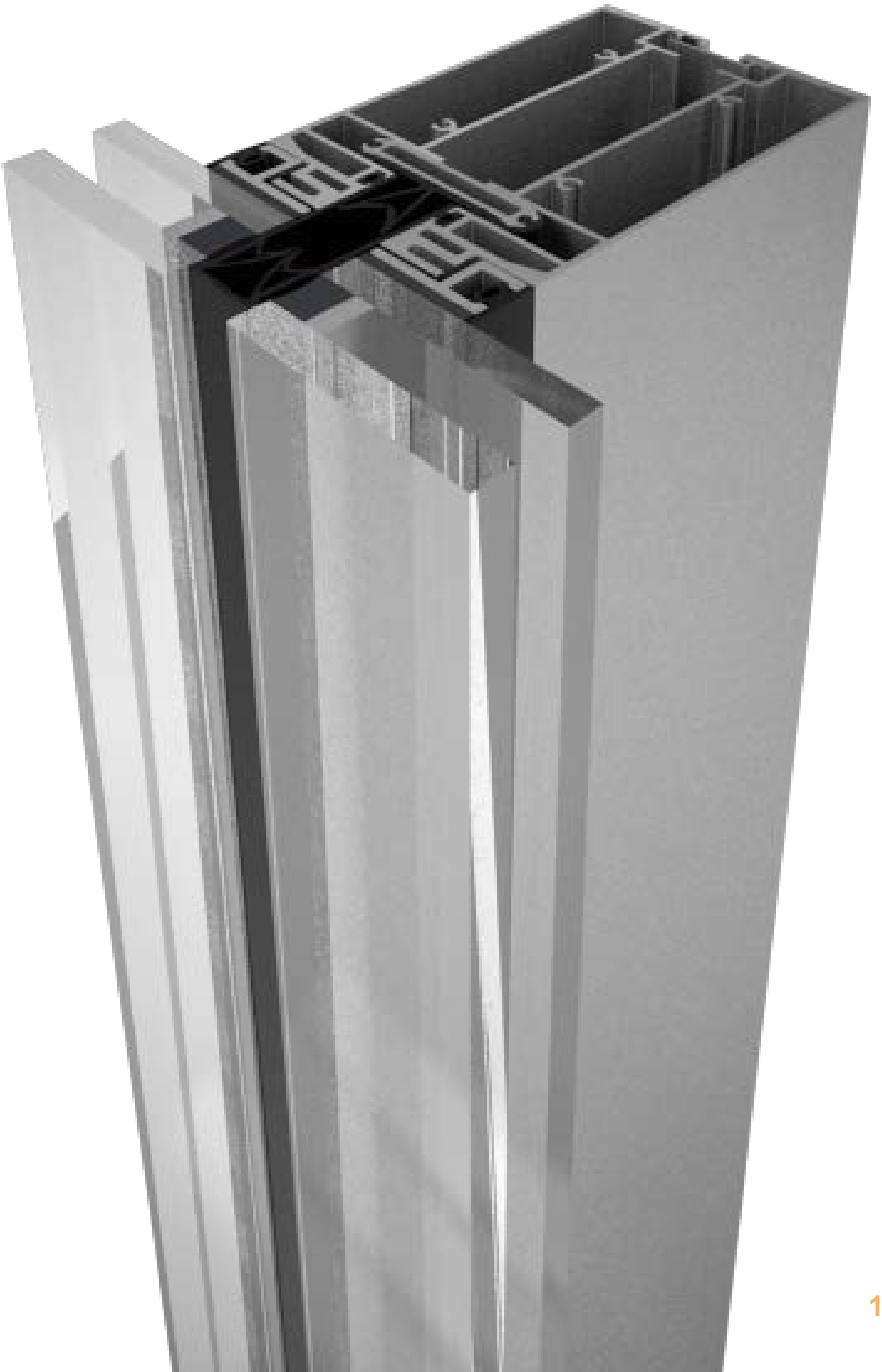
Besides these financial benefits it was also possible for the Permasteelisa Group to work on a procedure, together with Sika, to be able to get a warranty from Sika on the total structural bond and not only on the sealant itself. This means an extended warranty, where more than only the structural sealant will be remunerated in case of failure by the cause of Sika.

In the case of 3M, on this moment it is only possible to get a warranty on the tape itself. In other words, they will refund the tape or give you new tape in case there is a problem/failure with this tape. This is a complicated issue, that is involved by a lot of factors. As mentioned in chapter 5, an improvement like this will as for a whole new warranty system with new contractual relationships with new suppliers or an 'automotive' like system where the product for fixation is trusted by tests. In that case no extensive warranty system would be required. Yet, this might still be a too big risk to take.

More research should be done on this by precedent analysis, supported by 3M. There has been established a contact with 3M. With their help it will be possible to contact other companies which used their tape and review their project process and warranty system.

Last remark will be a project specic remark. The suggested system, where the subframe can be loosened and fastened from the interior side might not be applicable for every project. The reason for this is that in some projects they have a closed parapet, where it will not be possible to reach the screws.

Yet, this is also not the way of working at Scheldebouw, where every facade is a unique system. This suggested improvement shows a new concept, where a tracer profile is integrated into a replacement frame. This concept can be further influenced by project specific properties.



7.0 Evaluation

This chapter will give an evaluation of the proposed redeveloped design. For a clear evaluation, this will be done by splitting this into two parts:

- Design aspects: Aspects like design, production, cost, waste etc.

- Procedure aspects: Aspects like quality assurance and therefore a comparison in critical factors in the production process, tracing and replacement.

This evaluation will be done by a comparison with the current basic system and its accompanied process.

For this an example project will be used. Specifications for this project will be established and design with structural sealant and VHB tape will be compared.

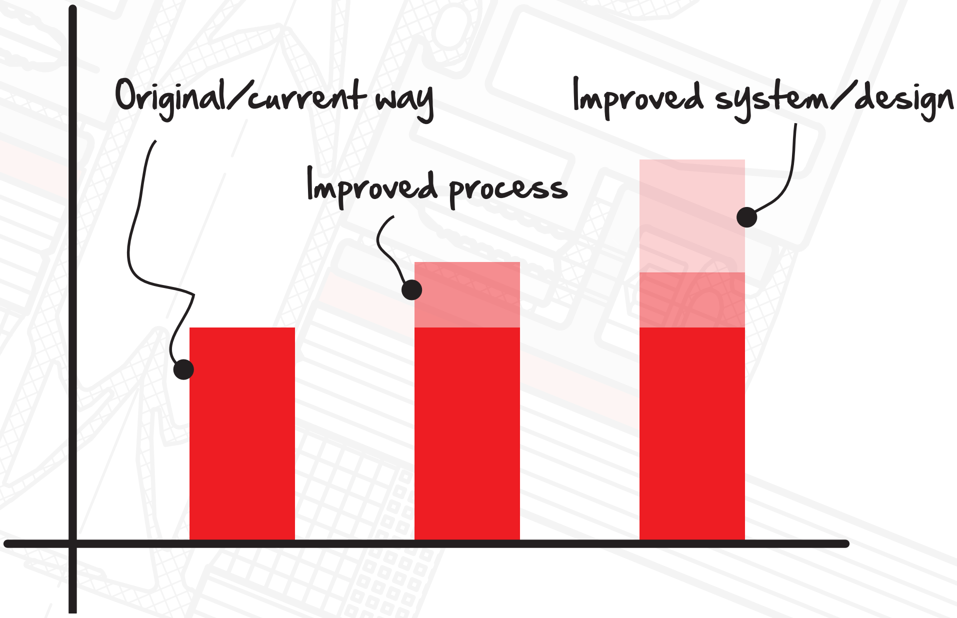
The result of this evaluation will be a conclusion on the significance of improvement that is achieved with the suggested concept.

This evaluation has been conducted in cooperation with 3M. For this I arranged two meetings. One with Martin Breemer (3M / Technical Service Engineer) and myself to discuss the proposed process and design. A second meeting has been arranged to work with this tape in practice: build test samples, a mock-up and to have a second meeting/discussion in the presence of René Koster (Quality Inspector) and Guido Caubo (System Design Managed and my mentor at Scheldebouw).

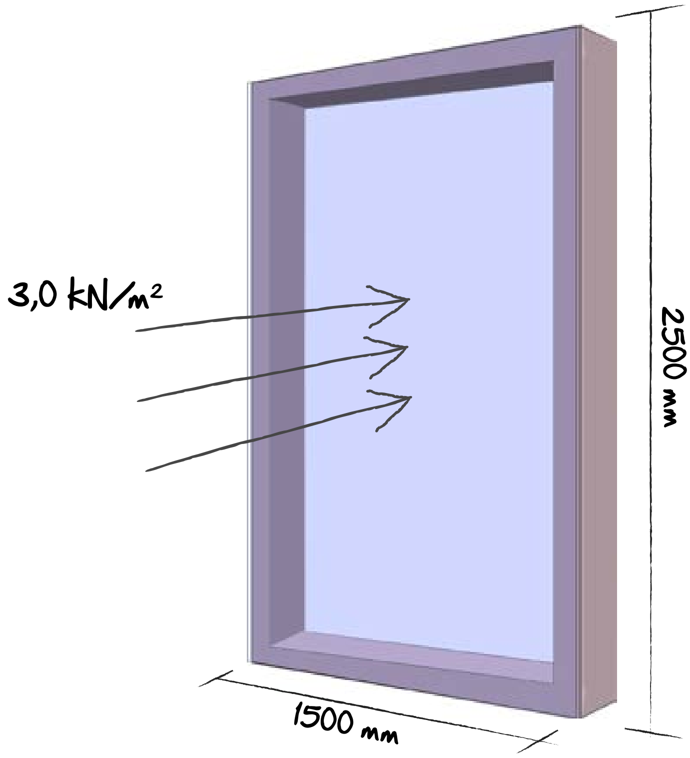
By this it was possible to get a confirmation on the feasibility of the proposed design. Also these discussions resulted in points for further attention.

Hereby, 3M could confirm the feasibility of the proposed design and provide in points for further attention. Also their assistance was needed for the acquiring of reference projects and/or clients.

With this the design could be evaluated and the feasibilty can be checked.


Original/current way
Improved process
Improved system/design

7.1 Design aspects



7.1.1 Feasibility check

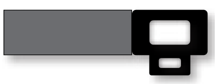
For the design comparison an example project will be used. This project will be represented by a single element. The project and element have the following specifications:

Location: England

Maximum wind load: 3.0 kN/m^2
Pane dimensions: 2500mm x 1500mm
T_{max} of building ext.: 85 °C

Calculations, which are collected in appendix 4, gave the following results for joint dimensioning:

Sikasil SG-500 2-part silicone sealant



Bite: 17 mm + gasket
Thickness: 6 mm

3M™ VHB™ Tape

Bite: 30 mm
Thickness: 2,3 mm

(Representative scale 1:1)

At first calculation the use of VHB tape seemed a aesthetic disadvantage, based on the larger bonding area, which results in less transparency. Yet, with the use of structural sealant also a gasket between glass and frame is needed to limit the flow of sealant. This gasket can be different sizes, but will need width for stiffness.

Generaly, these gaskets are not a lot smaller than 10 mm, which brings the comparison to 27mm / 30mm for this situation. Actually, calculation resulted in 26,5mm but the first stock available tape widht is 30. When custom ordered, which is possible, the result would be a similar joint width (including gasket) for both options.

Additional advantage for the tape is no colour mismatch between structural silicone and the gasket. Also no streaking will appear, which can happen with the fluid silicone.

Properties like acoustic and thermal insulation are not susceptible to change by the use of the tape instead of a sealant. This, because in every case the outer layer ofglass which influences these properties for the biggest part, stays the same.

	ETAG			
	σ_{dyn}	τ_{dyn}	τ_{stat}	Allowable shear strain
SG-500	0.14 MPa	0.105 MPa	0.0105 MPa	x 125 %
3M™ VHB™ Tape	0.085 MPa	N/A	N/A	x 300 %

Figure 7.1.1 - Design strength properties (Own ill.)

Calculating the Joint Bite h

Joint bite h as a function of the wind load in supported constructions

$$h = \frac{a \times w}{2 \times \sigma_{dyn}}$$

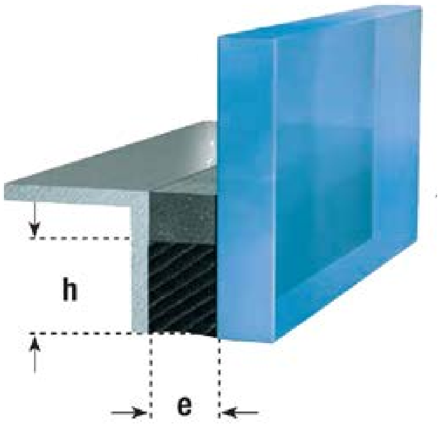
h = minimum bite of the adhesive joint (mm)

a = length of the short edge of the glass pane or of the element (mm); with irregularly dimensioned glass elements: longest of the short glass edges[1)]

w = maximum wind load to be received (kN/m^2) ($100\ kp/m^2 = 1\ kPa = 1\ kN/m^2$)

σ_{dyn} = maximum adhesive stress for supported constructions (kPa). For σ_{dyn} values of Sikasil® products see page 13

[1)] If the sides of the glass panes are of varying length, then the length of the longest side is used for the calculation.



Calculating the Joint Thickness e

Total movements

$$\Delta l = \sqrt{\Delta l_v^2 + \Delta l_h^2}$$

The calculated deformations of the long and short panel edges yield the total movements according to the formula above (Pythagoras' theorem).

Δl = total change in length
v = vertical
h = horizontal

Calculation of the minimum Joint Thickness e (ETAG 002)

$$e \geq \frac{(G \times \Delta l)}{\tau_{des}}$$

G = Modulus of elasticity in shear tangential to the origin: (G = E/3)

E = Modulus of elasticity in tension or compression tangential to the origin

τ_{des} = permissible stress in shear of the adhesive for supported constructions (MPa). For τ_{des} (= τ_{dyn}) values of Sikasil® products see page 13

According to ETAG 002 a joint ratio of $e \leq h \leq 3e$ is advisable. For a joint ratio > 3:1, the bending effects in the elastic joint must be considered.

Figure 7.1.2 - Formulas for joint dimensioning (Sika Facade Systems Specifications, 2013)

For the dimensioning of the joint bite or tape width the design strength for tensile forces is specified in the suppliers manuals. These design strengths are respectively:

Design strength *VHB™ Tape* σ_{dyn}: 85 kPa
Design strength *SG-500* σ_{dyn}: 140 kPa

Theoretically, following from these design strengths, the tape width will always be at least 65% larger than the silicone joint. Yet, the tape is only stock available in multiples of 5 mm, which can result in up to four millimetres extra by round-up. Yet, custom sized can be ordered, which excludes this effect. This might not be significant costly if the project is large enough.

To discover the possibilities in panel dimensions with the VHB tape, a graph has been created. This graph is shown in figure 7.1.3. In this graph the possible dimensions for a given wind load and tape size are visualized. This shows that in high wind load areas, like 5 kPa, the length of the short edge of a panel will be limited to less than 1400 mm.

In accordance to the previous observation, for the same joint dimension, the length of the short edge can be 65% longer for a panel bonded with Sikasil SG-500.

Additional requirements for the design with VHB tape are lower tolerances in production. With the 2-part silicone sealant it is possible to easily fill up irregularities in the assembly. With the 2,3mm thick VHB tape it is only little (< 0,5 mm) irregularities are allowed. The bond area of the profile should be flat and parallel to the glass surface to promote good adhesive contact.

It can be concluded that purely design wise the joint dimensioning will not be critical for the choice of one of the options, mainly caused by the necessity of a gasket for the silicone sealant.

Yet, as mentioned in chapter 6.4, the lower thickness of the tape made it possible to design a fixation on the inside which could be covered by a gasket. This will resulted in only a little wider gasket than before with the 2-part silicone sealant. Yet, from the outside this gasket is nearly invisible. Therefore, design wise this tape can be seen as a better option, also allowing for improvement on other factors that follow in this chapter.

Colour availability

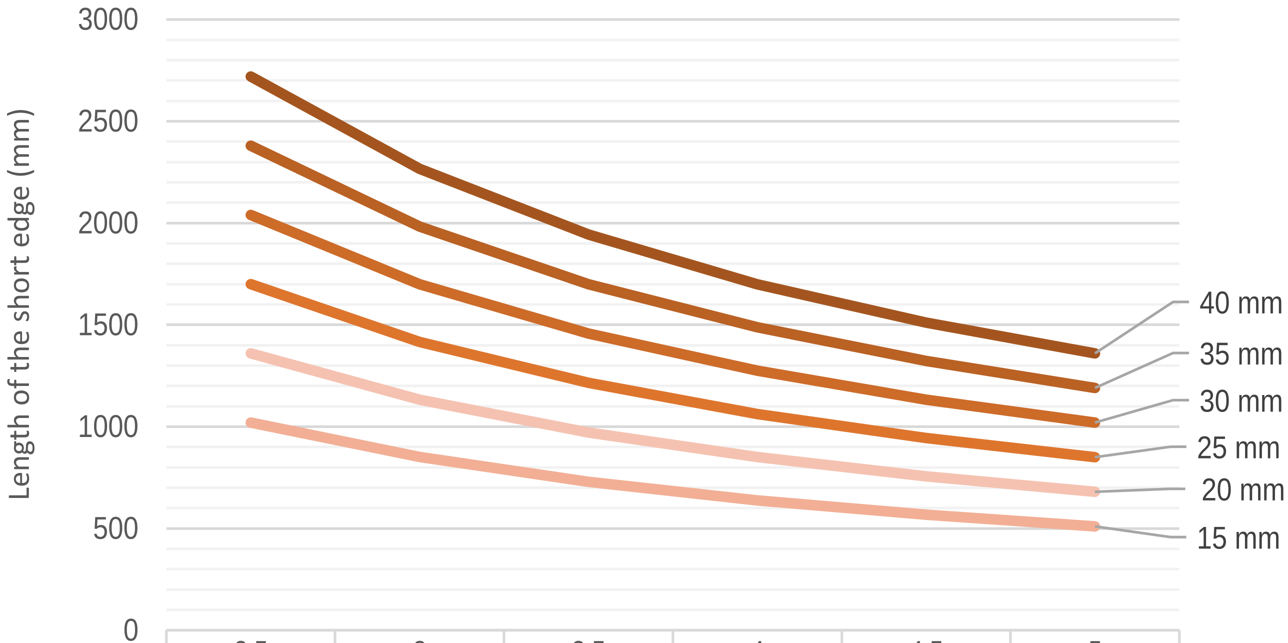
Architects can demand certain aesthetic features, like specific colours for facade elements. Therefore, the colour availability of structural sealant could be an important aspect.

The currently used 2-part sealant SG-500 is available in black and grey. It has been possible to request special colours, but latest developments are that Sika withdraws this availability because of warranty issues. 3M VHB tape is also available in black and grey.

Gasket or weather sealant

To prevent exposure to moisture and solvents, 3M advices to use a weather sealant to cover the tape. Though, it is also possible and allowed to use a gasket in stead of a sealant. This has been requested at the technical deparment of 3M and is also stated in the 3M Technical Bulletion, 3M VHB Durability.

It states that after splashes or incidental contact with solvents such as fuels, alcohols, adhesive removers like MEK, and even weak acids or bases, no affect is measured on the bond performance. Only after continuous submersion in harsh fuels or solvents is softening of the adhesive/foam experienced. Note: While VHB™ Tape products may withstand occasional contact with these types of chemicals, continuous exposure is not recommended.



	2,5	3	3,5	4	4,5	5
Tape 15	1020	850	729	638	567	510
Tape 20	1360	1133	971	850	756	680
Tape 25	1700	1417	1214	1063	944	850
Tape 30	2040	1700	1457	1275	1133	1020
Tape 35	2380	1983	1700	1488	1322	1190
Tape 40	2720	2267	1943	1700	1511	1360

Wind load (kPa)

Figure 7.1.3 - Overview of possible panel dimensions for a specified wind load and tape width. (own ill.)

The use of a gasket in stead of weather sealant ensures a clean production process, which is already possible with the tape. If weather sealant will be needed, it would be more logic to use a structural sealant to bond and seal in one operation.

Furthermore, references for structural glazing projects with VHB tape, provideded by 3M, are included in appendix 5

7.1.2 **Production proposal and comparison**

To compare both production processes of a design with structural sealant and the new design with tape and a sub-frame, both processes have been observed and researched in practice.

For he production process with structural sealant you can read the findings in this in paragraph 4.3.4. For the production process with VHB tape, I organised a meeting with 3M, which is one of the producers and suppliers of this kind of tape.

This meeting is arranged to do some prototype testing, get a feeling on how to work with these tape, what could be an efficient build order and check for the feasibility of certain production proposals.

This is a logical step, also following from the 3M system qualification process which they suggest. Feasability check has been done in paragraph 7.1.1. Substrate testing has been discussed with Martin Breemer (Technical Service Engineer, 3M) and there should be no problems with glass, anodized aluminium and Sikasil weather sealants. These weather sealant might be needed for a feasible production process, where tolerances need to be taken into account. For example it might be needed to seal the corners of the sub-frame.

3M has tested multiple types of weather sealants in combination with the VHB tape in a long term exposure test and dynamic adhesions tests before and afterwards this exposure. Results of these tests can be requested at 3M.

Production proposals are tested by assembling prototypes in different order. Options are:

- Sub-frame installation and bonding afterwards
- First bonding of sub-frame to the glass, second installation of the sub-frame with glass.
- First application of tape to the aluminium.
- First application of tape to the glass.

Pre-treatment and cleaning are similar to bonding with structural sealant so this will not be discussed here.

Pictures of the meeting are shown in figure 7.1.5. Tape is easily applied with a special applicator which ensures perfect alignment and clean, straight tape edges. After this, the liner is removed and the elements are combined.

Measures need to be taken to ensure correct alignment of glass and frame. This can be ensured by using some kind of guidance, which should be designed project specific.

After this, most reliable method for pressure appliance is a special pinch-roller. This roller is also a clamp. This can be clamped to the composition and indicates when enough pressure is applied. After this, the roller can be rolled along the edges, with the guaranteed correct amount of pressure.

Yet, this roller can not be used in case two glass panes are adjacently bonded on a centre mullion. Also bonding on glass will have a consisted bonding process, independent on the design.

For this reasons I conclude that it would be best to have a separate production line that assembles the sub-frames and installs this on the glass panes. At the end of the lines these can be combined with the main element and fixated with the screws from below the element in an elevated position. Also the gasket can easily be installed in this way.

A separate production line will also give more flexibility in the process, where sub-elements can already be finished beforehand.

Finally, figure 7.1.6 shows it is better to first apply the tape on the glass. This reduces the amount of visible air encapsulations. There will be some invisible air encapsulations on the aluminium side, but these have been taken into account by 3M in the design strength.

Points of attention:

- Build order is highly important for practical and also to a lesser extend for aesthetic reasons.
- Low tolerances need to be taken seriously. With structural sealant it is much easier to cover irregularities or small errors in alignment.

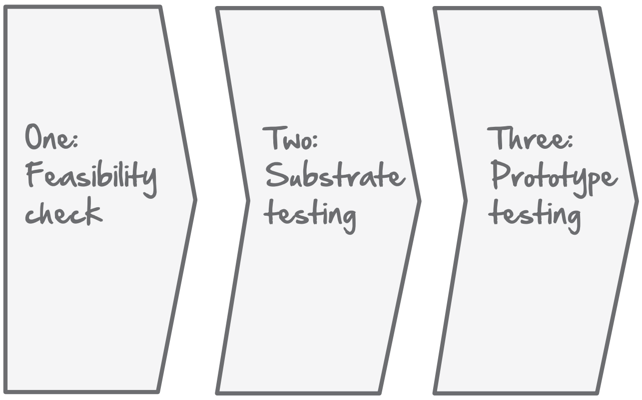


Figure 7.1.4 - The 3M system qualification process, which is also used for this evaluation. (own ill.)

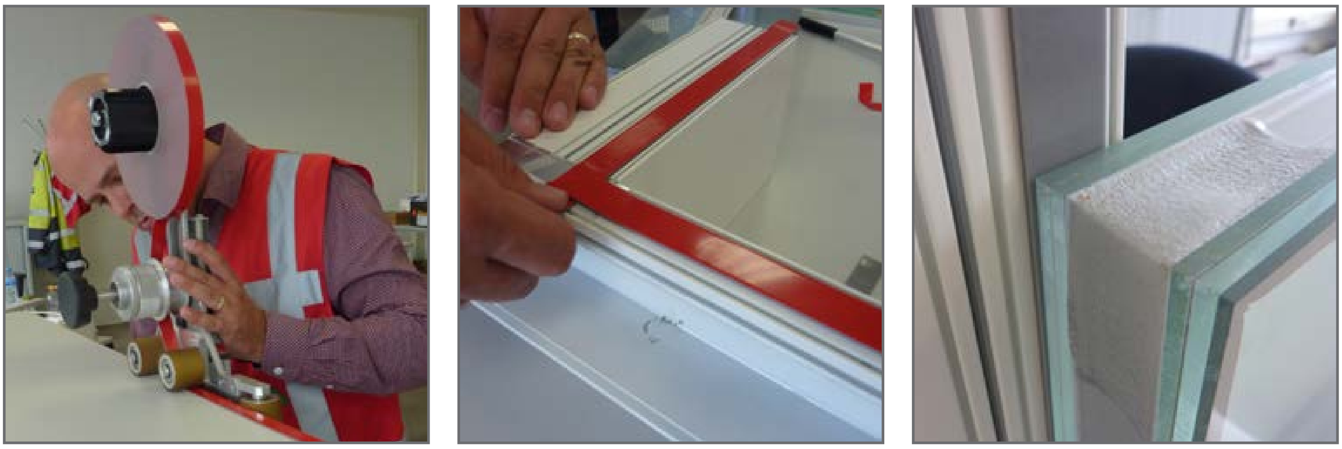
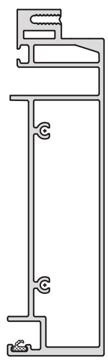


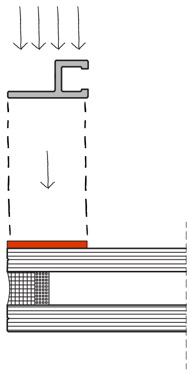
Figure 7.1.5 - Meeting with 3M at Scheldebouw and prototype building (own ill.)

Figure 7.1.6 - Minor air encapsulation which are rarely visible. Wider tape will give more risk on air encapsulation. First application of the tape on glass, decreases the chance on visible air encapsulation. Right picture is a hand presser with pressure indicator (own ill.)

Production



[1] Element frame is assembled in production.

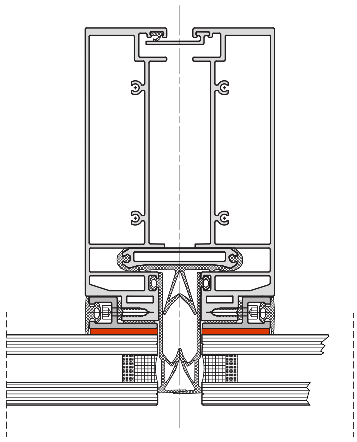


[2] Tape is applied to the glass. Frame parts are accurately placed and pressure is applied

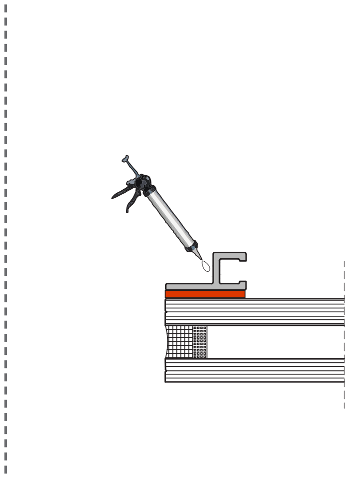
These pages illustrate the proposed production and replacement process. As illustrated, in production the sub frame is installed prior to the bonding. This ensures an easy process, where after the installation of this sub-frame the process is just like the current process, except for the tape in stead of the 2-part silicone sealant.

An issue with the VHB tape is the placement of the glass. The glass needs to be accurately positioned in one go. If else, the glass will be directly bonded to this tape in a wrong position. Measures need to be taken for this, like the use of temporary spacers for maintaining glass alignment.

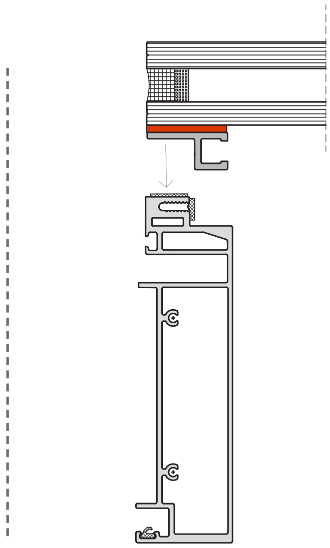
Replacement



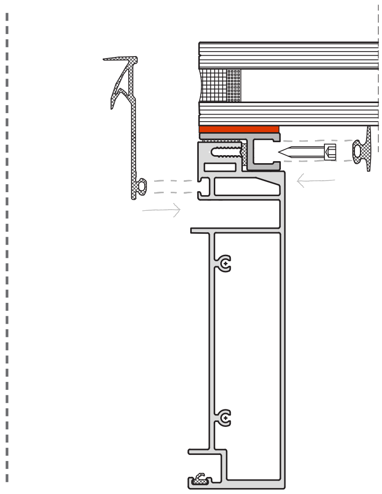
[1] Facade with a damaged glass pane.



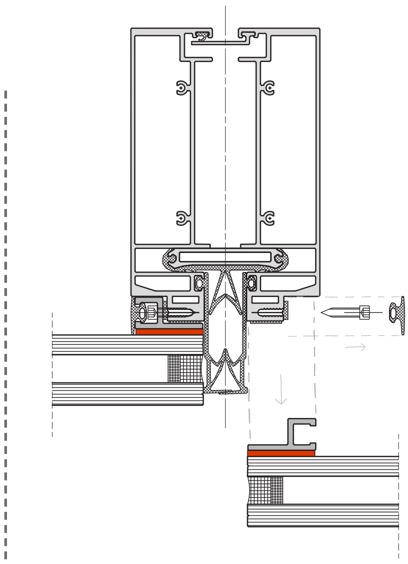
[3] Corners of the sub-frame are finished and sealed.



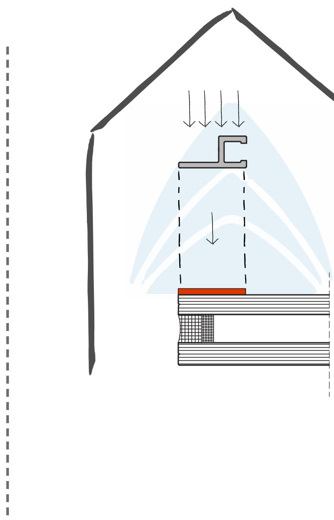
[4] Sub-frame with glass is placed in the element frame.



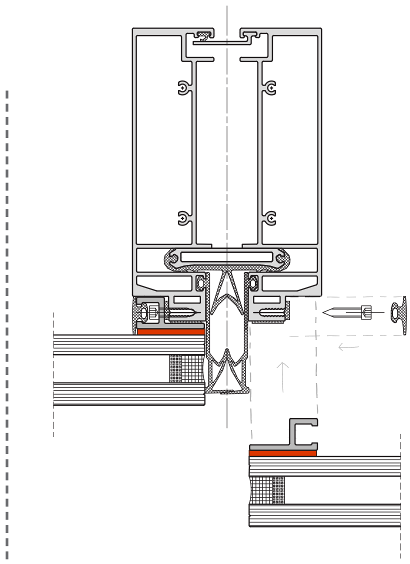
[5] Fixation of the sub-frame and installation of the gaskets.



[2] Damaged glass pane is easily removed by loosening the screws on the inside.



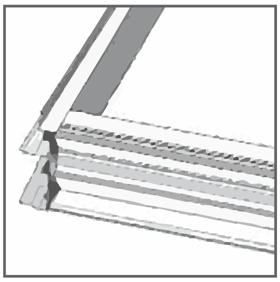
[3] A new glass pane is factory bonded to a new subframe.



[4] On site installation of the new element by placing and fastening the screws.

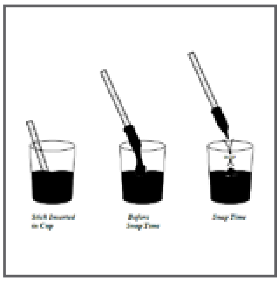
Overview production comparison of a standard frame, bonded with SG-500, and the new design proposal with the multifunctional subframe.

Sikasil SG-500
2-part silicone sealant

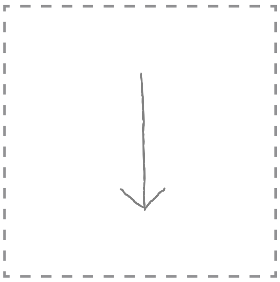


Frame assembly.

Surface preparation.

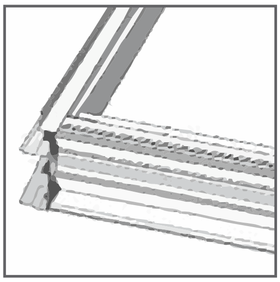


Production tests for the quality assurance of 2-part silicone sealant.



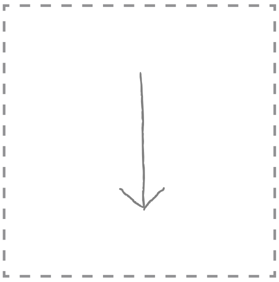
Placement of glass on frame.

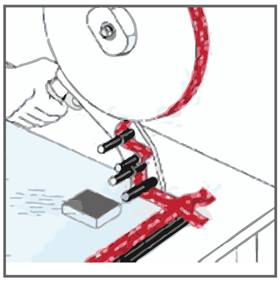
New design with
3M™ VHB™ Tape



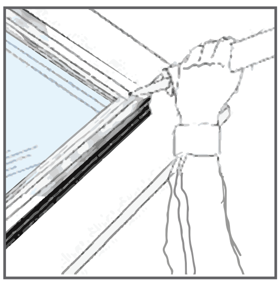
Frame assembly.

Surface preparation.

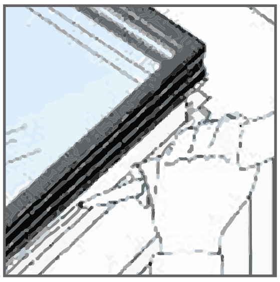




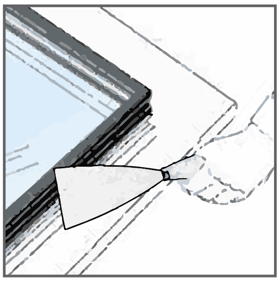
Tape application



Placement of sub-frame on glass and sealing of the corners.



Application of structural sealant



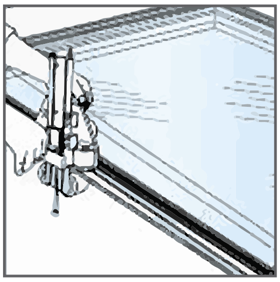
Tooling. Applying gentle pressure to assure maximum contact and remove of excessive sealant and cleaning

24 hours

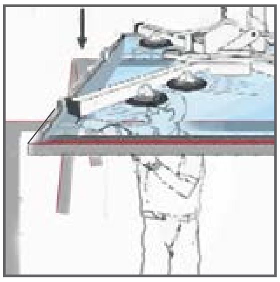
Storage

72 hours

Installation



Pressure appliance



Joining and fixation of the sub-frame and element frame in raised position.

Installation of gaskets.

Immediate handling strength. Storage is directly possible.

Storage

24 hours

Installation

For the VHB tape at room temperature (21ºC/70ºF), approximately 50% of the ultimate strength will be achieved in 0 to 20 minutes after pressure application, 75% after approximately 1 hour, 90% after 24 hours and 100% after 72 hours. In some cases, bond strength can be increased and ultimate bond strength can be achieved more quickly by exposure of the bond to elevated temperatures (e.g. 50ºC/122°F) or when the surfaces are either abraded or primed. In these cases ultimate bond strength may be achieved in as little as one hour. (Source: Technical Guide, 3M)

This is compared to the curing time of SG-500 in figure 7.1.7. This learns us that faster put-through times are possible with VHB tape. This can be a large benefit when there is time pressure, which is often the case in this business. By faster put-through times, penalties can be prevented.

Main differences, following from this production comparison can be divided in improvements and challenges by the use of VHB Tape.

Yet, for every way of production a certain amount of experience needs to be build up. 'Trial and error' are part of every new production line set-up. Therefore, challenges are there to be solved. Also with the set-up of the 2-part silicone sealant production line there have been challenges that are solved by experience in time.

Improvements are:

- More flexible production process by having a separate subframe and glazing assembly.
- No need for production tests
- No hard to reach places for the appliance of adhesive. With tape you can still stand 'inside' the frame. For sealant the glass pane already needs to be in its place and therefore the applier needs to kneel on top of the glass pane, bend over, to apply the sealant.
- No mixer open time, which is a distraction in process. Work is abandoned to open the mixer and let flow the sealant into the wastebin to prevent clogging.
- Immediate handling strength. Glazed units can be handled immediately and stacked for storage or shipment.

Downsides:

- The extra step: installation of the sub-frame.
- Investment is needed (time and money) to master a new production technique.

The mastering of this new production technique contains some challenges:

- Frame assembly within the tape tolerances
- Correct glass allignment
- Pressure appliance

For the glass alignment it can be possible to use a kind of sliderblocks that are slid upon a lid or an edge of the frame.

For projects with large series of the same elements a vacuum table could be used for the pressure appliance. This is a relatively cheap machine, which can be customized to the size of the elements. Rubbers are placed on location of the profiles. By placing the element on this rubbers a vacuum can be used to apply a negative pressure (figure 7.1.8).

Step	Conditions	2-part SG-500	VHB tape
Initial curing and adhesion build-up	Store units stress-free in horizontal position	< 1 day	Immediatly, 50% in 0 - 20 min
Strength-build up and increase of adhesion	Store units with dead load support vertically	3 days	75% in 1 hour
Further strength and adhesion increase	Transportation of units vertically with support	4 days	Immediatly, when out-side temp is > 15 °C
Ultimate strength and adhesion reached	Installation of elements	> 7 days	24 hours (90%, after 72 hours 100%)

Figure 7.1.7 - Curing times for respectively SG-500 and VHB Tape. (own illustration, according to technical specifications Sika and 3M, 2014)

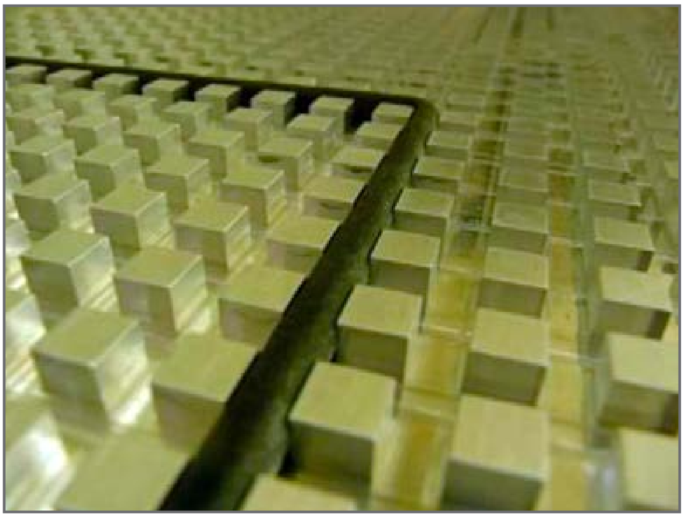


Figure 7.1.8 - Adjustable vacuum table that could be used for applying a negative pressure (technocnc.com, 2014)

7.1.3 **Waste / sustainability**

To do a fully fledged comparison on waste, an identification of the amount of waste is needed. For the 2-part silicone sealant, there where no known figures for this. Therefore, I assesed a measurement in the production faculty.

This has been done by measuring the volume of the joint that is applied in one day and weighing the waste bin that is used for sealant disposal.

Detailed cacluation for this is included in appendix 6.

Sikasil SG-500 2-part silicone sealant

It was estimated that the amount of waste for the Sikasil SG-500 could be significant, because of the mixer open time of 6 minutes and the tooling. The mixer open time means that when no sealant is applied in a time, longer than 6 minutes, the nozzle must be opened and the machine has to be flushed.

Tooling is the appliance of light pressure on the sealant and the removal of excessive sealant.

The measurement, which is elaborated in appendix 6, gave a result of 24 kg waste in one production day. In this day 32,4 dm^3 of joint has been applied, which is 44,6 kg. Together with the sealant, used for the test samples, which is about 0,6 kg, a total of 69,2 kg is used in one day. More than 35% of this is not used for the actual joint.

3M™ VHB™ Tape

Less than 5% waste because of more accurate forecasting of materials. This, because of easy calculation of the total bonding length, no risk of clogging and therefore wastage of product during down time and the accurate appliance. Figure 7.1.10 illustrates this appliance. The overlap that is used to create a perfect corner finishing is the only waste there will be, together with insufficient lengths on the end of each roll.

Conclusion

More than 35% of sealant waste, compared to 5% tape waste, seems significant. Yet, as can be red in the next paragraph, the material cost of silicone sealant is a lot lower than the tape. Therefore, also when the waste is accounted, the material cost for a silicone joint in stead of a tape is a lot lower. Results are visualised in figure 7.1.11.

Environmental impact of both products are unknown and would require further research, where both suppliers do not provide information on this subject. Yet, less waste is not only sustainable but also financially profitable.

More and more procurements are not only evaluated on financial level, but also on the level of sustainability. This is often done by the use of Green Building Certification Programs like BREEAM, LEED and HQE. The amount of sealant waste (without any danger of environmental contamination), does not directly influence the score on these certification programs, but it can be a selling point if you reduce the amount of waste by a significant amount. The measurement of sealant waste on one production day for one project resulted in 24 kg of sealant waste. For tape this would be as little as 0,3 kg. (See appendix 6 for the calculation.)

Additional note: the Sikasil SG-500 can be disposed as normal non-chemical waste when mixed. Yet, there might be situations where the sealant is not properly mixed and still disposed as non-chemical waste.

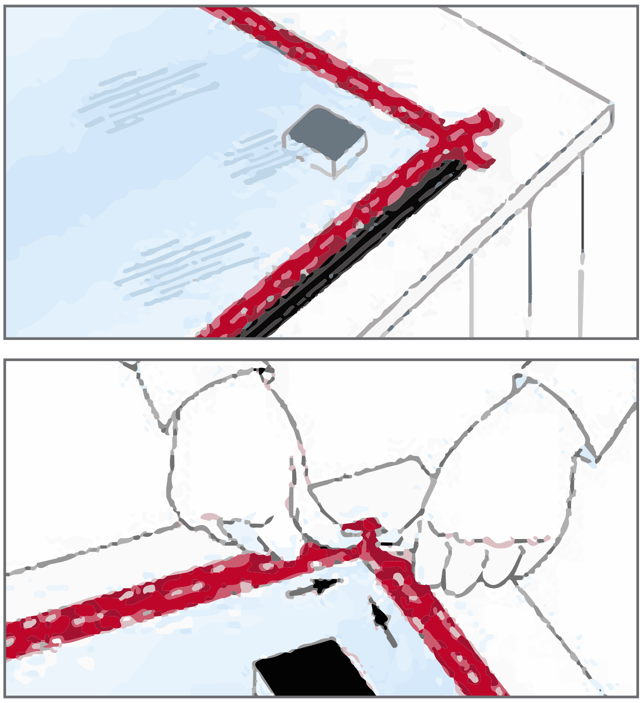


Figure 7.1.9 - Flushing of the mixer / pump and the sealant before tooling illustrate waste. (own ill.)

Figure 7.1.10 - Tape, before and after finishing. Only the overlapp is wasted. (own ill.)

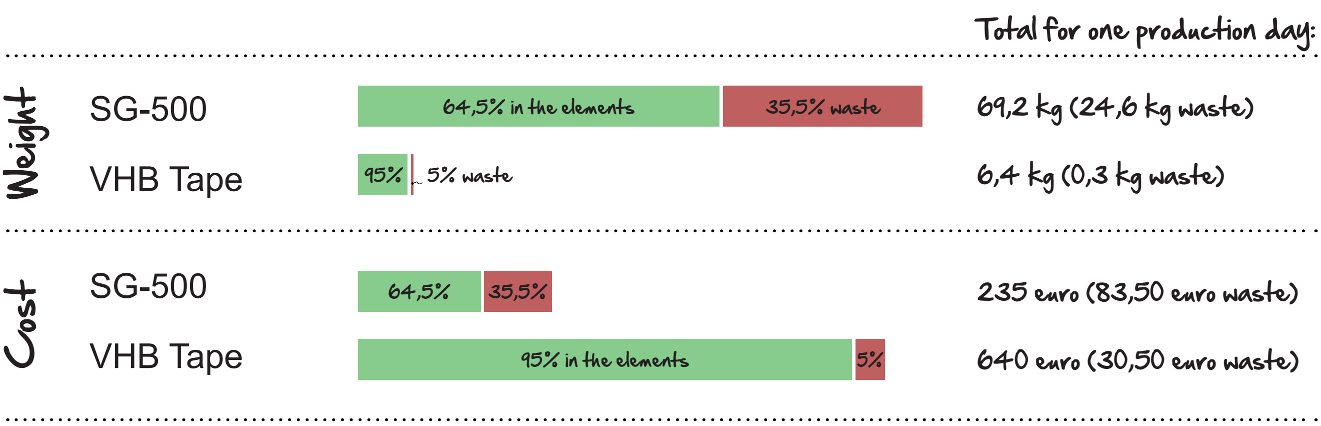


Figure 7.1.11 - Visualised calculation results. Typical for a usual production day of around 12 elements. (own ill.)

Figure 7.1.12 - Measurement of waste: Content of waste bin on one production day, weighing of the waste and the production list of that day. (own ill.)

7.1.4 **Costs**

Now the amount of waste is determined, an extensive cost calculation can be made.

The cost calculation is partly done by own research in the material costs and complemented by the experience and knowledge of Rene Dautzenberg (budgeter at Scheldebouw Heerlen). With his experience it was possible to estimate both material costs and cost of manpower per linear meter.

Actual costs of the SG-500 are requested from the logistics department and the cost of the VHB tape are requested at 3M. Note that the price for the SG-500 is a heavily bargained price, due to the Permasteelisa Umbrella contract. The price for the VHB tape is a non-bargained regular price. Therefore, also a calculation has been made for a version with a discount on the VHB tape of 25%. According to Rene Dautzenberg this is a usual amount of discount for bargained prices on bulk.

For this evaluation four situations are calculated:

Situation 1: Basic system with SG-500
Situation 2: Basic system with VHB tape
Situation 3: Quaternario system with SG-500
Situation 4: Sub-frame system with VHB tape

By this, comparisons are made purely on the way of fixation (structural sealant or tape) and on two system where replacement and traceability is possible. Therefore, two situations with equal properties (benefits) are compared in price.

The calculations are collected in appendix 7. Results are visualized in figure 7.1.13. As can be seen, the results are visually divided in cost for manhour, material and the additional elements as the quaternario system or the new sub-frame system. In this, also additional costs for stepped glazing with the Quaternario system is taken into account. These additional costs are highly dependant on the project size and amount of purchase. Yet, for a normal situation the square meter price of stepped glazing can be 250% higher than regular glazing. This ratio in prices has been requested at Saint-Gobain on june 20th 2014. For a large scale project (large batches) it is expected that this can be lowered to 150%.

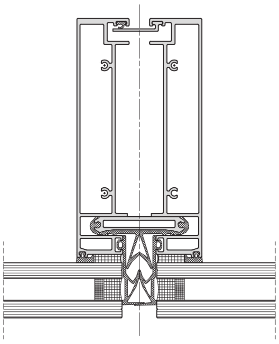
For the situations with VHB tape, also a calculation has been made with a bulk discount on the tape of 25%. This is to make a fair comparison, yet, this discount is not granted but according to Rene Dautzenberg these can be expected when having large purchases.

As can be seen, the manhour costs with the VHB tape is significantly lower. This is expected because of the easier appliance with the available tools. Also there is no need for the appliance of masking tape and/or cleaning.

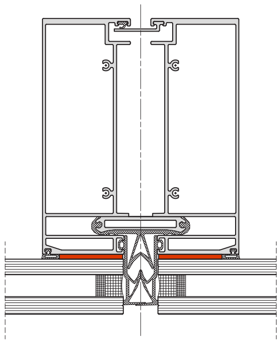
It can be concluded that the VHB tapes gives a lot of options in optimizing the structural bonding process. The higher material costs can be compensated by a faster production process. The variant with the new sub-frame doubles the costs, compared to a basic system with VHB tape. Yet, a comparable variant with SG-500 that is used on this moment (Quaternario system) is much more costly. This system also requires the extra elements and steps in the production process. In addition to that, the special stepped glazing makes it even more costly.

Compared to the basic system with VHB tape, the sub-frame system is relatively costly. Yet, in comparison to the Quaternario system it is a feasible option for replacement, tracing and optimization of the production process.

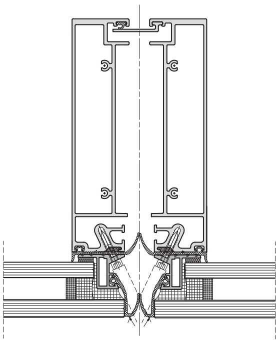
It is complicated what these prices per meter mean on project level. Therefore a case study will be made in chapter 7.2 to have a comparison of the different aspects on project level.



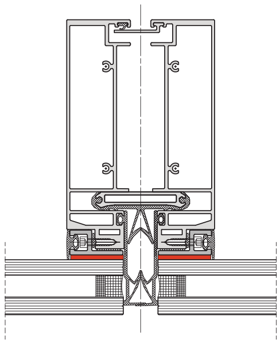
Situation 1: Basic system with SG-500



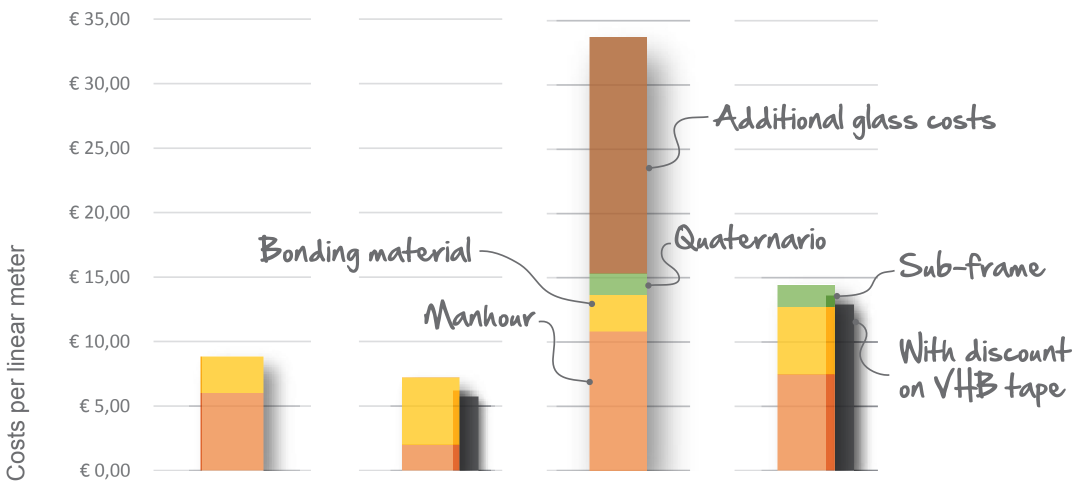
Situation 2: Basic system with VHB tape



Situation 3: Quaternario system with SG-500



Situation 4: Sub-frame system with VHB tape



/ linear meter	Situation 1	Situation 2	Situation 3	Situation 4
Manhour	€ 6,00	€ 2,00	€ 10,83	€ 7,50
Bonding material	€ 2,82	€ 5,23	€ 2,82	€ 5,23
Quaternario / Sub-frame material	-	-	€ 1,70	€ 1,70
Additional glass cost (stepped)	-	-	€ 18,40	-
Tape discount	-	€ -1,49	-	€ -1,49
Total:	€ 8,82	€ 7,23	€ 33,75	€ 14,43
Total with discount:	-	€ 5,74	-	€ 12,94

Figure 7.1.13 - Cost comparison results. See appendix 7 for the detailed calculation. (own ill.)

Except for the direct financial benefits, there can be long term financial benefits with VHB tape. These can not directly be calculated, but because of a shorter lead time which will be discussed in the next paragraph, money can be saved.

For example, together with the significantly quicker curing time it will be easier to achieve deadlines and avoid penalties.

7.2 Procedure aspects

7.2.1 Compliance to the ETAG

In the research, the following remarks have been made on the current procedure in combination with the ETAG 002:

Due to the difficulty of quality control during on site repair, a factory-glazed replacement frame must be installed. Therefore, it is necessary to make an assessment and to comment on the ease of future replacement. And:

Tracing on each batch of anodised aluminium (e.g. group of aluminium profiles anodised in the same bath at the same time for one day maximum)

The new design design supports the compliance to these statements by combining the properties needed for this compliance into one element. This relatively lowers the cost, which is normally the reason not to comply to these directories.

Except for the better compliance itself, there will also be less project risk and an easier process for Scheldebouw. Like mentioned in paragraph 5.4, by using one batch for the bonding area, no tracing of the profiles has to be done during the project. This results in less paperwork and an easier way of quality assurance.

7.2.2 Process flow comparison

A comparison of the regular process flows of both suppliers resulted in figure 7.2.1.

It can be concluded that both process flows are build up in the same way. Both projects contain the following key elements:

- Assisted initial projects assesment.
- Technical assesment by the supplier: compatibility checks.
- Project specific recommendations and procedures.
- Assistance in fabrication: instructions and training (followed by a training certificate).
- Daily quality and process control.

Support, assistance, recommendations and training are usefull in products, where the supplier is the expert of its product.

Daily quality and process control will be different for both variants. Where the SG-500 will need the preparation and testing of samples, the tape is factory ready, withc consistent properties. Therefore, the main improvement in this process flow lays in step 6. Yet, there will still be quality and process control on the appliance, which is the same for both.

In the end, what kind of warranty 3M gives and on which conditions has to be agreed upon between the 3M sales department and the staff of Scheldebouw.

Improvements in the process flow are:

- Unitisation (no material specific tests)
- No production tests (tape has consistent properties)
- No tracing of the profiles (one batch)

These improvements will result in a shorter put-through result, which can mean financial benefits and more flexibiliity.

Sikasil SG-500		Performed by
Design Phase		
Step 1	Project manager (customer) or responsible Sika persons send all relevant design details (drawings - including bonding situation) and project details (wind loads, max. temperatures, glass/panel sizes) to Sika (ch-fcc@ch.sika.com or Fax +41 58 436 5407) for inspection	Customer
Step 2	Sika - checks joint details - checks joint dimensions - assesses the materials used - recommends the correct sealant for these applications based on all the details known	Sika
Test Phase		
Step 3	Project manager sends all substrates and ancillary materials to Sika for testing. The number and sizes of the samples are described in the leaflet "Project Submittal Information"	Customer
Step 4	Sika conducts the following tests: - Adhesion tests to all substrates (glass, facade panels and frame materials) - Testing compatibility with all materials that our adhesives and sealants come into contact with - Based on the results, Sika makes recommendations for cleaning and, if necessary, priming the surfaces. The results and recommendations are summarized in a laboratory report. A guarantee can only be given if all submitted samples are compatible and the adhesion is sufficient	Sika
Application Phase		
Step 5	Sika instructs the applicator on all matters of the applications: - Adhesive application - Quality control during application - Help with machine application Sika also helps with the correct application of its products (e.g. weathe-rsealing) on site. After successful instruction, the customer receives a training certificate from Sika	Sika
Step 6	The customer applies the Sika products as instructed and diligently carries out the recommended quality controls during processing. The quality control is documented on the appropriate Sika forms. If desired and agreed, the customer sends the test specimens to Sika. Mechanical properties are measured in one of the FFI Competence Centers	Customer
Warranty Phase		
Step 7	Once application of the products is complete, the customer sends all documents to Sika for inspection	Customer
Step 8	Based on the umbrella contract, Sika provides an extended warranty on the sealant, where consequential damage by failure of the sealant is included	Sika

3M™ VHB™ Tape		Performed by
Design Phase		
Step 1	Initial contact and project review with 3M Sales Representative. Fill out of a Customoer Warranty Request Form. Project drawings and a Project Initiating form is submitted to 3M for review	Customer
Step 2	Initial project assesment by 3M. Checks joint details, dimensioning and asseses the materials used	3M
Test Phase		
Step 3	Materials submitted for adhesion testing. Representative glass and frame samples have to be used for this	Customer
Step 4	Based on testing on the samples 3M completes project specific technical report. 3M fills out project specific documents: - Standard operating procedure - Required application procedures - Application description and material list Based on these, the project is approved by agreement on these project specific requirements and recommendations	3M
Application Phase		
Step 5	3M representative provides project specific training to fabrication personal prior to start of production. Training aplication document is signed by fabrication personel	3M
Step 6	Customer performs daily quality and process control procedures and documents on a production control sheet. 3M representative conducts production audits and documents.	Customer
Warranty Phase		
Step 7	Once completed, the documents must stay available in the event of a warranty claim or inspection for review by 3M and/or the local official	Customer
Step 8	? Warranty needs to be discussed with a representative	3M

Figure 7.2.1 - Process flow comparison. (own ill.)

7.2.3 **Warranty**

The main reason for Scheldebouw, not to use the 3M VHB Tape is on this moment a warranty issue.

As a group, Permasteelisa has an ‘umbrella‘ contract with Sika. This umbrella contract has financial benefits. For example, as a group they can get a discount if they purchase more than a certain amount of these products.

Besides these financial benefits it was also possible for the Permasteelisa Group to work on a procedure, together with Sika, to be able to get a warranty from Sika on the total structural bond and not only on the sealant itself. This means an extended warranty, where more than only the structural sealant will be remunerated in case of failure by the cause of Sika.

In the case of 3M, normally it is only possible to get a warranty on the tape itself. In other words, they will refund the tape or give you new tape in case there is a problem/failure with this tape. In agreement and under certain conditions it is possible to get a warranty with a refund of a maximum value of 5 times the tape value. Yet, the tape value will not even be 1% of the total project cost (Source: Rene Dautzenberg, budgeter at Scheldebouw Heerlen). Therefore, this is expected not to be a sufficient warranty system for the scale of projects that Scheldebouw executes.

This is a complicated issue, that is influenced by a lot of factors. As mentioned in chapter 5, an improvement like this will as for a whole new warranty system with new contractual relationships with new suppliers or an ‘automotive‘ like system where the product for fixation is trusted by tests. In that case no extensive warranty system would be required. As said, it is expected that this will not be a sufficient warranty system for the scale of projects that Scheldebouw executes.

Next step in the process would be to perform consultation and discussion on high management level, where certain agreements can be made on a warranty system wherein both parties will feel confident.

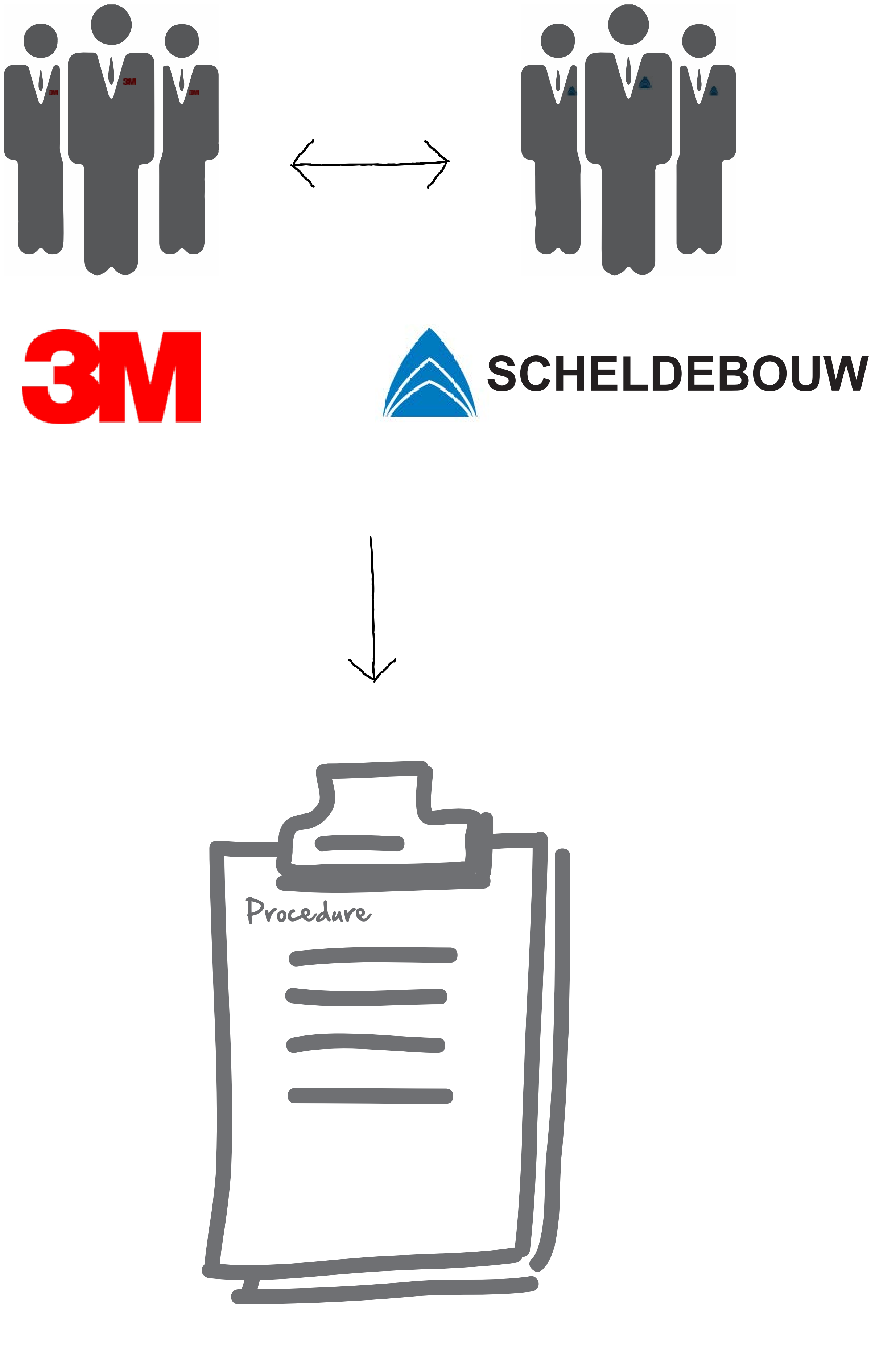
It can be expected that 3M is willing to put their effort in this to gain a new client. Also 3M already puts a lot of effort in assuring their quality by long term tests and experiments with this tape since the 1990’s. Reports and results of these are widely available on their website.

Therefore, they should have enough proof that their product is performing as expected and be able to give this warranty.

Yet, in this agreement, human errors and other varying conditions should be excluded as uncertainties. In other words, a system is needed where all risk factors need to be excluded to be sure the error is in the tape to get a warranty on this tape.

Therefore, a procedure will be needed like that is used with Sika on this moment. Though, this procedure can be less extensive because of the elimination of testing of 2-part systems for glass/butterfly, snap time, and mix ratio.

The exact extend of this procedure will need to be agreed upon by both 3M and Scheldebouw.


3M
SCHELDEBOUW
Procedure

7.3 Case study

This case study should present an average size project, primary consisting out of structural glazing. By doing this case study, a full size comparison on project scale can be made.

In consultation with Guido Caubo, 240 Blackfriars has been selected as the project for this case study.

This project consists out of a 15.500 m^2 curtain wall facade. This facade consists out of fully structural glazed panels, glass roof, ground floor retail units and plant room enclosures. The roof has been partially clad with various louver systems and the plant room floors are provided with a 1.500 m^2 plant room enclosure.

The curtain wall detail for this project is similar to the basic system for structural glazing with SG-500, used in this thesis. This makes it an ideal project for comparison.

Based on the project drawings and specifications a comparison will be made. Input for this comparison will be the content of paragraph 7.1 and 7.2, which will be up-scaled to the size of this project.

For this case study, the project will be simplified. The total facade area will be divided by the area of one panel to get an amount of standard panels. Of course, in a normal situation a large part of these will consist out of specials.

Again, four situations will be compared:

Situation 1: Basic system with SG-500
Situation 2: Basic system with VHB tape
Situation 3: Quaternario system with SG-500
Situation 4: Sub-frame system with VHB tape

Situation 3, the Quaternario system, is a system that can be used in two ways. It can be fully implemented in the production, but it can also only be used for replacement glazing. For this comparison the fully implemented option is calculated to compare with the most common system where factory bonded replacement ánd traceability is possible. A situation where the Quaternario system is only used for replacement, costs will be comparable to situation 1.

By this it is possible to make a fair comparison in systems with the same properties. Situation 1 and 2 are basic systems which either use SG-500 or VHB tape for the bonding. Situation 3 and 4 are both situations where factory bonded replacement is possible.

Yet, situation 3 is the currently most used system for factory bonded replacement. Situation 4 is the new sub-frame system in combination with VHB tape, proposed by me as a possibility for the improvement of the structural bonding process.

This case study will show the overall effects of these situations. In this, most interesting will be to see the relation of situation 4, which is my proposal, with the other situations.

The conclusion will show if the new design with the sub-frame system which I propose can be feasible.

240 Blackfriars

SCHELDEBOUW

Architect: AHMM

Developer: Great Rope maker

Contractor: Mace Ltd.

Start production: October 2012

- Project-sum of € 12.000.000
- 15.500 m^2 of curtain wall facade
- Panelsize: 3535mm x 1500mm (5,3m^2)
- + / - 2900 panels
- Bonding joint length of 29.203 m

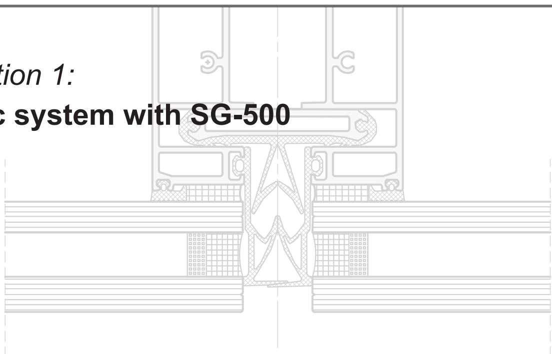
Full size comparison, based on 240 Blackfriars, London UK

Quantitative comparison

Relative costs
(Only bonding and additional elements. Non-bargained price of VHB tape, not with the 25% discount)

Amount of waste
(Only SG-500 and VHB tape waste)

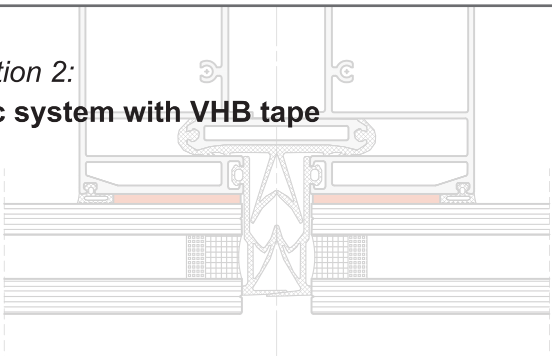
Situation 1:
Basic system with SG-500



€ 257.600 (base price)

5870 kg

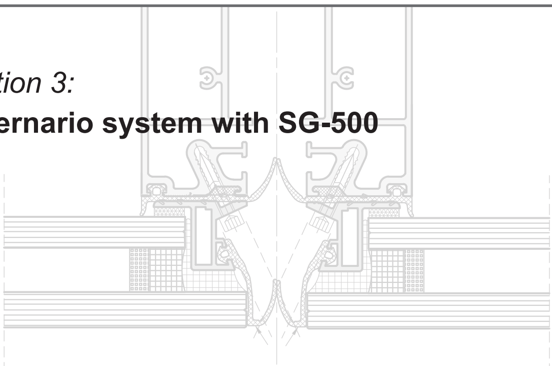
Situation 2:
Basic system with VHB tape



€ 211.100 (– € 46.500)
*With discount a decrease of € 43.500

72,4 kg

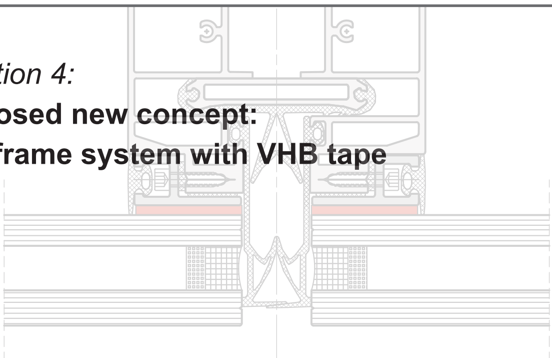
Situation 3:
Quaternario system with SG-500



€ 985.600 (+ € 728.000)

5870 kg

Situation 4:
Proposed new concept:
Sub-frame system with VHB tape



€ 421.400 (+ € 163.800)
*With discount a decrease of € 43.500

72,4 kg

Qualitative comparison

Factory bonded replacement	Traceability	Reduced procedure	Additional comments:
(✓)	–	–	This system can be factory bonded replaced with the Quaternario system. If estimated there will be 2% replacement, this will have an additional cost of 14.500 euro on the Quaternario system for the replacement elements.
–	–	✓	Shows a direct comparison in bonding with 2-part structural sealant SG-500 and VHB tape. Additionally, there will be an improved production process and indirect financial benefits because of a shorter put-through time. This also accounts to situation 4.
✓	✓	–	Currently most common used sytem by Scheldebouw when factory bonded replacement is requested. Mainly expensive because of stepped glazing. Yet, even without taking the glass into account this situation will be slightly more expensive than situation 4. **!** Inferior thermal properties.
✓	✓	✓	With better properties than situation 3 and possibility for a reduced procedure, this situation is significiantly cheaper. Compared to situation 1, there is an increase of +1,4% on the total project sum in stead of +8,2% for situation 3. Yet, situation 4 brings additional benefits above situation 3.

Conclusions on the case study

It can be directly seen that the basic system with VHB tape is a financially interesting system. It could save from 46.500 euros up to 90.000 euros with an expected discount of 25% on the tape.

The new concept I propose is 163.800 euro more expensive than the basic system with SG-500. Yet, this brings the additional benefits of easy factory bonded replacement, traceability , reduced procedures and an improved production process.

Compared to the Quaternario system, which also provides in easy factory bonded replacement and traceability, this is a more feasible system. Reason for this are the higher costs of this system and the inferior thermal properties.

On the project sum of 12.000.000 euro, with situation 4 there will be a cost increase of 1,4%. This will bring the following benefits. These can be divided into direct and indirect financial benefits:

Direct:

- Saves the time, labor, and materials of spacer tape, gasketing, masking, and clean-up.
- Eliminates the time and testing of 2-part systems for glass/butterfly, snap time, and mix ratio

Indirect:

- Unitized production method excludes material specific tests
- Less administration and testing
- More efficient production will result in shorter production periods. This can result in lower costs in manhours other than the workers directly related to the bonding.
- Shorter put-through time can prevent penalties and speed up backorders.

Compared to the Quaternario system this shows that you get a lot of interesting benfits for relatively little additional costs (+1,4% in stead of +8,4% for the Quaternario system).

It is expected that ultimately, costs for systems with VHB tape will decrease when indirect financial benefits will become profitable in time.

Finally, there is a significant difference in waste for a VHB tape project or a structural sealant project: Only 72 kg compared to 5870 kg for the total project.

Yet, this is not directly of influence on any rating system like BREEAM or LEED, but it could be a selling point.

In the end, the most important aspect is to issue a certain degree of quality to the customer. What the customer expects is partly directly requested and partly provided by Scheldebouw.

The only aspect that is directly on influence on the client, except for the overall performance of the facade, is the replacement. If only for the quick factory bonded replacement, this is also possible with the basic system and a replacement Quaternario frame. This will save the client almost 150.000 euro (with discount 110.000 euro). Yet, with the new sub-frame concept this will be easier, quicker and cheaper.

The client has to be willing to pay 100.000 for this future easy replacement. An other option is to see if the costs for Scheldebouw can be further reduced by indirect financial benefits to make up for this while delivering a product with an easier controllable quality.

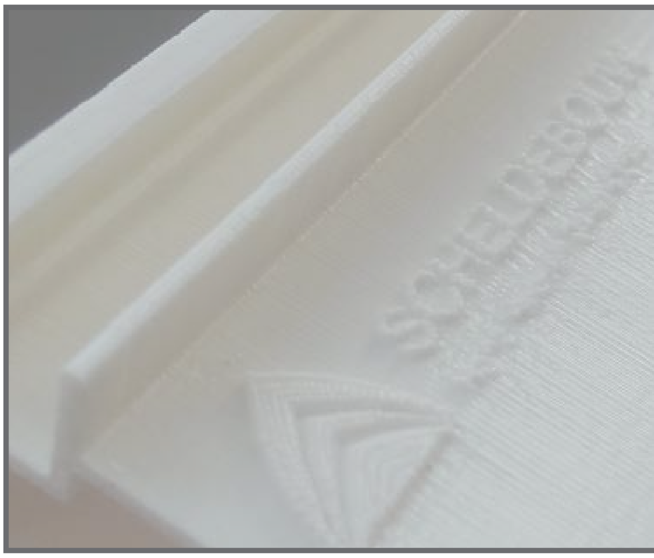
Yet, in comparison with a comparable system which is currently used, like a full Quaternario system, the new proposed sub-frame system is a much more feasible system.

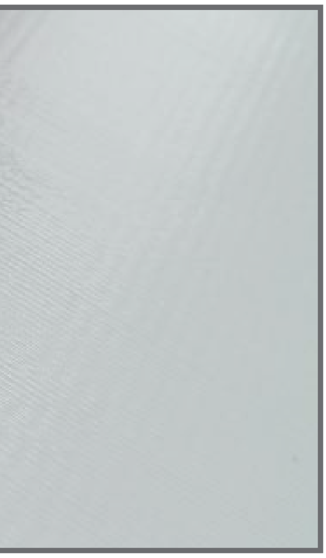
8.0 Mock-up

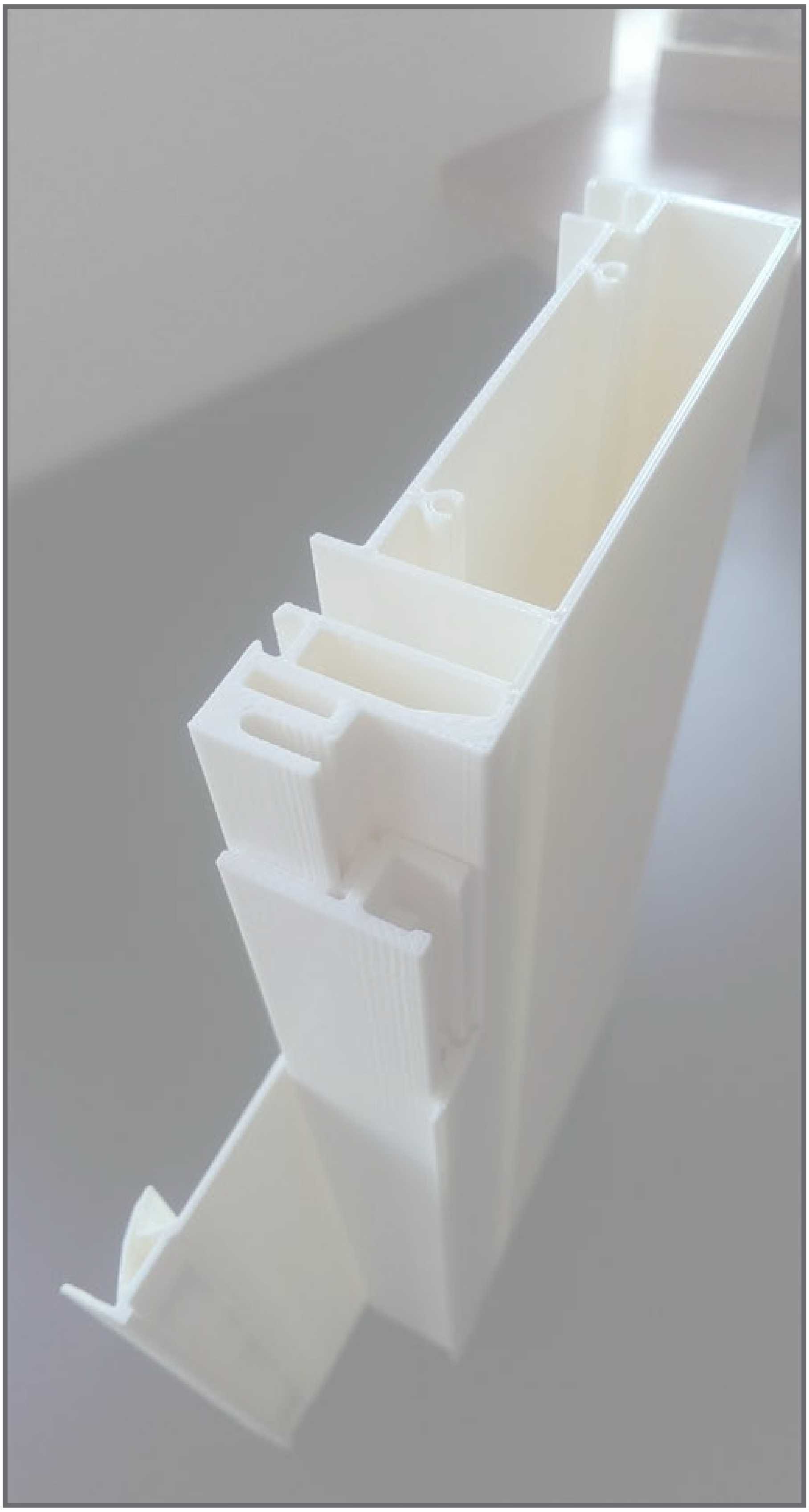
A mock-up has been printed, primary for presentation purposes. To achieve a realistic result, the decision has been made to 3D print the mock-up. Without this it would not be possible to create the actual profile, which would normally be made by extrusion. Yet, this is only feasible in large batch sizes.

After the round-up of this thesis, the mock-up will be finished and painted in the corresponding colours to achieve a realistic look. Also VHB tape will be applied on this element.

In the mock-up you can see the build-up: location of the gaskets, sub-frame and fixation. From this mock-up you can get a representative look on how the facade would look in a project.







9.0 Conclusions

9.1 General conclusions

Starting point for this research was to improve the process of structural bonding. The sub-questions that apply to this paragraph of the conclusion are:

- *How and to what extend can the process be improved, merely on process level?*

- *What reasons are there to change, or to not change, the current process? In other words: What benefits are needed to make a proposed improvement feasible?*

This research concludes that there can be different approaches in improvement. The extend of the improvement is dependant on the approach the company is willing to take. As concluded in chapter 5.0 there are the following approaches:

- When current contractual relations are respected.
- When the current procedure, based on guidelines and Sika is disregarded.
- When the current provider of sealant (Sika) is disregarded or influenced.

As can be red in chapter 5.0, theoretically, largest improvement need large changes, like the switch to another system and/or adhesive product. Improvements in the first approach are little possible because of the demands of Sika to obtain warranty and a certain level of quality. Yet, even if allowed, these demands should not be changed because they are needed to assure the quality of the product.

This process of quality insurrance can be improved by minor improvements and adaptions in design, like the use of a tracer profile.

Most intrusive approach would be to disregard or influence the current relation with Sika. By this, a product can be used that eases the process of production and quality assurance. Conclusions on this approach are in chapter 8.2.

The choice for a specific approach will be influenced by different factors. These can be reasons to change or not to change current procedure / product / system. These factors are:

- Aesthetics
- Performance
- Production process
- Sustainability
- Cost

- Intensity of procedures
- Quality assurance
- Warranty

These factors are evaluated in chapter 7 and therefore assist in the conclusion of the second paragraph.

9.2 Conclusions on the final design

Chapter 6 and 7 gave an answer to the following sub-questions:

- *How and to what extend can the process be improved by implementing a new system and what should these improvements be?*

- *How should the detailing of such an improvement be?*

The design achieved to comply with the challenges that followed from the research: traceability, replacement and improvement of the production process. Concluded from the research, these where the most interesting aspects to improve on.

This is not exclusively the only design that could improve the process, but it is engineered on conclusions that should be used for improvement by design:

- Improvement can be by excluding risk factors, like the mixing of the 2-part silicone sealant. In this case the solution is the VHB Tape.

- Design measures, only for replacement are nearly not feasible, if not obligatory. Therefore, a solution should be found in the combination of multiple benefits in this measure. In this case this is the tracing issue with the replacement.

Evaluation in chapter 7 shows that the proposed new concept with the sub-frame and VHB tape brings significant additional benefits: better compliance to the ETAG and therefore quality control (replacement and traceability), improved production flexibility and shorter put-through times which can mean financial benefits and more flexibility.

In the end, the most important aspect is to issue a certain degree of quality to the customer. What the customer expects is partly directly requested and partly provided by Scheldebouw.

The only aspect that is directly on influence on the client, except for the overall performance of the facade, is the replacement. If only for the quick factory bonded replacement, this is also possible with the basic system and a replacement Quaternario frame. This will save the client almost 150.000 euro (with discount 110.000 euro). Yet, with the new sub-frame concept this will be easier, quicker and cheaper.

The client has to be willing to pay 100.000 for this future easy replacement. An other option is to see if the costs for Scheldebouw can be further reduced by indirect financial benefits to make up for this while delivering a product with an easier controllable quality.

Yet, in comparison with a comparable system which is currently used, like a full Quaternario system, the new proposed sub-frame system is a much more feasible system. Both financially and performance wise.

Implementing this new concept will bring both improvement for Scheldebouw, as for the client, which is a key point in this research.

Investment in time and money will be needed to implement a new concept like this. A new warranty system has to be agreed upon by both 3M and Scheldebouw and prototype testing needs to be done before a concept like this can be implemented.

10.0 Reflection

10.1 Motivation

This graduation project has started with my interest in working with a renowned company, to gain experience in practical work and working with professionals in my field of interest. My personal interest lays in technical aspects and knowledge of new and innovative technologies in architectural and urban design, combined with a focus on sustainable design. This can be in detail, but also on macro scale concepts.

The choice to work with Scheldebouw, came from their interest in a specific subject, namely a graduation research on the structural bonding of glazing in unitized curtain wall façades. This would give me the possibility to work on a specific part in building technology. A specific subject means a more in dept research which I preferred. This to gain experience in mastering a specific subject in a practical environment. The subject of adhesives and sealants is an interesting subject, where the right detail might not be the most important aspect. More important aspects with structural bonding might be the right process, procedures and in that way the assurance of quality. This is accompanied by concerns like time, money and image, which are practical aspects that are currently generally missing in the education program.

10.2 Challenges

During the course of this research several challenges have been faced:

- Since the topic of structural bonding is a quite specific topic it was relatively demanding to obtain all general knowledge on this topic. Yet, it would not be possible to design, discuss and improve the current process without the total understanding of all relations, reasons and ideas behind every aspect that is involved in this process. Therefore, I more or less started at zero with this research. To not influence the result, little to no information about the process has been given directly to me.

  I needed to collect this information by self-study, interviewing and practival experience from being at Scheldebouw. In this, the distance was also a challenge. Both locations of Scheldebouw, Middelburg and Heerlen, required a long commuter time of respectively 3 and 4 hours. Because of this it was a bigger challenge to achieve the level of understanding and experience that was needed, but this has partly been solved by staying in a hotel near one of the locations for a period of time.

- It was also a challenge to understand and work with external factors that can not be easily influenced, like a supplier of a specific product. Because of the practical approach it becomes a challenge to decide what is a good approach. The best technical solution might not be the most feasible solution because of warranty issues and current relations. Yet, this might still be the best solution if this external factor can be influenced and/or changed.

- During the process of working on this research it was a challenge to plan the work. Because of the start at zero, during the process more and more knowledge was achieved. This caused the ultimate goal and result to change. Therefore, later in the process it became easier to plan and work because the end-result became more clear.

10.3 **Relevance and significance of the research**

The value of the this graduation project mainly lies in improving an existing facade system, which is a benefit for the company Scheldebouw. Though, it should be viewed in a wider angle, where there is research in safety regulations, quality assurance and manufacturability. This all is connected to the durability of the product, which is a very relevant topic these days.

In the scientific framework it is interesting to see how in the described process practical possibilities and regulations do not always line up in an efficient way. This might be because of outdated regulations and new developments. Scientific research on this will increase understanding in the misconception between regulations and practice.

Also the process analysis gave general significant knowledge on influences from quality assurance, time, money, production and the actual product.

This research relates with the topic: *Design vs. Development.* Which is a relevant and important topic in almost every industry. This was also the topic of last annual Facade Conference in 2013, held in Detmold, Germany. At this conference was stated there is an ongoing debate between designers and engineers, whether our worldwide innovation comes from artistic aims or from technical possibilities.

This conference was a negotiation between the different positions, like architects, engineers, research institutions and other companies, to start a dialogue about how to improve the innovation process for façades.

In the end, the conclusion was that both design and development are important and have to be considered. Yet, a dialogue between these parties would increase the efficiency of this process of harmony between design and development.

This thesis clearly shows the significance of available technologies that fit the clients needs.

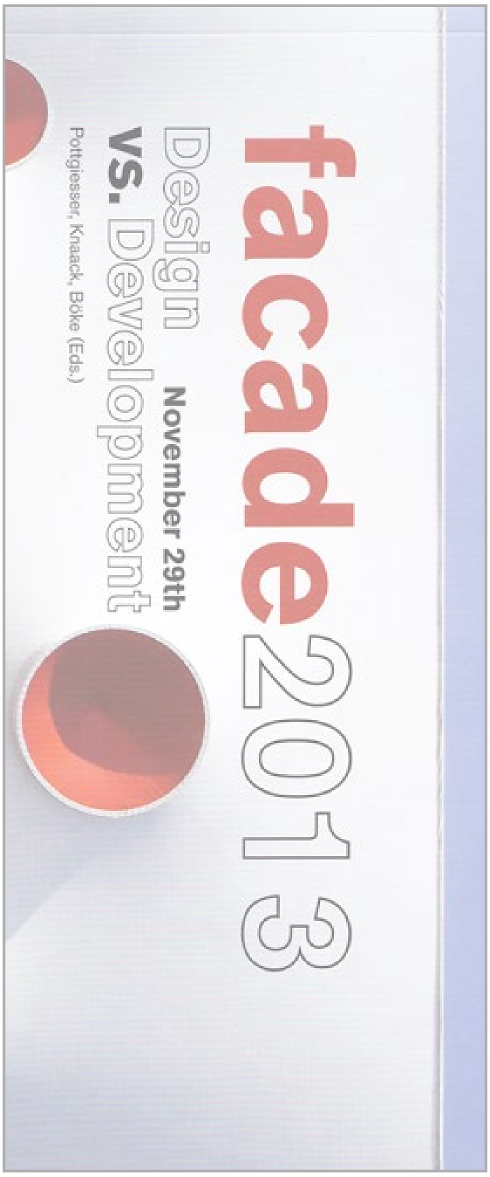


Figure 10.1 - Facade Conference Cover: Design vs. Development (Pottgiesser eds., 2013)

10.4 **Approach versus result**

As stated in the challenges, the topic of structural bonding is quite a specific topic. Therefore it was relatively demanding to obtain all general knowledge and understandment of the total process, prior to be able to improve this process.

Already in the graduation plan the approach/ method this was taken into consideration. The approach contained background literature study, interviews and discussions with the people at Scheldebouw, working in production and quality assurance and evaluation of concepts and ideas by consulting experts in the industry.

This obtainaning of knowledge and practical experience took a considerate amount of time for this research. Yet, also this total overview of process and the reasons behind this process should be seen as a result. Without this, the proposal of an improvement, which is in this case the final product, would not be possible.

As said, at the start of this process planning was a challenge. The project started at zero and more and more knowledge was achieved. Hereby, the direction in research and the ultimate goal could change during the obtaining of this knowledge. This is visualized in figure 9.2.

After obtaining enough information to form a goal it became possible to exactly plan to the final result, which is symbolized by the large 'round-up' arrow. This is the process of processing all obtained information from the done research into the end result.

Figure 10.2 - Sketch process diagram (own ill.)

10.5 **Further research suggestions**

Indirect financial benefits
It is expected that this new concept will bring indirect financial benefits because of process optimalisation. Yet, it is hard to predict these benefits, because they will be on a long term basis and are highly dependable on a lot of uncertain factors throughout the process.

Prototype
Next step in research would be the start of a pilot project. This could be by using a 1:1 prototype. Suggested improvements need to be practically put to test by a physical 1:1 prototype, as a test project that will show the performance of this new concept. Together with this, arrangements can be made with 3M as the tape supplier. Together they need to bring this concept to a feasible solution.

Project specific solutions
Variations on this new concept need to be researched to find project specific solutions. For example, in some projects it will not be possible to reach the glass from the inside because of a closed paparet.

Permasteelisa research
The Permasteelisa Group should use its position as an umbrella organisation to conduct research on the actual amount of failures, what kind of failures and costs as a result of these failures. In this way it will be possible to declare extra costs and/or procedures feasible or infeasible. On this moment this information is not available.

Sika
If the implementation of the VHB tape appears to be unachievable by means of warranty and/or other factors, further research should be by Sika. As the supplier of structural sealant they should supply the client with a practical solution for their clients. The solution they have now is working, but they could do research on other types of bonding that are less risk-full, like a tape or a one component bonding, and therefore need less extensive procedures. Another option could be an easier way to assure the quality of the mixed 2-part silicone.

Figure 10.3 - Possible partners in research (Various)

Toggle glazing
Further research should be conducted on toggle glazing. For this thesis toggle glazing was not an option because it would not improve the process of structural bonding: it would exclude it.

Therefore, this option would not be an answer to this research. Yet, this option should be further researched, because it might be a better option if the implementation in a half-frame system is found to be a feasible option.

Advantages would be:

- No structural bonding, which means less procedures for safeguarding the quality
- Relatively simple replacement

Disadvantages are among others: extra parts and probably a more complex assembly and point loads on the glazing. Yet, it would be interesting and possibly rewarding to conduct further research on this concept.

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Practical sources:

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- Scheldebouw, Heerlen (various contacts)
- Terberg Specials Belgium, Genk (Jong de, J.)
- Carglass Nederland, Eindhoven (Klomp, R.)
- 3M Nederland, Zoeterwoude (Breemer, M)

Technical information Sika:

http://nld.sika.com/nl/solutions_products/ → product for structural glazing

- FFI Sikasil Product Overview
- Product Information Sheets
- Product Data Sheets
- Product Safety Sheets
- Structural Glazing Application Guidelines
- Certificates of ETA Conformity Sikasil
- Calculation Value Sheets

Technical information 3M:

http://solutions.3m.com/wps/portal/3M/en_US/Adhesives/Tapes/Industries/Architechure/VHB/

- *3M VHB Structural Glazing Tape Performance Test*
- *3M VHB Structural Glazing Tape Technical Data Page*
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Appendix 1 Interviews

Elaboration of the individual interviews

Frederic Mussche
February 13th, 11:15.

Studied mechanical engineering in Vlissingen. He is mainly functional in the sales department, which is most active in London. Acts as a link between the market and Scheldebouw. He listens to the different stakeholders: client, architect, advisors and finds out how Scheldebouw can help them in the best way possible.

It is a very client-driven function that needs different attitudes to different kind of stakeholders. His response to the question why to use structural glazing was that most of the time the only reason for this is that the architect wants the appearance of this kind of facade. For all other reasons it might only be more complicated with higher risk than a more regular framing system. By this also his response is that he would always try to dis encourage the use of structural glazing, unless the client or architect really wishes for this.

Problems encountered during processes are often the differences in authorities.

Tapes (3M VHB tapes) have been discussed and used, but have not been further used because no enough warranty would be given. The difference from far away in structural glazing and a framed facade is only a few millimetres and still more risk is taken for this appearance. Though, the facade is flush with structural glazing, without the frames that lay in front of the glazing. Detailing of the rubbers also seems an important aspect.

Conclusion:
States that risk with structural glazing is higher. What kind of risks are these and are they really higher?
The only reason for a client to wish for the use of structural glazing would be because of the flush appearance. This appearance might also be possible with a different kind of detailing, without the mentioned ‘higher risks‘ of structural glazing.

Though, another reason for a client to use a specific type of facade will be the costs. A client might be willing to take more risk if a facade is significantly cheaper.

Keywords:
No preference for SG, preferably a mechanical fixing, more risk with SG

Hans Jansen
February 13th, 13:00.

Studied civil engineering in Delft. He is located in the tender department. They translate the design question into a working design, accompanied by details about costs from all aspects.

Experience as design manager on a project with structural glazing, made calculations on structural glazing and as said now functional on the tender department.

Most important reasons to use structural glazing are the better thermal properties and also the acoustic properties. Furthermore, often there is the aesthetic reason of a flush design.

Most important problems are the (on site) replacement of structural glazing when broken. Also there is the discrepancy of different stakeholders in the projects. There is also more risk involved because of the involvement of adhesives. This risk can be controlled but never fully excluded.

Structural glazing is still fully requested, especially for office buildings. They often ask for floor to floor glazing with maximum transparency. Actually this can also be achieved with framed glazing, but will have a less flush appearance. The environmental question for this type of glazing is fully in development and mainly lies at the glass manufacturers, which keep improving their glass pane properties.

Possibilities for improvement are not necessarily in other materials or shapes, whereas these are just other applications of existing systems. Though, in detail other material might improve the detailing, for example to facilitate movement.

All fixings can be categorised in mechanical, glued or structural sealant fixing. It can be discussed if there should be wished for glued/ sealant fixation because of the risks it brings with them. Most important reason might be the aesthetics, but these might also be reached by other detail of the mechanical fixation. Second comes the cost. A rule of thumb might be: the fewer the parts, the lower the costs, where it is probably impossible to have fewer parts than with structural glazing. Though, it might be possible to improve the competitive position by improving on other parts.

Conclusion:
Mentions the good thermal and acoustic properties for a very simple detail and again the aesthetic reason of a flush design. When developing a detail, with flush appearance and less risk, also these properties have to be taken into account. It might be hard or even impossible to find a detail that is this simple with comparable properties.

Focus should be on finding a way to improve the competitive position in a way that makes up for the costs that will probably be a higher, but kept as low as possible.

Keywords:
Stakeholder analyse, competitive position, is shift in risks wanted, cold bended flush facade.

Gerlof Steenbeek
February 14th, 8:00.

Quality Manager. Has been working on improvement of the structural bonding procedure and its correct implementation, together with Eric Vliegen. This procedure covers the total process from design engineering to projects office, procurement, production to installation. He is the main person in ensuring the quality all over the total process of projects in Scheldebouw. The improvement showed to be necessary, where problems started to occur in different projects around the world. This caused the CEO of Permasteelisa to force an audit team to check all establishments around the world on compliance.

Structural bonding, whereas his vision on this subject is about more than only glazing, has a lot of risks. He explains that there are a lot of individual risks that endanger the total product. A mistake by one person can make the total fail. By his experience, every time there was a problem with a structural bonded facade this was an internal error, mostly at production.

Unfortunately, there is no or not enough feedback from front to back. When a building is finished and in maintenance there might be problems that are not fed back to the original engineering department, where they could learn from their possible mistakes. Also, it might show that there is a significant amount in error that might ask for improvement in process or product. By a better feed back it is possible to indicate if better process monitoring might be viable, economically as well as image wise.

Quality wise it would always be better to just have a mechanical fixation, but sometimes the client or architect does not want this. Also a mechanical security is always more expensive than no mechanical security.

A good reason to use structural bonding is to just use it as a sealant. Sometimes this is used without structural purpose because it has a much quicker curing time than regular sealant. This will speed up the process significantly. This brings us to the point that there is a discrepancy between quality insurance for structural sealant and regular sealant. Structural sealant is bound to strict procedures for testing and regulation, whereas regular sealant is often not tested at all. Though, a lot of money and imago is involved if a facade has a failure in waterproofing. Also for this case the front to back feedback is missing, which could prove monitoring and testing sealant application is viable.

There is a difference in procedures for the ETAG and Sika, which cause questions in what procedure to use. On this moment the ETAG is a more expensive procedure whereas original materials need to be tested. For Sika it is is also possible to use the sealant on random sheets.

An interesting approach in research could be to do a cost-benefit analysis. In this, a difference should be made in stakeholders.By this is should become clear if there are interests for certain stakeholders that can be improved without a significant increase in costs or other disadvantages for other stakeholders.

Conclusion:
Risks are caused by individual persons and their mistakes. Procedures are there, but a failure to comply with this procedure can endanger the product.

There is not enough feedback from front to back. Could this be improved?

It is indeed a remarkable fact that for sealants there is no official procedure. Though, a lot of money and imago is involved if a facade is not water tight. A comparison could be made with a structural bonded facade. What is the difference in risk and costs that makes a strict procedure for structural bonding practicable and a procedure for sealant not.

Again, focus could be on finding a way to improve the competitive position in a way that makes up for the costs that will probably be a higher, but kept as low as possible. In this interview the suggestion came up to use a cost-benefit analysis for this, where all interests for the stakeholders can be analysed and valuated. Interests for certain stakeholders can than be improved without a significant increase in costs or other disadvantages for other stakeholders.

Keywords:
Cost-benefit analysis, eliminate risks, think about the testing of sealant in general, view the procedure with a fresh look.

Boris Kock
February 14th, 10:00.

Has been a project design manager and is now on system design. Also is an unofficial glass expert inside the company. Project experience with structural glazing, mainly at 'The Shard' in London. Is a four sided structural glazed facade, with supports for vertical loads. Totally structural is allowed but will need bigger dimensions for the sealant.

Main reason to use structural reason is from a very practical point of view. By using just a profile and glazing a lot of problems are excluded, like thermal bridges, acoustics and water and air seals. The design and principle can not be any more simple than the current detail.

Problems in process with structural glazing are mostly in the procedure, which is quite complicated, but manageable. In engineering the detail the problems are just like with other types of facade in water sealing and air. Discussion if the edges of the glass should be exposed and ventilated or kept inside the outer layer.

Most important reason and advantage in working with structural glazing is the simplicity in the detail, the performance and also the tolerance. It is very easy to cover slight irregularities in aluminium profiles by just having a bit more sealant. Overall, the most important reason to use it will always be the architect or client that wishes for this type of facade because of its appearance.

Personally Boris sees no reason to not use structural glazing. He explains: There are enough buildings that already have a structural glazing facade. These buildings are still functioning. Of course, there some examples of dysfunction and even of glass panes coming off. In contrast with this, there are also a lot and maybe even more examples of glass mounting frames that are falling from buildings. These are also potentially dangerous. Also, he is fully convinced by the procedure that should be followed for structural glazing. If everything really should follow this procedure and make no errors in production, everything should be fine.

As another example, he states that actually because of this very strict procedure the structural glazed façades should be even safer than framed façades or other types of facade cladding. The process of structural glazing is strictly monitored, in opposite to other façades where it is less monitored if everything is correctly fixed. There are examples of façades where in the production or installation screws have not been applied where they should.

His conviction is also showed in the question if in his opinion a mechanical security should be used. He clearly answers no, plainly because of the reason that it is possible without, and to keep the detail as simple as possible.

Further discussion included the very large safety factor (7 by mind), if tolerance is included or not in guidelines and the large flexibility in production. He sees possibilities in SG for facades that are based on their extraordinary geometry and shape, which should have a very simple and clear detail. Structural sealant is easy to apply, where a screwed system will always need a specific angle and designed location for attachment.

Conclusion:
Focusses on the simplicity and high performance of this detail as an engineer.

States that from a design point of view there are no problems in detailing, except from the problems just like with other type of façades.

Procedure might be complicated, but should guarantee the quality of the facade. Because of this procedure the quality and safety might even be higher than with other façades, where there is less monitoring.

Question is if this is really the case. Is the risk with a structural glazed facade smaller because of this procedure? And for who is this risk smaller? For Scheldebouw the risk might be lower, by placing the assurance to SIKA by following their procedures, but for the client there might still be the risk of flaws in the facade.

Keywords:
Fully convinced by structural glazing, no double systems (security), free-form façades

Rody Rotte
February 14th 11:00.

PPM, or Project Production Manager. In the future this will be called Project Logistics Manager. Is in contact with production through the foreman.

Interesting experience with structural glazing was the project: 240 Blackfriars, where it was not allowed to apply structural sealant on location. Therefore a new detail had been introduced where the inner glass plane was retracted and made place for an aluminium profile (quaternario profile) that could be screwed onto the used aluminium window frames.

Reason to use structural sealant is that it is also easier in production. Rubber seals and glazing beads are often hard to get in place in a neat way, where sealant is easier to apply.

One of the encountered problems was that on the project: One Hyde Park, the PVB foil had been affected by the structural sealant. This caused delamination of the glazing. Learned by this, now a lot of care is taken in protecting the edges, by detailling differently and sometimes by temporarily masking them with tape.

Possibilities for improvement can be in the production by ensuring that there is a continuous educated occupation of the appliance task of structural sealant, where now multiple people are used on these jobs which are not continuously on this job.

Biggest problem lies in the traceability. On this moment it is not completely possible to follow the procedure, because of the fact that it is just not possible to trace all parts in the production.

Conclusion:
Talks about a solution for replacement with a quaternario profile. This is not always done because of the extra work and material that this entails. Though, it is a solution for the issue of on site replacement.

As a production manager he also mentions the production, which is to his opinion easier with structural glazing. Workers need to be asked more about this for multiple opinions and points of concern for an easy production. Also joining a day in a production team would give me my own view on this ease on production

Risk in affection of the PVB foil by the structural sealant should be taken into account when designing a detail.

Keywords:
Tracking/traceability, improve process management, costs of individual testing vs change in detail

Ralph Dubbeld
February 14th 13:00.

MTS mechanical engineering. Service and Maintenance (Dutch: Nazorg). Difference in aesthetic maintenance and technical maintenance. Has to cope with the mistakes and problems caused by design, production or installation. Is currently active in maintaining 116 buildings. Not all these buildings are original Scheldebouw projects.

This field of work is crisis driven, where decisions are made to not build new buildings or move, but maintain the current building stock and maintaining this in a good way. On this moment this part of Scheldebouw is actually one of the biggest generators of profit.

Ralph states that for structural glazing, almost 100% of the UK projects have structural glazing and in the Netherlands maybe 5% have this. This is caused by difference in trends, but also by culture to choose for a more traditional solution.

As a guideline, to replace a structural glazing pane it takes up to four times more time, which is a downside to structural glazing. This makes it also more expensive, where replacing normal glazing it will cost around 3.500 euro. With structural glazing this will cost more in the direction of 10.000 euro.

Another (big) disadvantage on SG is that on average it is only possible to replace a broken pane by glueing on site between May and October. Also this system is more sensitive in maintenance because of exposed glass edges. These edges are the weak point in a glass pane.

In the end Ralph concludes that indeed structural glazing is more difficult and expensive in maintenance, but it will always be the choice of architect and/or client, which they full-fill and will also keep in maintenance without concern.

Personally, Ralph sees the biggest possibilities in automation. By this, whole Scheldebouw would become more modern, procedures will be easier to follow, a lot of paper will be saved, and maintenance will be easier. A similar system has been used for The Shard, where there was an application that tracked all the facade element and showed where on the building these elements are.

Automation gives possibilities in traceability of elements, which would also be profitable for the structural sealant procedure. If it becomes clear that there is a certain problem with a batch, all these elements should be inspected. On this moment this would be a difficult task because of the current documentation. Also for maintenance, it would be easy to digitally find out which element and what kind of element is damaged. It could be directly visible what elements to order and bring with you for reparation.

Conclusion:
Disadvantage in replacement: time and money. Also more sensitive for damage because of exposed edges. For these, solutions should be researched.

Automation could lead to an easier and more clear procedure with better traceability. What advantages could this have and are these in such way that an automation in the process could lead to a better system?

Keywords:
Automation, instructions for replacement, much more difficult to replace SG

Eric Vliegen
April 9th 16:00.

This interview turned out to be a conversation, mainly about the ETAG. From his experience, there are some peculiar points of remark in the ETAG. For example, this ETAG is a guideline which is written on the assumption that a working life of 25 years is intended for the system. Though, buildings usually are build, intented to last for at least 50 years. This creates a gap of 25 years.

Also the ETAG states it is a requirement of this Guideline that all structural bonds are made in a factory under well-controlled conditions. However, for some projects also on site bonding is practiced for replacement of damages glass panes.

Clients want to have a guarantee and Scheldebouw has to prove to them how they are going to give this guarantee of a quality cladding. Most common guideline for this is the ETAG and PassVec in some countries. Most of the time the client asks to work according to these guidelines. In case they don't, these still give a support for a quality assurance for the company itself.

With Eric, different variants on structural glazing are discussed. Each variant has his own reasons, often because of various legal issues, depending on location, but also by customer demand.

Conclusion:
The ETAG needs to be looked on in a critical way. Why is there a discrepancy in the ETAG and in practice, while stating that the ETAG is followed. Also the different variants on structural glazing raise the question if there is not a clear 'best' solution, that could be used as a general principle.

Though, it seems there is a basic principle, that is influenced by a lot by external factors, like local governments, costs and environmental issues. These cause the principle to change in a variant.

Keywords:
Discrepancy ETAG / practice, variants in structural glazing

Jo Beckers
April 10th 9:30.

Is the production manager at Scheldebouw Heerlen.

From a production point of view he does not see any particular problems with structural glazing. All types of production should be done with care and attention, only for structural glazing it might be necessary to have a continuous focus, promoted by supervision. This because a step in production, like cleaning, is easily forgotten and will not easily be noticed if not paying attention. Though, he has confidence in the people that are working on this production lines.

It is tried to always have experienced people on applying the structural sealants on the production line. This gives better results, both in build quality as in aesthetic properties.

He mentions the possible change in location and execution of test samples, like the H-samples. They are now made at production and tested at quality management by a quality manager himself. There is the idea to also do the testing at production. Jo states this might cause a loss in supervision and control.

Conclusion:
Focus is important and the right workers in production are from big importance for quality. Though, this is not only the case for structural glazing, but also for other projects.

Changes in execution of particular tasks in the procedure might have large effects in awareness and control.

Keywords:
Quality is in production, location and execution of steps in procedure

Appendix 2 Production logbook

SCHELDEBOUW — **Logbook form**
Application of structural sealant — **QCR 9.0**

General info:	Project name:		Date of application:	
	Project number:		Sub-lot number:	
	Application according to Procedure QU-11: "managing and applying structural bonding" and corresponding Instructions.			

Application info:		Morning:	Afternoon:		Morning:	Afternoon:
	Temperature:	.... °C	.... °C	Relative humidity:	.... %	.... %
	Sealant device nr.		Location:		Production line:	

Material information:		Batch number:	Expiry date:		Batch number:	Expiry date:
	A-Component:		..... - ..... -	Cleaner-P:		..... - ..... - ....
	B-Component:		..... - ..... -	Cleaner-205:		..... - ..... - ....
	Datasheet finish:		Datasheet glass:		Datasheet other mat:	

Production tests:		Morning:	Afternoon:	Component change:	Component change:	QC-check:
	Mixing ratio:	.... : 1	.... : 1	.... : 1	.... : 1	
	Butterfly test:	yes / no	yes / no	yes / no	yes / no	
	Snap time test:	.... min.	.... min.	.... min.	.... min.	

Traceability of panels and components:	Panel number morning shift: *unique serial number*	Panel number afternoon shift: *unique serial number*	Panel number after Component change: *unique serial number*

Quality Control Tests:		Morning:	Afternoon:	Change component:	Date:	Time:
	Tensile adhesion:	.... kg/cm²	.... kg/cm²	.... kg/cm²	..... - ..... -	.... : ....
	Hardness test:	.... Shore A	.... Shore A	.... Shore A	..... - ..... -	.... : ....
	Peel test 1:	........................%	........................%	........................%	..... - ..... -	.... : ....
	Peel test 2:	........................%	........................%	........................%	..... - ..... -	.... : ....

Final sign off:						
	Name applicator:		Sign applicator:		Date:	..... - ..... - ....
	Name Quality Insp:		Sign Quality Insp:		Date:	..... - ..... - ....
	This control record must always stay at the application location until the Quality Inspector has collected the form and all production tests and samples.					

Comments:

Document: Quality Control Record 9	d.d. 11-12-2013	Rev. 00

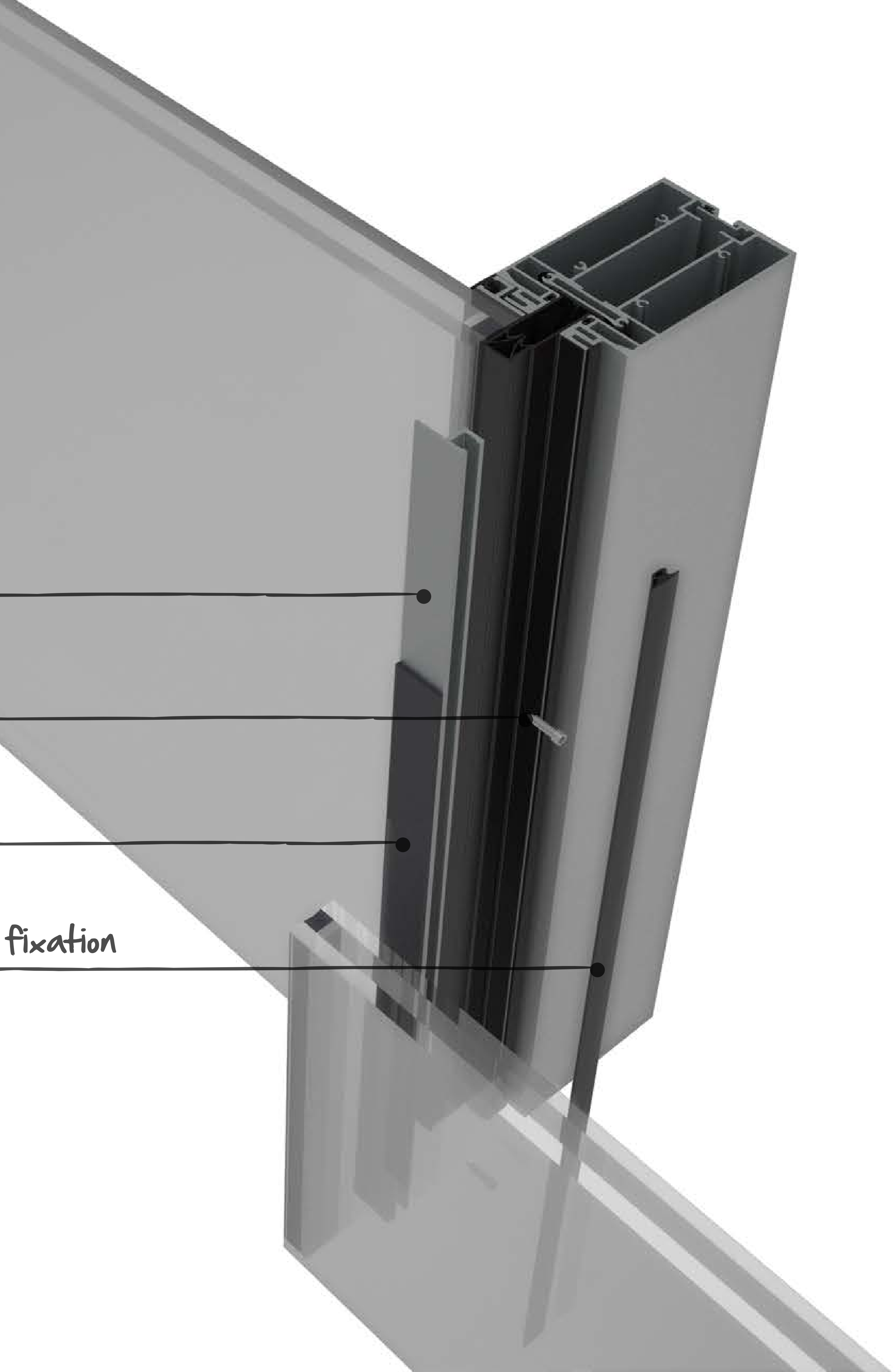
Appendix 3 Final design - exploded view

Sub-frame

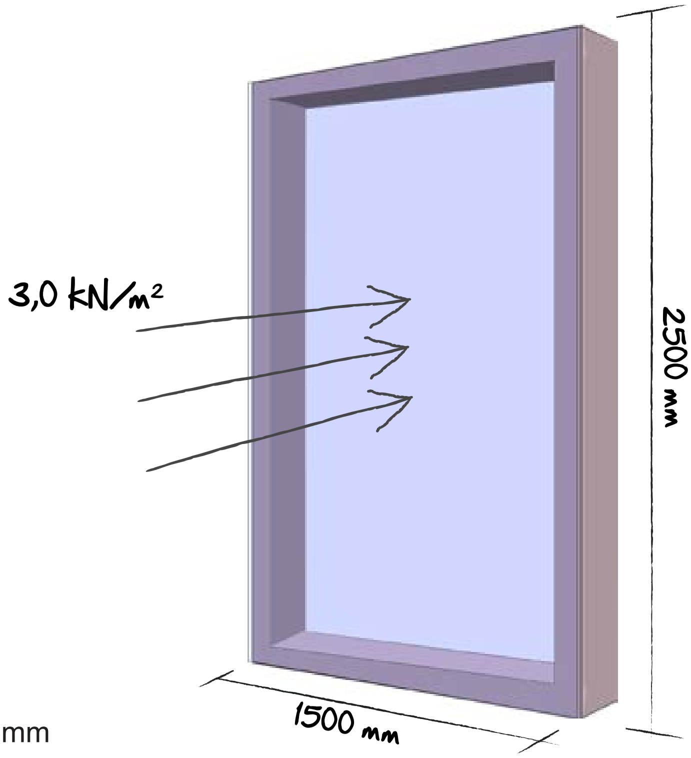
Sub frame fixation

3M™ VHB™ Tape

Gasket for conceiled


fixation

Appendix 4 Joint dimension calculation



| *Input:*

Location: England

Maximum wind load: 3,0 kN/m2
Pane dimensions: 2500mm x 1500mm
T_{max} of building ext.: 85 °C

| *Calculations:*

3M™ VHB™ Tape

Design strength σ_{dyn} : 85 kPa

Required tape width: h= (1500*3,0)/(2*85)= 26,5mm
Tape is only available in measures dividable by 5, so: **30mm**

Shear strain check:
Total % strain = √(panel short edge % shear strain)² + (panel long edge % shear strain)² with:
% shear strain = 100*((frame length)*(frame CTE – glass CTE)*(max temp change))/tape thickness

Short edge: $100*((1500) \times ((24\times10^{-6}/°C - 9\times10^{-6}/°C)*(85-20))/2{,}3 = 64$ %
Long edge: $100*((2500) \times ((24\times10^{-6}/°C - 9\times10^{-6}/°C)*(85-20))/2{,}3 = 106$ %
Total strain: $\sqrt{(64)^2+(106)^2}$ = **124% < design limit 300%**

Sikasil SG-500 2-part silicone sealant

Design strength σ_{dyn} : 140 kPa
τ_{des} : 105 MPa

Joint bite: h= (1500*3,0)/(2*140)= **17mm**

Joint thickness:
$\Delta l_{v,h} = l_{v,h} * [(\alpha_f * \Delta T_f) - (\alpha_g * \Delta T_g)] \rightarrow \Delta l_v = 0{,}44$ mm; $\Delta l_h = 0{,}13$ mm
$\Delta l = \sqrt{\Delta l_v^2 + \Delta l_h^2} \rightarrow \Delta l = 0.45$ mm
$e \geq (G * \Delta l) / \tau_{des} = 2{,}14$ mm

According to ETAG 002 a joint ratio of e ≤ h ≤ 3e is advisable for silicone joints. For a joint ratio > 3:1, the bending effects in the elastic joint must be considered. The joint thickness e should be at least 6 mm. This fulfils the recommended ratio of h:e ≤ 3:1. **e = 6 mm**

	ETAG			
	σ_{dyn}	τ_{dyn}	τ_{stat}	Allowable shear strain
SG-500	0.14 MPa	0.105 MPa	0.0105 MPa	x 125 %
3M™ VHB™ Tape	0.085 MPa	N/A	N/A	x 300 %

Figure 7.1.1 - Design strength properties (Own ill.)

Calculating the Joint Bite h

Joint bite h as a function of the wind load in supported constructions

$$h = \frac{a \times w}{2 \times \sigma_{dyn}}$$

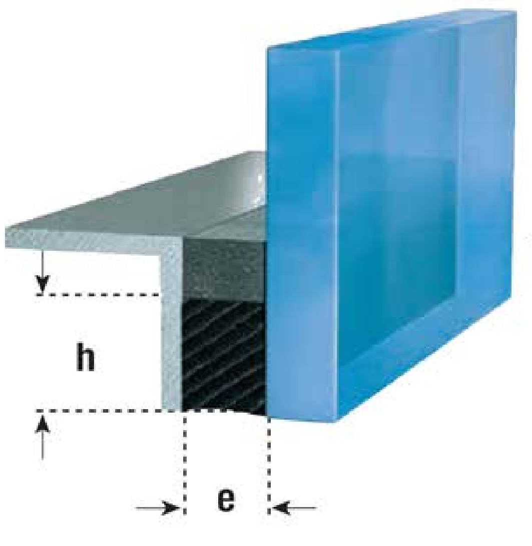
h = minimum bite of the adhesive joint (mm)

a = length of the short edge of the glass pane or of the element (mm); with irregularly dimensioned glass elements: longest of the short glass edges[1)]

w = maximum wind load to be received (kN/m²) (100 kp/m² = 1 kPa = 1 kN/m²)

σ_{dyn} = maximum adhesive stress for supported constructions (kPa). For σ_{dyn} values of Sikasil® products see page 13

[1)] If the sides of the glass panes are of varying length, then the length of the longest side is used for the calculation.



Calculating the Joint Thickness e

Total movements

$$\Delta l_{v,h} = l_{v,h} \times [(\alpha_f \times \Delta T_f) - (\alpha_g \times \Delta T_g)]$$

Calculation of the deformation of the long and short panel edges to take account of the different expansion and contraction of glass and adapter frame (thermally induced movements in the shear direction).

$\Delta l_{v,h}$ = change in length (mm)

l_v = vertical reference length (mm)
in dead load supported systems:
l_v = total height of glass unit in
non.-supported systems:
l_v = half the height of glass unit

l_h = horizontal reference length
l_h = half the width of glass unit (mm)

T_f = average temperature difference of frame (approx. 30 – 60 K)

T_g = average temperature difference of glass (approx. 30 – 60 K)

α_f = expansion coefficient of the frame material (aluminum: 23.8×10^{-6} K^{-1}, stainless steel: 12×10^{-6} K^{-1})

α_g = expansion coefficient of glass 9×10^{-6} K^{-1}

Total movements

$$\Delta l = \sqrt{\Delta l_v^2 + \Delta l_h^2}$$

The calculated deformations of the long and short panel edges yield the total movements according to the formula above (Pythagoras' theorem).

Δl = total change in length
v = vertical
h = horizontal

Calculation of the minimum Joint Thickness e (ETAG 002)

$$e \geq \frac{(G \times \Delta l)}{\tau_{des}}$$

G = Modulus of elasticity in shear tangential to the origin: (G = E/3)

E = Modulus of elasticity in tension or compression tangential to the origin

τ_{des} = permissible stress in shear of the adhesive for supported constructions (MPa)
For τ_{des} (= τ_{dyn}) values of Sikasil® products see page 13

According to ETAG 002 a joint ratio of $e \leq h \leq 3e$ is advisable. For a joint ratio > 3:1, the bending effects in the elastic joint must be considered.

Appendix 5 3M VHB tape reference projects

Casa Confetti (Utrecht, Netherlands)

Sorba 2009

• Overall height of 51m

•15 storeys

University residence project.

Both panels and glazing are structurally bonded with VHB tape. In this case it is a 4-sided structural glazing.

Poort van Veghel (Veghel, Netherlands)

Lealti 2006

• Overall height of 34m

•10 storeys

Two sided structurally glazed stairwell. A unique stairwell application for an office building.

Heron Tower (London, United Kingdom)

Scheldebouw 2009

• Overall height of 230m

• 46 storeys

• 40,836 m^2 of commercial office space

In this project a combination of VHB tape and structural sealants has been made. Details on this project are currently internally investigated at Scheldebouw.

Philips Headquarters (Hamburg, Germany)

Bug-Alutechnic 2006

• Overall height of 55m

•17 storeys

Clad in dark natural stone. In the two offset high-rises themselves there are offices, while the wing is home to conference areas and a cafeteria.

In terms of quality the aluminum façade elements, which in each case extend across two stories, ensure the high design standard down to the very last detail. For this, VHB structural glazing tape is implemented in the design.

More on:

http://solutions.3m.com/wps/portal/3M/en_US/Adhesives/Tapes/Industries/Architechure/VHB/

(Therre are 7000+ 3M™ VHB™ Structural Glazing Tape Projects Since 1990)

Appendix 6 Waste calculation

Element New Ludgate

Top		533750	mm^3
Side L		842710	mm^3
Side R		842710	mm^3
Bottom		495625	mm^3
Total volume sealant		2714795	mm^3
in one element:		2,71	dm^3
Joint length in one element:		10,2	m
Elements in one day:		12	elements

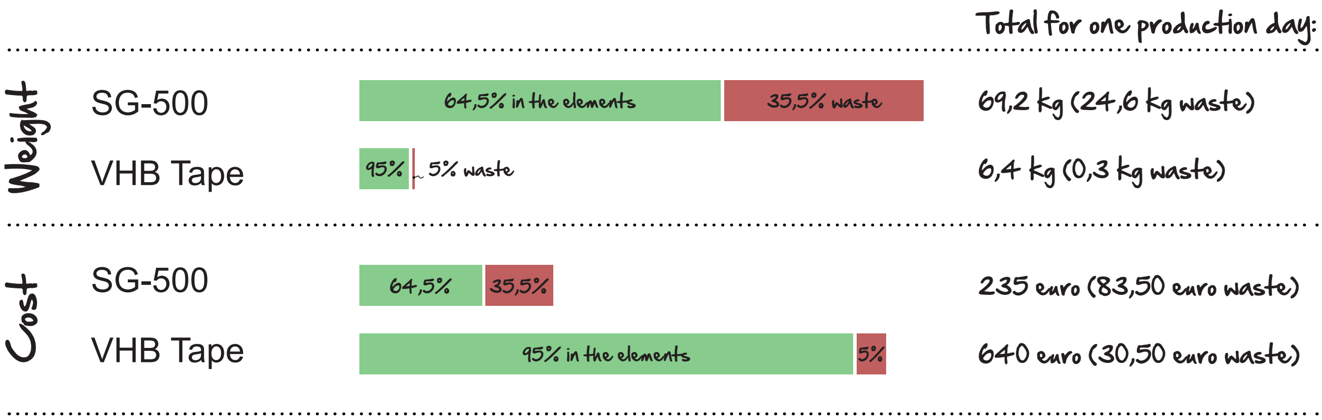
SG-500

SG-500 mixed		1,37	kg/dm^3
Cost	€	3,48	/kg
Sealant weight one element:		3,72	kg
Total day weight:		**44,63**	**kg**
Cost of sealant:	**€**	**155,32**	
Samples weight:		0,6	kg
Sealant waste weight:		**24**	**kg**
Total disposal:		24,6	kg
Cost of waste:	**€**	**85,61**	
Additional sealant (waste):		**+ 55,1**	**%**
% of total amount		35,5	%

VHB Tape

Total joint length:	122,4	m
Tape with:	0,03	m
Tape thickness:	0,0023	m
Tape cost:	4,98	/m
Tape volume:	0,0084456	m^3
Tape density:	720	kg/m^3
Tape weight:	**6,1**	**kg**
Cost of tape:	**€ 609,50**	
Waste of **5%***:	6,12	m
Tape with:	0,03	m
Tape thickness:	0,0023	m
Tape waste volume:	0,0004223	m^3
Tape density:	720	kg/m^3
Tape waste weight:	**0,3**	**kg**
Cost of waste:	**€ 30,50**	

* waste of 5% is a number provided by 3M



Appendix 7 Cost calculation

Cost VHB Tape (without any discounts)

	Per meter	25% discount:
25 mm	4,15	
1 mm	0,166	
30 mm	**€ 4,98**	€ 3,74

Cost SG-500 (current prices for Scheldebouw)

Verhouding 13:1	price part /kg
Component A	3,05
Component B	9,00

Waste

	%
SG-500	0,551
VHB	0,05

Cost for sealant joint dimension 'x'

1000000 mm3 (liter)	€ 4,76
1 mm^2*m	€ 0,004761
300 mm^2	€ 1,43
260 mm^2 (per meter)	**€ 1,24**
102 mm^2 (per meter)	€ 0,49

Time

	min / meter	euro
SG-500	9	€ 6,00
VHB	3	€ 2,00
Sub-frame	Specified in cost calculation	

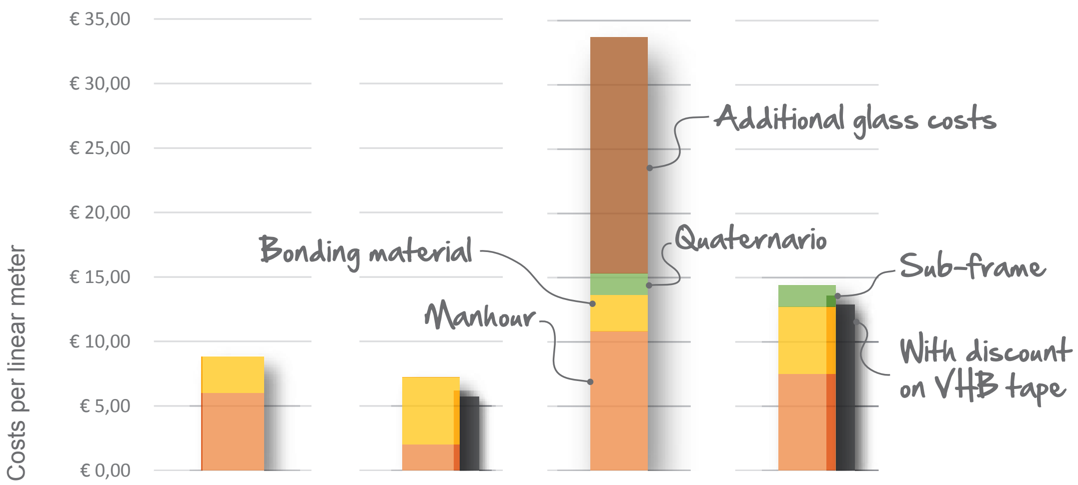
Additional glass cost

	Frame 1,5mx3,5m	5,25 m2
		10 m
	Regular glazing	70 € / m2
+150%	Stepped glazing	105 € / m2
	Additional cost /m	€ 18,40

(5,25m2*price2 / 10m) - (5,25m2*price1 / 10m)

Labour costs

€ 40,00	/h
€ 0,67	/min



	Situation 1	Situation 2	Situation 3	Situation 4
Manhour	€ 6,00	€ 2,00	€ 10,83	€ 7,50
Bonding material	€ 2,82	€ 5,23	€ 2,82	€ 5,23
Quaternario / Sub-frame material	-	-	€ 1,70	€ 1,70
Additional glass cost (stepped)	-	-	€ 18,40	-
Tape discount	-	€ -1,49	-	€ -1,49
Total:	€ 8,82	€ 7,23	€ 33,75	€ 14,43
Total with discount:	-	€ 5,74	-	€ 12,94

	/14 kg		price total /kg	price total /liter
	39,65			
	9,00			
Totaal:	€ 48,65		€ 3,48	**€ 4,76**

Cost calculation

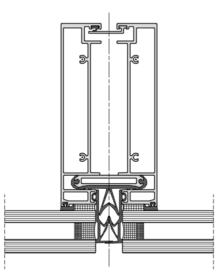
/ meter	**SG-500**	**VHB**	**SG-500 + Quaternario**	**VHB + subframe**
Manhour	€ *6,00*	€ *2,00*	€ *6,00 + Quaternario*	€ *2,00 + subframe*
Backing rod	€ 0,90	-	-	-
Silicone/VHB	€ 1,24	€ 4,98	€ 1,24	€ 4,98
Waste	€ 0,68	€ 0,25	€ 0,68	€ 0,25
Waste + sil/VHB	€ *1,92*	€ *5,23*	€ 1,92	€ *5,23*

Quaternario system	Labour costs (min)	Material	Total
Building subframe	€ 2,00 (3 min)	€ 0,50	€ 2,50
Fixation with screws	€ 1,50 (2,25 min)	€ 0,10	€ 1,60
Gasket	€ 0,67 (1 min)	€ 0,80	€ 1,47
Sealing tape	€ 0,67 (1 min)	€ 0,30	€ 0,97
Stepped glass cost (add.)	-	€ 18,40	€ 18,40
		Total:	€ 24,93
		Total (glass excluded):	€ 6,53

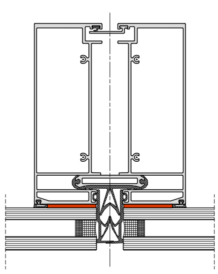
Subframe elements	Labour costs (min)		Material	Total
Building subframe	€ 2,00 (3 min)		€ 0,50	€ 2,50
Fixation with screws	€ 1,50 (2,25 min)		€ 0,10	€ 1,60
Gasket	€ 0,67 (1 min)		€ 0,50	€ 1,17
Sealing tape	€ 1,33 (2 min)		€ 0,60	€ 1,93
			Total:	€ *7,20*

Total all per meter:	€ *8,82*	€ *7,23*	€ 33,75	€ *14,43*
		(When glass excluded:	€ 15,35	)
With tape discount 25%:		€ 5,74		€ 12,94

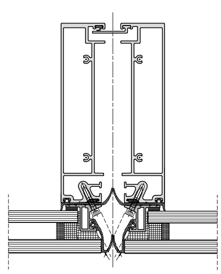
Situation 1:
Basic system with SG-500



Situation 2:
Basic system with VHB tape



Situation 3:
Quaternario system with SG-500



Situation 4:
Sub-frame system with VHB tape