Upcycle in Architecture :

Reuse NS train windows as a new construction component

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This thesis research booklet is dedicated to my nephiew Giannis who patiently staied quite and helped me with his drawing during it's most critical phase.

CIRCULAR ECONOMY IN CONSTRUCTION

RE-USE NS TRAIN WINDOWS AS A NEW CONSTRUCTION COMPONENT

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“If it can’t be reduced, reused, repaired, rebuilt, refurbished, refinished, resold, recycled, or composted, then it should be restricted, designed or removed from production.”

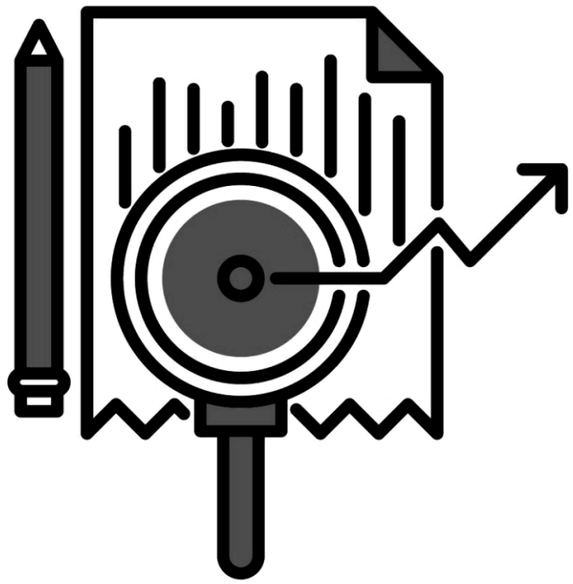
– Pete Seeger, Folk Singer & Social Activist

0.Abstract

Keywords: Circular economy, close loop, open loop, recycling, reuse, rail industry, train windows, train renovation,

The building industry is a significant waste contributor. Especially at the end-of-life of the building it causes an enormous impact on the environment. Construction solid waste has caused serious environmental problems. Reuse, recycling and reduction of construction materials have been advocated for many years, and various methods have been investigated. However, the effectiveness of its applications seems limited. Waste will be reduced by extending the lifetime of the materials giving the second life.This research aims to the design of a construction component made of reused train windows of the old VIRM trains of NS. The continuous flow of the train windows due to the renovation of the trains demands a multiadaptable solution that offers different design scenarios.

I .Theoretical framework



1.1 Problem Statement

Current and future advancements show that the request for natural resources will rise three times in 2050. The main reasons under these advancements are on the one hand the global economic growth and on the other hand the increase of the world population, from 7 billion people today to 9 billion people in the next 50 years. (Swilling, 2011).

At the same time, the middle class will significantly increase, which will lead directly to the doubling of consumption per capita. (WBCSD, 2008) Because of the abovementioned advancements, improving the life quality for many is a case in danger. (Ellen MacArthur Foundation, 2012). Adding to this the waste production is continuously increasing.Since the introduction of the “Ladder van Lansink: (in 1970) and the introduction of the Circular Economy concept by the European Union, waste prevention becomes a priority. (Icibaci 2019)

‘Circular economy is a sustainable act by thinking the circular supply chains and maximizing the value of materials in which products can be re-used re-manufactured or/and re-cycled.’ (EMF, 2012).

Nowadays the built environment is the major way of use 40 to 50% of the raw materials and 10 to 30% of the waste flow in the European Union. (Uihlein & Eder, 2009).Natural resources processed and extracted from the operation and construction of buildings and infrastructures are considered for the major consumption of resources, energy, and materials. (Adriaanse, 1997; Matthews, 2000; Boardman, 2004; Graedel and Howard-Grenville, 2005; Ortiz, 2009; Wiedmann, 2015, Icibaci, 2019). The circular economy in the building sector is a systematic approach that could gradually lead to the confrontation of the abovementioned situation. A method towards circular constructions is to recycle the materials used in the built environment, a process in which constructions are designed in a way that allows their materials to be reused, upcycled and downcycled. (ABN, 2014).

The circular economy is now gaining attention, but knowledge and tools for bringing this concept in reality still need to be developed. A lot of research has been conducted regarding the ways in which different parts of a product or construction can be reused or recycled after the product’s or building's expected lifespan.

A large proportion of companies and startups are focusing on creating a Circular framework for their products and services.
Under a Sustainable plan, Dutch railways - NS is focusing on further reducing its CO_2 footprint by reviewing the maintenance and the production of the new trains and the life extent of the existing by upgrading the life cycle of them as long as possible. Furthermore, during the renovation, a lot of high-value materials are becoming available. A large percentage namely 86% of these materials are meant to be reused in the renovated trains and 10% of them could find a new purpose outside the train. Although there is a remaining 4% for which a new use is in request.

NS gets in contact with creative teams with different skills and the expertise who can help in the long run to get to a fully sustainable and circular, public transport system.

According to this, NS came in touch with the architecture office *“Superuse studios”* knowing their ingenious ways of material reuse, in order to find a way to reuse the remaining 4% of the withdrawn trains materials.

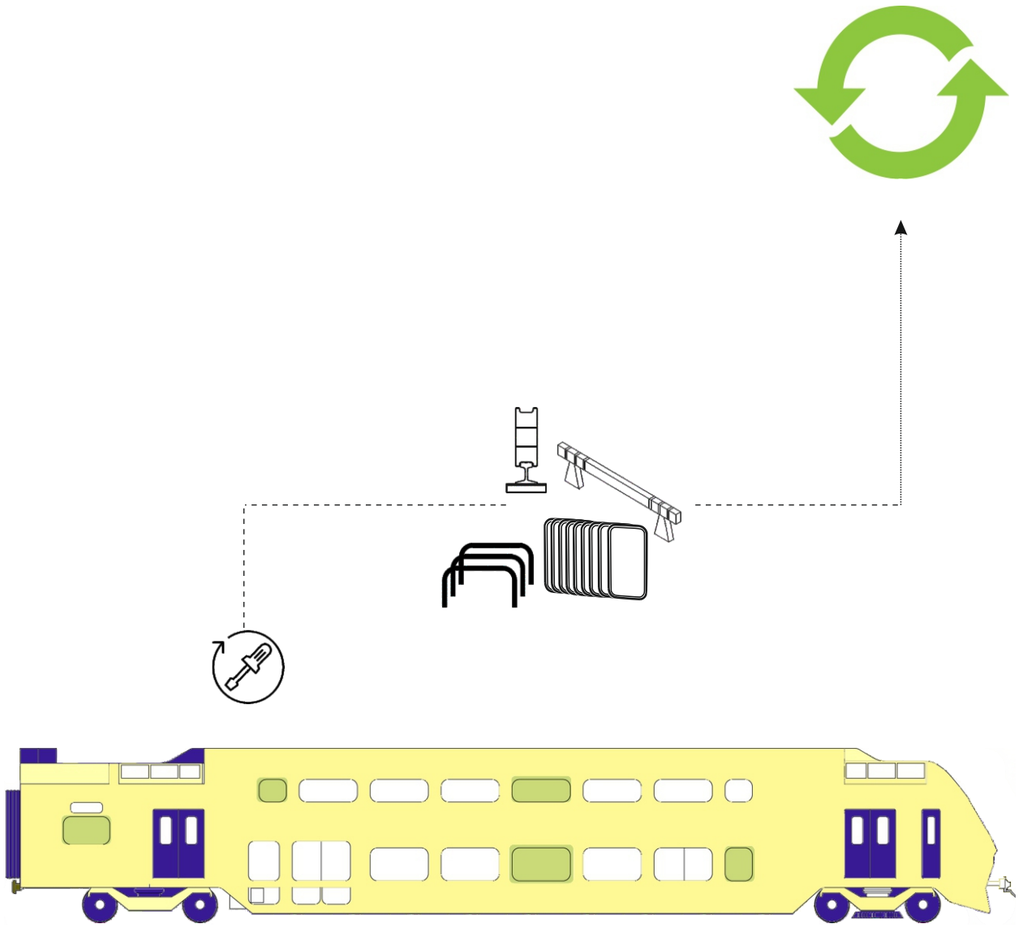


Image 1.1.1: NS waste windows can acquire a second life

1.2 NS Sustainable train renovation

As mentioned before, following the old train renovation, a lot of high grade materials are becoming available.The major percentage namely 86% of these materials are reused in the modernized trains after proper disassembly and maintenance. A 10% is able to be reused outside the train and for the remaining 4% a new purpose has to be found.

This 4% is consisting of six different interior train part categories:

- Floor
- FRP Wall Element
- Windows
- Tables
- Bins
- Coat Hooks

To achieve maximum modularity the decision to use only one of these materials has been made. From these six categories the windows have been selected to be reused to design a new modular construction component.

The wall elements and the hooks were the least preferred. The FRP wall elements need a lot of precessing to acquire another use than their first one since there are several metal parts attached to the FRP. also the possible and also because of their shape in combination with their weight are not easy to be handled. The hooks are too small and a huge amount of them would be needed to built a pavilion. This amount is not available.

The bins the tables and the windows are easier to be handled because of their shape and their dimensions. In order to finalize the choice of the material the objective value of the material has to be discussed. The bins are made from steel the tables from wood and plastic (cover) and the windows from aluminum, ruber and mainly laminated safety glass. With a roughly objective estimation the windows present higher value than the other two options.

During 2016-2020 Dutch railways re-modernized eighty one VIRM train sets. After appropriate disassembly around 50 train windows per week are available ready to acquire a second life. The next years more and more train renovations would follow so there is going to be a large flow of available windows, for this reason a proposal that would lead to a readaptable solution for the upcoming renovation is a demand.

As mentioned in the previous chapter NS after appropriate disassembly and maintenance NS the 86% of the old trains are used to the renovated ones. The logical question the come up from this fact is:

“Why cannot the train windows be reused into the renovated trains?”

The most important properties of train windows glass are the insulation values (acoustical and thermal) and their strength against the wind pressure. The NS windows are manufactured in 2003-2004 and present outdated values for reuse in the rail industry. Moreover, nowadays there are several train windows technology innovations such as trains windows with integrated touch screen and frequency-permeable windows.

Floor

Number per section:
Dimensions (LHB) variable
Material: sandwich panel
disassembly: in broken pieces Wrecks
Other:

Tables

Number per section: 12
Dimensions (LHB) 351 x ..... x .....
Material:
Removal: whole
Other:

Wall elements lower

Number per section: 12
Dimensions (LHB) 1930 x 1,471.5 x 97.5
Material:
Removal: whole
Other: available

Bins

Number per section: 12
Dimensions: Material (LHB) 400 x 97.5 x .....
disassembly: whole
Other: come in three colors: pink, gray, blue-gray

Wall elements upper

Number per section: 12
Dimensions (LHB) 1930 x 1,328.3 x (77.5 + 175.6)
Material:
Removal: whole
Other:

Coat hooks

Number per section: 24
Dimensions: Material:
Removal: whole
actually be returned to
Other: manufacturer side to melt

Window lower

Number per section: 12?
Dimensions (LHB) 1597 x 769.8 x .....
Material:
Removal: whole
Other: More information can be found in tt 'wall element under'

Window upper

Number per section: 12?
Dimensions (LHB) X 510.1 x 1497 .....
Material:
Removal: whole
Other: More information can be found in tt 'wall element above'

Table 1.1.1: NS 4% remaining materials fro reuse

Image 1.1.2: Intregated LCD in train windows
Retrieved from: https://fortune.com

Image 1.1.3 :The heat-insulating metal layer of the windows is processed with a laser in such a way that it becomes transparent to all frequencies of radio waves.
Retrieved from: https://www.web24.com

Train window glass specifications

According to the given data of NS, the VIRM's train windows are manufactured in 2003 and 2004 with a U factor of 3,00 W/m^2K and 36% light transmittance when the new generation train windows present a U factor of lower than 2 W/mK and 60-70% of light transmittance. Which means great relation of thermal insulation and optical properties.

The U-factor is the standard way to quantify insulating value. It indicates the rate of heat flow through the fenestration product. The U-factor is the total heat transfer coefficient of the fenestration system, in W/m2K, which includes conductive, convective, and radiative heat transfer for a given set of environmental conditions. The smaller the U-factor of a material, the lower the rate of heat flow.

Visible transmittance is an important factor in providing daylight, views, and privacy, as well as in controlling glare and fading of interior furnishings. These are often contradictory effects: a high light transmittance is desired for view out at night, but this may create glare at times. These opposing needs are often met by providing glazing that has high visible transmittance and then adding attachments such as shades or blinds to modulate the transmittance to meet changing needs.

In the past, products that reduced solar gain (with tints and coatings) also reduced visible transmittance. However, new spectrally selective tinted glasses and selective coatings have made it possible to reduce solar heat gain with little reduction in visible transmittance.

Image 1.1.4:VIRM's windows glass stamp

VLT Visible Light Transmission %	36	U U Value	3,00
VLR Visible Light Reflectance %	8	R R Value	0.33
UV UV Elimination %	83	SHGC Solar Heat Gain Coefficient	0,74

Table 1.1.2: VIRM's glass values

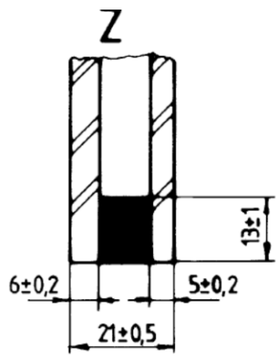


Image 1.1.5: VIRM's glass dimensions

Description of the window system:

Frame:

- aluminum frame
- powder-coated color RAL 7021 black-gray, polyester powder according to KVNS 6.201 A.
- Execution curved and straight, geometry according to drawings M1080-M1086
- Quantity according to the number of windows according to the parts list
- Mounting holes available, number and position identical to those in the IRM multiple units used window frames
- When installed, the outer surface of the window frame is flush with the Side wall of the car body
- Replacement of the insulating glass packages is possible from inside the vehicle

Glass:

- Insulating glass package: total thickness according to the IRM multiple unit design 21 mm
- sun-repellent glass with a light transmission of approx. 36%
- Outer pane toughened safety glass, Parsol gray, thickness 6 mm
- Inner pane toughened safety glass, clear glass, 5 mm thick
- Glass edge design according to DIN 1249, part 11 - Edges hemmed
- Execution curved and straight, geometry according to drawings M1080-M1086
- Quantity according to the number of windows according to the parts list
- Labeling according to technical delivery conditions DB, TL 918 511 on the
- Outside of the inner pane, arrangement on the top right, readable from the inside

Image 1.1.6:VIRM's windows specifications

Properties	Tempered Glass
Thermal Shock Resistance	Up to 250°C
Mechanical Strength	Four to five times stronger than annealed glass
Tensile Strength	65 MPa
Bending Strength	120-200 N/mm2
Surface Compression	> 95 MPa
Design Stress for Architectural Purposes	50 MPa
Fragmentation	Small round crystals
Conducive for Processing	Cannot be cut after Tempering

Image 1.1.7: Tempered glass specifications

The glass panes of the train windows are fully tempered safety glass panes manufactured in 2004 and 2005. *tolerance. In addition, all cracks and scratches are pushed close reducing the possibility of propagation and failure. Any intervention made to the component like drilling or cutting is done before the* Thermally toughened glass (or fully tempered glass) is forced to a cooling and heating cycle that consequents the surface to solidifie first."*In this way compression forces are introduced to the outside surface of the glass element essentially increasing its tensile stress toughening takes place.*

This thermal treatment also causes panels with impurities and major flaws to shutter on the process rather that when applied on the building. Moreover, the internal stresses introduced cause the glass element to fail in many little pieces in the way of an explosion, making it less dangerous if there is the possibility of falling onto people." Argyro Chiou refers to her research report "The cast glass travelling Pavilion,2019)
Tempered glass is used when extreme strength, safety ,thermal resistance, are priorities.

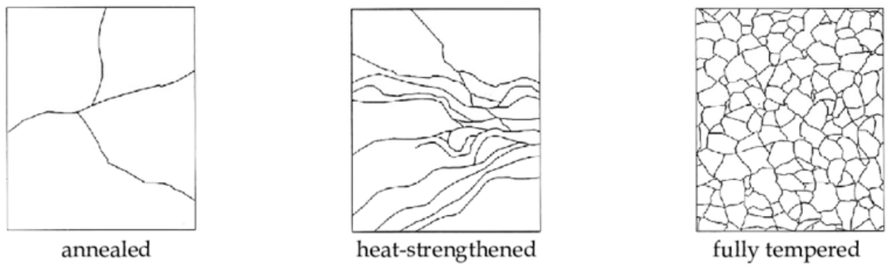


Image 1.1.7: Fracture pattern of annealed, heat-strengthened and fully tempered float glass (Schittich, 1999)

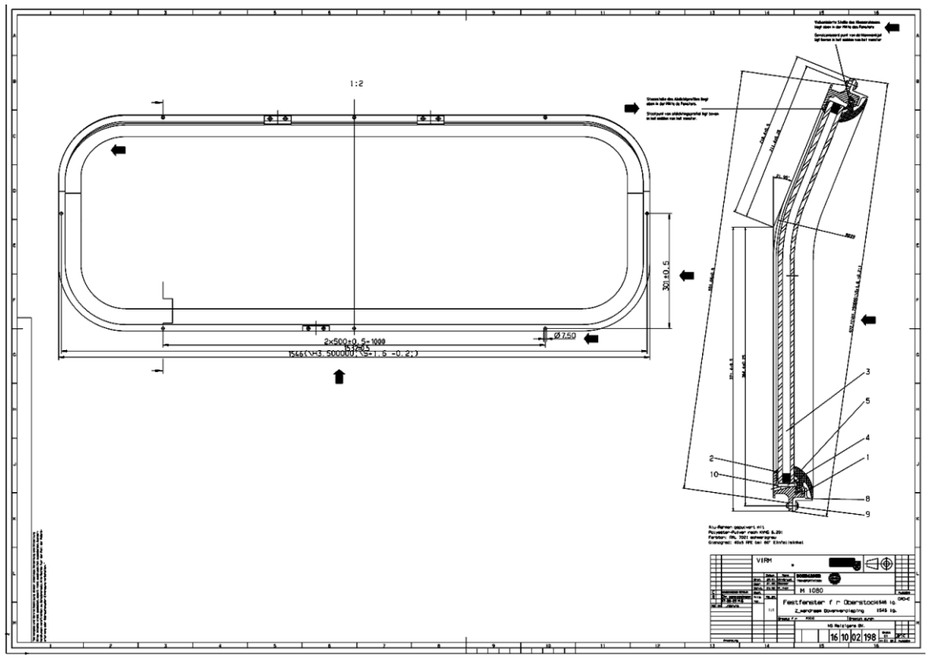
Window types

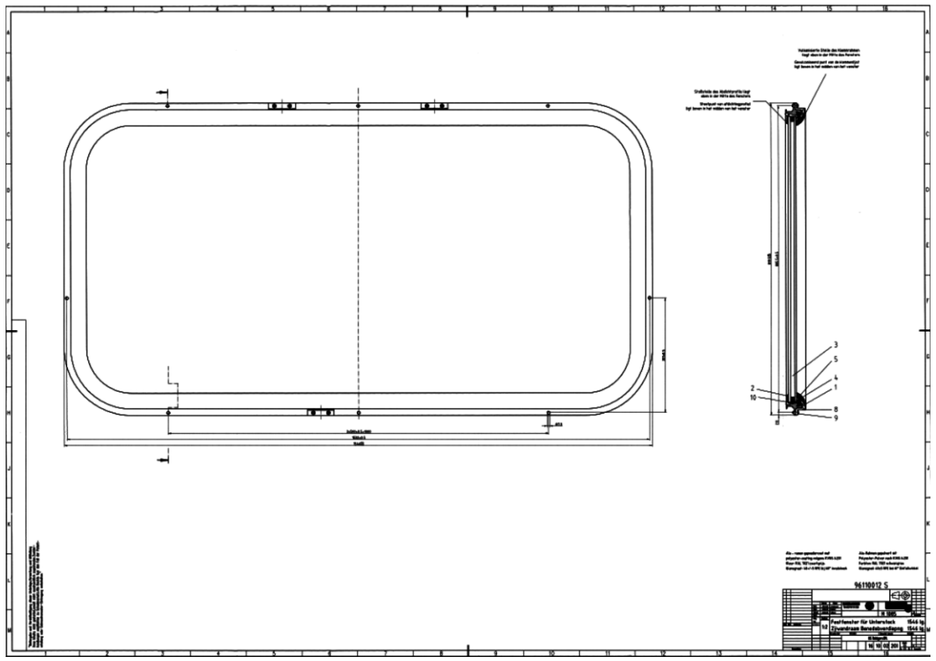
The two types of train windows, available from NS are depicted in the images and drawings below.

The first type is the amount of the large windows of the first floor of the train with main dimensions 1476X759 mm and the second the large windows of the top floor with dimensions 737,5 X 750 mm which present a slight curve on the top side due to the curve of the carriage.The large window weights 40 kilos, 27 kilos the glass and 13 the aluminum-rubber frame.The curved window weights 30 kilos 22 the glass and 8 the aluminum-rubber frame.

Material	Photo	Dimensions	Amount
Safety tempered glass and rubber frame: Second level Window		737,5x750	4000 pieces 50 every week from January 2019
Safety tempered glass and rubber frame: First level Window		1476x750	4000 pieces 50 every week from January 2019

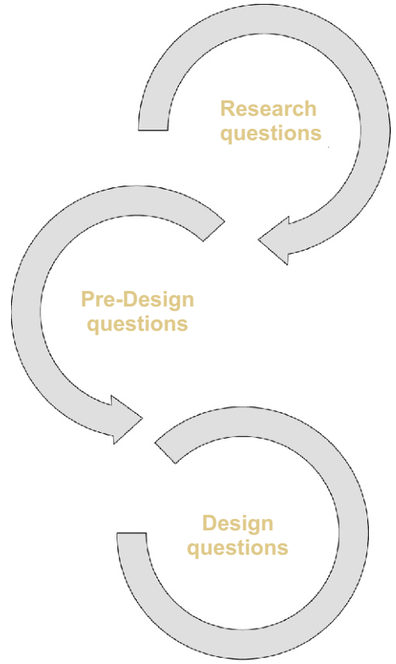
Image 1.1.8: VIRM's window types





Technical Drawings of the windows : The windows consist of Rubber and Aluminum Frame
And double pane safety laminated glass.(Source: NS)

1.3 Research questions



The research in cooperation with Superuse-Studios aims to deal with the reuse of the withdrawn train windows as a new construction component.
The main aim is the design of a component that can adapt in different constructions since there will be a continuous flow of the withdrawn materials.

The design case study used in this research will be a Pavillion for the Circular Economy week 2020 in TU Delft's Architecture Department.

In order to establish whether disposed windows can be used as a building component under a circular design, several research questions were formulated:

Which component design made from NS reused train windows will allow the creation of a circular, simple, temporary and flexible construction?

Sub-questions

- What connections will be most suitable for the creation of a circular, simple, temporary and flexible construction?

- Could the component be load bearing?

Design Questions:

Pre-design:

-Which design typologies could be possibly achieved with the use of the train windows?

-Which of them allow the creation of a circular, simple, temporary and flexible construction?

Design

-Which connections could lead to a circular, simple , temporary and flexible construction?

-How can the component proposal be assembled?

3.Methodology

Starting to formulate the base of the research it is important to take into consideration the background of the relevant stakeholders.
In this case, these are NS (Nederlandse Spoorwegen) and SuperUse Studios.
The next step is to formulate a theoretical framework in which the project will be based. This will consist of :

Literature study concerning Circular Economy in Construction, Urban Mining, Upcycling, and existing Rail vehicle's deconstruction waste management.

Reference projects study by exploring different design, relevant to transport, automobile materials, and windows upcycle design.

Design by research: Basic design decisions, with knowledge of this research.

Design Methodology

Each project stage would be broken down into manageable portions enabling meaningful analysis after the material and literature review, case study and initial evaluation stages, and in-depth, specific and informed exploration through the subsequent design stages. These would lay the foundation for the following design work:

Material Overview – Possible reuse, types, treatments and sources.

- Literature Review (Theory) – Consisted of research into circular economy in terms of upcycling, and into prefabrication including portable design and modular construction and train carriage elements recyclability

Reference Projects

- References analysed to understand exemplary ways in which windows have already been reused architecturally.

- Materiality study: Specific dimensioning and material properties evaluation,of the windows and the rest of the elements.

- Initial Evaluation (Proposals) – Initial thoughts answering to design program demands

- Preliminary Design: (Modular) modular + scale tests

- Contextual Design (Structure) modular + structure + connections

- Contextual Design (System) modular+ structure + system + assembly

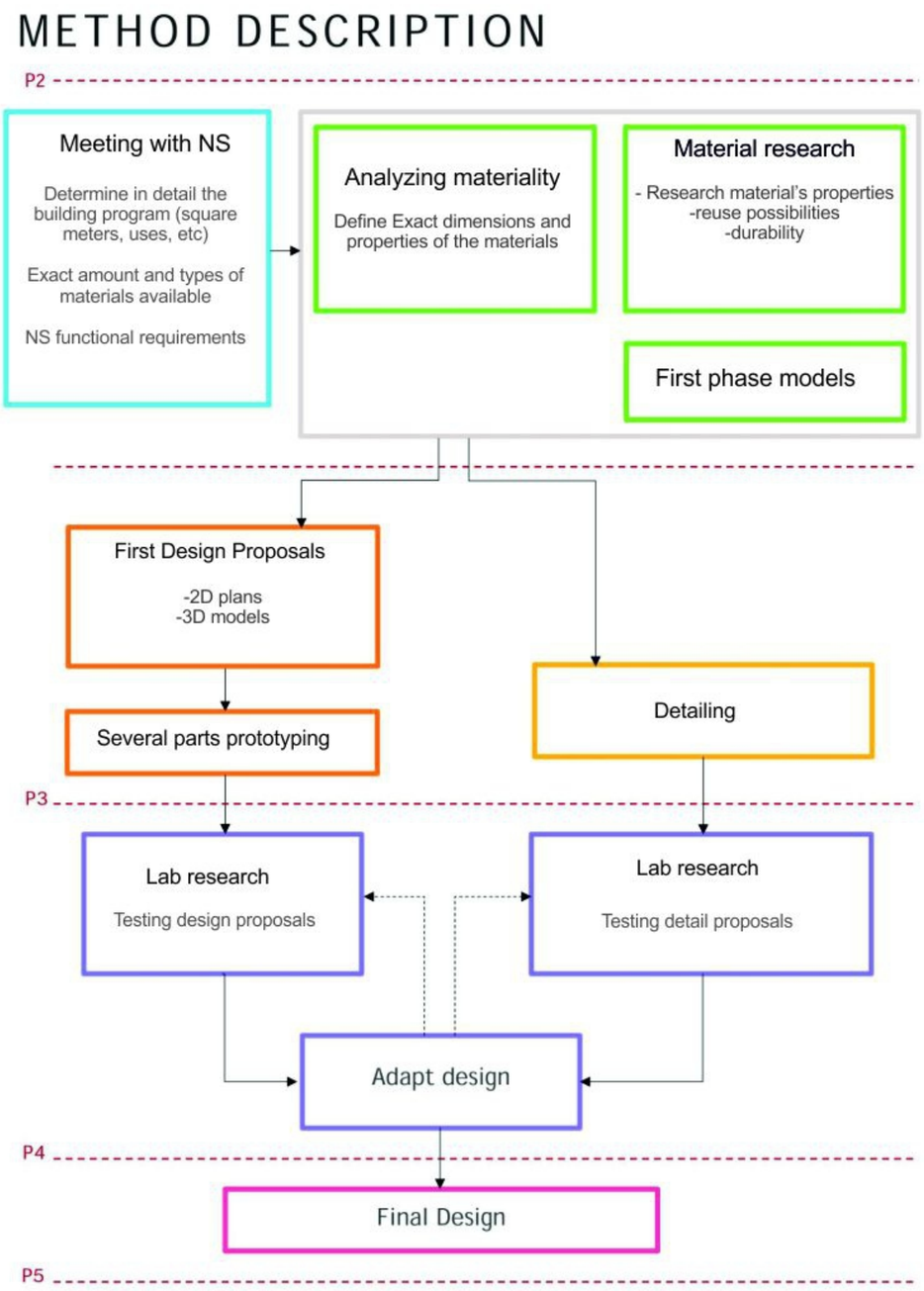
- Full-Scale Pavilion (Feasibility) modular + structure + system + details

- Feasibility Design Test

- -Concepts (Universal Component)–modular + structure + connections + adaptability + universality

- -Final Design (Adaptable Composition)
- modular + adaptability + universal component + details

- -Physical models: require and enable a greater understanding of the design – structure, and buildability, in particular, are aspects perfectly testable by this method (Lin,1999). Small scale models enable rapid prototyping of ideas, while 1:1 scale real-world experiments provide a contextual understanding of the whole issue. Digital 3D modeling and hand sketching have also been important design methods for conceptual thinking.



1.4 Literature review

Circular economy

Nature is a dynamic and cyclical system, based on ever-changing interconnections and diversity. The general nature processes are growing and shrinking continuously, but diversity keeps its main state.

On the contrary, our society is a rigid and linear system, characterized by typified production methods. As a result parallel processes are raising and diversity is driven to a minimum. As a result that leads to waste of amounts of waste. Criticizing our linear system, huge amounts of trash energy waste and unemployment, are the obvious drawbacks.As a solution, an interconnection of the systems in our society and the systems of nature would lead to more efficient resources use, manpower and energy.

Facing a construction, neighborhood, region or city as a system, it can be obvious how much resource, energy and manpower are flowing in and out of every system. Most of it comes out as 'waste'. Consequently, by connecting different parts in the system an effective use of the waste flows could be made. (Superuse Studios, 2019). The circular economy seems to be a systematic approach towards the confrontation of the above-described issue of modern society.
he circular economy concept is presenting great acceptance both among practitioners and scholars. Kirchherr, Reike and Hekkertclaim in their paper "Conceptualizing the circular economy: An analysis of 114 definitions" claim that "Circular economy means many different things to different people T." For this purpose, 114 definitions of the circular economy have been gathered. The findings present that the circular economy is most frequently depicted as a result of the 3R's reduce, reuse and recycle approaches although often is highlighting that Circular Economy is not necessary a strong systemic approach.

It is also argued that in the same research "The main aim of the circular economy is considered to be economic prosperity, followed by environmental quality. Furthermore, neither business models nor consumers are frequently outlined as enablers of the circular economy." (Kirchherr, Reike, Hekkertclaim, 2019)

There are several combinations of the R's of the circular economy (table) are creating different circular economy approaches and definitions. Various R frameworks have been used in research and practice for decades (featuring that the main novel idea of Circular Economy is grounded in established thinking (Blomsma and Brennan, 2017, p.611 ff.,Kirchherr, Reike, Hekkertclaim, 2019) Many authors, for example (Zhu 2010a, 2010b) and Reh (2013), face the R combinations as the main definition of Circular Economy and thus a core principle to specify it. The 3R framework is the most known and established R framework (King, 2006, 2015; Ghisellini 2016), moreover, it is accepted as the main approach of the 2008 Circular Economy Promotion Law of the People's

Although on the other hand, the European Union uses as a core the 4R framework is as the core of the Waste Framework Directive (European Commission, 2008) introducing ‘Recover’ as the fourth R since many definitions are referring to ‘recover’. Scholars have presented R frameworks, such as the 6Rs (Sihvonen and Ritola, 2015) or 9Rs (Van Buren et al., 2016; Potting et al., 2017) with the latter framework, possibly the most known one, (Fig. 1). (Kirchherr, Reike, Hekkertclaim, 2019)

The circular economy concept written by the Ellen MacArthur Foundation has to be defined to be used effectively in a scientific context. A proper definition has to cover represent the meaning of the circular economy as a whole and provide a base to define the circularity of a flow. As mentioned above there is no commonly accepted definition of Circular Economy, the core of Circular Economy is the closed flow of materials and the use of raw materials and energy through multiple circular stages (Z. Yuan, Bi, & Moriguichi, 2006). According to Allwood (2014) ‘The dogma of today’s pro-environmental discussions in politics and mass media reporting assumes that aspiring to a ’circular economy’ is one of the key technical fixes that will solve our environmental problems and allow the economy to keep on growing.’

The European Union argues however that the transition is a promising pathway to regional prosperity, enabling the ’re-industrialization of the European economy on the basis of resource-efficient growth that will last’. (Hobson, 2016).

An attempt to define the circular economy could be:

A circular economy is defined as an economic system characterized by methods that focus on the ‘end-of-life’ process by reducing, reusing, recycling and recovering materials in production and consumption processes, repeatable in different levels. In detail: micro level meaning: products, companies and consumers, meso level: eco-industrial parks and macro levels: city, region, nation and beyond.Having as main aim to evolve environmental quality, economic and social equity. (Sacchi Galvão, Gamboa , Carvalho, 2018)

Circular Economy in the built environment

Circular economy is gaining more and more fame among professionals working in the construction industry. Research of circular economy in the build environment are detaily dealing with construction and demolition waste (H. Yuan & Shen, 2011).

Traditionally C&DW (construction and demolition waste) has been landfilled. Because of the disposed of material volume, proper management, and space availability, landfills are gradually becoming more complex to work efficiently (Symonds et al., 2000). In 1990 buildings were producing 40% of the material waste and where responsible for one-third of the energy consumed globally. (Rees, 1999, Pomponi, Moncaster, 2017)

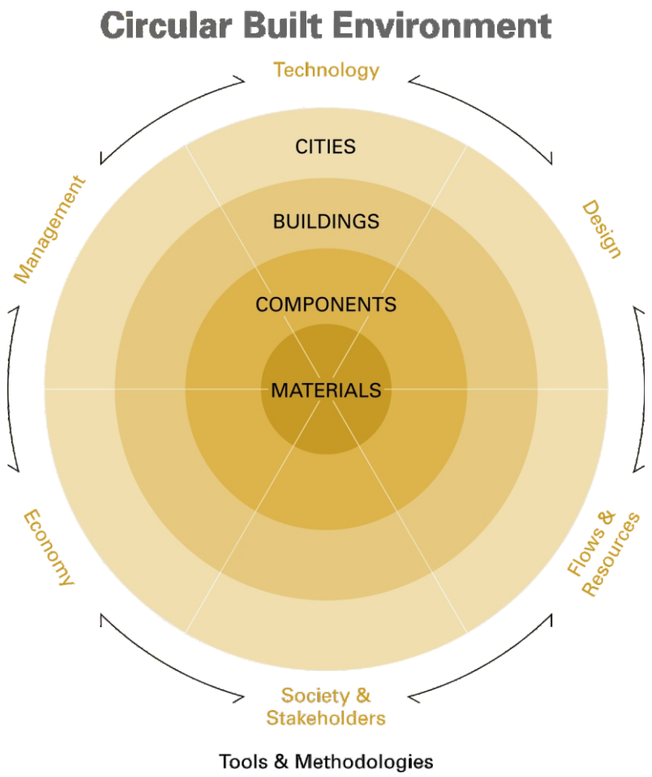


Image 1.4.1: Circular Economy in the build environment Retirieved from:https://www.tudelft.nl/bk/onderzoek/onderzoeksthemas/circular-built-environment/

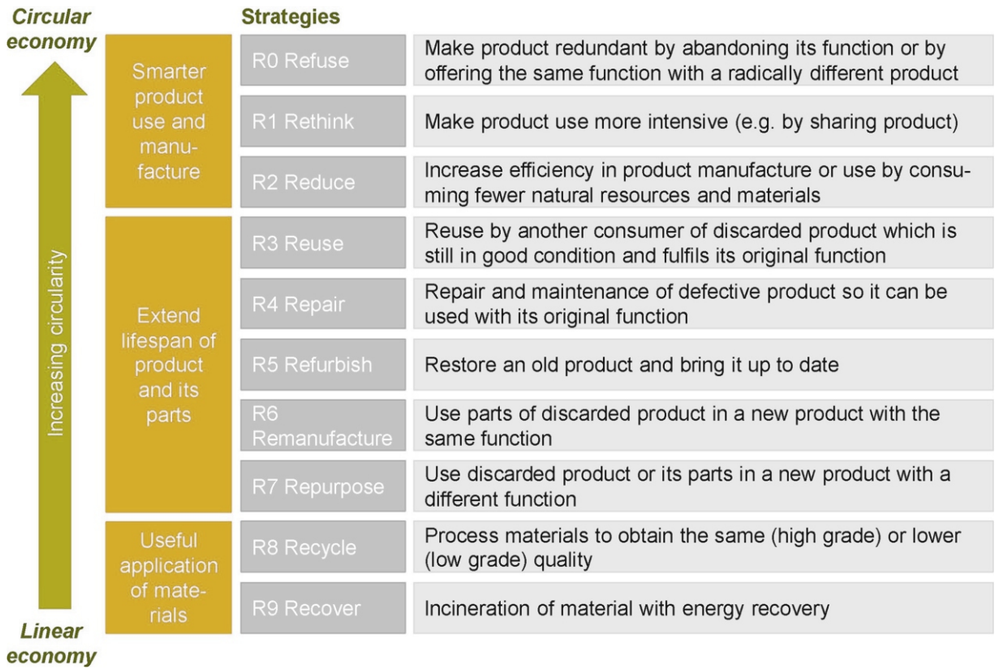


Image 1.4.2: the 9R Framework.
Source: Adapted from Potting. 2017, p.5

Image 1.4.3: The 3R of Circular Economy: Reduce, Reuse, Recycle, Retrieved from http://sustainablepossibilities.blogspot.com/2014/07/the-sustainability-rs-reduce-reuse.html

Twenty years later, the construction sector is still the world's largest consumer of raw materials and accounts for]40% of global carbon dioxide emissions (WEF, 2016, Pomponi, 2016, Pomponi, Alice Moncaster, 2017). Although building's CO2 emissions are continuing to increase. The International Energy Agency (IEA) supports that emissions are going to twice as big in 2050 (IEA, 2014).

The circular economy in construction is becoming a trend among construction developers and researchers, and it aims to conquer the conflict between environmental and economic prosperity. The main principles of the circular economy in construction concern the better management of resources. Characteristic examples of circular economy in construction proposals are the UK Green Building Council dealing with waste, materials, water, and waste (UKGBC, 2016), and the EU plan concerning closing the loops (EC, 2015) on demolition and construction. (Pomponi, Moncaster, 2017)

Circular Economy Research and Tools

Pomponi and Moncaster in their article "Circular economy for the built environment: A research framework" is presenting as the three main techniques for building research in a Circular Economy in the Building industry the "Life cycle assessment" (LCA) ,"Material flow analysis" (MFA) and Cradle to Cradle approach (C2C).

Life cycle assessment (LCA)

Life cycle assessment is a process for evaluating the environmental facets concerning a product during its life cycle. The main applications are the following:

•Contribution analysis of the stages of the life cycle to the general environmental load, usually by prioritizing improvements on processes or products.

•Comparison among products or processes.(Iyyanki,Muralikrishna, Manickam,2017)

Material Flow Analysis (MFA)

Material Flow Analysis (MFA) is the evaluation and quantification of different matter types and substances processes and mass flows inside a system during a specified period. The base of MFA is the law of matter conservation.As Lydie Yougo states in her article "The method is identifying problems and quantifying the impact of potential measures on resource recovery and environmental pollution. It can be used to compare different sanitation technology options regarding their environmental and financial impacts in order to support decision-making for choosing within different sanitation options." (Yougo, 2018)

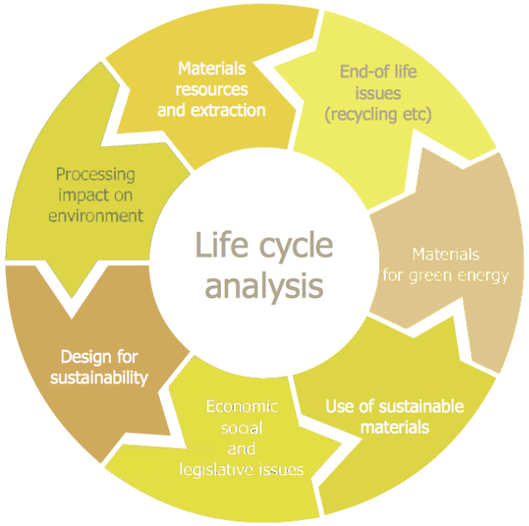


Image 1.4.4: http://eyediagrams.personaljesus.de/diagram/erp-life-cycle-diagram

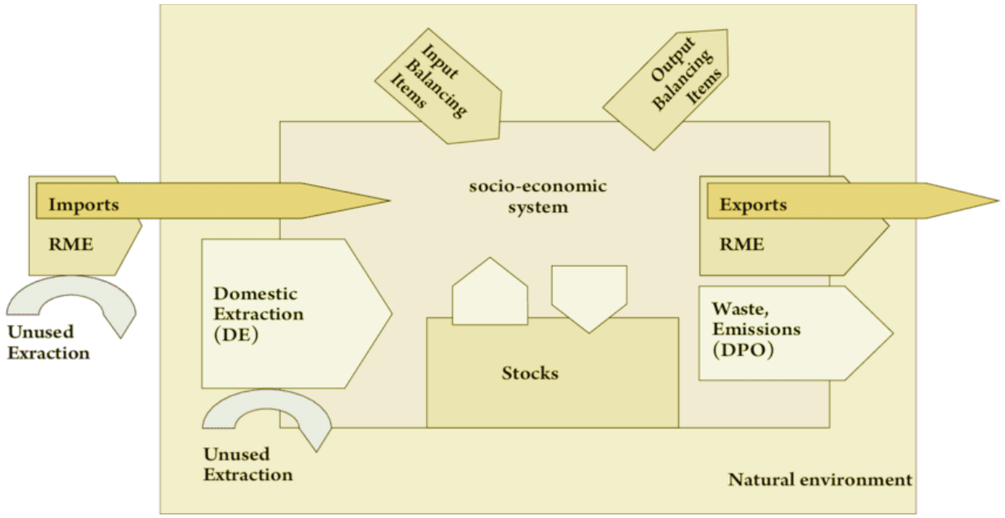


Image 1.4.5: https://www.researchgate.net/figure/schematic-presentation-of-material-flow-accounting_fig4_293175213

Cradle-to-Cradle

Cradle-to-Cradle invented by Walter R. Stahel in 1970 and became popular by William McDonough and Michael Braungart in 2002's book of the "Cradle to Cradle".It's framework tends to create production techniques that are efficient and free of waste Production in cradle-to-cradle terms, all material inputs and outputs accepted as technical or biological nutrients. Technical nutrients can be reused or recycled without loss of quality and biological nutrients consumed or composted., ideally never turned into waste but continue in the loop for as long as possible with minimum quality loss.

Main Circular Process Techniques

There are different tools and combination of them to attempt a circular process.

The most known and used from circular economy practitioners are :Open and Closed Loop Recycling,Reuse Upcycle and downcycle.

Recycling, Upcycling & downcycling

To determine if a product or a process are considered circular it is not enough for them to be recycled.After all, resource flows should keep circling.According to Circular Economy principles, resources should be multi-cyclic.To form a good measure of an application's circularity the concepts McDonough & Braungart (2002) introduced the concept of up-cycling and the opposing concept of down-cycling. Upcycling means recycling without loss of quality. Upcycling introduced clearly in 2002 in the book "Cradle to Cradle." from William McDonough and Michael Braungart. Upcycling (or creative reuse)gives a discarded item a new life with a higher quality and keeps it out of the waste system for long. Upcycle gives a new purpose in the product therefore could be also refer as "repurpose" them. (McDonough, Braungart, 2002)

Down-cycling is the recycling process that recycled resources are turned into things that cannot be recycled further.Specifically down-cycling is the delay of a resource's end-of-life , whereas up-cycling is a step in the cycle of a circular economy (Adams , 2017).

Open and Closed Loop Open-loop Recycling

Open-loop recycling means that a material is not recycled endlessly but it is excluded from the loop and ends as waste. The diagram shows the material flow through a linear or open-loop approach. oxes.According to that natural resources are becoming a product using manufacturing and technology. After the use, the product would be discarded in two scenarios: (a) whole product without use (b) whole product still functional, © whole product non-functional, (d) reusable / recyclable materials, and (e) refused parts. The outputs enter one of the next channels: reuse, recycle, disposal. Recycling loop results in other material production, of lower grade than the original.

Closed-loop Recycling

Closed-loop recycling means that the recycling process of a material can continue indefinitely avoiding the degradation of its properties. Conversion of the used product back to raw material results the repetitions of the creation of the same product continuously.
Diagram 2 summarizes the above mentioned. Having as the beginning the extraction, manufacturing, and use steps, the outputs are becoming equally used as a resource in the manufacturing chain. Greater fraction of materials are designed for reuse and recycling. The featured disposal is unavoidable but biodegradable which means no harm by returning to the environment.

High-value recycling or reuse

Current Reuse Practises:

The decline of reuse in favour of recycling means that many opportunities for reclamation do not get utilised and the chances for energy savings are missed. Circular awareness has led to the rise of new initiatives attempting to revive component reuse, but these initiatives have not found their way to become mainstream yet (‘AboutRotor Deconstruction’, n.d.; ‘Gebruikte bouwmaterialen - Dé circulaire online bouwmarkt - Gebruiktebouwmaterialen.com’, n.d.; Adams, 2017)

Why reuse?

According to Iacovidou & Purnell (2016), the environmental benefits of recycling cannot be generalised as these can vary widely from one material to another. While open-loop recycling has become mainstream for CDW more value can be maintained when materials are used at a higher level. This is represented by the loops of the circular economy diagram, but has been described more explicitly in the Delft Ladder.

The production of components requires resources such as raw material and energy. Energy used for the production of a component is lost when that component is recycled on a material level. However, in the case of reuse, the embodied energy of components is not lost. While components may require some minimal remanufacturing, the energy requirements for this are much lower than those for recycling (Iacovidou & Purnell, 2016).

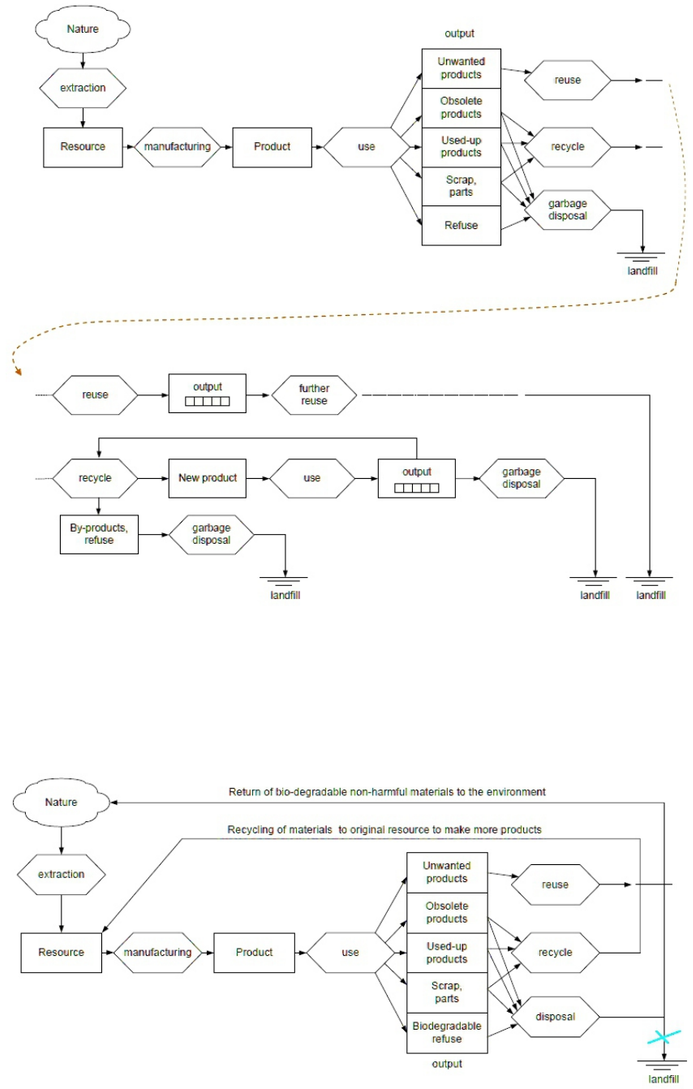


Image 1.4.6: https://www.e-education.psu.edu/eme807/node/624

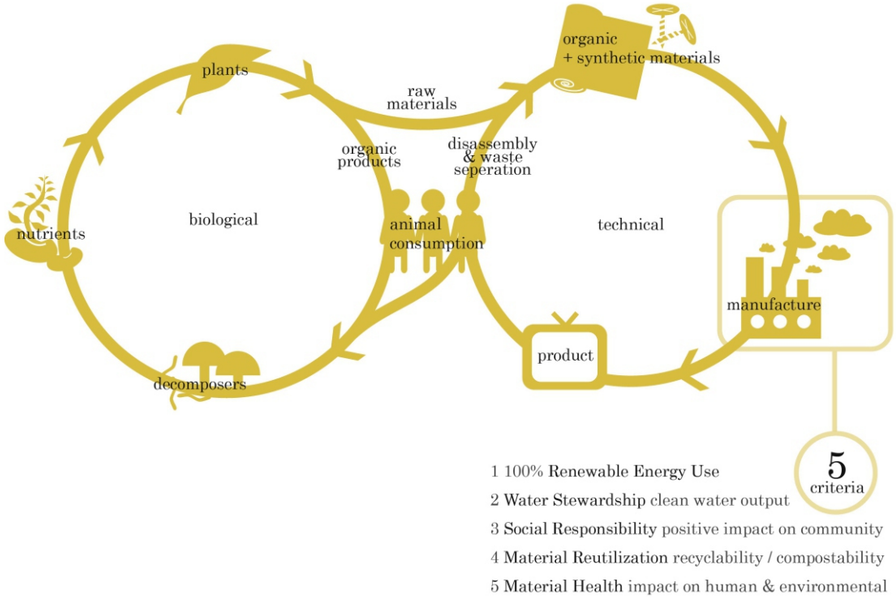


Image 1.4.7: https://www.slideshare.net/Jetfire/cradletocradle-design-creating-healthy-emissions-a-strategy-for-ecoeffective-product-and-system-design

Image 1.4.8 https://www.mariaarrieta.net/post/differences-between-recycling-upcycling-and-downcycling

The 10 steps	Consequences
Prevention	'Design for recycling' (DFR), recovery, based on remaining lifespan (technical and economic)
Reuse of constructions	DFR, oversizing, selective dismantling, remaining lifespan
Reuse of building elements	DFR, selective dismantling, reprocessing, return system
Reuse of materials	DFR, selective dismantling, reprocessing, return system, leaching and content of contaminants
Useful application as residue	Quality equal to reference (with regard to leaching)
Immobilisation with useful application	Leaching and content of contaminants
Immobilisation without useful application	Dumping conditions
Incineration with energy generation	Emission limitation
Incineration	Emission limitation
Dumping	Dumping conditions

Image1.4.9: The Delft Ladder: Retrieved from: A new vision on the Building Cycle: https://books.google.nl/

1.5 Train window recylcing

In order to understand the different types of recycling we will use the current exapmle of the VIRM's train windows:

Closed loop recycling

In the case of the train windows a closed loop would be achieved if the windows would be in the appropriate state to be reused again in the renovated NS train , only by be recovered and maintained.

Closed Loop is not possible in the NS train windows case. New technologies are applied in new generations train windows a fact that highlights the importance of their replacement.

Open Loop recycling

The open loop recycling could be either Downcycling or Upcycling. In this case, considering as product the whole window (glass, aluminium frame and rubber) and since the material cannot be reused for the same purpose again the loop remains open.

Downcycle

As downcycle choice of the reused train windows would be the decision to dismantle the several parts of them (aluminium frame, glass, rubber) and recycle every each of the separately.

I

1.5.1,2,3: VIRM's train windows Photos from NS

Rubber frame recycling

"Rubber is related to thermo-plastic-elastic materials and is turned to thermosetting on vulcanization during manufacturing of rubber products . This occurs as a result of the formation of three-dimensional structure due to the presence of the so-called vulcanizing system in rubber mixes." (Abbas, 2004)
For this reason, it is challenging to recycle rubber waste by the generaways prefered for thermoplastic materials. Consequently, recycling of rubber waste is very important problem as such waste is not biodegradable and has its negative impact on environment. (Price, Smith, Edgar, 2006)

There are two main ways in which recycled rubber is generated: Cryogenic process and ambient shredding. As a materials, is used by manufacturers in many applications today. They appreciate it as a raw material input due to the cost and energy savings.

- Some of the sector where recycled rubber is used the most are:
- In playground surfaces in mulch and mats.
- In the medical sector in surgical gloves and hospital floors.
- In infrastructure as rubberized asphalt on roadways.
- In agriculture, in products such as vegetation protectors and windbreaks, sheds, livestock mats, bumpers.(Recycledrubberfacts)

Aluminium frame recycling

Aluminium recycling process requires re-melting the metal, which demands less cost and energy than creating new aluminium. Recycling waste aluminium requires only 5% of the energy used to make new aluminium. (The Economist, 2007)
The major aluminium amount used means that *'even small percentage losses are large expenses, so the flow of material is well monitored and accounted for financial reasons. Efficient production and recycling benefits the environment as well'.*(Aluminium organisation, 2010)

Glass recycling

Laminated glass is manufactured by sealing two layers of glass together with a polyvinyl butyral (PVB) interlayer. The PVB interlayer helps the glass sheets to remain intact in the event of crash.

During windshields recycling, PVB schould be removed. At the beginning, the used sheets are crushed in small pieces (cullet). After that, a machine separates the glass from the PVB. In the next phase the glass is processed into glass cullet, which can be used in a variety of applications, such as concrete, fiberglass insulation, asphalt and more. The PVB also can be used for various adhesive applications.
(Thompson, 2016)

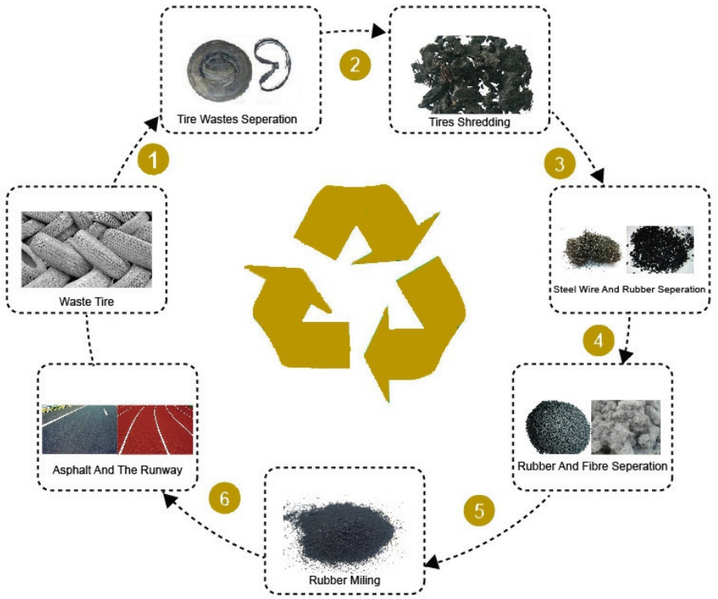


Image 1.5.4: Rubber Recycling process Retireived from http://www.greentirerecycling.com/

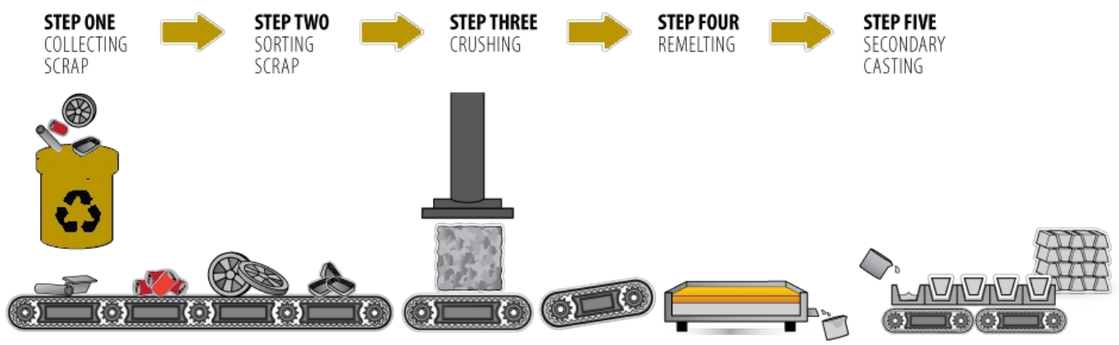


Image 1.5.5:Aluminium recycling process:
https://aluminium.org.au/interactive-flowchart/recycling-aluminium-chart/

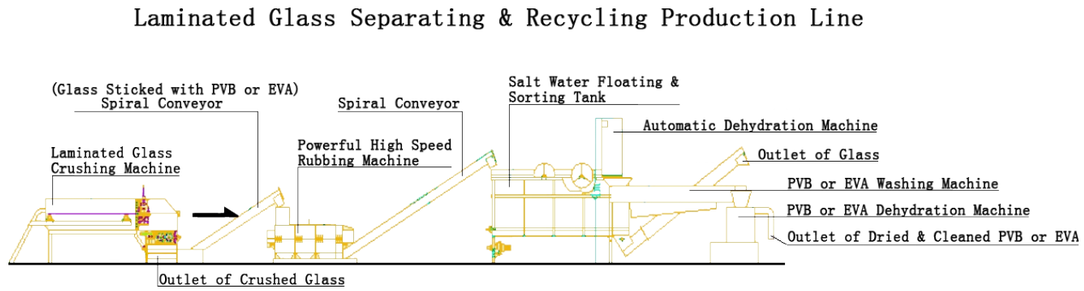


Image 1.5.6: http://www.xinology.com/photo/GPESC/glass-recycling/laminated-glass-recycling-system

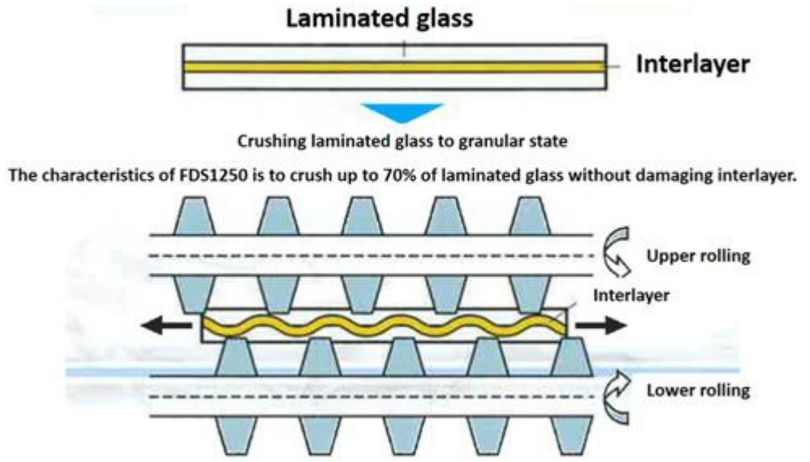


Image 1.5.7: Pvd Separation: Retrived from : http://www.unido.or.jp/en/technology_db/1649/

Upcycle

With upcycling could be described the procedure under which the train windows are used without destroying their original form, to create a new higher value product. For example an architectural construction (pavilion, canopy, etc).

Semi open - close situation

There is also the semi open - semi closed situation. In these case some parts of the product can be reused again on their initial purpose (closed loop) and some of them are reused for different purposes outside the cycle (open loop). In the train window case a semi open semi closed scenario could be the reuse of the frame of the window in the renovated trains and the reuse of the glass pane as a new building component.

Conclusion - Recycling Choice

In order to decide which recycling choice is the best in this case is important to stay critical upon the existed data.

The critical question that has to be answered is:

“How many resources we have to spend in each recycling scenario?” (resources=energy,money,human effort,material)

Aiming to spent as less resources as possible.

At the beginning of my internship in Superuse studios there was the need to exercise this critical ability. Lizanne Dirx introduced me to the “Value System game” .A method under which the resources spent during the life cycle of a material ot product can be visualized and determined.

I used the alue system game as a tool to decide in which recycling method is the best possible in this case. With the reductio ad absurdum method it was already obvious the the downcycling was not the best possible option.For this reason the value system game could be established to decide between upcycling and semi open semi closed method.

“

A CIRCULAR THINKING TOOL - A PLAYFUL NEW ECONOMY

The Value System Game is an a way to introduce the circular economy and principles to everyone.

It is consisted of cards, and the aim is to shape the life cycle of the designed product or decision. When putting cards in order it is visible where circular connections can be established that lead to added value. In this way, actions and shortcutting, that lead to a positive impact can be made.Its aim is to help “every organizations and students to take small steps today, that lead to circular innovation tomorrow.”

In the following pictures is depicted the application of the Value system game on the above mentioned dilemma concerning the upcycling or the semi open semi closed situation.

Looking at the pictures it is visible tha the upcycling method is the far more sufficient than the semi open semi closed situation.Less processes are used less energy and effort therefore is itself a shortcut that lead to a higher value product.

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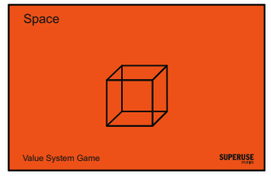
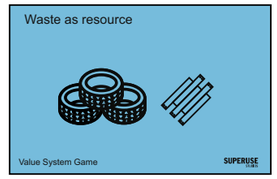
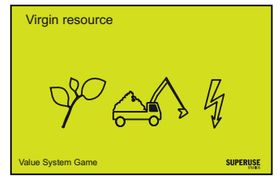
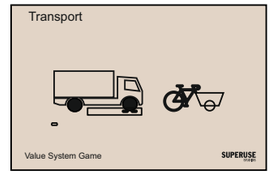
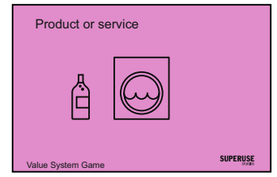
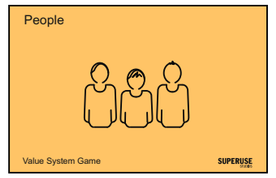


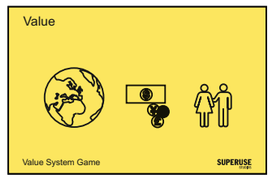


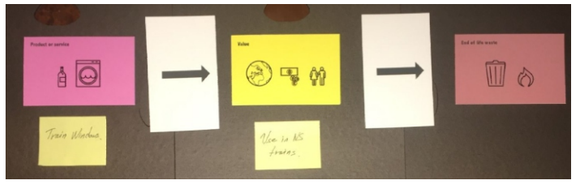




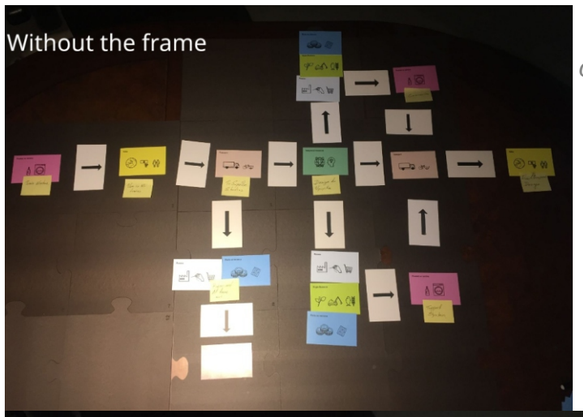


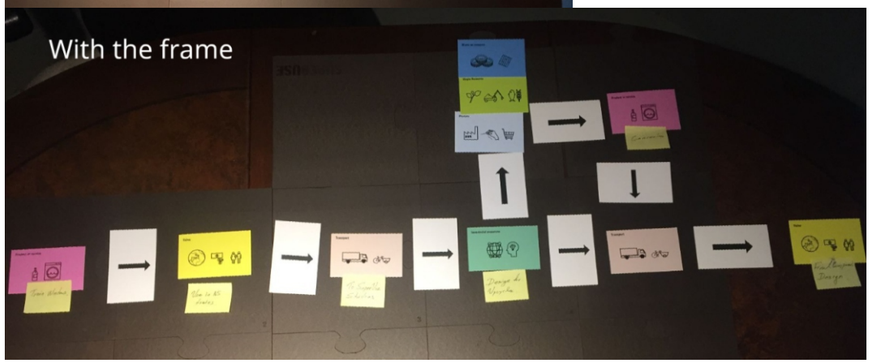






The current situation of windows life cycle





Two options of reusing it as a construction component

Image 1.5.9,10: Photos by the author

1.6 Research on reference projects

It is a demand to research the possible existing examples of recycling in the rail industry. Above examples on closed and open loop recycling are presented:

Closed Loop Recycling in the rail industry

It is important to takCurrently there are no regulations related to the recovery and recycling in the rail industry. At the design and the developing to a new vehicle,the amount of the generated waste needs to be minimized (reduce). At the operation phase, a reuse of the greatest possible number of parts and subcomponents is already a success by directly or following refurbishment reuse. At the stage of disposal of a rail vehicle the greatest possible amount of waste needs to be recycled (recycle). (Merkisz-Guranowska, Merkisz, Jacyna, Pyza & Stawecka , 2014)

For this reason there is a need for effective end-of-life rail vehicles treatment.It could be summarized as follows: higher raw material costs, stricter landfill legislation and need for landfilled waste reduction, other environmental regulations connected to producer's responsibility, (Merkisz-Guranowska,Merkisz,Jacy na, Pyza & Stawecka , 2014)

As it is referred in the "Information material and rail vehicle" handbook "The recycling issues of rail vehicles have not been specified by the legislation on the EU level. Hence, there are no unified egal regulations related to the recycling or recovery rates or the obligations of manufacturers, owners or other entities related to the rolling stock disposal". (Informational materials of Rail Vehicles ,2013) Some European member states,As it is referred in the "Information material and rail vehicle" handbook "The recycling issues of rail vehicles have not been specified by the legislation on the EU level. Hence, there are no unified egal regulations related to the recycling or recovery rates or the obligations of manufacturers, owners or other entities related to the rolling stock disposal". (Informational materials of Rail Vehicles ,2013) Some European member states,are forced by local regulations to solve the disposal problem by issuing a product technical documentation.
For example in Poland, the Regulation of the Ministry of Infrastructure on the general technical conditions for railway vehicles exploitation enforces the manufacturer to establish the recycling activities in the Operation and Maintenance Manual (O&M).(The Ministry of Infrastructure's Regulation of Warsaw, 2005)

As it is mentioned in the "Review of European Renewal and Maintenance Methodologies Technical Appendix Number 2"by Balfour Beatty Rail Technologies: "In most areas of Europe, and in particular in Switzerland, old components are returned to a depot where they can be sorted, refurbished where possible and then re-used on the railway infrastructure as required.

This report will concentrate on the Swiss experience as a case study."
Furthermore in 2006, the Union of

Railways developed the ‘Environmental specifications for new rolling stock’ that explains the sustainable requirements that must be taken into account at the design of rail vehicles concerning energy efficiency, minimizing exhaust emissions and noise, and recycling.(UIC International Union of Railways, 2006)

Consequently, there are European rail companies that are following recycling methods by closing the loop of the materials of the rail vehicles by recover, maintain and reuse them.

The following photos are part of the “Review of European Renewal and Maintenance Methodologies Technical Appendix Number 2” by Balfour Beatty Rail Technologies, showing captures of the recovering procedure of rail vehicle materials.

Stockpile of old motors awaiting refurbishment

Old point motors waiting to be cleaned and stripped (up) Testin (down)

Upcycling in the Rail industry

Except for the closed loop recycling of the rail vehicle parts there are several examples worldwide of open loop reusing of train vehicles.There are many different uses.From using them as hotels and restaurants to museums,libraries and houses.Following there are five characteristic examples of amusing architectural repurposing.

1) Hotel in Amsterdam by Frank and Irma Appel

Controversy Tram Inn Retrieved from https://www.controversy.nl/

5) Restaurant in Brownwood, TX

. 2) Hatchery (Michigan 1921)

Retrieved from https://www.flickr.com/photos/42876347@N00/3654494795

3) Church

Retrieved from EnglishRussiahttp://englishrussia.com/2009/01/29/railway-car-churches/

4) Bookstore *La Caverne aux Livres*

Image: Alexandre Duret-Lutz Retrieved from https://www.flickr.com/photos/gadl/394

Conclusion of the recycling references in the rail industry

From the abovementioned examples is clear that there are not references of reusing train windows in a closed loop, back in the train renovations.

The NS's answer on this topic is that the reuse of the old windows in the renovated trains is impossible due to the old technology used as far as it concerns the thermal and acoustic properties of the windows.

Furthermore there are not examples of Upcycling of train windows which highlights the importance of the present research.

1.7 Windows Upcycling references

In the previous chapter the example of the several recycling methods in the rail industry have been presented. In this chapter references of the different upcycling references of windows in general would be presented.

Quirky, Superuse Studios

Superuse Studios used 350 car windshields out of Audi100 , to create the interior of a store in the Hague.

Retrieved from: https://greendwellings.com/100-salvaged-car-shed

Het Glaspaviljoen

The Glass pavilion is an community project of the residents of Strijp-S (Eindhoven), who constructed a temporary, multifunctional building with reused materials, such as a number of window frames and disbanded shipping containers.

Retrieved from : http://www.pluginpaviljoen.nl/

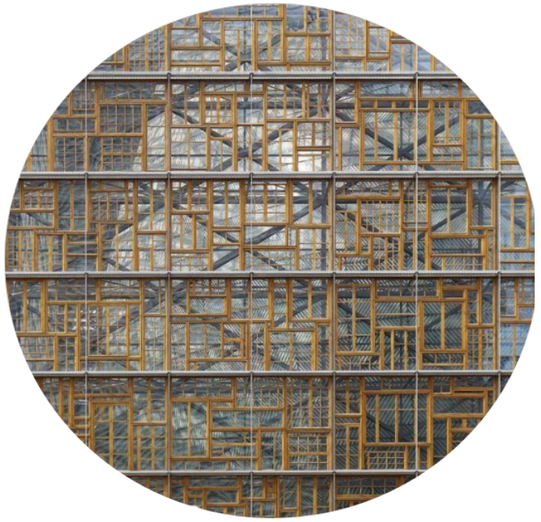
MASONS BEND COMMUNITY CENTER Forrest Fulton Architecture

Built with rammed earth, a facade from automotive glass build completely from reuse materials. The construction ,executed and designed by Auburn University Rural Studio, is an open-air space on a privately owned site.

Retrieved from :https://archello.com/project/masons-bend

EUROPA BUILDING IN BRUSSELS BY PHILIPPE SAMYN

Salvaged wooden window frames are mounted across two facades of the Europa building.



Retrieved from : www.samynandpartners.com/potfolio/europa-new-headquarters-of-the-council-of-the-european-union/

Conclusion from the upcycle references

From the abovementioned references two different categories are obvious, and differ on the use or not of the window frame.
In Quirky and Masons Bend center only the glass is used and in the Glasspavilion and the Europa Building the glass and the frame are used.
The common characteristic of all the examples is the external main construction that also works as connection between the components and the building.

Two Different cases:

Common Characteristics:

External main construction

Differences:

Frame/No frame
Edge Contact/Cover

1.8 Personal Statement - Conclusion from the theoretical framework

It is becoming obvious that not every design is suitable to be constructed out of waste material. The important thing is the awareness of the interaction between design , availability of existing materials energy consumption and waste of material or immaterial resources.In my opinion Circular economy is difficult to be defined using a general definition for the reason that every circular challenge is completely different. Different material properties different balance between decisions. energy consumption and waste of material or immaterial resources .

In detail:

In any case awareness concerning the waste (energy, cost ,resource) , being alert and reevaluate having in mind to close the loops by shortcutting the flows of every stage and every process could result in a successful circular product or service .

“Superuse is a way of creating architecture by shortcutting the flow of products and elements from their state of maximum added value to the stage at which value has either been dissipated, by storing them in a warehouse or dumping them on some landfill, or been broken down in order to be able to recreate it all over again.”

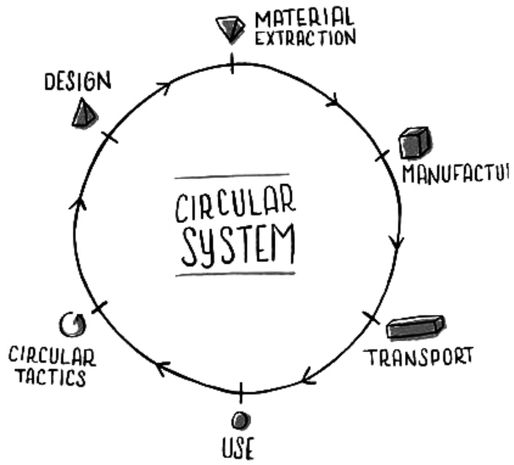
To conclude, architectural design under the umbrella of upcycling requires a strategy of forming definitions, boundaries and open mind design approach always ready to be reevaluate.

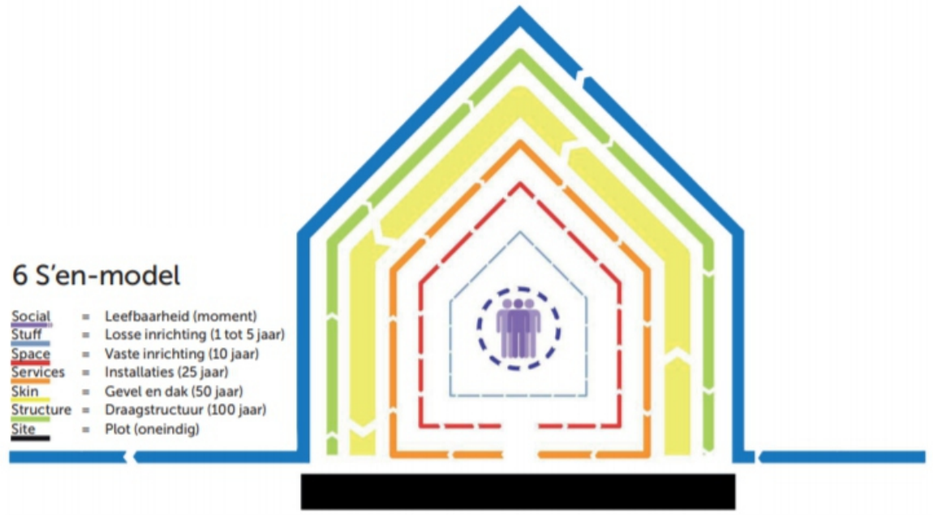
2.Circular Design Tools

In this chapter the tools that alert the circular critical thinking during the design development would be clearly explained.

These are:

- The circular design criteria in this established in this project
- The LCA (Life Cycle Assessment): Which makes clear the purpose of the exact close loop
- The Harvest map: A platform used to search reuse materials
- The Material selection tool : To select the appropriate materials based on the energy and stiffness performance





Aangepast diagram van Brand: Mohammadi & Slob, 2014

2.1 Circular Design Criteria :

The main design criteria are influenced from the materiality considerations.In this case, starting from the most important the following criteria are formulated:

- Design using as main design component the reused train windows.
- Design causing the less possible harm to the materials,in order to be reuse again in different future projects, “looping again” .
- Design for Disassembly
- Keeping everything modular. Having in mind the multi-adaptable nature of the modulus.

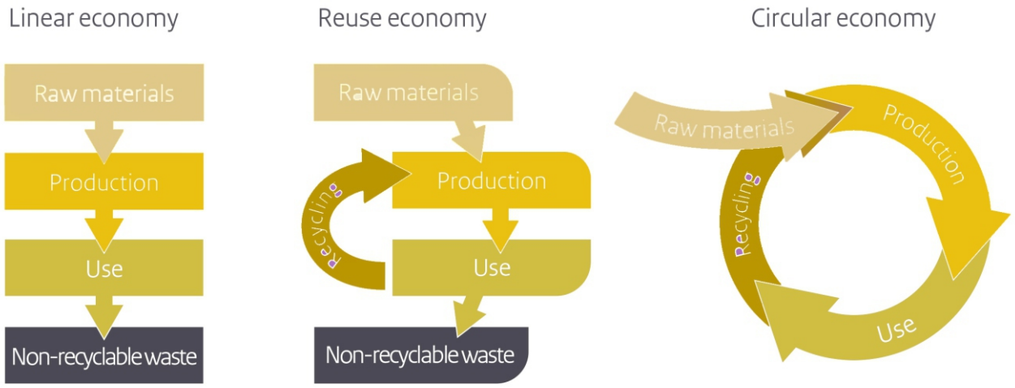


Image 2.1.1: https://www.government.nl/binaries/content/gallery/government/content-afbeeldingen/infographics/from-linear-to-a-circulair-economy.jpg

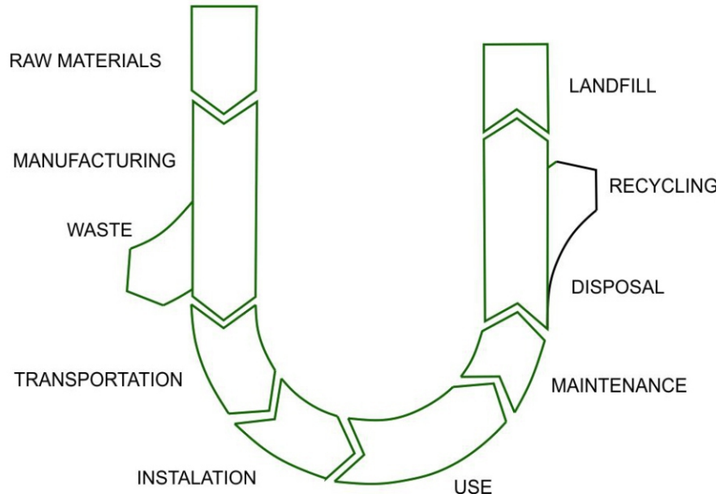
2.2 Life Cycle Assessment (LCA)

To start the LCA of the train windows the following question should be answered:
What is the current LCA of the train windows? What is the design’spositive contribution?

The first step towards the design process was the initial life cycle assessment of the main design component. The following diagram formulated according to the information received in a meeting with NS’s Sustainability consultant, concerning the life cycle of the waist windows. After the typical “Manufacturing, Use, End of Use “ life flow, (with the accompanying stages of transportation, installation maintenance) the materials are lead to disposal and a small part is recycled and in detail downcycle as glass cullet.

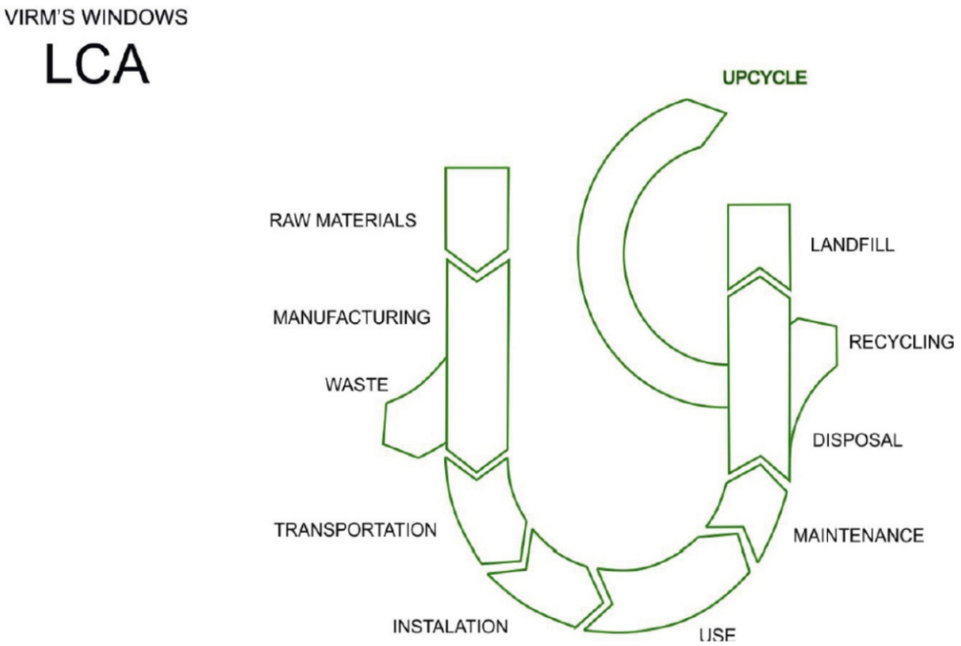
VIRM’S WINDOWS

LCA



Giving the solution of Upcycle by reusing the train windows as a new construction component the LCA diagram will be transformed as depicted underneath:

At the same time with disposal and recycling parts a part of them will be upcycled starting a new product loop.



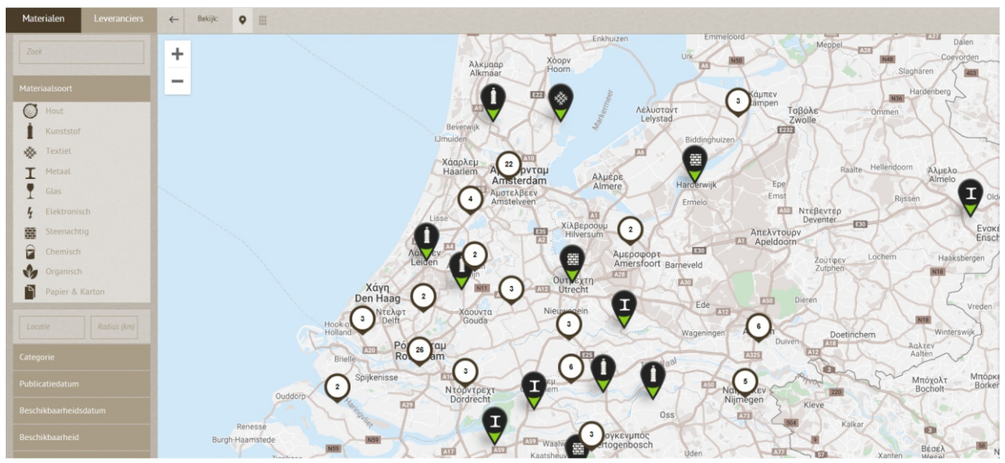
2.3 Harvestmap.org

Harvestmap (Oogstkaart in Dutch) is an online marketplace for redundant and second hand materials.

Harvestmap allows companies or individuals to make an inventory of their supply of materials, components or even buildings for reuse.

All those materials, ranging from continuous flows to small quantities of (industrial) leftovers, are represented.

The main aim of this project is to use the reused materials as the majority of the materials that have to be used. Harvest map will be used as the main tool for this purpose.



www.harvestmap.com

2.4 Material Selection

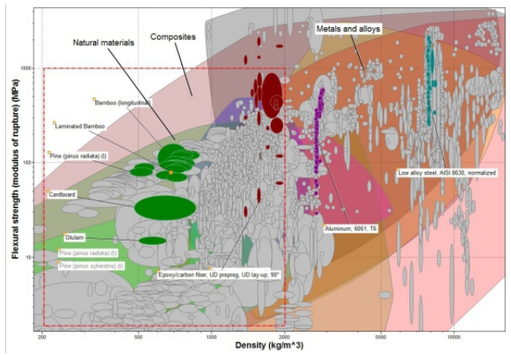
One of the main goals of circular design is the careful and reasonable selection of materials.The material performance, the durability and health are the main concerns. Beyond the performance , keeping toxic materials out of the product design can bring other also measurable advantages.

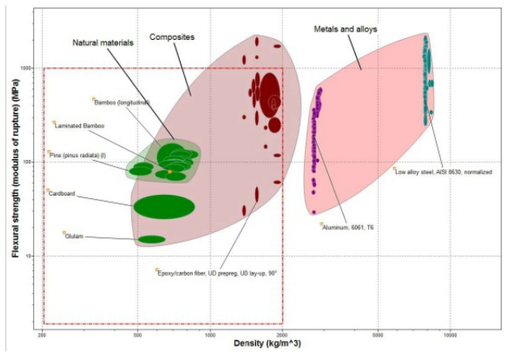
Loading in CES the most used categories of metals, composites, wood and natural materials, a balance between the strength and the embodied energy could be found and it is easier to take decisions about the materials that could be used in the proposed project.

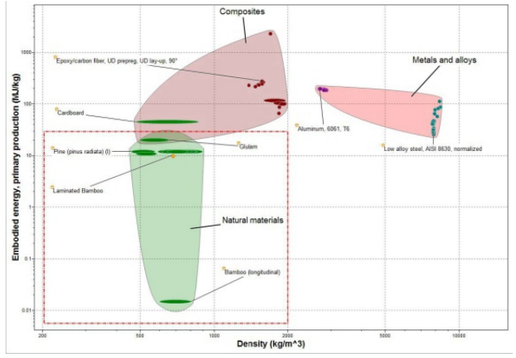
The aim of this project is to build a circular temporary pavilion and a strong stable structures with low environmental footprint.

The following criteria were established for the material selection:

- Lighter materials: Density below 3000kg/m3
- Strength (Flexural) with a range from 50MPa and 2200 Mpa
- Low embodied energy below 40MJ/kg



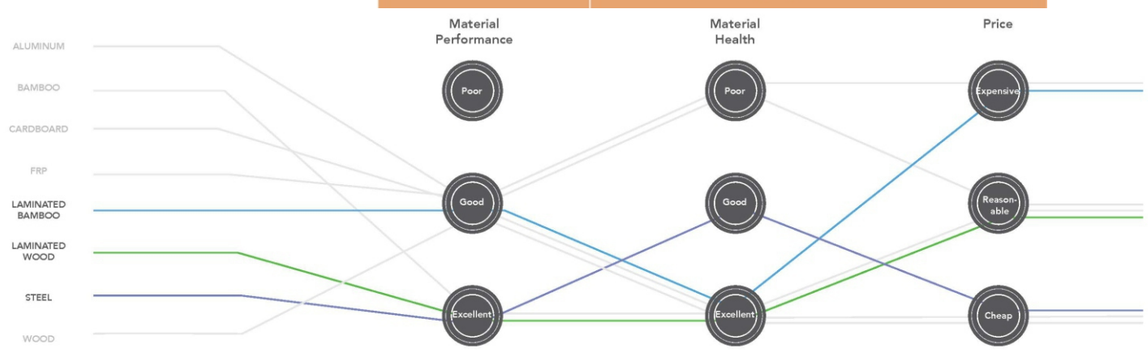




The above figures show the materials universe in CES Edupack before criteria selection. The first plotted graph is the Density x Flexural Strength diagram. The second, shows the same parameters, although in this case, also some lightweight materials filter the results. The third shows the embodied energy parameter plotted against density. Here, it is possible to see that natural materials have the least embodied energy (and density), while composite materials have similar embodied energy to metal and alloys.

Material Health
Embodied Energy (MJ/kg)
CO2 footprint (kg/kg)
Water Usage (l/kg)
Recycle fraction current supply (%)
Combust for Energy Recovery (yes/no)
Biodegradable (yes/no)
Renewable Content (%)
Material Performance
Density (kg/m3)
Flexural Strength - MoR (Mpa)
Strength-to-weight ratio (MoR/density)
Young's Modulus – MoE (GPa)
Compressive Strength (Mpa)
Tensile Strength (Mpa)
Thermal Conductivity (W/m.oC)

Most Used Materials	Alternative Materials
1) Metals & Alloys - Steel (AISI 8630) - Aluminum (Al 6061)	2) Composites - Fiber Reinforced Composite (EP-CF70) - Cardboard (CES Edupack standard)
	3) Natural Materials - Wood (Radiata Pine) - Bamboo (CES Edupack standard)
	4) Engineered Materials - Laminated Wood (acetylated Radiata Pine) - Laminated Bamboo (Moso)



The most efficient materials comparing material performance material health and cost (de Melo Morais Borges, Manuella, 2019)

Steel has excellent structural performance.Furthermore it is the cheapest material since cost is per kilo of product.Furthermore it presents great material health since steel can be recycled and consumes less water to be produced. However, its CO2 footprint and high embodied energy makes it a less sustainable option.

Laminated Wood: had excellent material health , excellent structural performance. and reasonable price.It is a great solutions for temporary structures. The type wood, treatment and laminating usually influence its . Although, since it is an engineered product, its quality is controlled before the material is used in construction. Furthermore, maintenance is decreased while durability increases.

Laminated Bamboo has a good structural performance, excellent material health but it is quite expensive. It is a new product famous for its sustainable performance, but usually it is avoided because of its high price. Moreover like laminated wood maintenance is decreased while durability increases.

(de Melo Morais Borges, 2017)

3.Outline of the design-task:

3.1 A Circular Pavilion for the Bouwpub

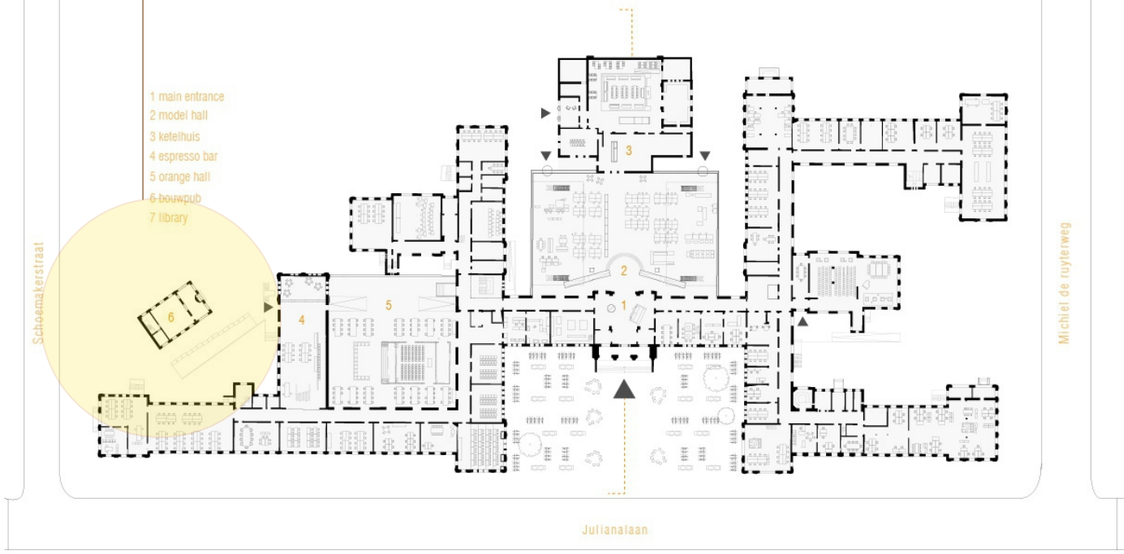
during the Circular Economy week 2020

The Bouwpub is the “soul” of the Architecture School of TU Delft. Every Tuesday and Thursday afternoon the tired students (and not only) are visiting the Architecture’s pub to rest, chill have a drink and hang out .

It is a perfect place for a small pavilion that could host information and stats about the Circular economy during the events of the Circular Economy week 2020 (3-7 February 2020). A small cosy space with a roof on top to protect the exhibition and its host from the rainy Dutch February. .

A temporary circular economy catalyst in the heart of fun inside the Architecture school made from reused materials from the VIRM intercity trains of NS, would be therefore the design case of this Thesis.

The Bouwpub



The photos and the drawing retieved from http://www.braaksma-roos.nl/project/bk-city/

3.2 Programme of requirements

- Plot :Outside the Bouwpub in the Architecture School of TUDelft.
- Construction area of the proposal: 60 -80 sqm
- Uses: Exhibition area
- Rain Protection
- Info point
- Main materials: Train Windows
- Type od construction: Temporary Pavilion

The photos and the drawing retieved from http://www.braaksma-roos.nl/project/bk-city/

An easily disassembled, temporary and circular construction

The construction has to be built in such a way that it can be fully reassembled.
In addition, as many parts as possible have to be reused products either train parts or harvested from it he waste sources.
Based on a design for disassembly plan the minimum harm of each part has to happen.

Modularity

Since the design of the construction is mainly based on the reuse of the train windows,it is becoming clear that it is going to be based on a modular design.The same principle has to be applied on the rest of the parts (connections, interior parts etc).This fact will provide construction speed (prefabricated modular elements) and maintenance possibilities.

Multiadaptability

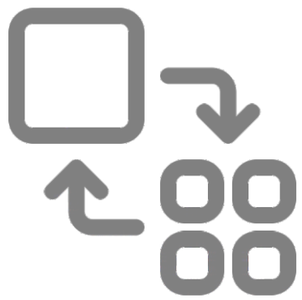
There would be a continuous flow of train windows as a deconstruction waste. For this reason, the modulus has to work as a design principle that could be adapted in several different applications. This would possibly be: Facad
Greenhouses, Canopies.

Temporary

Modular

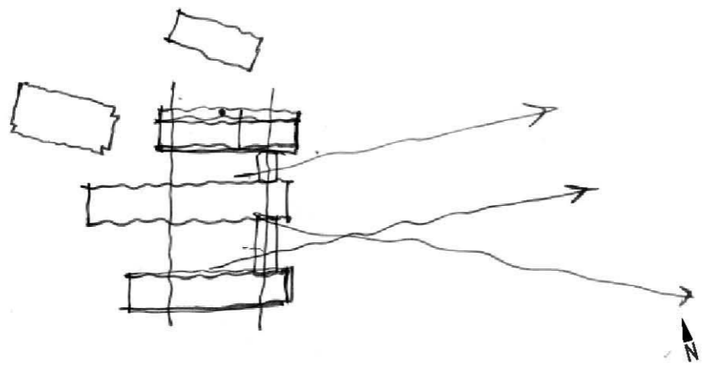
Circular

Easy to disassemble



Design requirements

4. Design



4.1 Form Finding Process

Based on the circular design principles named above, the goal of this research was to create a component with the windows train from VIRM intercity. The component would be made of one or more train windows, the connections between each other and between the other components.

Designing with a product that wasn't meant to be a construction component gives the architect freedom and uncertainty. There is a freedom of choice considering the purpose of the material and the uncertainty of the feasibility of the design. The form-finding process starts with the materiality when in most cases the materiality comes in later stages of the design. It is needed to "understand the material"."Architects creativity would be in ideas about the way in which the functionality of parts , elements, and components of any kind can be twisted and warped to do things they are more often than not were meant for,and thereby uses them exactly like normal building materials." Jan Jongert mentioned in Superuse book. (Superuse,2007)

During this formfindig process, several experimental designs came aiming to specify the forming and architectural abilities of the windows. The spacing shapes that could be designed the difficulties, the challenges, the drawbacks and the benefits that would arise.

In the first stage, starting with simple sketching and then using 3D software multiple ideas have been developed. In order to take decisions of how to proceed and conclude in forms and methods for the next steps tha main design criteria should be compiled.

Having in mind the temporality of the pavilion the necessity of a modular construction that would be build fast, easy and simply arise. The simplicity can be translated in several ways concerning the design. In this case has to do with the main construction of the windows, the connections of the components and the choices of the other material categories that would be used.
The stability of the structure, directly connected with the simplicity, refers to the ability of the structure to be standing safely with the minimum extra materials resulting in minimising the construction time the cost and the energy needed for the construction.
Last but not least the aesthetics, the ability of the final design to "charm" with an eye-catching design.
These challenges differ in different forms and this is visible in the early design stage.

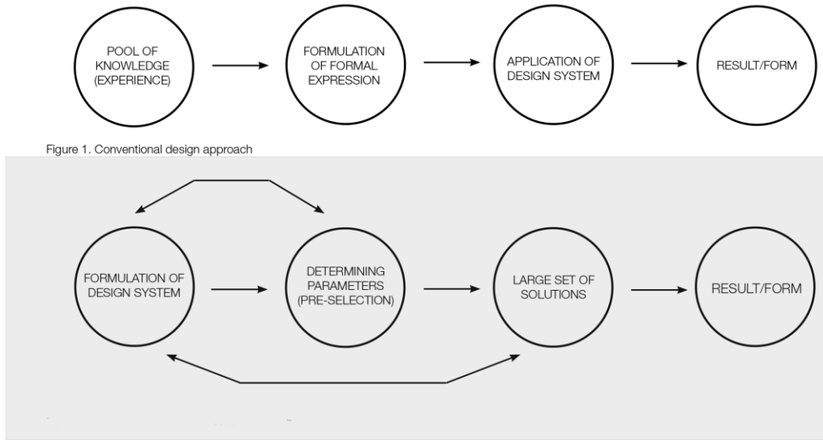


Figure 1. Conventional design approach

Image 4.1.1:Form finding process diagram- Retrieved from https://designito.files.wordpress.com/2015/07/form-finding-diagram.

4.2 Design Categories

The form finding process is equal to what researchers call research by design. In this chapter the process that was used to research the ability of the windows to form different space an modules would be analyzed.

Two different design categories with these subcategories were formulated with different pros an cons.

In this stage it is important to refer that most of the categories where characterized by which window categories used (curved or straight)

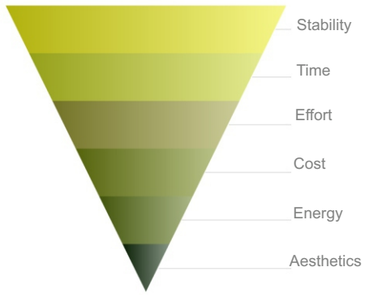


Image 4.2.2: The pyramid of design criteria
Design Criteria Importance

One window module:

1) Curved and straight window combination

2)Only curved windows

3)Only straight windows

4)Curved windows and straight windows and other reused materials

More windows as a module:

1)Triangle column with curved windows

2)Triangle brick with curved windows

3)Triangle column with straight windows

4)Triangle brick with straight windows

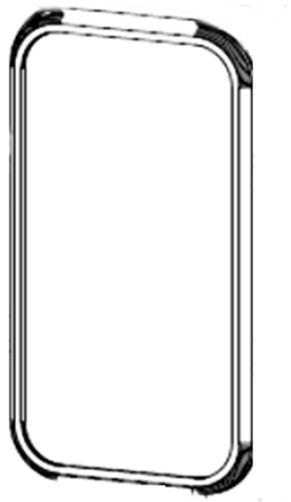
5)Square column with curved windows

6)Square brick with curved windows

7)Square column with straight windows

8)Square brick with straight window

4.3One window module



The start:

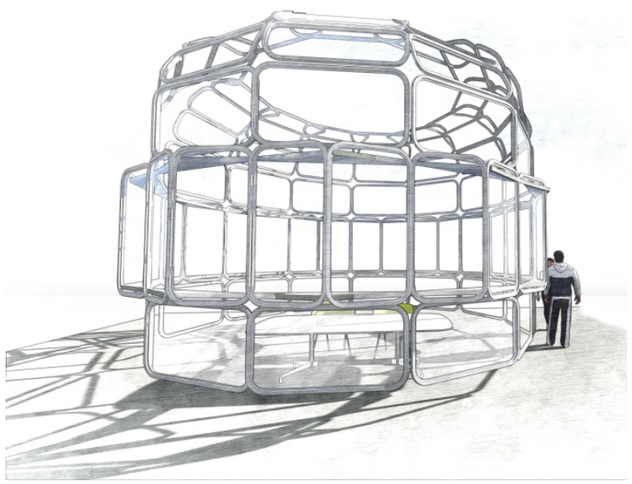
The form-finding process begun with the one window module category.
Since the variations and the forms are infinites, a categorization and evaluation was critical.

In this stage a bar chart with the design criteria formulated to help with the final decision. Different combinations and shapes came up some significantly better than others -based on the evaluation- ,athought the results seems to be insufficient.

The reason for this, were mainly the fact that using the one window as a module the stability of the structure was questionable. Either complicated strong connections needed, either an extra frame or main construction was a demand.

Knowing that the design task is a temporary structure that would last one week it is important to minimize that construction time as much as possible.

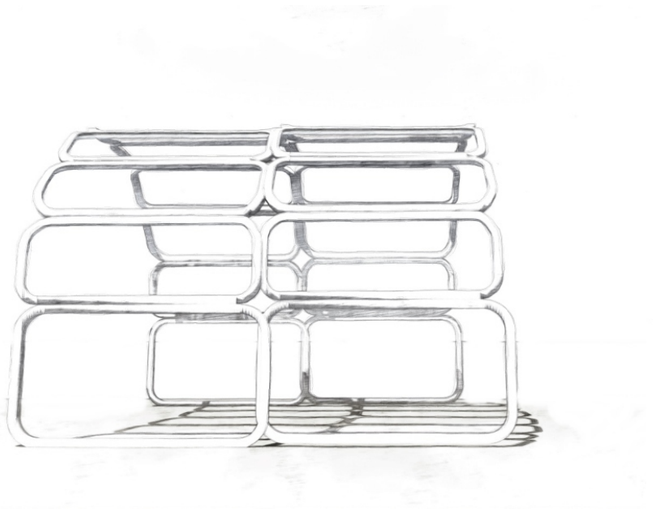
In the following sub-chapters the draft design categories and their comparison are explained.

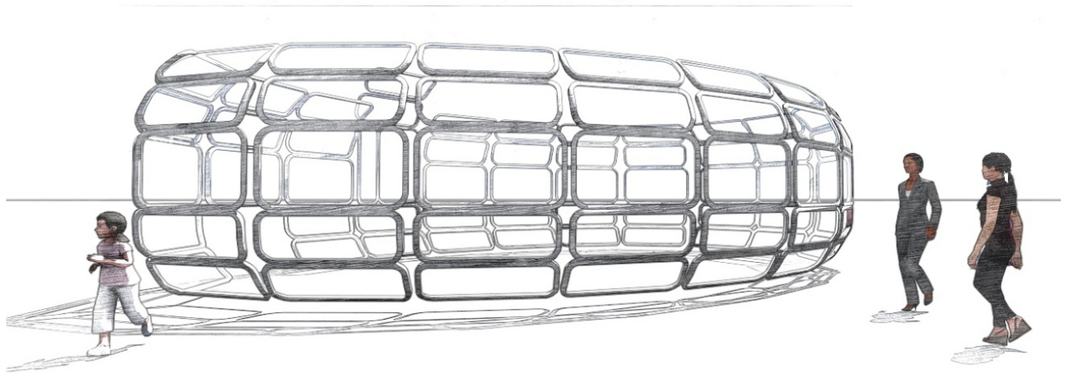


Curved and straight window combination

The designs arisen from this category where eye catching. Both of the available window sizes used anf the curve of the curved window influenced the design result.

Although a main construction or frame would be needed , a fact that increases the time the effort and the cost of the construction.



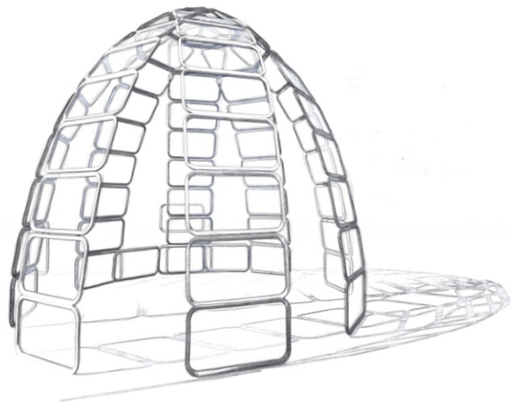


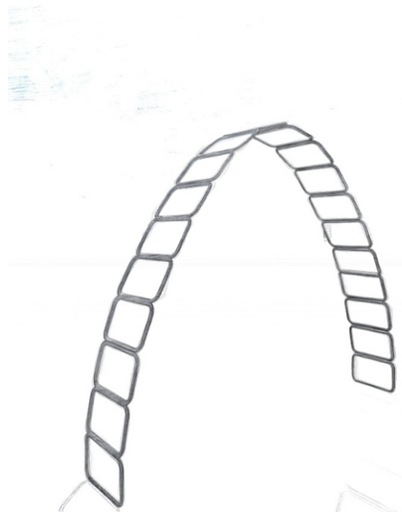
Only straight windows

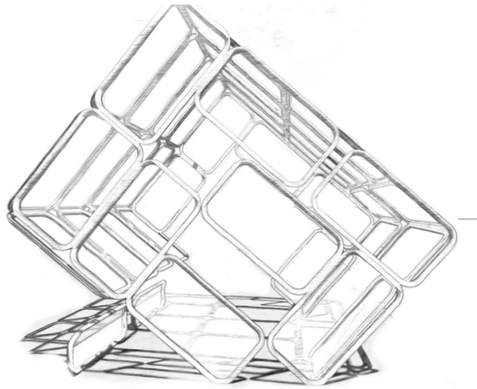
In the second category only the straight windows have been used.

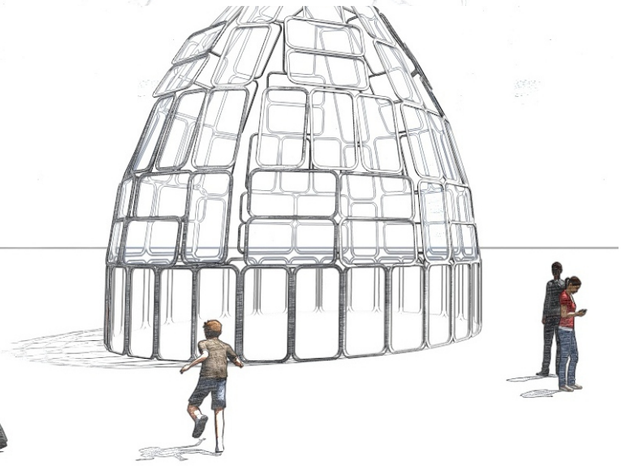
In comparison with the first category these results are impressive aesthetically but structurally wise are extreme, a fact that makes them insufficient considering the cost the energy and the time needed to be constructed.

Time	✗
Effort	✗
Stability	✗
Cost	✗
Energy	✗
Aesthetics	✓
Easy to tranport	✓







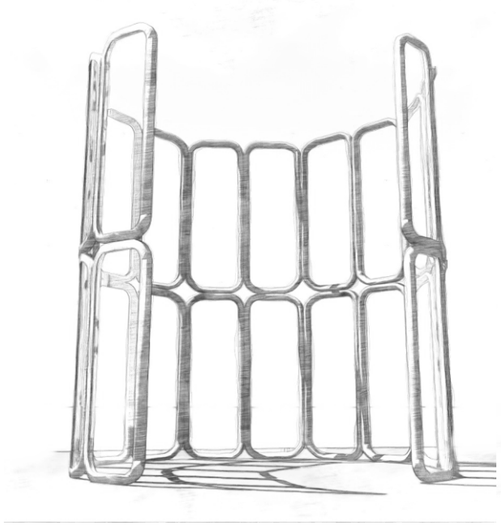


Only curved windows

This time only the curved windows have been used.

Following the already given curve of the windows interesting curvy designs arising. In comparison with the previous two categories structurally this one seems more sufficient which improves the cost energy and effort results. At the same time aesthetically the designs are quite interesting.

Time	✗
Effort	✓
Stability	✓
Cost	✗
Energy	✓
Aesthetics	✓
Easy to tranport	✓

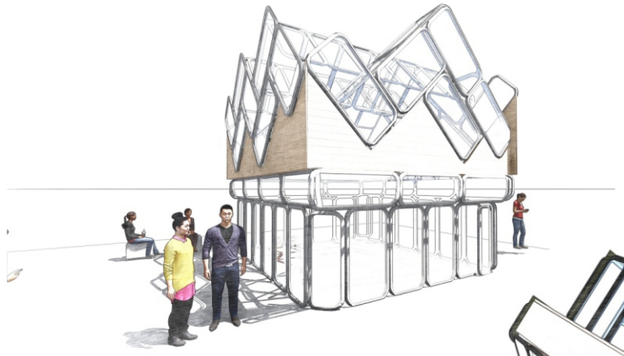


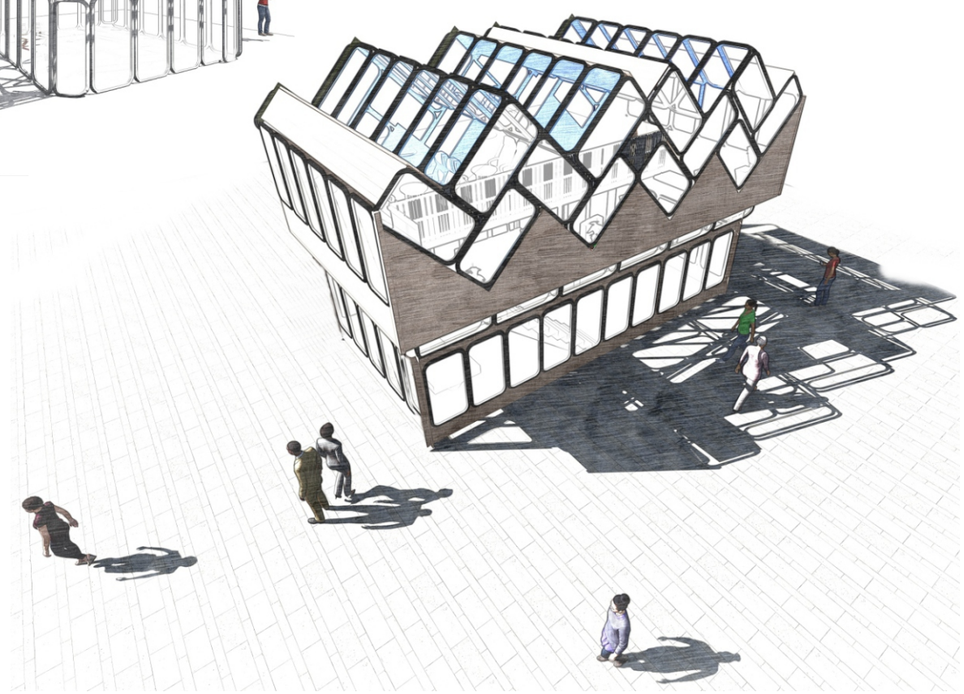
Curved windows , straight windows and other reused train materials

An effort of reusing the flooring wood for cladding in a combination with train windows was also one of the early design stage ideas.

The combination of the train windows with other materials in almost equal proportion, gave the possibility of bigger structures. Even though aesthetically the results are sufficient, cost-wise large construction with reused windows, lacks cost efficiency and self-stability, facts that directly affect the cost and the energy waste of the construction.

Time	✗
Effort	✓
Stability	✓
Cost	✗
Energy	✓
Aesthetics	✓
Easy to tranport	✓





4.4 Three or more windows module

The “golden ratio”

After several trials and forms the idea of designing a module that would use more than one window appeared.

In this case three or four windows could act as “brick” or column, formulating structures of different sizes and scales.

Several different designs came up either with straight or curved windows.

In comparison with the previous categories this module designs appears great self-stability, with impressive aesthetic results , with less effort ,cost , energy and construction time. S

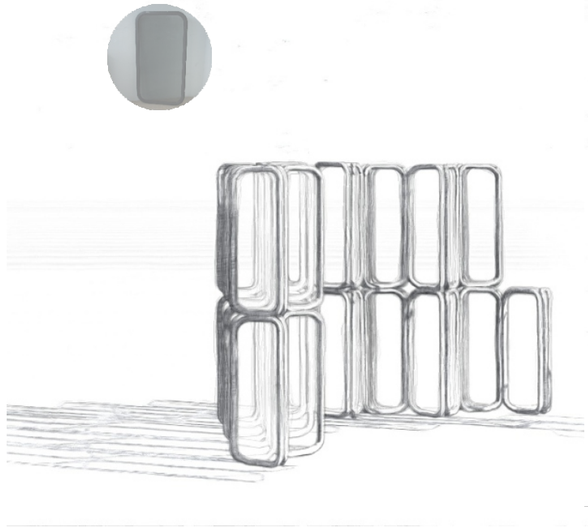
Seemed like the golden ratio of the material found out.

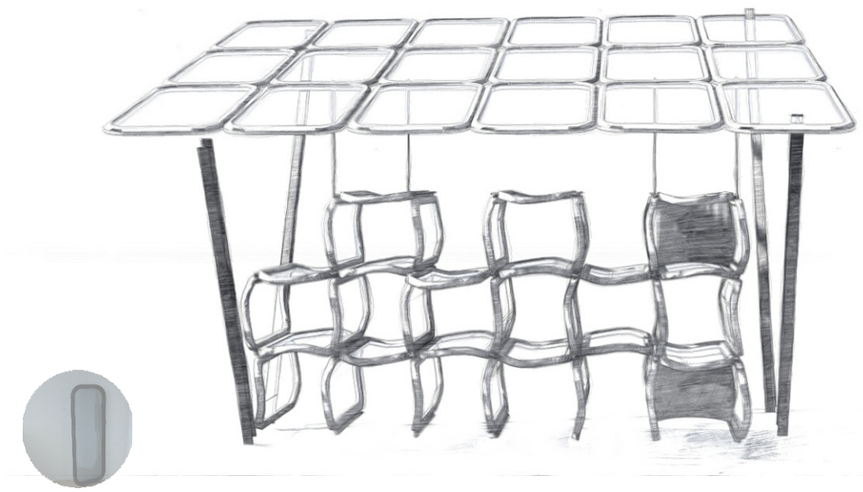
Brick or column?

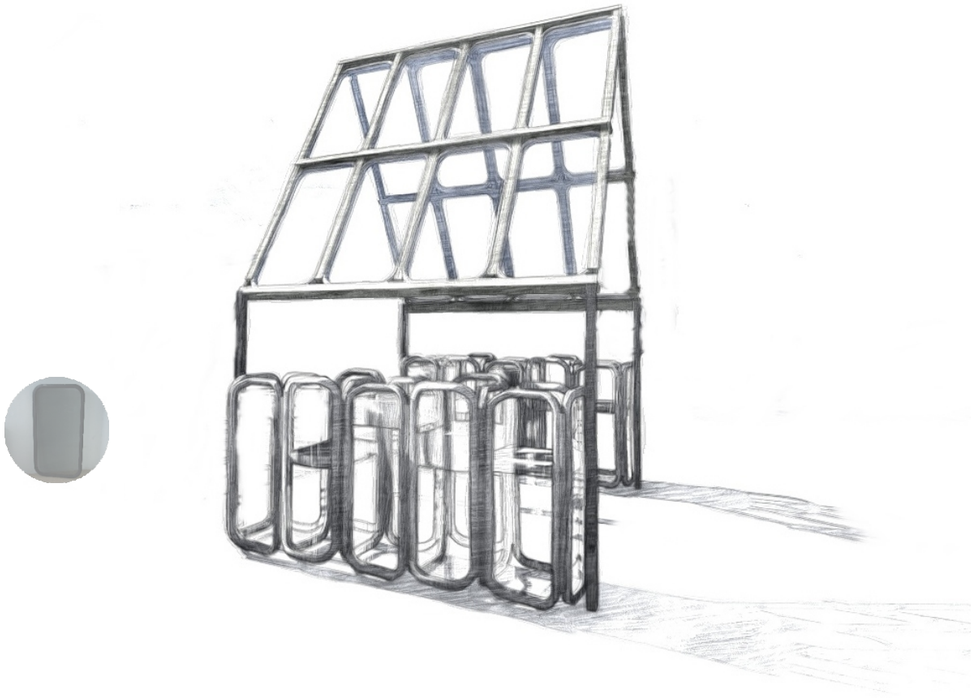
Even hough the brick window walls where very interesting and eye catching, the complexity of the structure in comparison with the column, and the connections between the modules made them an insufficient choice.

The window column has the ability to self standing, a fact that makes the assembly of the structure easier, minimizes the extra material needed and simplifies the connections between the windows.

Time	✓
Effort	✓
Stability	✓
Cost	✓
Energy	✓
Aesthetics	✓
Easy to tranport	✓







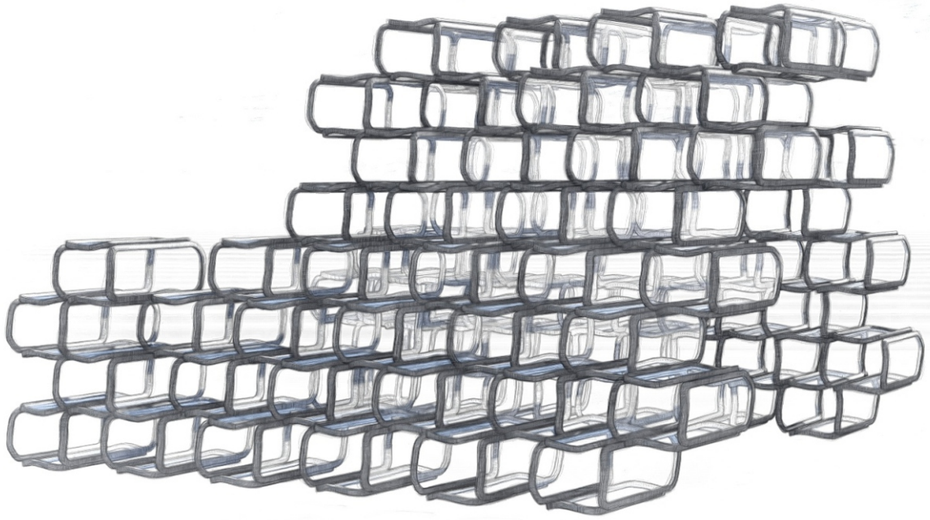
Three or four windows?

Even though with four windows a column is more stable that with three the difference is not that important.

But with three columns the construction would be lighter, and simpler and at the same time the triangles create shapes that are more elegant than those with the square columns.

Why triangular columns?

It is widely known that the triangle is the strongest shape as it holds its shape stable and from a base equally strong. The triangle is common in all sorts of building supports and trusses.
It is strong due to the fact that the three points of a triangle define one and only one triangle. If all three sides are made of a rigid material, the angles are fixed and cannot get larger or smaller without breaking at the joints, unlike a rectangle can turn into a parallelogram.



Curved or straight?

The curved windows are smaller and lighter than the straight ones. Although the fact that are curved, makes the connections between the modules different in each side a fact that makes the construction more complex and modular-wise insufficient. Therefore the straight windows are the best possible choice.

4.5 The final decision

The final decision for the module design is the triangle column from the straight windows.

The straight windows are easier to be handled since considering the modularity criterion (all of their sides are the same). The triangle is a the strongest possible shape with this windows to produce a column.

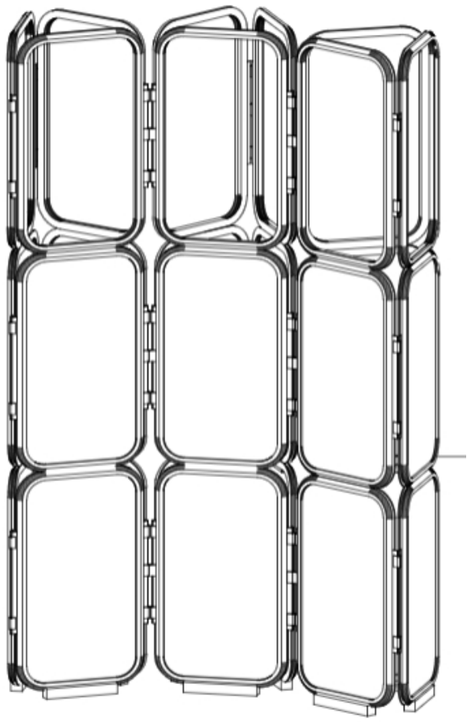
The modules maximum dimension is 1,5 m which makes it easy to be transported. The weight of each module is around 120 kg. A fact that shows that probably it is not easy to be lifted without a lifting machine, to create a larger column with a module on top of another.

There is also the possibility of using only the frames without the glass to create higher columns, but this is something that will be discussed later on.

To conclude the module follows the set criteria, it is:

-modular
-stable
-easy to be assembled
-easy to be transported
-economic
-gives interesting aesthetically results

In the following pages several design experiments exist. Every on of the played its own role to the final design decision.



4.6 Design experiments with the triangle window columns

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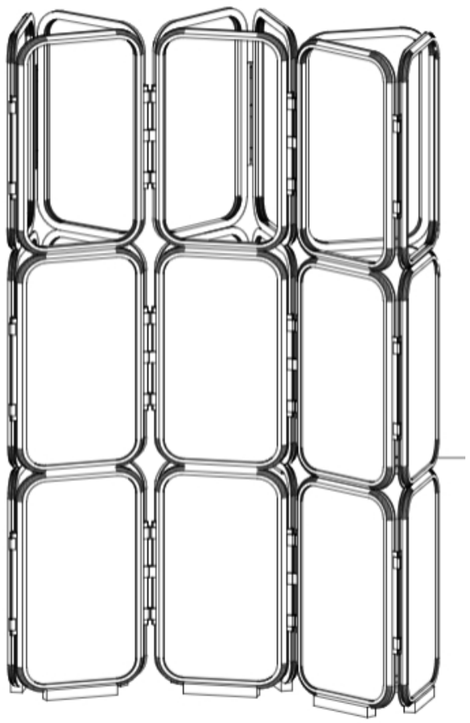

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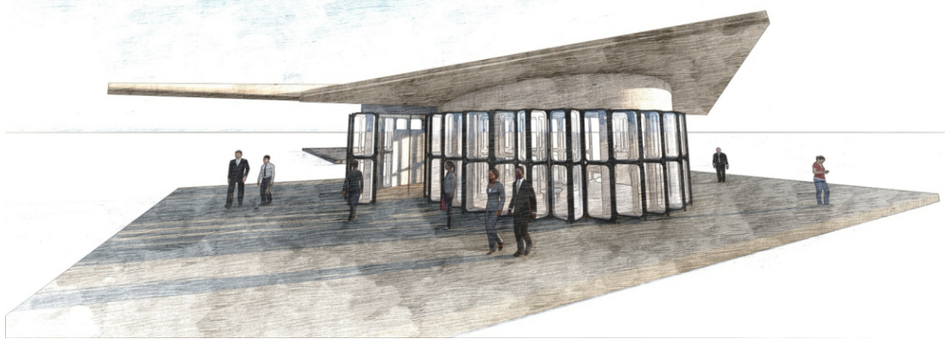
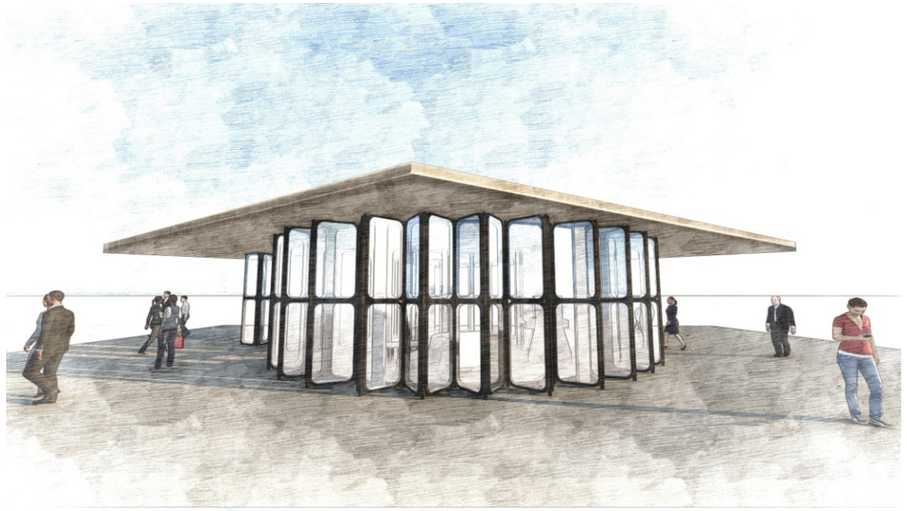
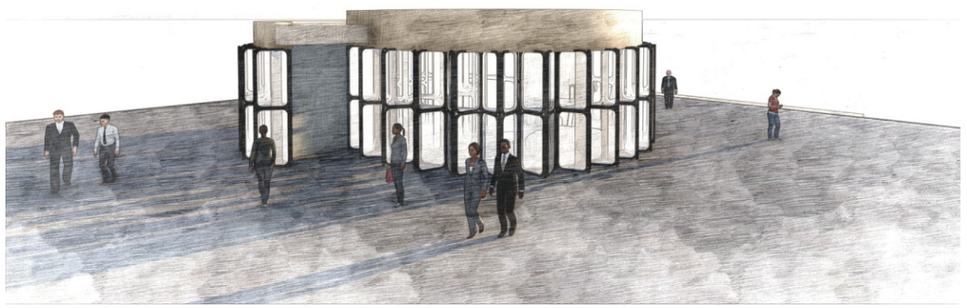
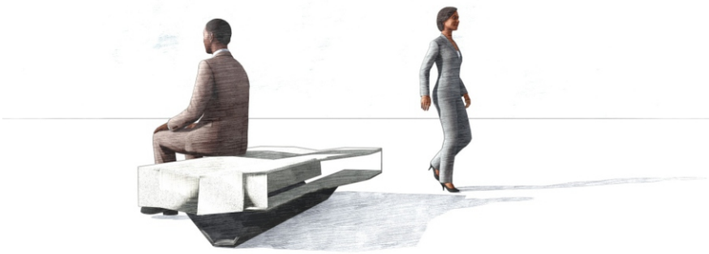
NS Pavilion



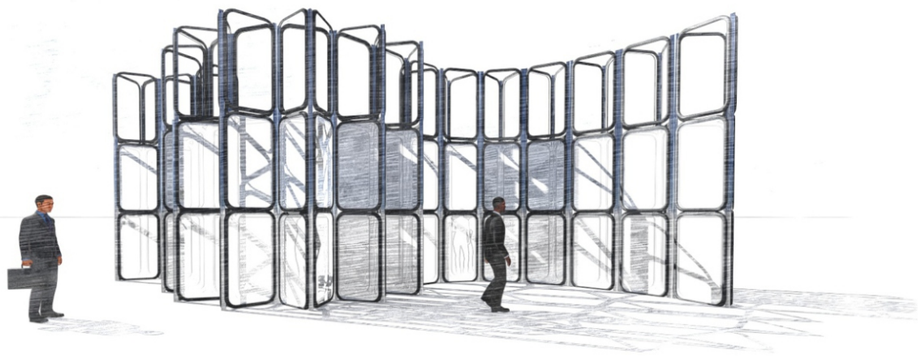




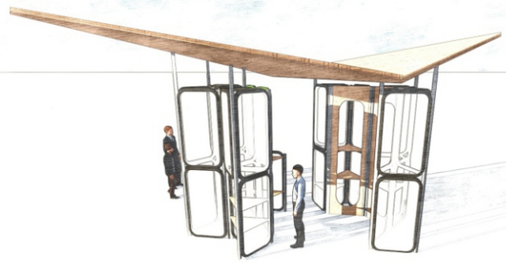
Interior Design with reused train materials

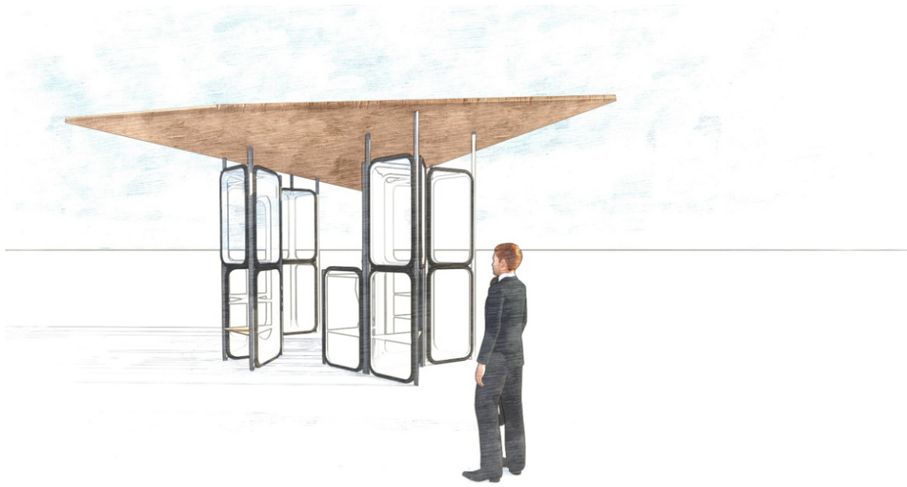


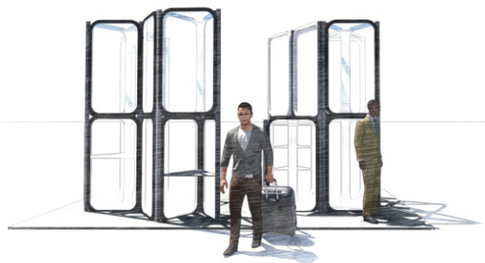
NS Station Exhibition



NS Info Kiosk







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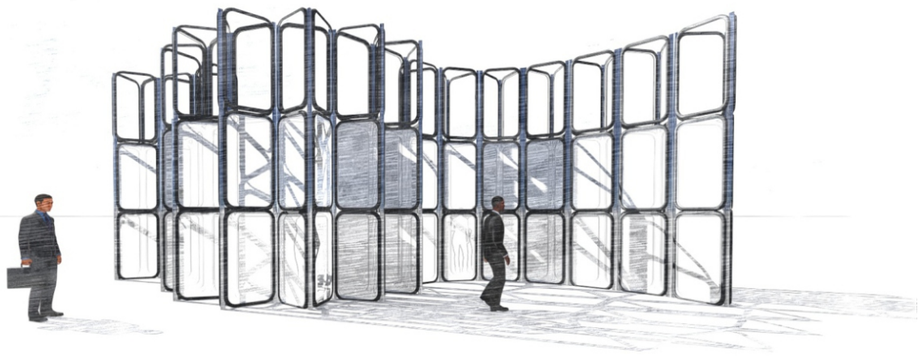

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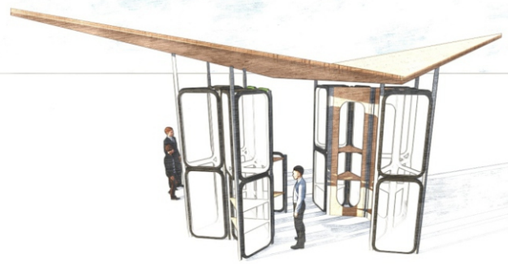
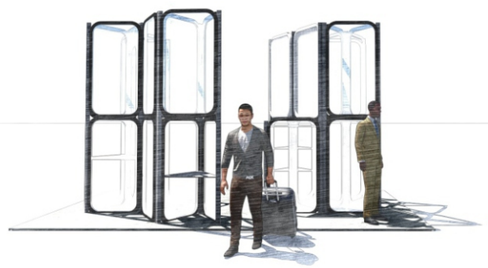
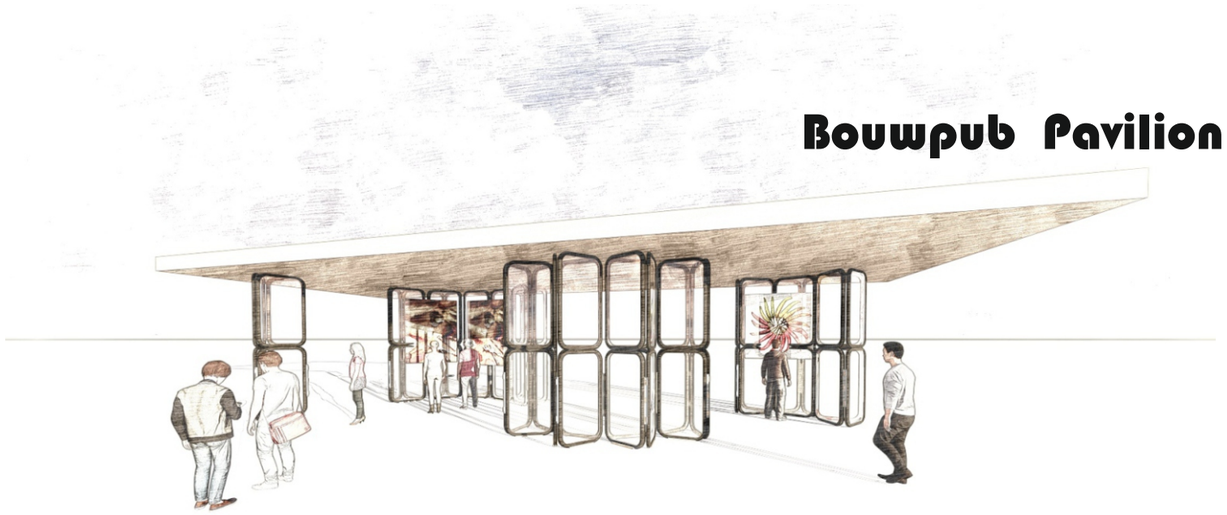






4.7 Final design

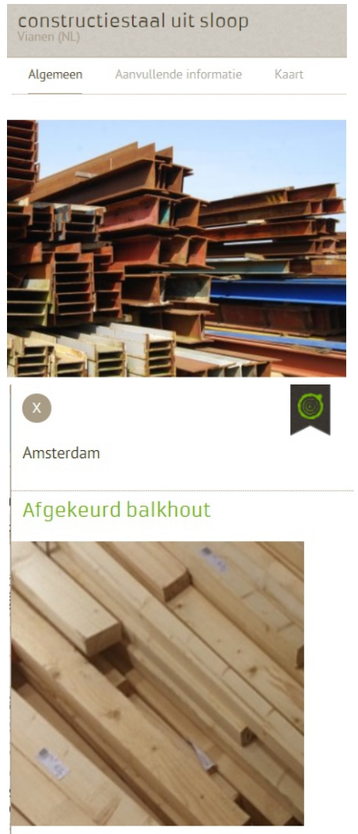
The bouwpub circular pavilion is an open entrance pavilion consisted of window columns on a spine designed route, with gaps that indicate the “entering” to it front different sides.

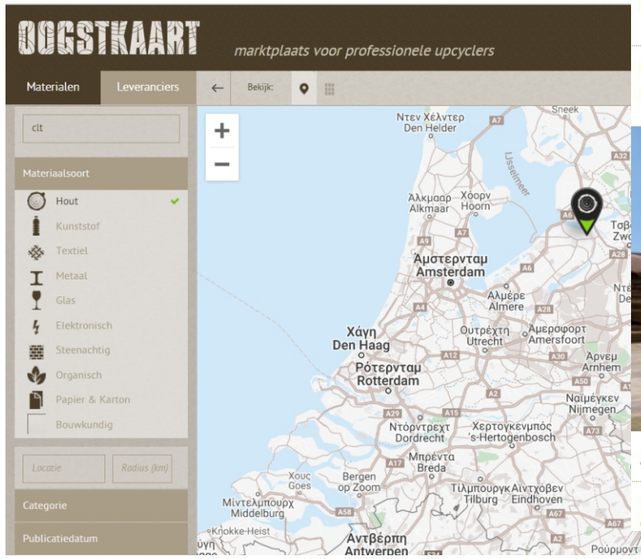
The flat side of the walls are offering place for posters and info material concerning the Circular Economy week .

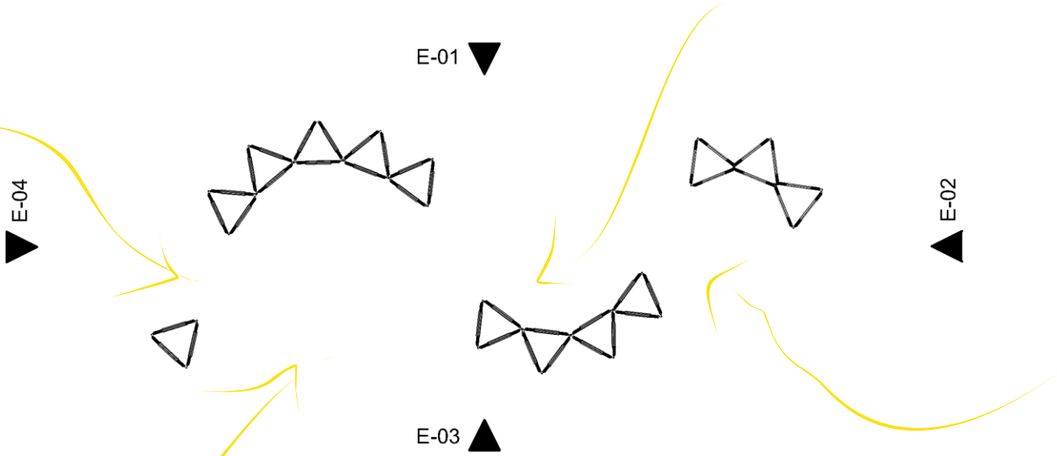
A 60sqm CLTslab lays on top of the window columns and offers protection of the rain .

The spine shape under it, was a decision that highlights the beauty of the triangular column and its ability to form variety of shapes.

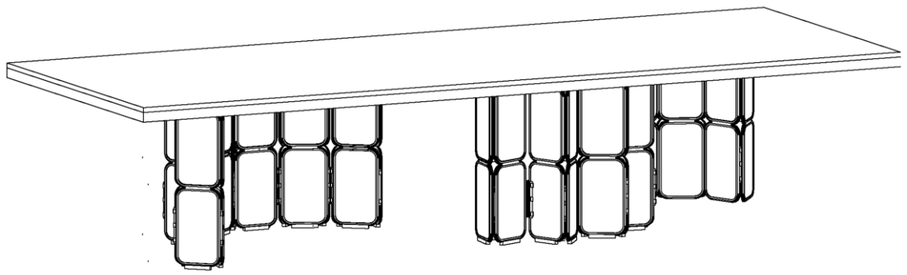
The CLTslab is also reused and found via the Harvest map.
The base wood, the metal profiles and the bolts are also reused materials found in the harvest map.



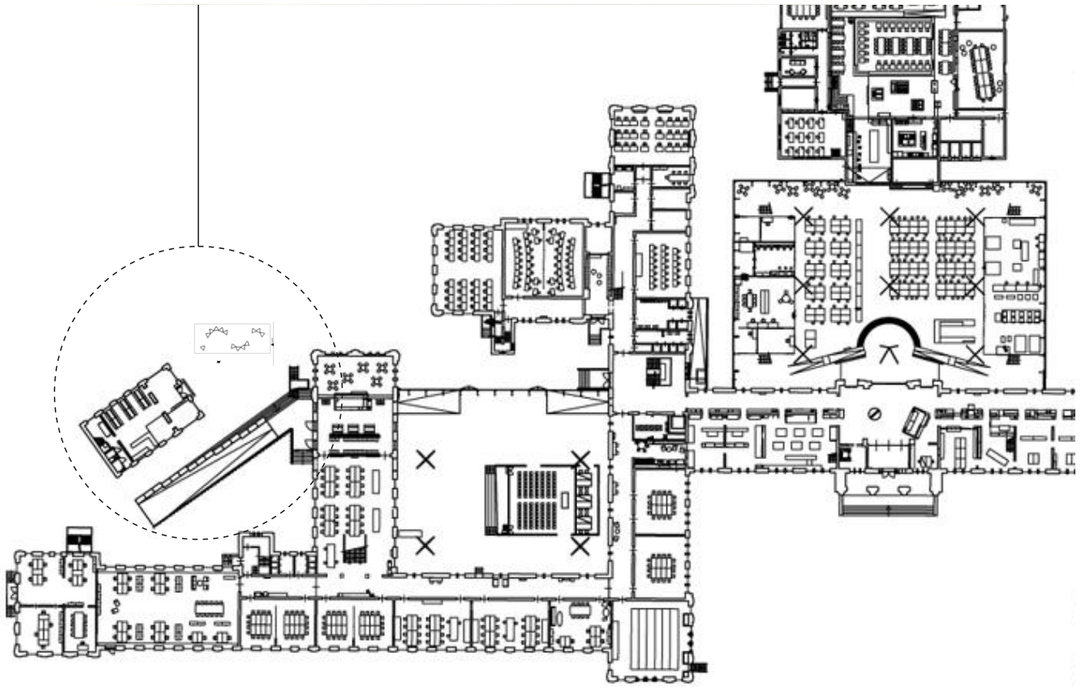


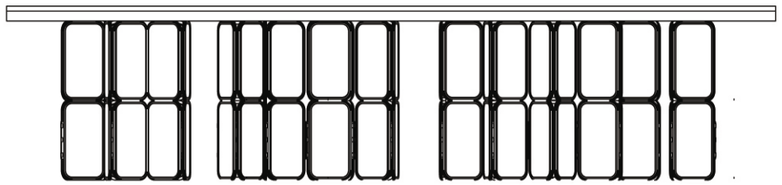


0. Ground Floor 1:100

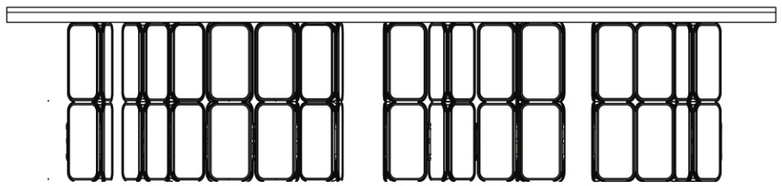


3D-02 Axonometry 1:100

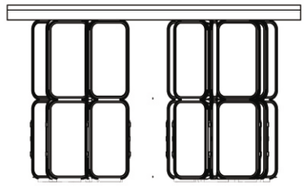




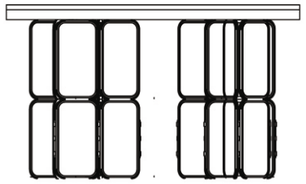
E-01 Elevation 1:100



E-03 Elevation 1:100



E-02 Elevation 1:100



E-04 Elevation 1:100

The Bowpub Pavilion is a temporary (built only for 10 days) structure, extrovert designed to welcome student from different directions under its roof. The windows are offering flat surfaces able to host posters and info about the Circular Economy week 2020. The darkness of the glass can crate a prefect screen for projection.
Also the gap inside the column can host an exhibition of models, circular materials and innovations.

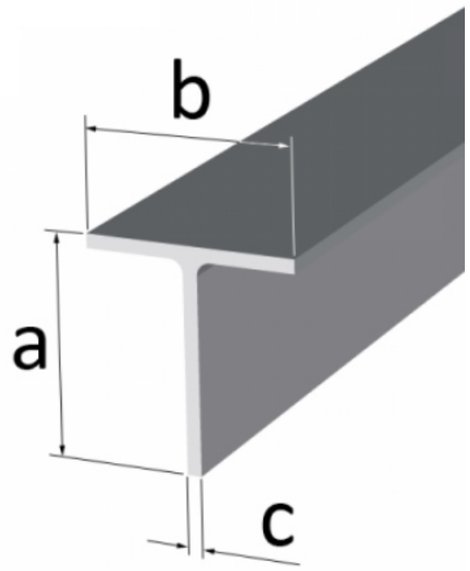
In total 96 windows that form 16 columns were needed. The Cross Laminated timber slab, the meta profiles and the wood for the base are reused materials from the Harvest map. This fact decreases the cost and the Embodied energy of the construction to minimum.

Since the proposal is a temporary structure it is one of the main criteria that the design is able to be fast and easy assembled.
The triangular modules can be preassembled and be placed and secured on top of each other in situ. This would minimize the time of the in situ construction.

The multiplication of the modules can take different forms and create different designs as it is obvious from the previous mentioned examples.
This fact highlights the multi adaptability of the project.
Different modular designs could be produced:
Pavilions, Bus Stops, Info Kiosks, Installations , Exhibition Walls, Interior designs. This reassures the main aim of this research : To design a module that could give different construction solution and second life to a continuous flow of materials.

Image 4.7.1 : Projection on the train window glass

5.Detailing Process



5.1 Detailing Process Framework

In this chapter, the detailing process of the project and its phases will be explained.
In general, the Design Process includes the detailed design of the connections among the windows and the connections among the modules. As previously explained, it was important to formulate a criteria list in an early stage to design the right connection.

These criteria are:

- Simplicity
- Cost efficiency
- Design for disassembly
- Structural stability

The simplicity criterion refers to the complexity of the assembly of the connection. The simpler the connection the faster the assembly of the whole structure which means directly cost efficiency. However, cost efficiency is directly connected with the material choice for the connection parts. About the design for disassembly, which is one of the major Circular Construction principles, the connections have to be easily disassembled in simpler parts that could be maintained and reused. Therefore glues, screws and welding are prohibited. The structural ability is strongly connected with the materiality. For this reason, a balance between a strong material and a stiff design should be achieved.

The detailing process evolved in three different stages of design-evaluation and redesign, that will be explained in detail in the following sub-chapters.

The circular aspect of the detailing:Design for disassembly:

Detailing for a design for disassembly requires specific restrictions.

- Using bolts and not screws
- Avoid glues and adhesives
- Avoid harming the materials
- As simple design as possible
- As modular design as possible (typical bolts and nuts limited variety)

The connection design involves:

- The connection between the three windows, to formulate a triangle
- A vertical connection to connect two (or more triangles and formulate a column
- The base of the column
- The connection between the column and the roof.
- A safety clamp connection, that connects the glass parts of the windows.

will be expanded further stage by stage.
For each of the abovementioned parts, the role of each criterion and the balance between them even though the decision-making process in each stage

5.2 Detailing Phase 1

The first phase of the detailing starts with the design of a connection between the windows to formulate the triangle. Having in mind the stability and the stiffness of the connection, the first trial includes a bolted metal triangle profile (60 degrees) that connects the windows in the three corners. Using the pre-existing holes on the windows the metal profile would be adjusted on the aluminium part of the windows connecting them in 60 degrees to an equilateral triangle. Having in mind the material selection procedure explained in the previous chapter, steel seems to be the best option.

For the vertical connection, the first option was: an RSC steel beam connected on the front side and a steel sheet (4mm thick) on the backside that could bolt the aluminium parts of the frames of the windows together using the pre-existing holes. The vertical and horizontal steel connection would be connected in the corners schematizing a frame.

For the connection between the modules, a hinge seemed to be a good option since it offers differ angle connection between the modules. A steel hinge with a rubber connection seemed like a sufficient option since it could be produced in 2m hight and the rubber connection gives extra strength against corrosion of the hinge.

In this stage due to the self-stability of the structure base seemed not a priority.

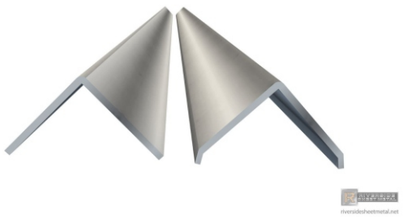
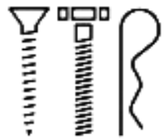


Image 3.1.1: Triangle meta profile: Retrieved from : https://www.riversidesheetmetal.net/edge-metal/corner-guards/

Image 3.1.2: Rubber hinge - Retrieved from https://www.vehiclebodyfittings.co.uk/products/continuous-hinge-aluminium-rubber

Nails damage the material.



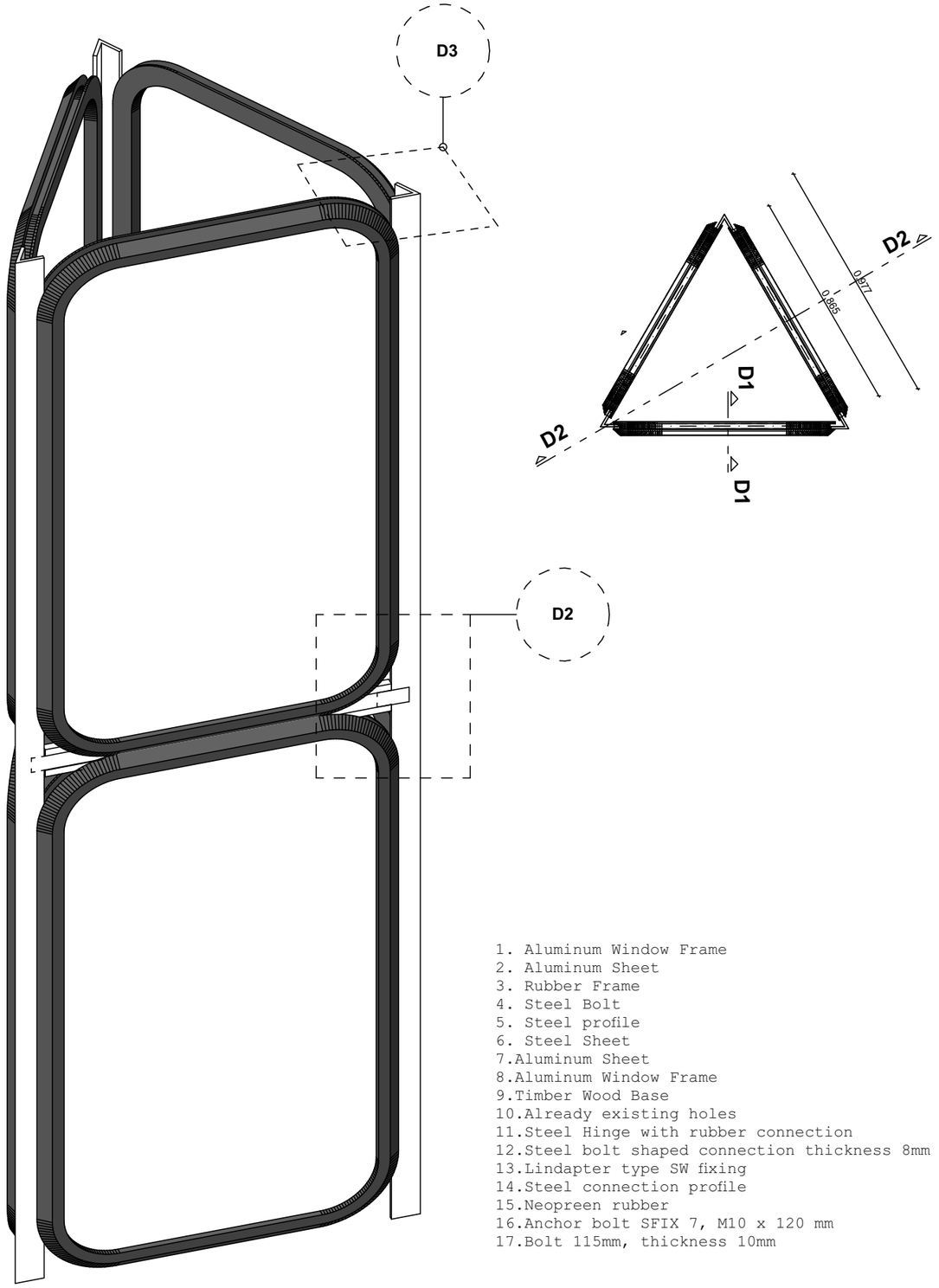
Use screws, pins, nut and bolts.

Fasteners can be found in all shapes and size.

Use common and similar fasteners.

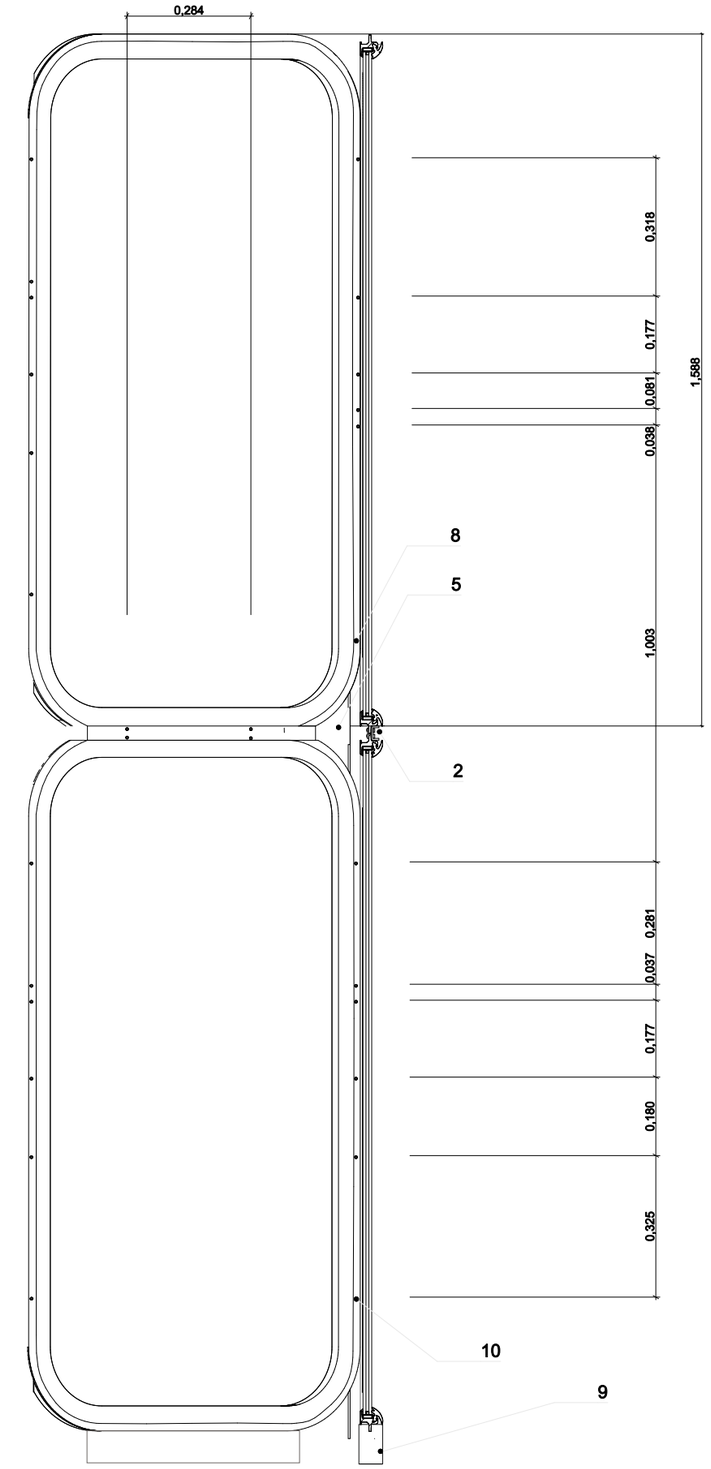
Avoid glue and sealants.

Use easy dissolvable binders.

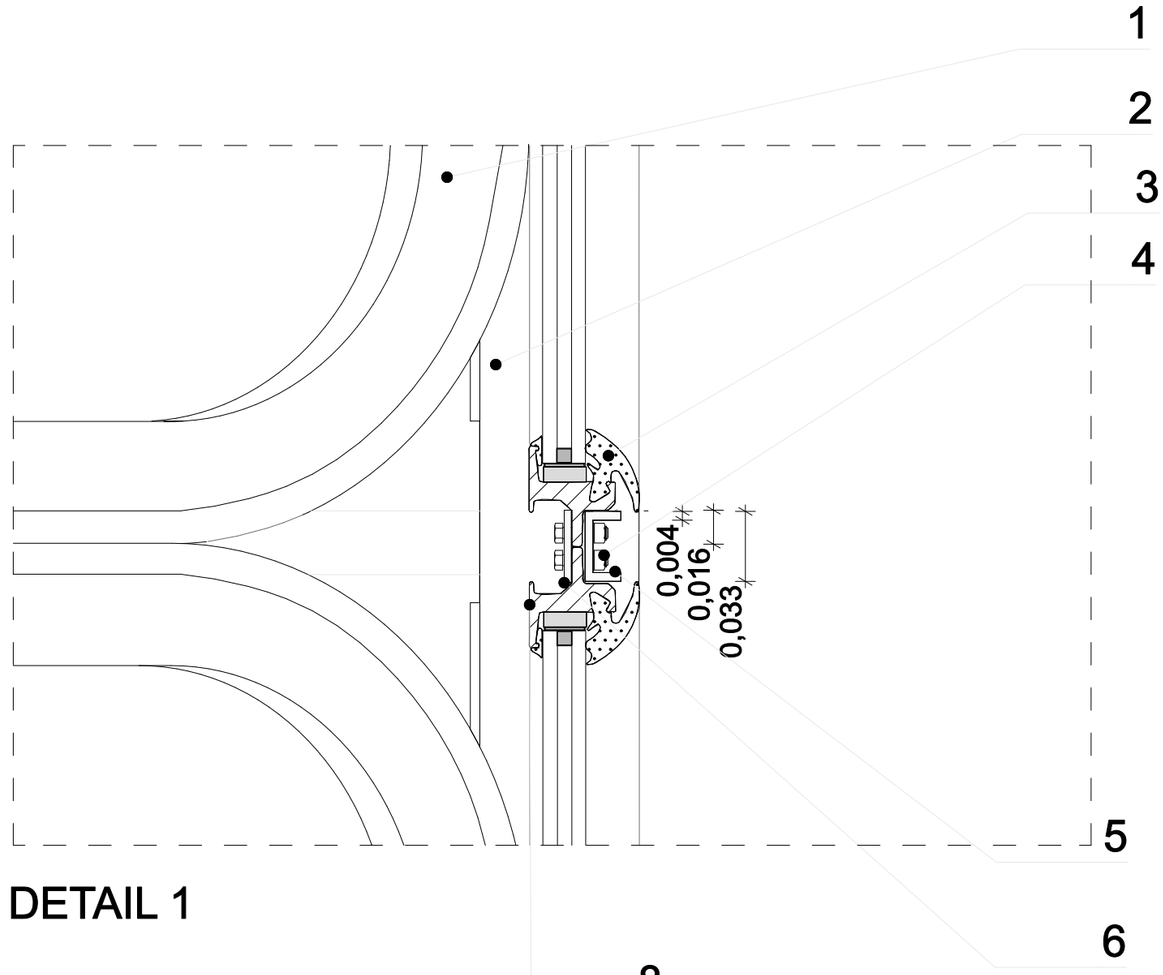


1. Aluminum Window Frame
2. Aluminum Sheet
3. Rubber Frame
4. Steel Bolt
5. Steel profile
6. Steel Sheet
7.Aluminum Sheet
8.Aluminum Window Frame
9.Timber Wood Base
10.Already existing holes
11.Steel Hinge with rubber connection
12.Steel bolt shaped connection thickness 8mm
13.Lindapter type SW fixing
14.Steel connection profile
15.Neopreen rubber
16.Anchor bolt SFIX 7, M10 x 120 mm
17.Bolt 115mm, thickness 10mm

Retireved from: https://issuu.com/3xnarchitects/docs/buildingacircularfuture



DETAIL 4



DETAIL 1

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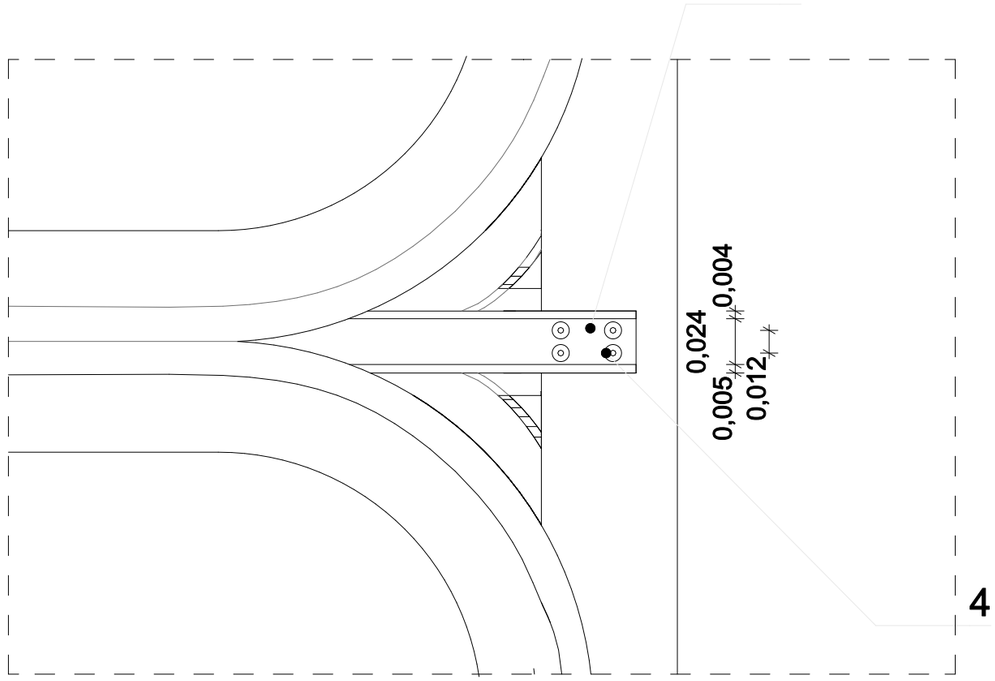

DETAIL 2

1. Aluminum Window Frame
2. Aluminum Sheet
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4. Steel Bolt
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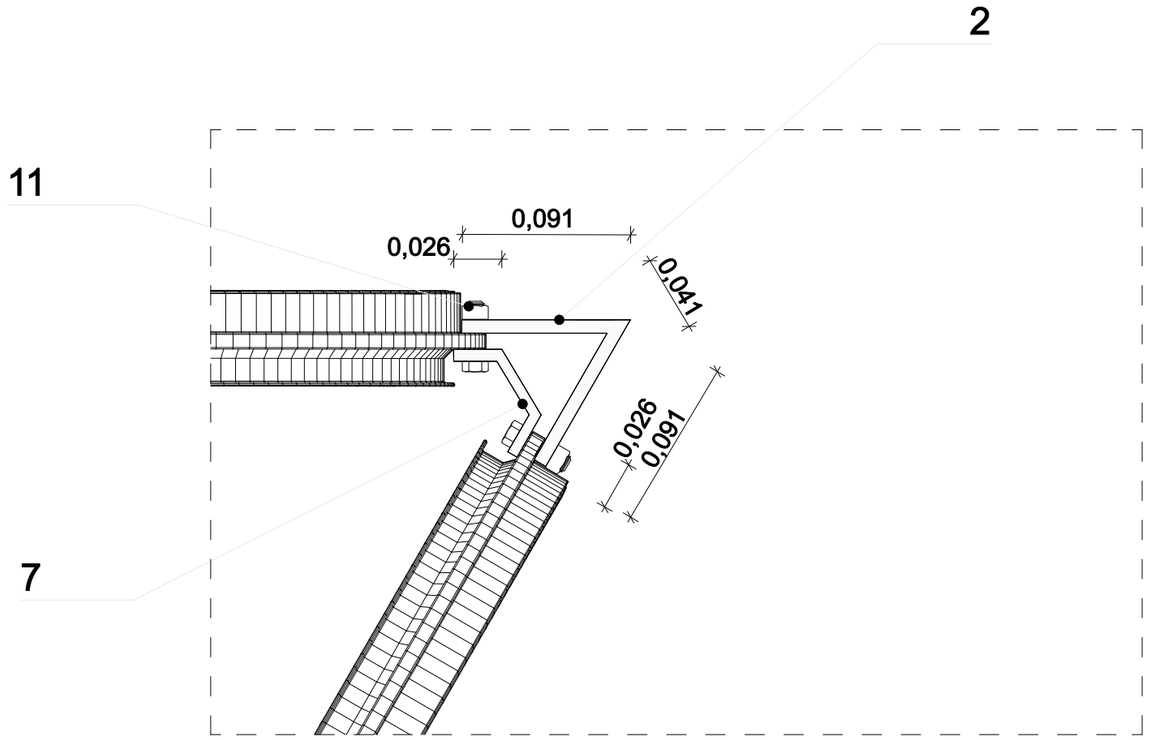

DETAIL 3

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8.Aluminum Window Frame
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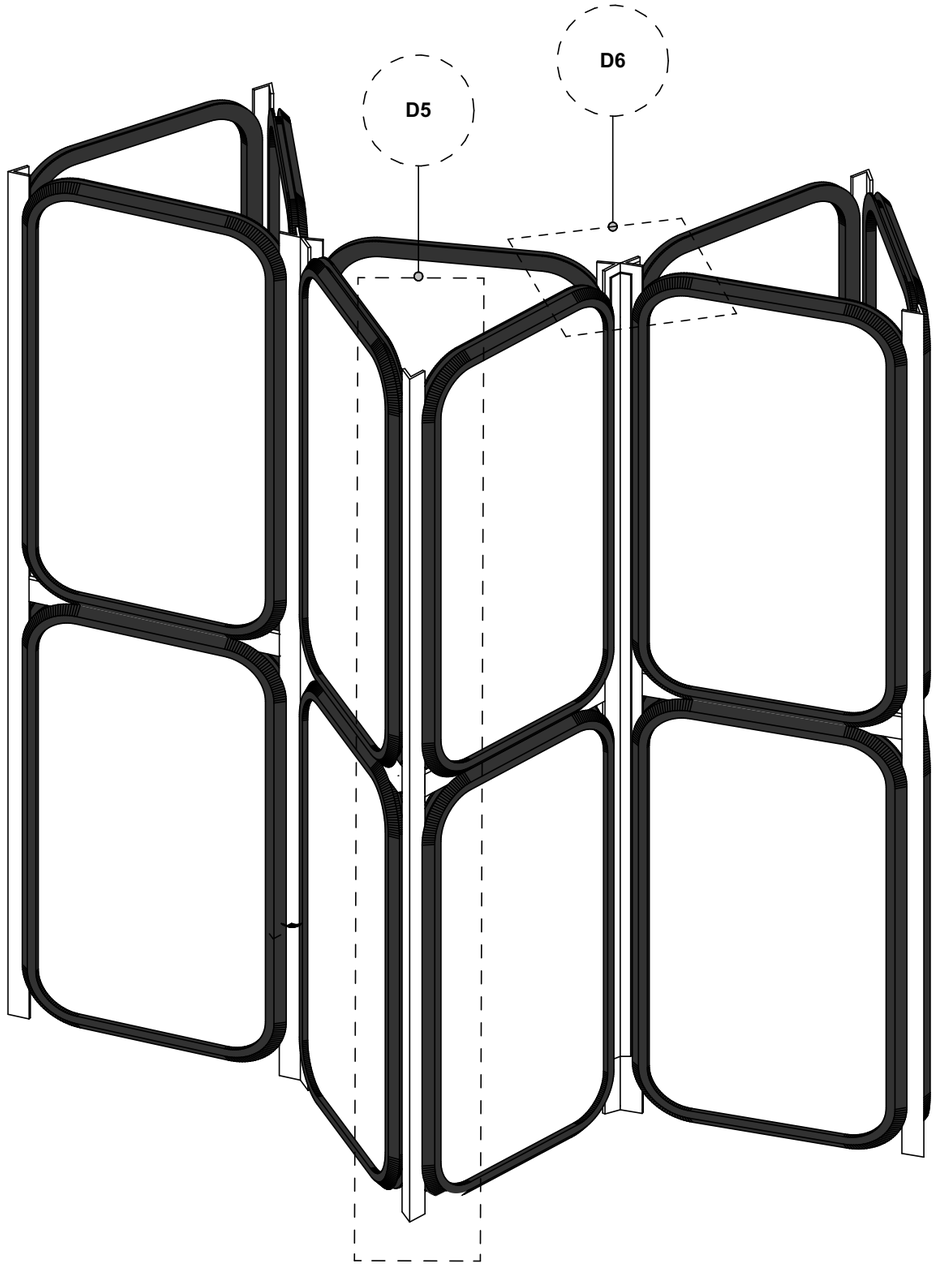
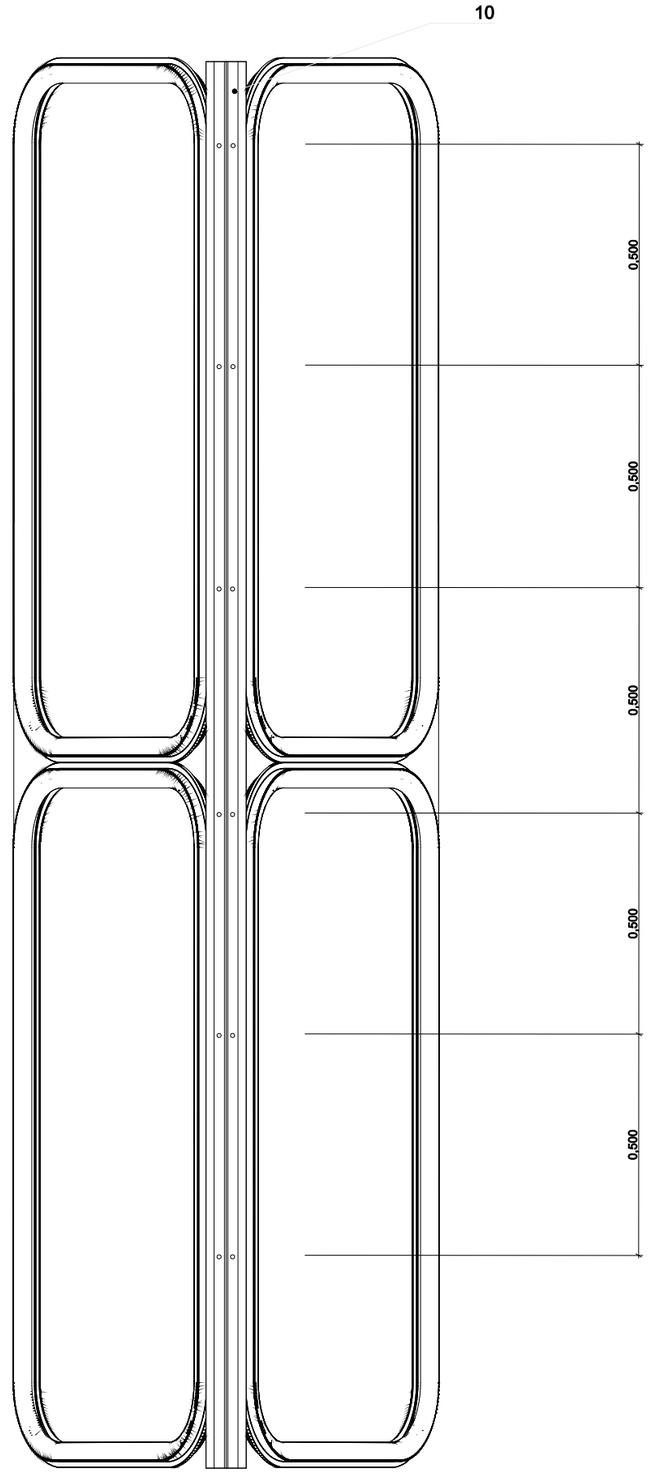
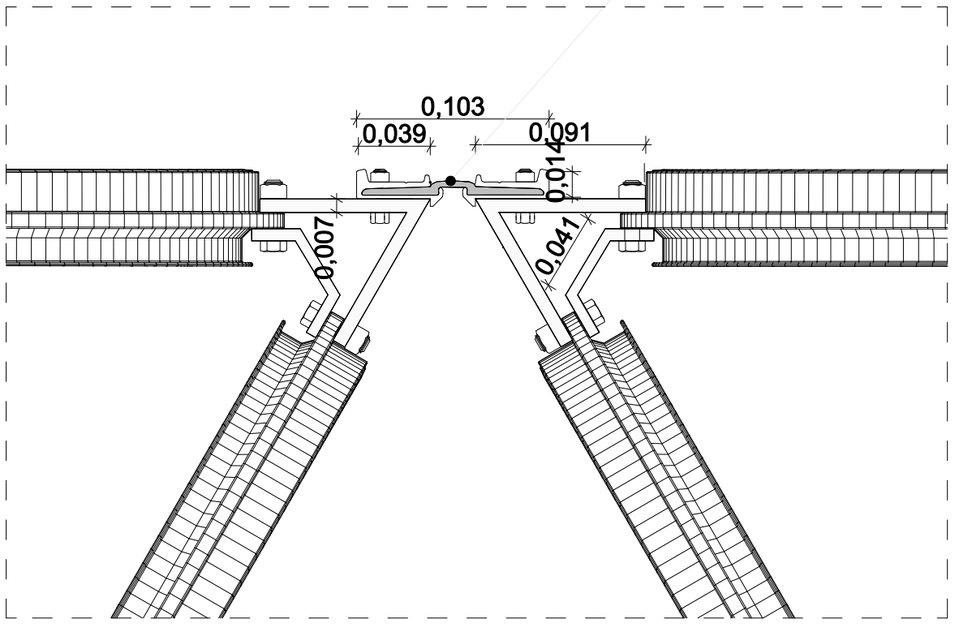
16.Anchor bolt SFIX 7, M10 x 120 mm
17.Bolt 115mm, thickness 10mm





DETAIL 5

11



DETAIL 5

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17.Bolt 115mm, thickness 10mm

5.2 Detailing Phase 2

Evaluating the first design phase and place it to the reality of the project several corrections had to be made.

Correction 1: The steel triangle profiles would have to be ordered since there are not prefabricated on the market.

Correction 2: This amount of steel for the horizontal and vertical connection, on the one hand, gives the security of the structural stability and stiffness of the connections but on the other hand, increases the cost of the project and the complexity of the assembly. Would it be possible to be made otherwise?

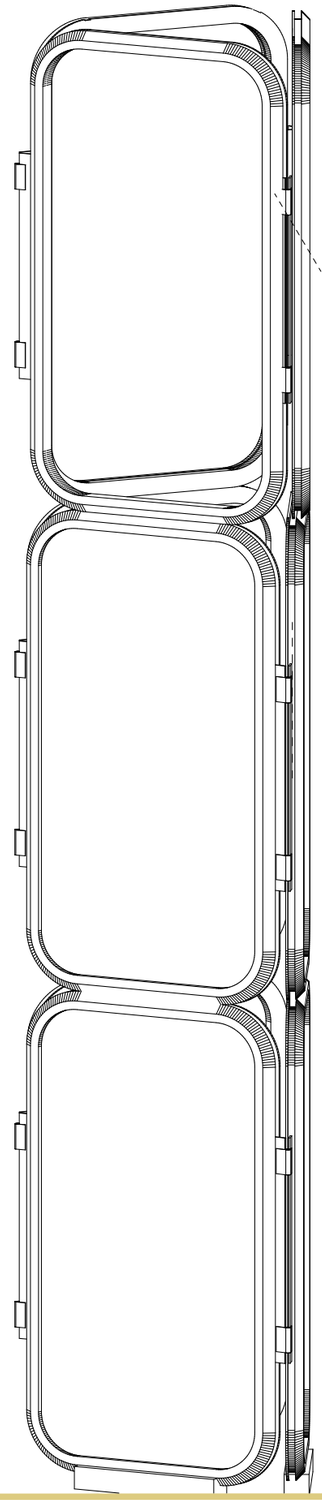
Correction 3: The steel and rubber hinge is a significant expensive choice that doesn't balance with what it offers to the project.

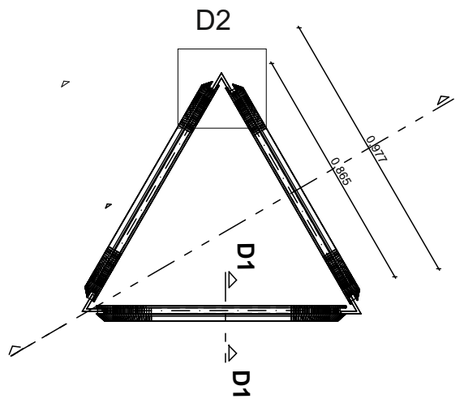
Correction 4: A simple base has to be designed.

After the above corrections, the steel triangle profiles were replaced by steel sheets of smaller hight connected with steel heavy load safety hinges (45x45mm). This way less material is used with a sufficient stiffness.
The steel and rubber hinge has been replaced by a regular safety heavy load hinge 89x89mm. Since the pavilion would be temporarily constructed an extra corrosion resistant hinge is not a priority.

For the base, a timber construction wood (75x120x50) bolted under each window offered a sufficient option that safely bares the modules.

Image 3.2.1: Steel hinge 45x45mm - Retrieved from https://www.homedepot.com/p/Onward-3-1-2-in-x-3-1-2-in-Brushed-Nickel-Butt-Hinge-821NBB/202206074





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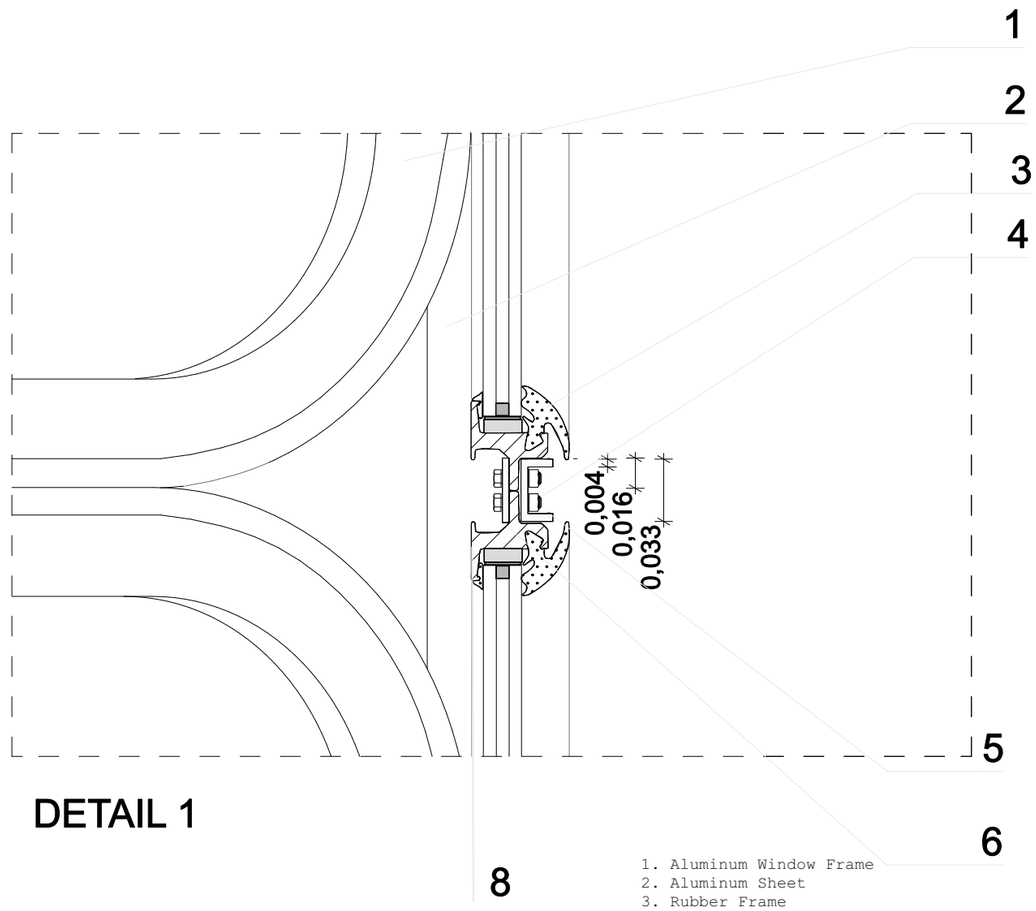

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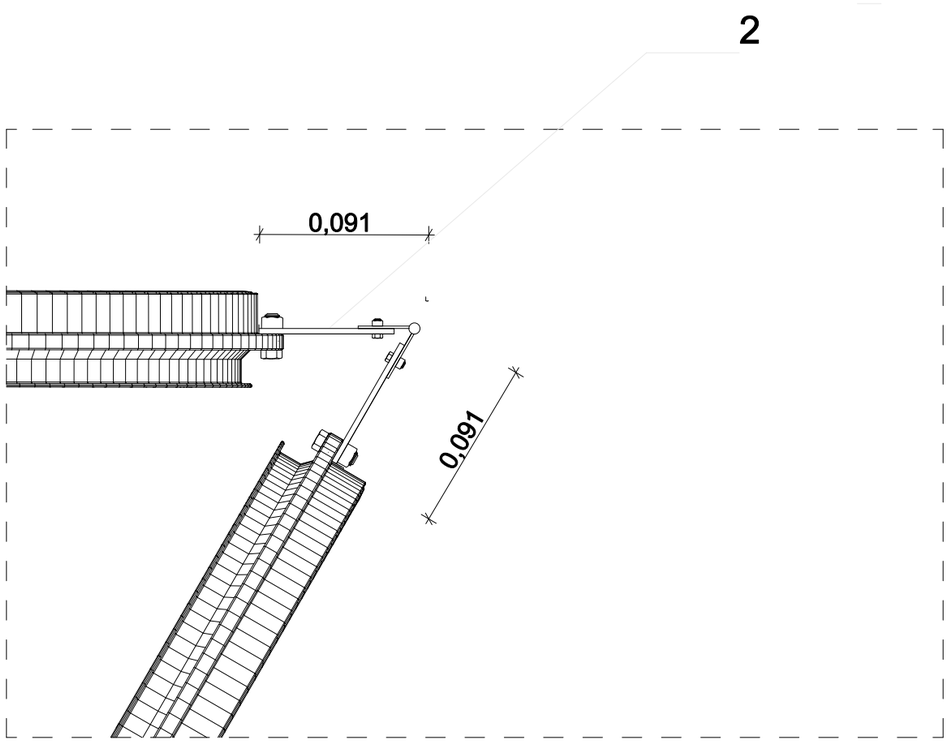

DETAIL 2

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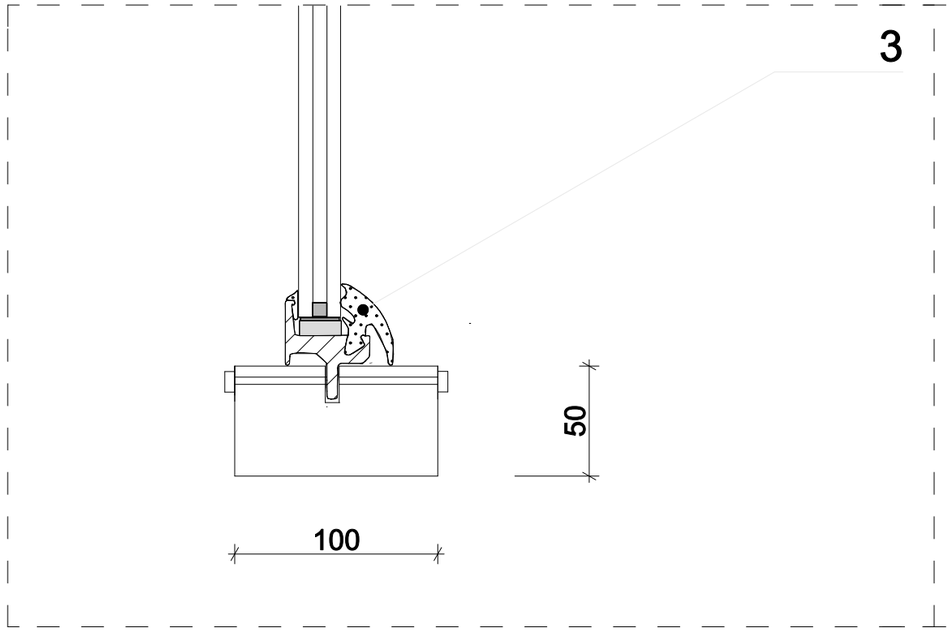

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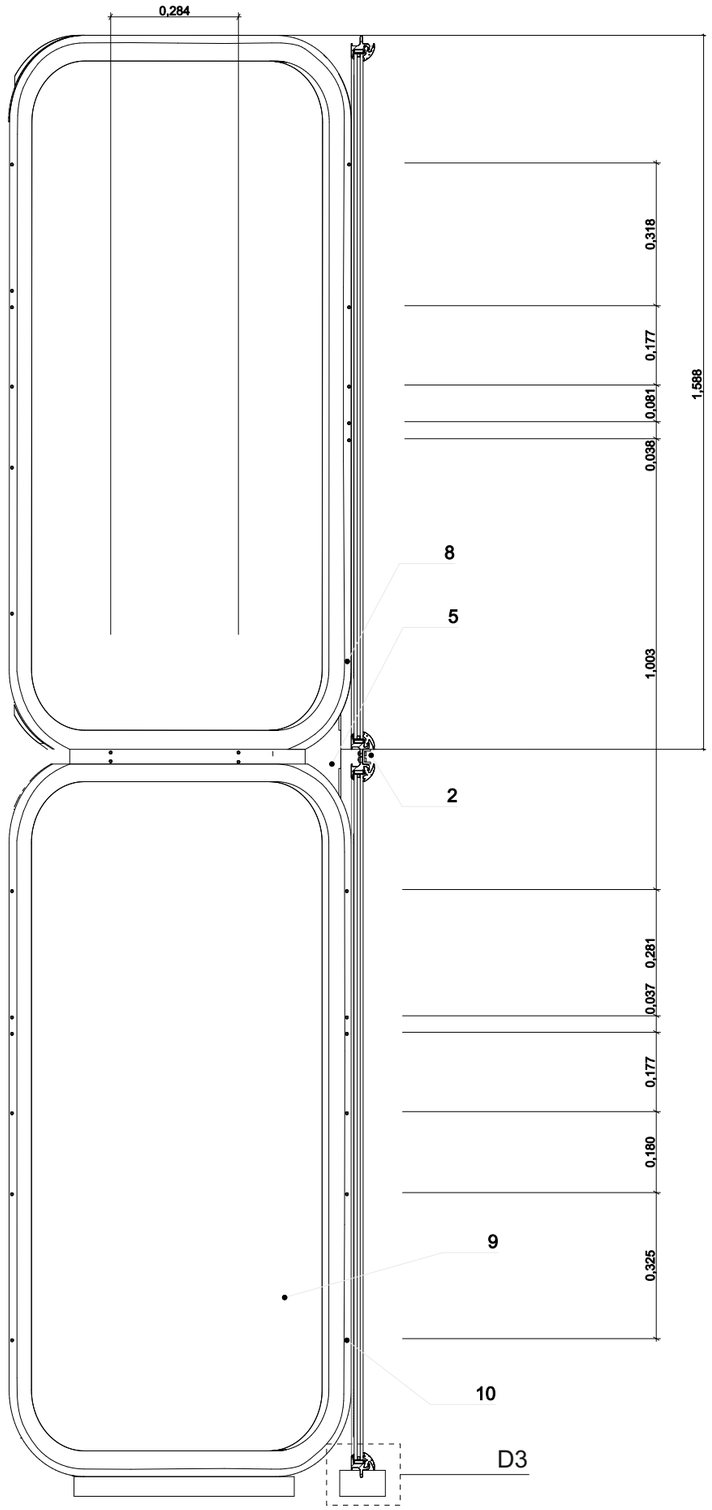
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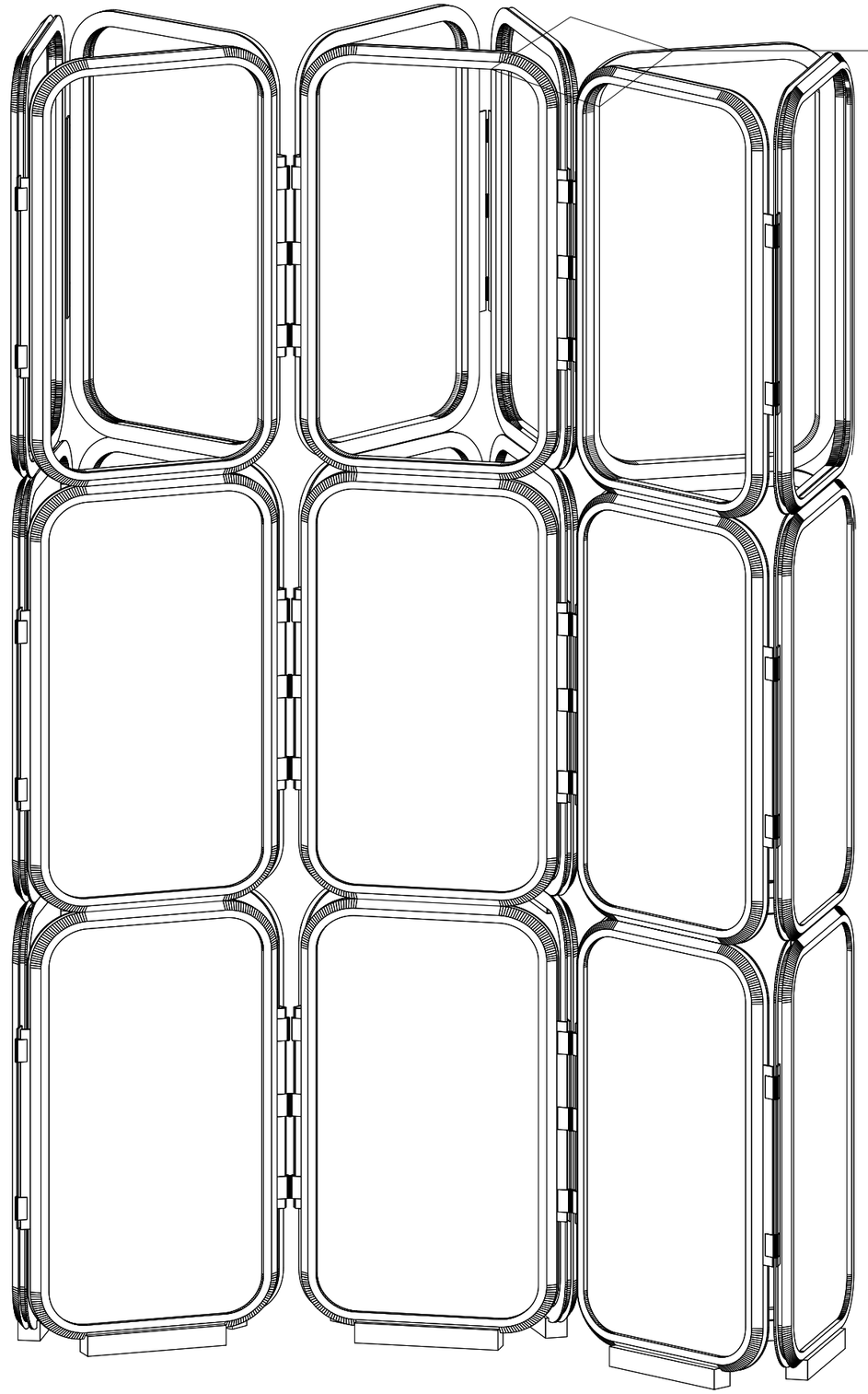
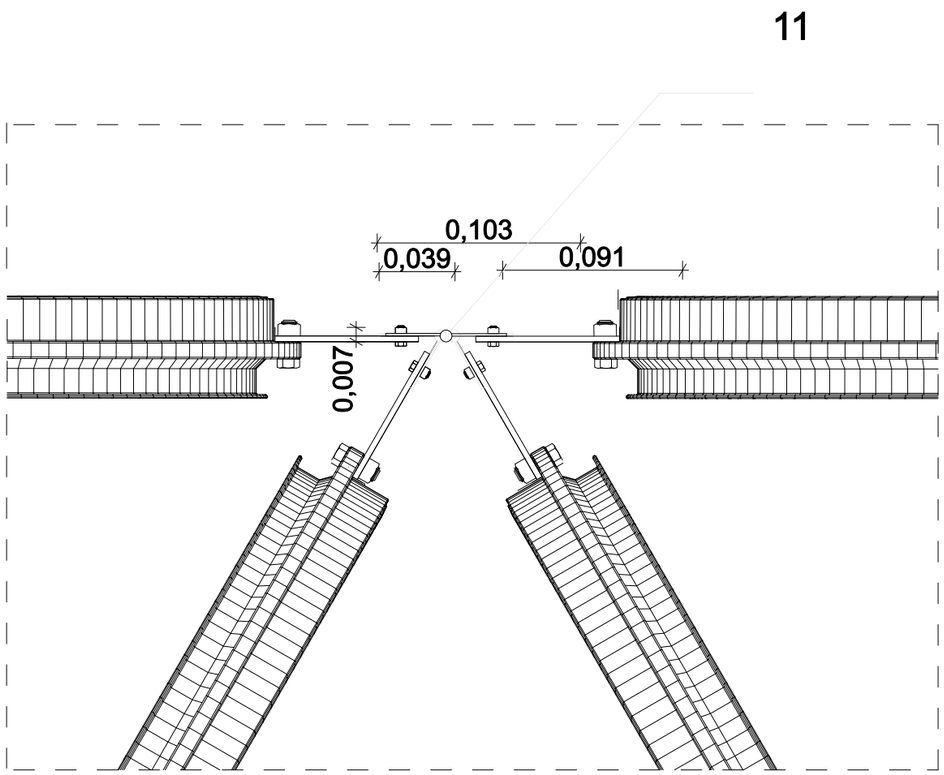
8
5
2
0,281
0,037
0,177
0,180
0,325
9
10
D3


D6



DETAIL 6

1. Aluminum Window Frame
2. Aluminum Sheet
3. Rubber Frame
4. Steel Bolt
5. Steel profile
6. Steel Sheet
7.Aluminum Sheet
8.Aluminum Window Frame
9.Timber Wood Base
10.Already existing holes
11.Steel Hinge 45X45mm
12.Steel bolt shaped connection thickness 8mm
13.Lindapter type SW fixing
14.Steel connection profile
15.Neopreen rubber
16.Anchor bolt SFIX 7, M10 x 120 mm
17.Bolt 115mm, thickness 10mm

5.3 Detailing Phase 3

Evaluating the second design phase and place it again to the reality of the project several corrections had to be made.

Correction 1: The metal sheets in the corners connected with the hinges might not be needed if we bring the windows a bit closer to each other and use bigger hinges.

Correction 2: A connection to the roof is needed.

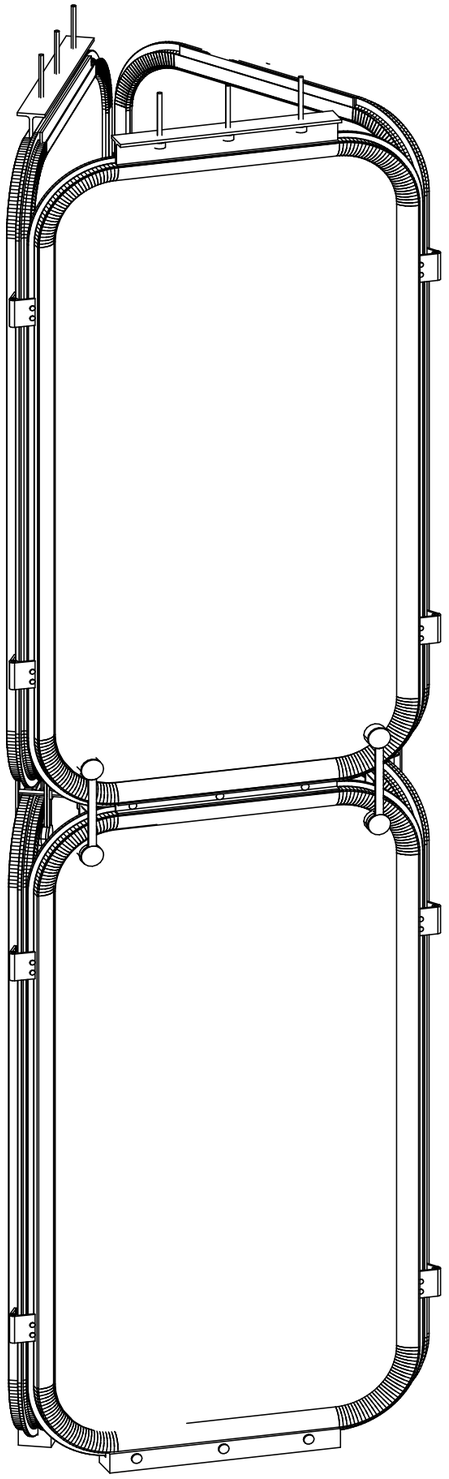
Correction 3: A safety connection that holds only the glasses in case of breakage of the frames or the hinges might be needed.

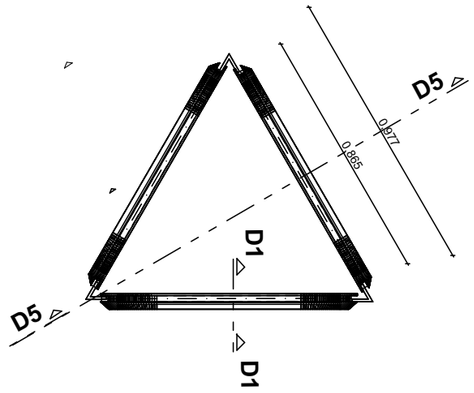
This stage started by designing the safety connection mentioned int the last correction. Is the only part of the structure that is uniquely designed for this project and it is not prefabricated and available in the market. It is a clamp connection the hold the glass of each module in the corners clamped together. Made from steel and rubber with a bolt-shaped core that is used to tighten the clamps is hold firstly the same side bottom and upper windows together, and using the core connects the beside 60-degree side of the module.

For the connection to the roof, a steel ST80 beam bolted on the existing holes of the windows and an Anchor bolt SFIX 7, M10 x 120 mm would be the parts of the roof to module connection.

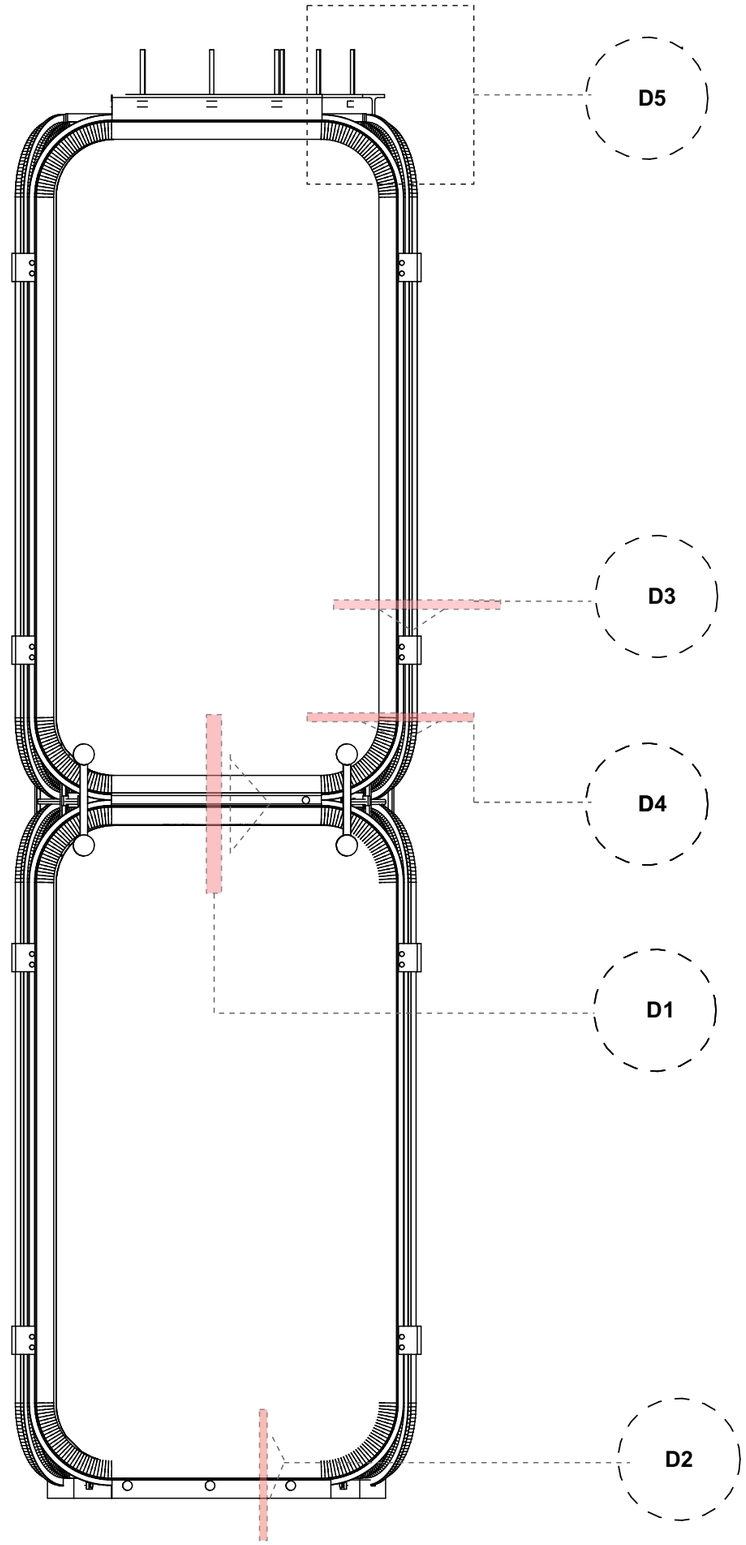
The metal sheets in the corner connection of the windows are replaced by only two hinges connecting the windows with bolts in the pre-existing holes, by bringing the windows 2 centimetres closer.

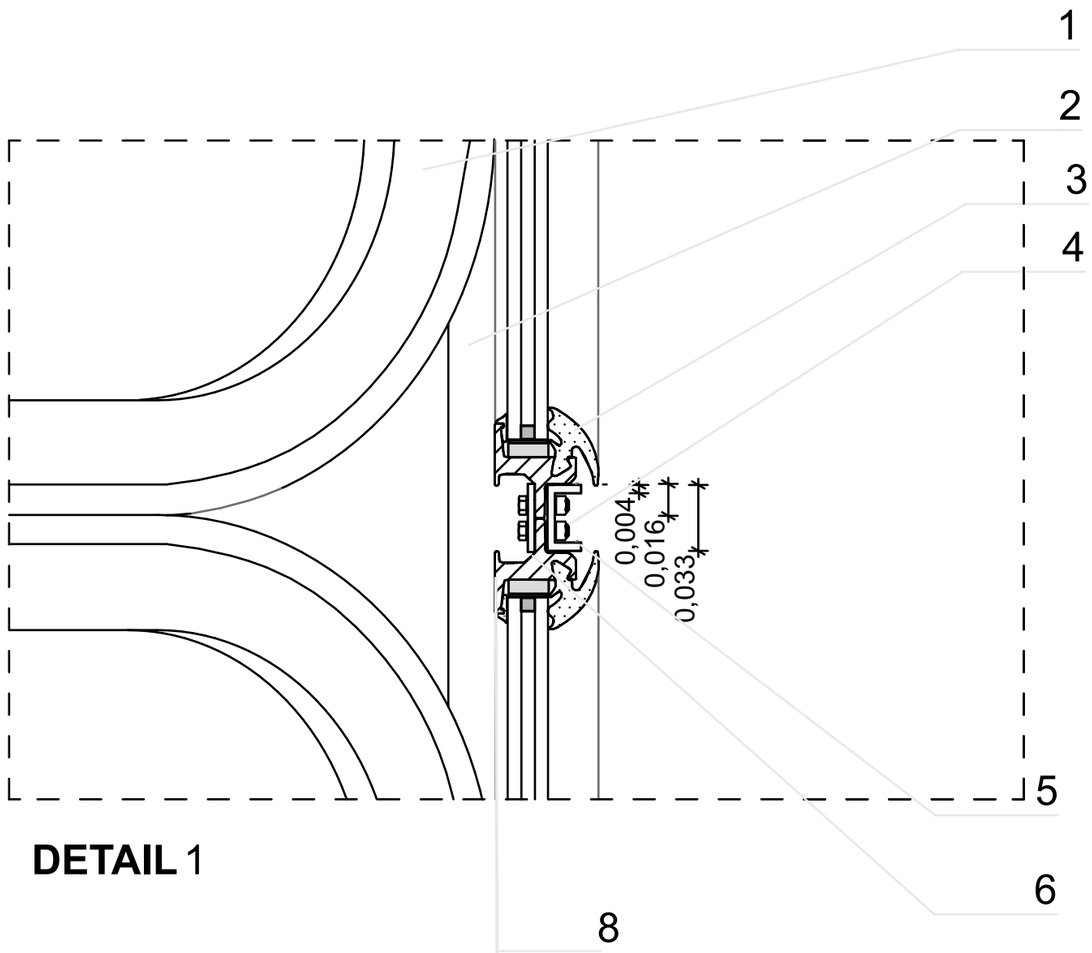
Image 3.3.1: T profile - Retrived from https://www.ostermann.eu/en/product/t-profile



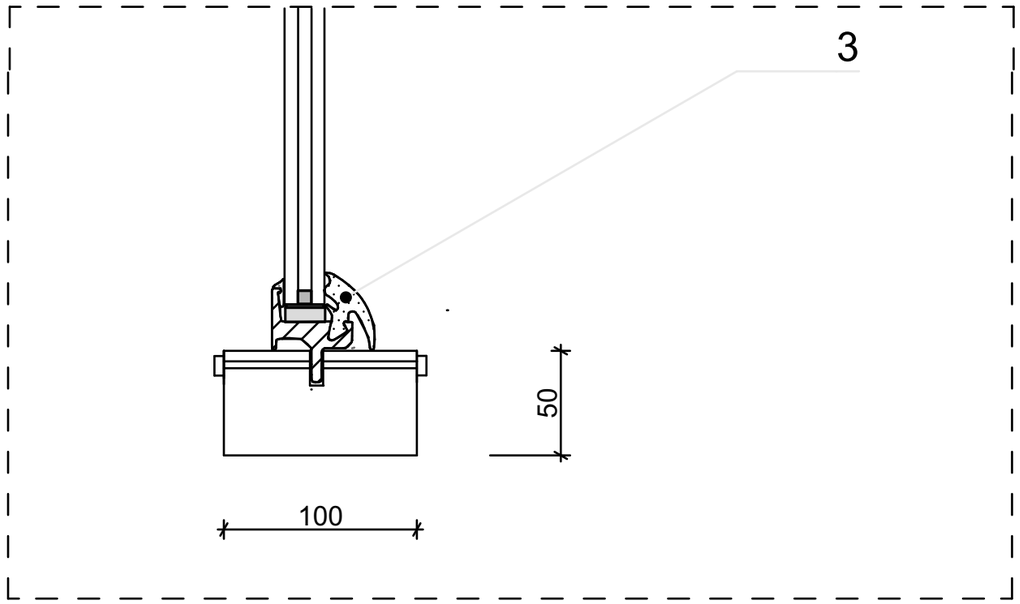


1. Aluminum Window Frame
2. Aluminum Sheet
3. Rubber Frame
4. Steel Bolt
5. Steel profile
6. Steel Sheet
7.Aluminum Sheet
8.Aluminum Window Frame
9.Timber Wood Base
10.Already existing holes
11.Steel Hinge 49x88mm
12.Steel bolt shaped connection thickness 8mm
13.Lindapter type SW fixing
14.Steel connection profile
15.Neopreen rubber
16.Anchor bolt SFIX 7, M10 x 120 mm
17.Bolt 115mm, thickness 10mm

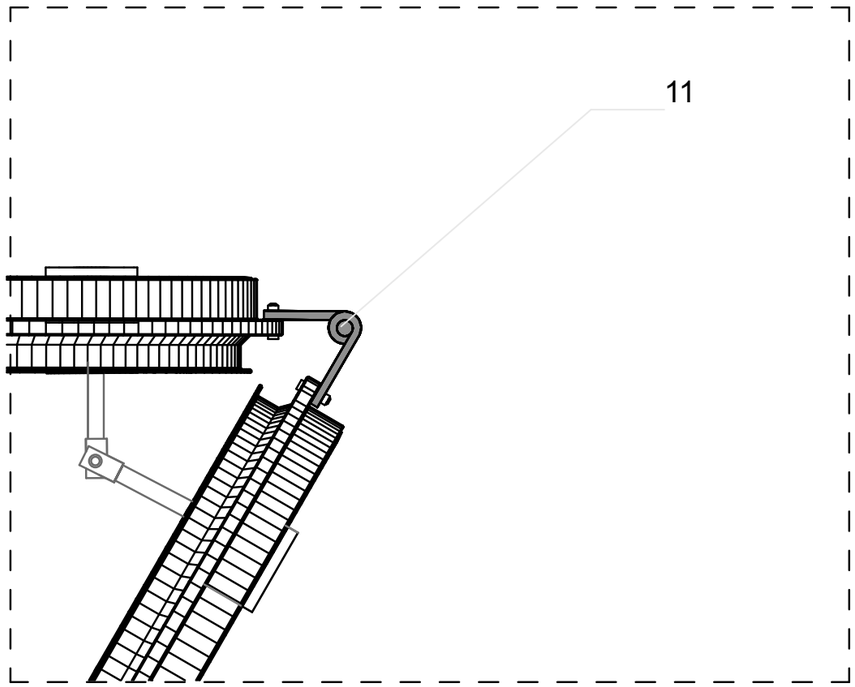




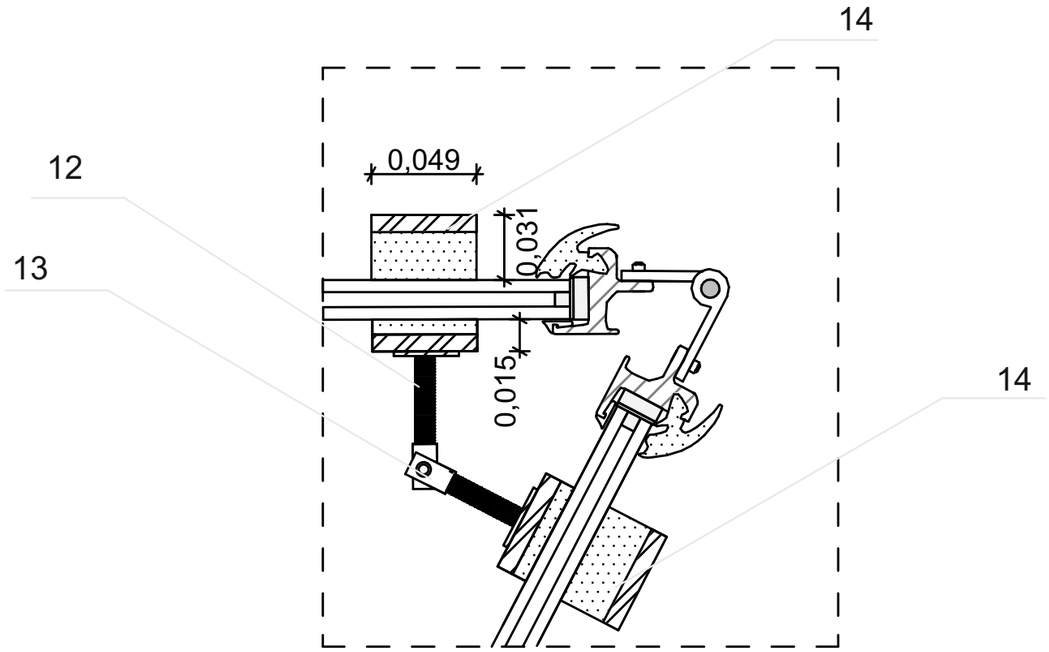
DETAIL 1



DETAIL 2



DETAIL 3



DETAIL 4

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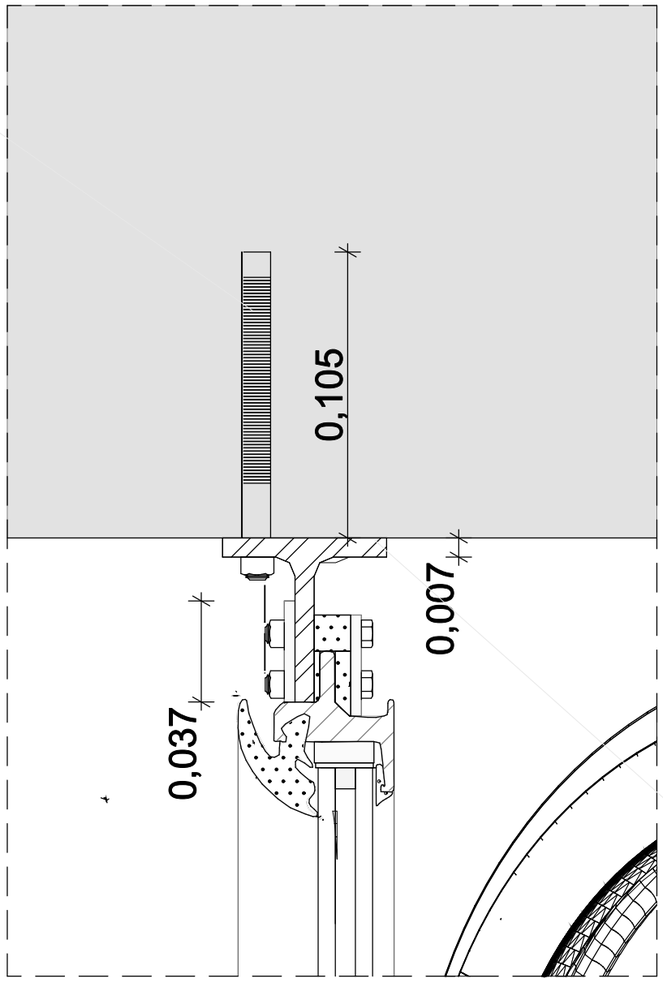

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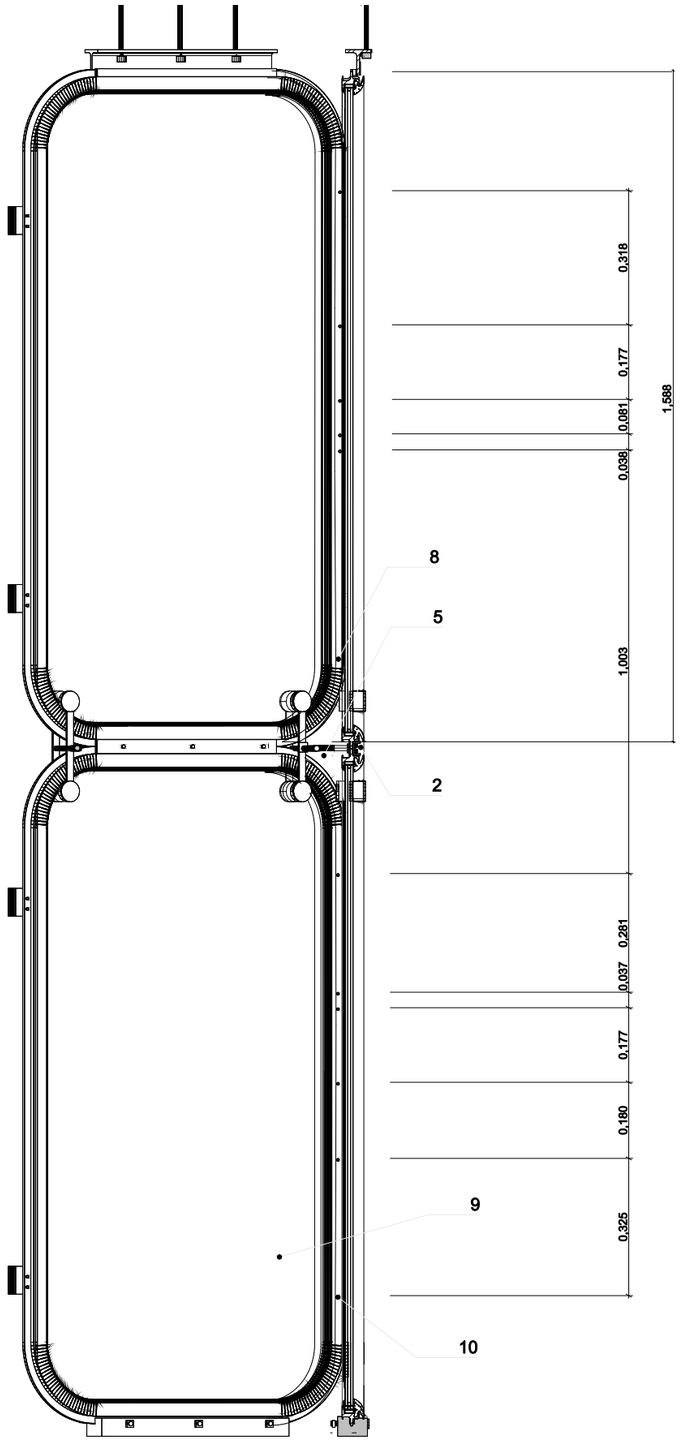
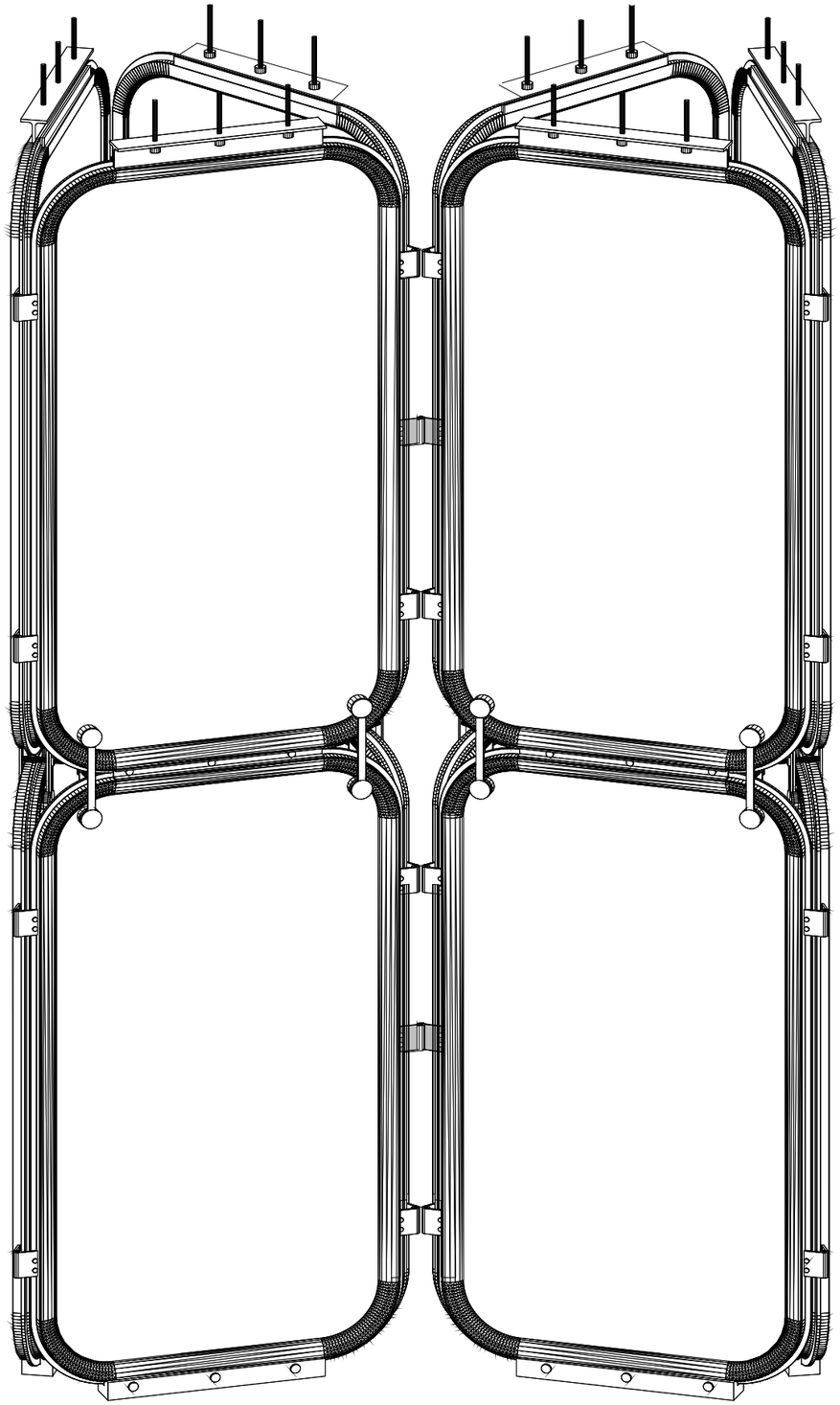
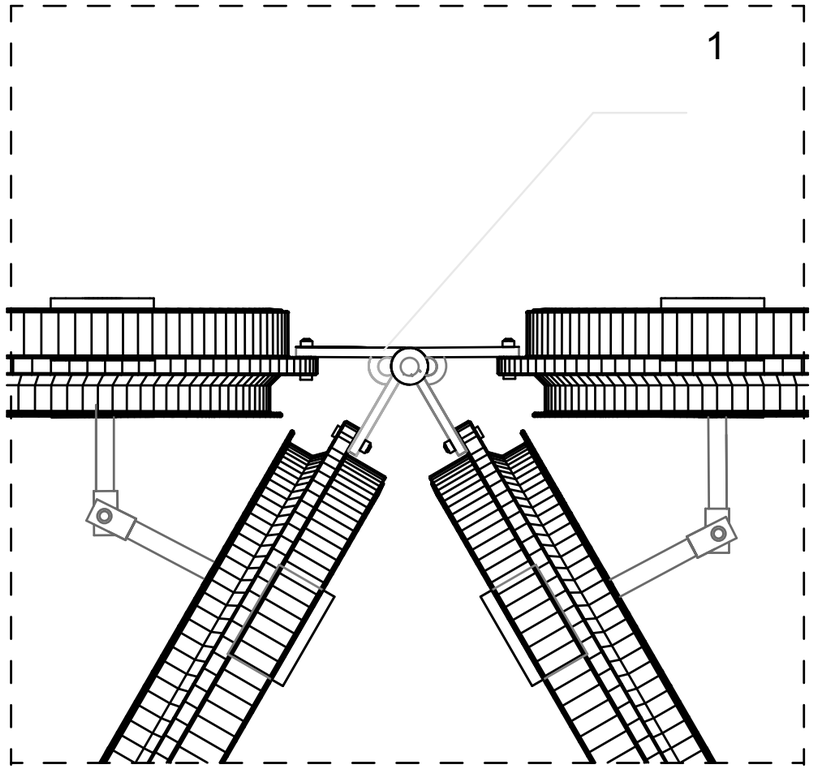
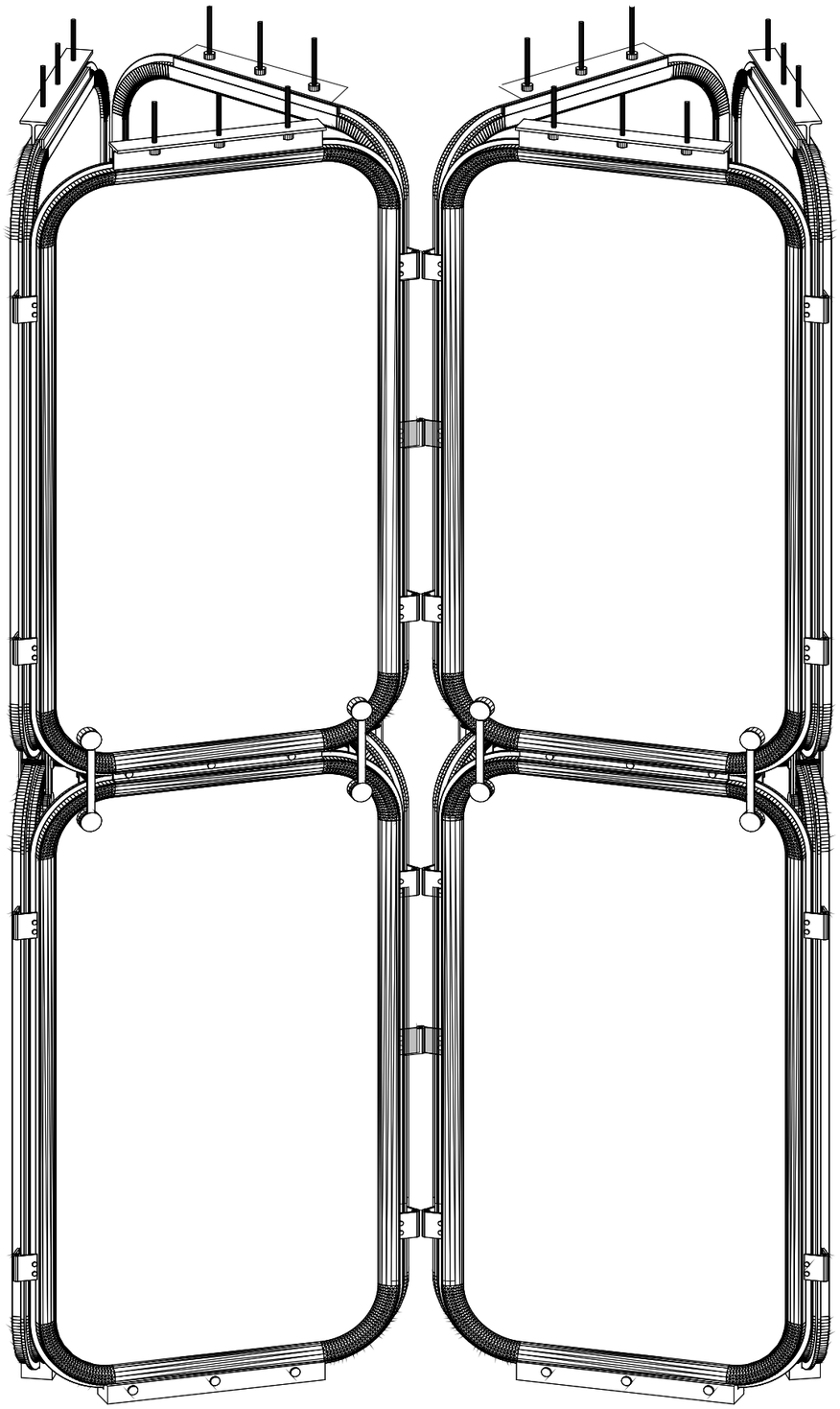


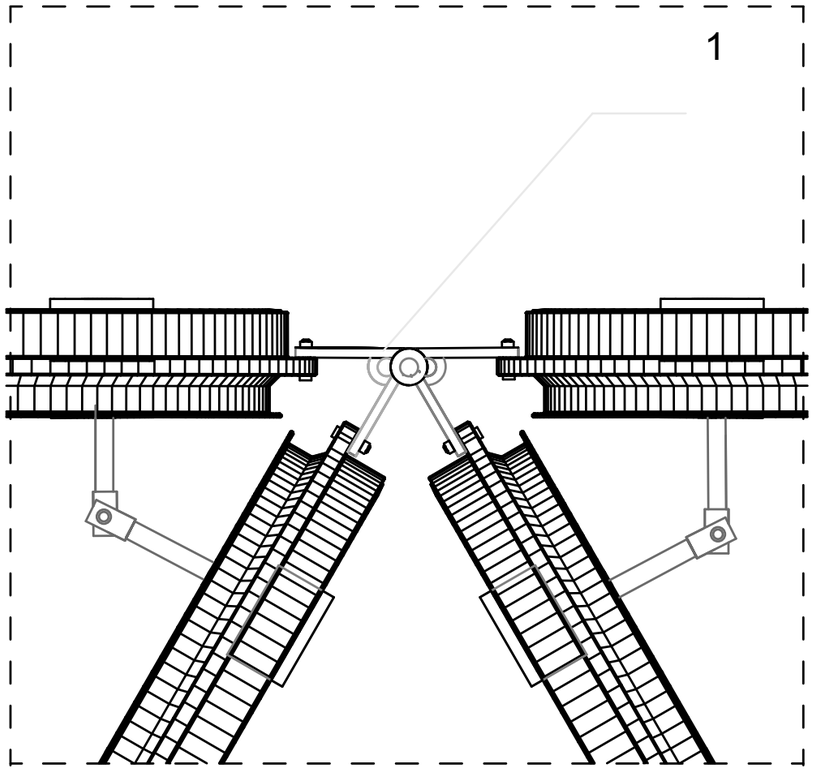
D-05 Detail 1:13





DETAIL 6





DETAIL 6

5.4 Re-think the Safety Connection

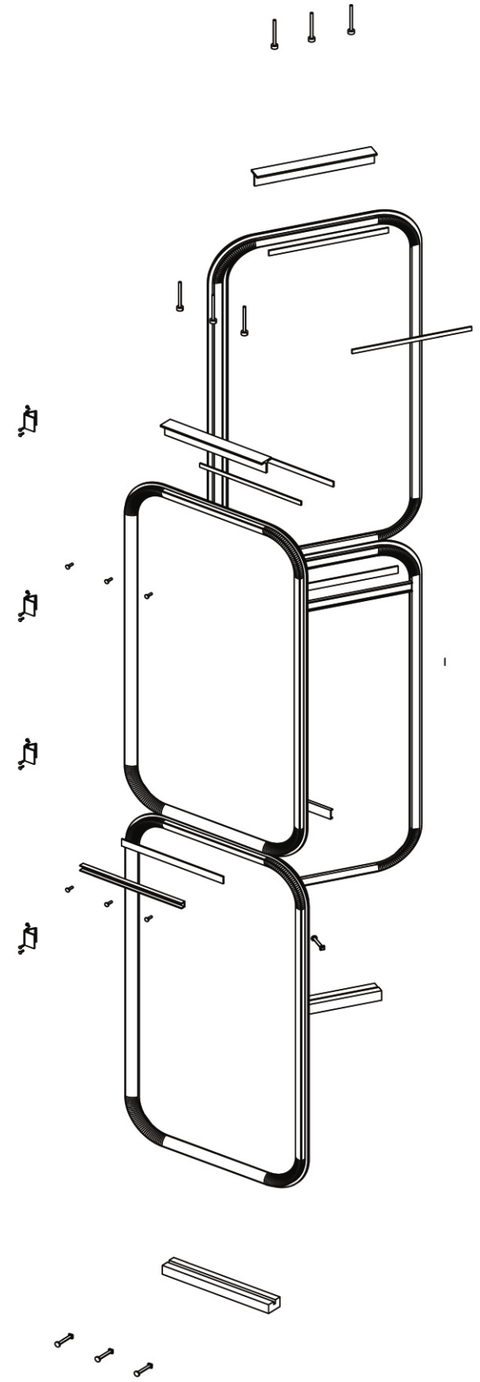
The designed safety connection proposed in the last phase of the detailing after proper consideration seems that it is not needed since the failure of the glass-frame connection is not really possible. This became obvious after the prototyping process and it will be explained further in the Build ability chapter.

But even if the failure between the frame and the glass was a case, the proposed connection should be measured with a FEM model to specify its shape or be over dimensioned which would be aesthetically not permitted.

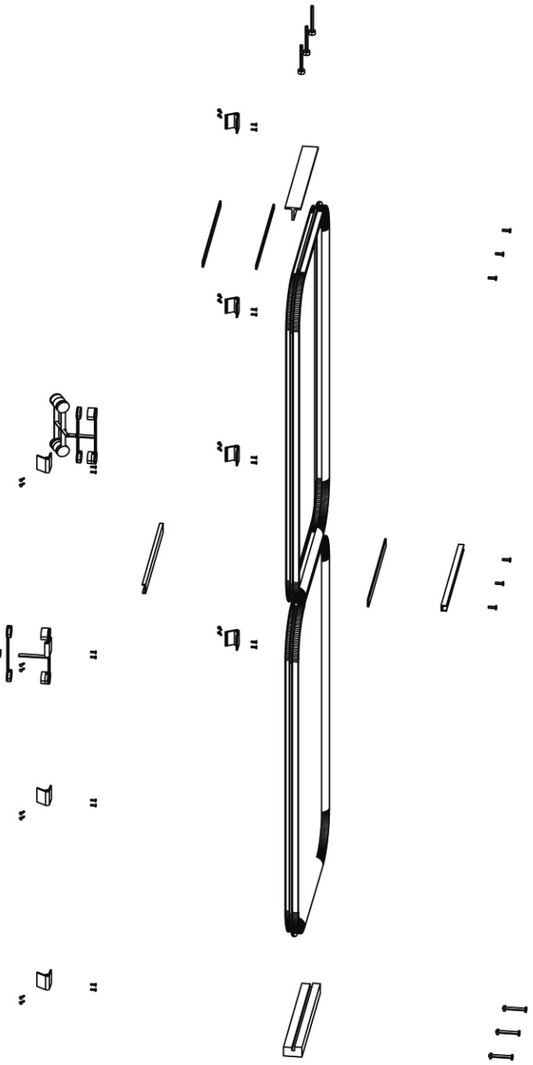
5.5 Detailing process conclusions

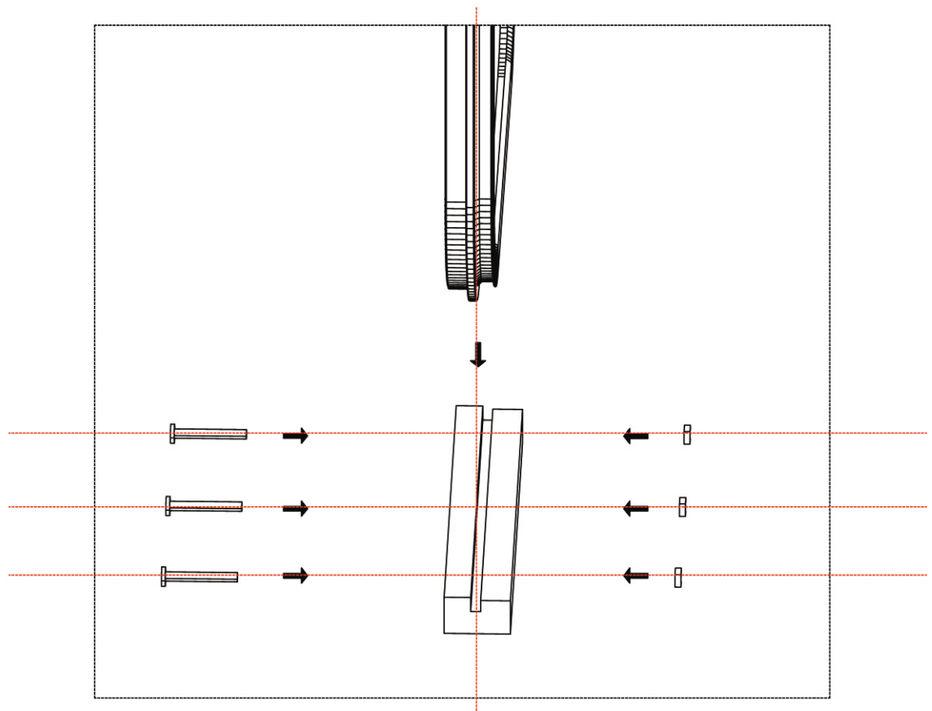
Macroscopically looking at the detailing process, it is clear that the insecurity of the first detailing phase gradually and through a material and market research process fades away and this is depicted in the final stage of the detailing design.

Participating in a real project bring in front of the detailing process all the issues that could be appeared during the assembly and construction of the project. This experience proved that a careful detailing process of a project is the secret to the avoidance of most of the in-site surprises that could come up.

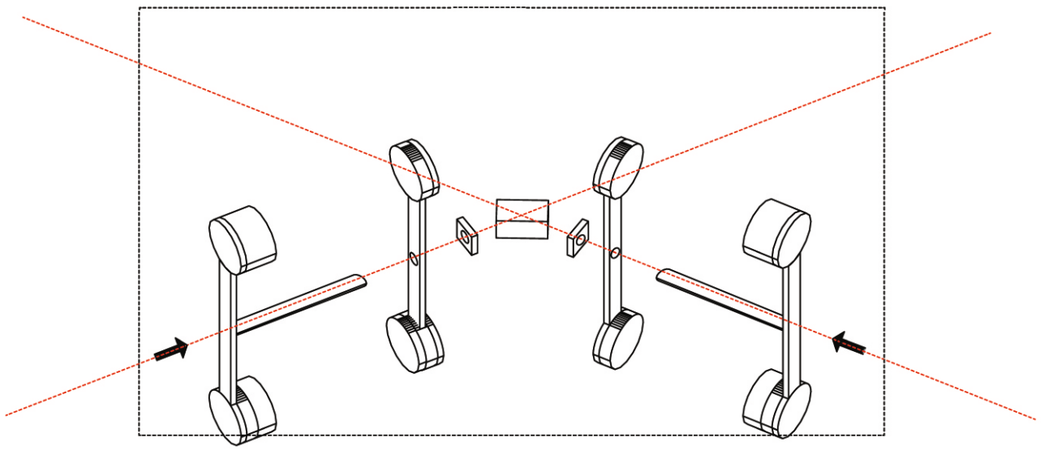


Connection Assebly Manual

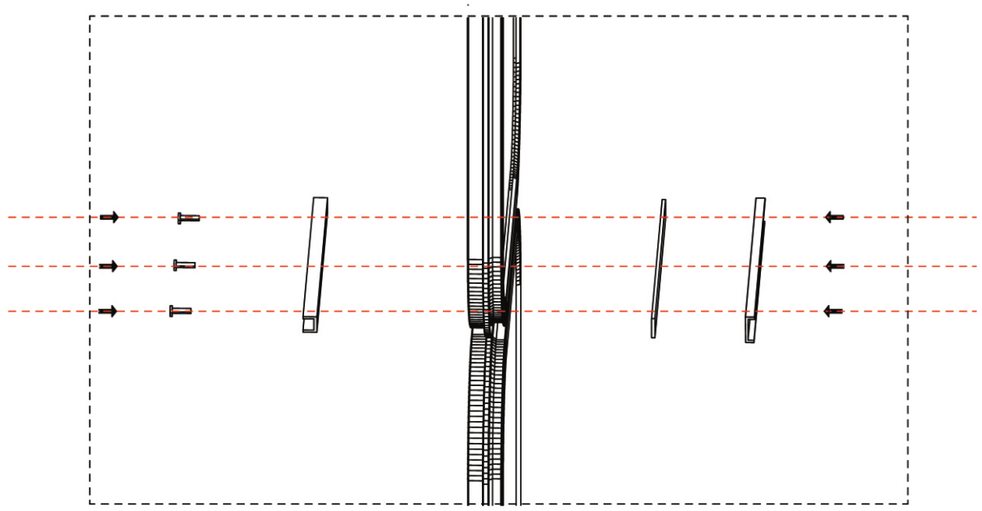




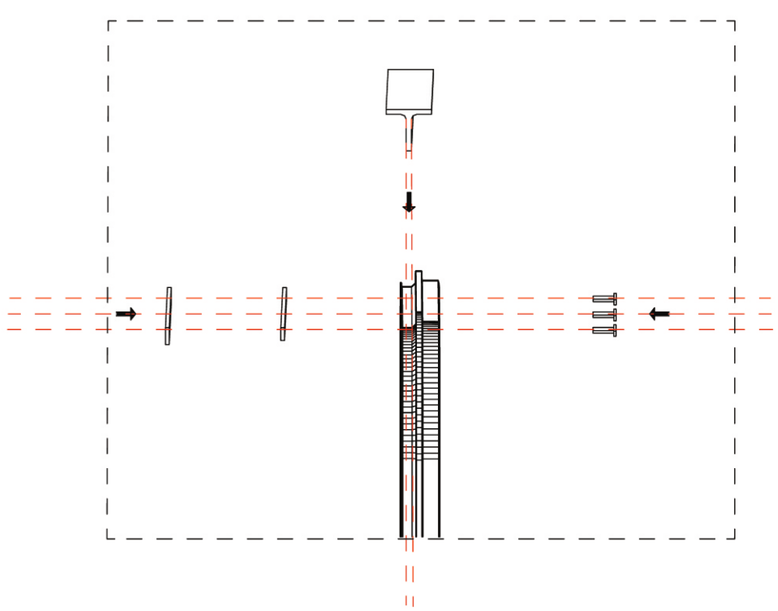
DETAIL 1



DETAIL 2



DETAIL 3



DETAIL 4

6. Risk Analysis

6.1 Risk Analysis of the BK Pavilion

Risk damage is a multiplication of different factors that influence the risk of an unexpected disastrous event. The following formula will be used to specify the importance of every risk possibility.

RISK DAMAGE = Probability * Exposure * Consequence at complete failure

Using the table 6.1.1, a risk analysis for every possibility of damage in the design would follow.

Risk Analysis of the BK Pavilion

The BK Pavilion will be placed between the Bouwpub and a parking lot. In between them, there is a cycle path. Therefore, it is possible for someone to fall on it while walking, running, cycling or driving. Since the weight of each module is more than 120kga simple fall of 1 or two persons on one of them could cause any damage, either by walking, running or cycling.

Although a fall of a car or a truck on it could cause different scenarios of important damages. To avoid every each of them we could place a barrier between the pavilion and the parking/road.

A possible barrier would be the existing big rocks in front of the Bouwpup with some more additional of them.
More rear possible damages could be caused by terrorism, vandalism or failure of a part of the module. The scenario of terrorism I likely impossible

The scenario of vandalism - breakage of the glass- is more possible but minor damages could be caused since the glass is safety laminated. The possibility of the failure of the glue between the glass and the frame is very rare. This is a tested fact because for the Gevel exhibition project Superuse asked NS to separate the glass from the frame and send to the office some parts separately..

Probability	WS	Exposure	BS	Consequenceat	ES
Virtual impossible	0,1	Very rarely	0,5	First aid	1
Practically impossible	0,2	Several times a year	1	Minor injury	**3**
Possible, but very unlikely	**0,5**	Monthly	2	Seriousinjury	7
Only possible in the longer term	1	Weekly	3	**Onedead**	**15**
Uncommon, but possible	3	**Daily**	**6**	More thanonedead	40
The best possible	6	Constantly	10	Catastrophe, many deaths	100
Can be expected	10				
RD= WS x BS x ES=	**< 70**				

Table6.1.1 : Risk Analysis table

lthough they contacted the office some days after the order and they explained that the separation of the glass from the frame is an extremely difficult procedure and the easier way to happen is if someone breaks the glass and then remove it from the frame. Breaking a safety glass is not easy either.

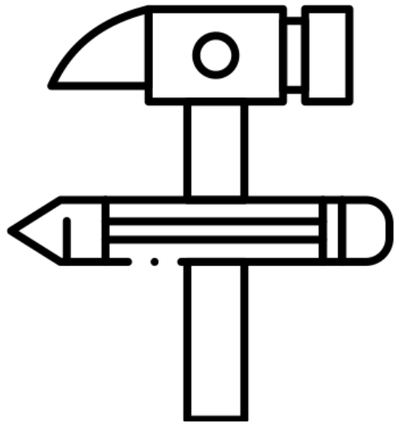
For this reason, this risk is not really possible. The failure of the aluminium frame or the hinges could only happen if severe non-vertical forces and moments act on them. This could happen from a human incident but only if e crush or extreme vandalism attack would happen.

In the following table, the possible risk scenarios ar measured according to the Risk Analysis formula:

Risk scenario	Probability WS	Exposure BS	Consequence ES	Initial RD-value	Measure	Change	new result
terrorism: fire,bombing	0,5	0,5	100	25	-		
vandalism:someone is litting the column with a slenger hammer	6	0,5	3	9	-		
failure due to accident: people/bike fall on the columns	6	6	1	36	-		
failure due to accident: car falls on the columns	6	6	40	1440	Use more of the existing type or rocks as a barrier	WS = 0,2	48
failure due to accident: truck falls on the columns	6	3	40	720	Use more of the existing type or rocks as a barrier	WS = 0,2	24
failure of the hinge between each column	3	0,5	0,5	0,75	-		
failure of the frame	1	0,5	0,5	0,25	-		
failure of one module	3	3	0,5	4,5	-		

Table 6.1.2: Risk analysis

7. Buildability



7.1 The Gevel Project: Prototype exhibition

In Cooperation with MVRDV as ambassador of GEVEL 2020 in Ahoy Rotterdam, Superuse exhibited the prototype of this design research.
The theme of the exhibition was *“Modern Utopia - The Pavilions Of the future”*.There were 4 pavilion participated in four different categories: Green, Circular, Parametric and Interactive,with Superuse participated for the Circular Pavilion proposal. Some simplifications and changes happened during the construction face which lead to an improvement of the design.They are going to be detaily explained in this chapter.

The first trial construction effort started in Blue City Lab with the help of their sta ff and the interns of Superuse Studios, 5 people in total, the final construction happened in Ahoy on the 27th of January 2020.The first try had a duration of 12 hours and the final had a duration of 2,5 hours. The disassembly lasted 1 hour in total.

7,2 Phase 1: Material Selection

The Building days started with the specific selection of the products for the prototype:

-Metal Hinges
-Metal profiles
-Bolts
-Nuts
-Base wood

Hinges

During the detailing process, the chosen hinges were those that can be heavy load-bearing.
(could bare up to 120 kg vertical load). Although the are locked-hinges. Which means that for assembling the triangle they had to be bolted and unbolted in situ. The bolting procedure of a locked hinge in 60 degrees is a difficult and time-consuming procedure.

To solve this issue the locked heavy load-bearing hinges have been replaced with unlocked hinges ones. The unlocked hinges can bear less but it is acceptable (40kg vertical load each).
This change simplifies the assembly and pre-assembly procedure.

Bolts

In terms of modularity, the decision to use only one type of bolts that could fit in all the holes has to be made. For this reason, 60 steel bolts type M8X20 were chosen.

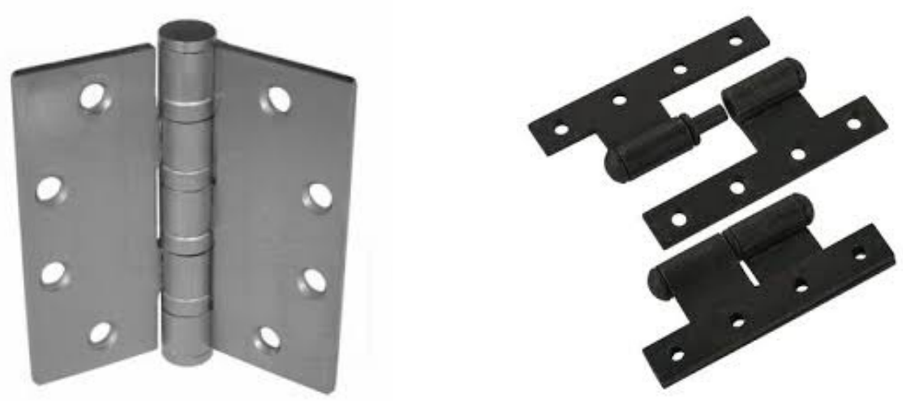


Image 7.2.1:Locked and unlocked hinges
Retrieved from:https://www.natman.com/category/hinges

Metal Profiles and Metal Plates

The metal profiles that designed during the detailing process were following the scenario of directing the vertical loads from the top of the structure (roof), through the frame and glass to the bottom (wood base). But in the case of the exhibition prototype, this was not necessary since there was no vertical pressure (no roof) but only the self-weight of the windows. To simplify the construction during the first assembly effort the decision to put out the metal part was made. In this way, only bolts in the existing holes are used with the window frames partly overlapping in the vertical direction.

Wood Base

In this case, the base was not necessary. The First attempt showed that in a typical interior floor the triangle column could stand perfectly without any base. An unnecessary base would be extra materials, cost, effort and time.

First Attempt - Small windows prototype

In January a first module with the smallest train windows has been made. This procedure helped with the detailed dimensioning of the materials needed for the connections and the realizations of the assembly difficulties of the triangle module as described above (change of hinges type, bolts, no metal profiles and base)

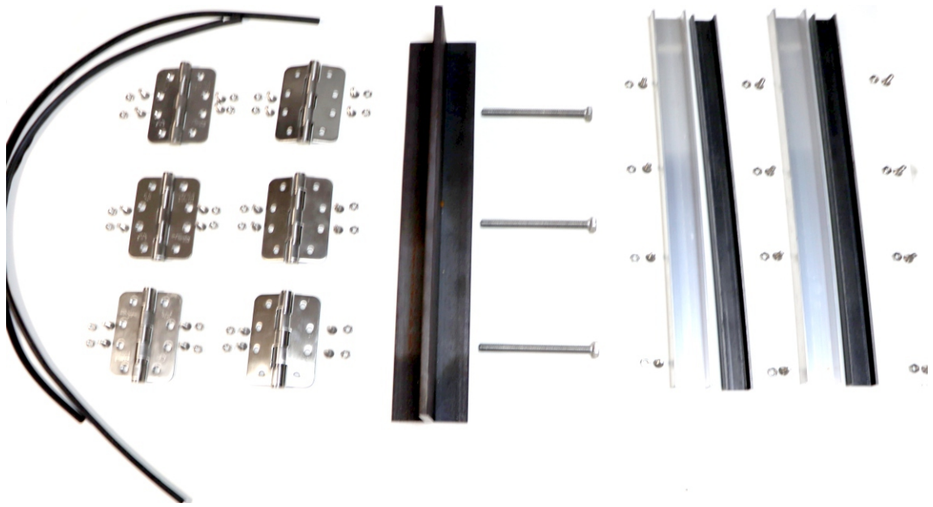


Image7.2.3: the materials needed for the prototype connection

7.3 Final Prototype - Pre-assembly

Step 1: Drilling

The preassembly procedure started with the drilling of the extra hole on the windows.
In each window extra, 12 new holes were needed and 8 of the pre-existing were used.

Step 2: Placing the hinges

The hinges were opened (unlocked) before placed and drilled. Then each female-male side was placed properly under a specified diagram (see photo). Using the bolt the hinges placed properly on the window frames.

Step 3: Placing the triangles on top of each other.

In this step, an important realization has been made. The big windows triangle weights in total 123kg and has a height of 1,5 meters. Because of its weight its shape and its dimensions, it is impossible for 4 or even 8 people to lift it 1,5 high and place it on top of the other one. There was no possibility of using a lifting machine so another solution has to be made.

The solution given was to use one with the large windows two triangles made of the smallest train windows, (30kg in total and 0,75m) high instead of another one made from the large windows, on top. In this case, it was relatively easy for three to four people to lift them and place them on top of the large triangle;e one by one.

Image 7.2.4: Organizing the materials

7.4 Final Prototype - Final Assembly in situ

Step 1: Assembling the triangles

The puzzled like (female-male) method with the hinges made the assembly fast and easy.In this step, 3 triangles were assembled.

Step 2: Placing the triangles

Firstly, the bigger of the modules was placed and after that the two of the small modules one after another.

Step 3 - Final: Bolting the modules

The modules were extremely stable on top of each other without the bolts. Although to ensure the safety of the structure three bolts were placed in each overlapping part of the window frames.

The module was stable even when the whole construction team was trying to slightly move it. Without creating the insecurity of instability or failure.

The extras: Checking the designer's concerns

During the whole construction procedure, my biggest personal concern was the strength of the frame. The connection part of the frame (where all the hole exist and all the connection parts are attached) is 2 cm in total with a width of 4 mm.

The holes on it are 8mm. So what actually remains is a 1,2cm aluminium that should take all the non-vertical possible forces of the hinges that connects the modules.

Image 7.2.5: First attempt triangle column

"What if someone pushes one module and creates non-vertical forces on the aluminium?"

"Is the 1,2mm aluminium enough? Could it break and cause a disconnection between the modules."

To ease my concerns and because there was time available with the help of the construction team we decided to create a cantilever module using the hinges for a connection to test the vertical load between the modules to the extreme.

"Could the 1,2 mm aluminium bare 60 kg vertical load? Would it break? What if we put extra pressure?"

We attached the cantilever module with the same hinges and it was perfectly steady.

After pushing pressure with our hands there was no change.

Since the cantilever was steady even under mil pressure, this test proves that the hinge connection between two steady - on the gound modules is perfectly enough and safe even if someone (or more) falls on a part of the construction and creates non-vertical forces to the hinges and the aluminium.

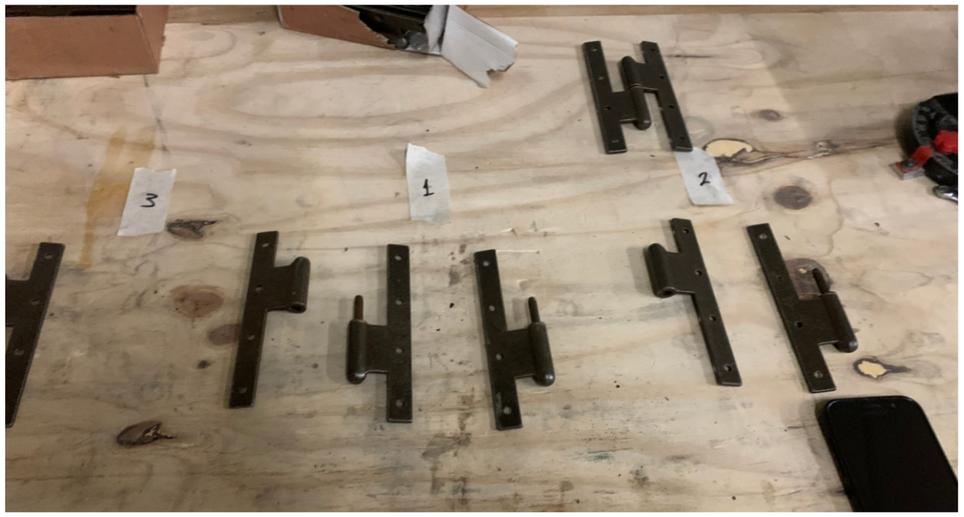
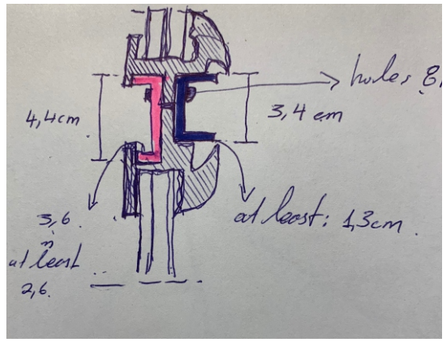
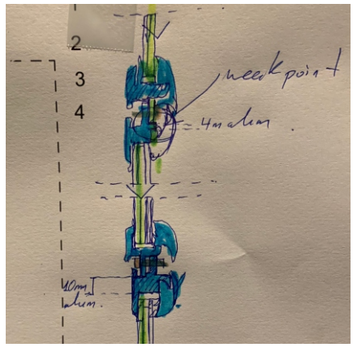
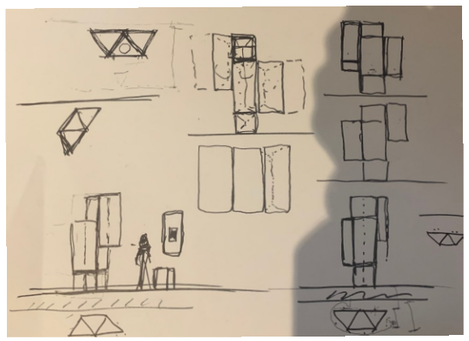


Image 7.2.6: Organizing the hinges and drilling the windows





Decision sketch to avoid the metal parts



Small triangle module

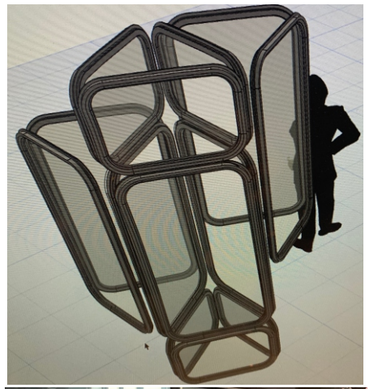
Image 7.2.8:Put one module on top of each other

7.5 Discussion: What we learn from the construction procedure

The first and most important conclusion that came up from the construction of this module, is that the lack of experience causes fear and the fear causes over-dimensioning and over dimensioning causes loss of time, money and resources.

The lack of experience with a product that its first life cycle was irrelevant to the construction sector, creates insecurity about the structural feasibility of the project. In this case, all the changes that came up simplified significantly the construction, a fact the lead to the conclusion that the was an over dimensioning and over-use of materials to cover the insecurity and lack of knowledge of the material.

After this realization, we can assume that the repeatable testing of the actual material is a demand before the final design when we reuse materials that were not meant to be construction components.

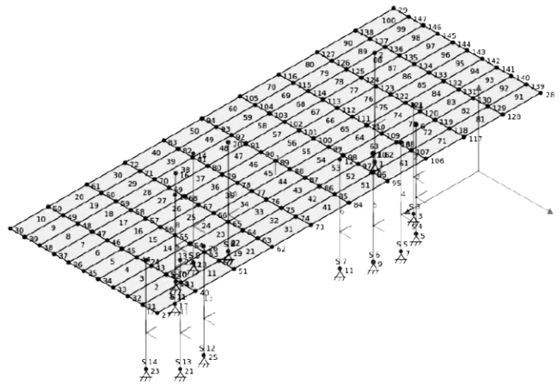


Cantilever design and attachment

Image 7.2.9: Final construction

Image 7.5.1 Final prototype

8.Structural Capability



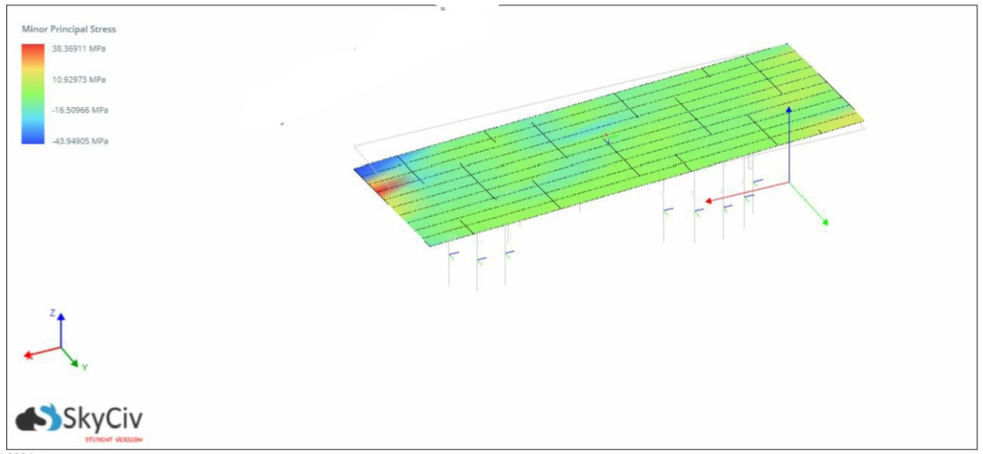
Is it load bearing?

As the designed module is column, its role is to bare loads. But could a triangle column of reuse train windows bare loads? Could it bare 2 Tones? Could series of columns bare a CLT slab without extra support?

These answers will be answered in this chapter after calculations with FEM 3D model.

The revit structural model in combination with FEM skyciv software were used to obtain the structural analysis.

The triangular columns considered solid laminated glass of 11mm. The base support and the connections between the slab and the column as pins



000.jpg

8.1 Data

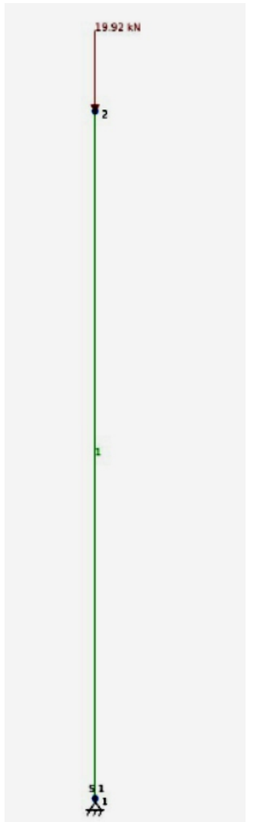
To begin with, assuming that the triangle module is completely made of glass its load bearing capacity would be tested.

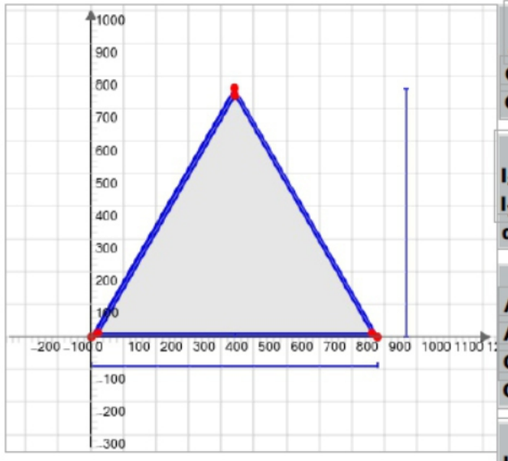
Choosing to load the column with 2 tones, which equals 19,92KN is enough to test its structural abilities to the extreme.

The tonne (metric ton, abbreviation: t) is the unit of mass in the metric system. 1 tonne-force (tf) = 9.80665 kilonewtons (kN) = 1000 kilogram-forces (kg).

A pin connection has been chosen in the base of the column.

Length Units	m
Section Length Units	mm
Force Units	kN
Moment and Torsion Units	kN-m
Pressure Units	MPa
Material Strength Units	MPa
Material Density Units	kg/m^3
Mass Units	null
Translation Units	mm
Stress Units	MPa
Nodes	2
Members	1
Plates	0
Meshed Plates	0
Supports	1
Sections	2
Point Loads	1
Distributed Loads	0
Moments	0
Pressures	0
Area Loads	0
Self Weight	ON





Geometric Properties		
A	28411.22068	mm^2
C_z	440	mm
C_y	254.03315	mm

Bending Properties		
I_z	1755787069.93272	mm^4
I_y	1755797922.74803	mm^4
α	0	°

Shear Properties		
A_z	11080.20623	mm^2
A_y	11080.11981	mm^2
Q_z	3138794.79983	mm^3
Q_y	3058069.98934	mm^3

Torsion Properties		
J	1771450000	mm^4
r	292.832	mm

MATERIALS (MPa, kg/m³)

Material	Name	Young's Modulus	Density	Poisson's Ratio
2	Glass	68000.00000	2500.00000	0.24000

Section	Name	Shape	Depth	Width	Shear Area z (STRESS)	Shear Area y (STRESS)	Shear Area z (TIMO)	Shear Area y (TIMO)	Torsion Radius
		-	-		-	-	0.00000	0.00000	-
2	equilateral	Hollow Triangular	762.10000	880.00000	11080.20623	11080.11981	-	-	292.83200

Section	Centroid y	Centroid z	Area	y-Axis MoI	z-Axis MoI	Torsion Constant	Principal Angle
2	254.03315	440.00000	28411.22068	1755797922.74803	1755787069.93272	1771450000.00000	0.00000

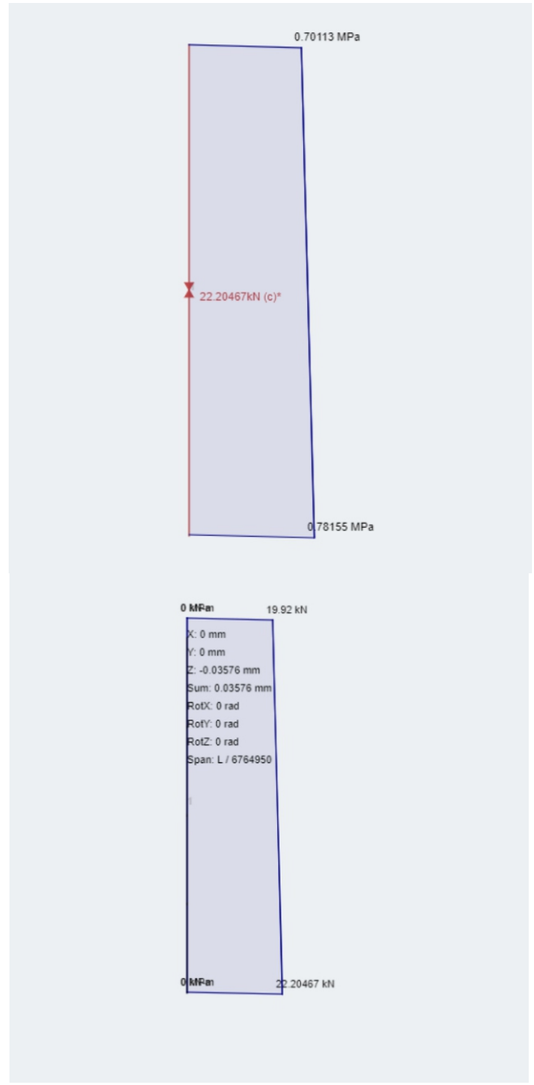
In the above tables the material and sgape properties of the triangular glass section are visible.

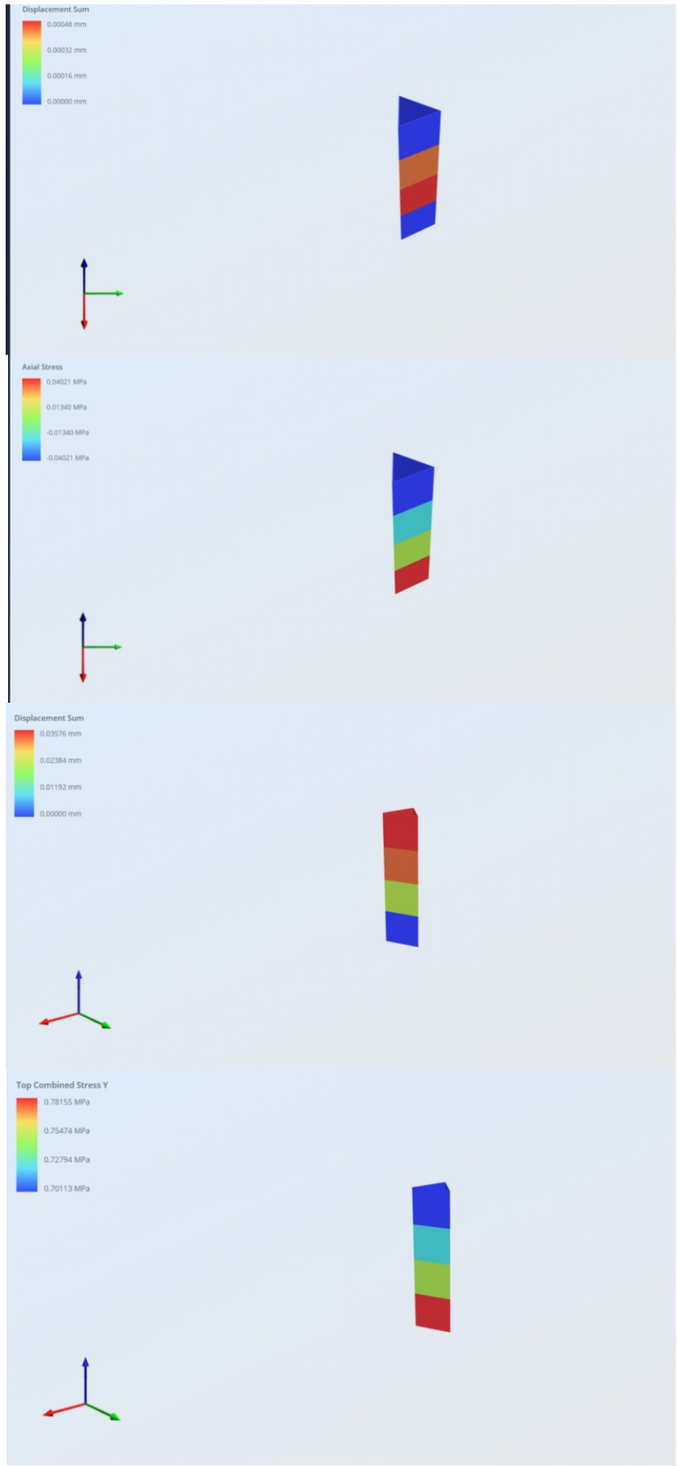
The section have been designed in Scyciv Section tool , in order to Calculate the moment of Inertia the torsion and the shear properties as seen above,

Furthermore the Material library set.
The materials used:
Laminated Glass of 11mm

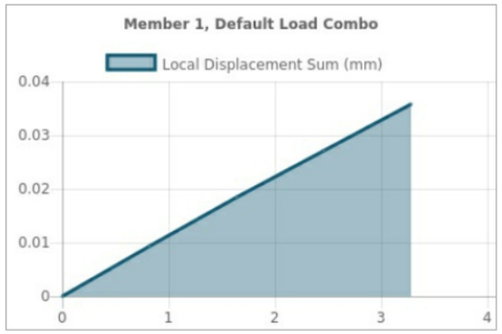
8.2 Results

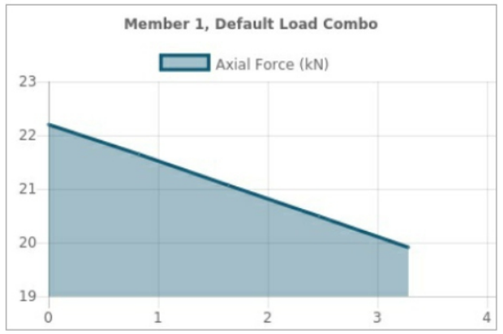
The first results about the structural capability of the glass triangular column under a pressure of two tones (2T) gave the results given in the folloing diagramms: Max stress of 0,8Mpa





Simulation results of stresses in the triangular glass column





MEMBER STRESSES (m, MPa)

Red Cells = Maximum value of a result in the member/plate.
Green Cells = Minimum value of a result in the member/plate.

Member	Station Location	Axial Torsion	Shear Y Shear Z	Top Mom Z Btm Mom Z	Top Mom Y Btm Mom Y	Ax + Top Mom Z Ax + Btm Mom Z	Ax + Top Mom Y Ax + Btm Mom Y
1	0.00000	0.78155	0.00000	0.00000	0.00000	0.78155	0.78155
		0.00000	0.00000	0.00000	0.00000	0.78155	0.78155
1	0.82000	0.76144	0.00000	0.00000	0.00000	0.76144	0.76144
		0.00000	0.00000	0.00000	0.00000	0.76144	0.76144
1	1.64000	0.74134	0.00000	0.00000	0.00000	0.74134	0.74134
		0.00000	0.00000	0.00000	0.00000	0.74134	0.74134
1	2.46000	0.72124	0.00000	0.00000	0.00000	0.72124	0.72124
		0.00000	0.00000	0.00000	0.00000	0.72124	0.72124
1	3.28000	0.70113	0.00000	0.00000	0.00000	0.70113	0.70113
		0.00000	0.00000	0.00000	0.00000	0.70113	0.70113

Load Group: 1

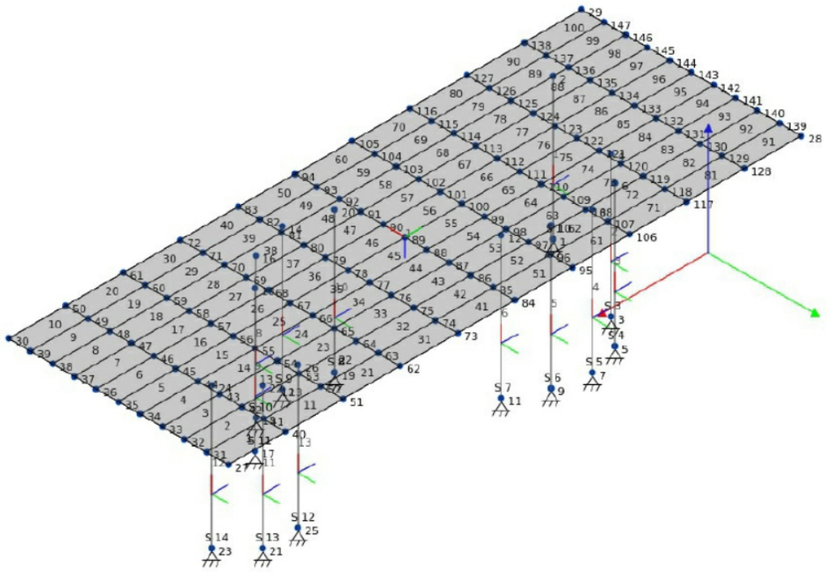
INTERNAL MEMBER FORCES AND MOMENTS (m, kN, kN-m)

Red Cells = Maximum value of a result in the member/plate.
Green Cells = Minimum value of a result in the member/plate.

Member	Station Location	Axial Force	Y Shear	Z Shear	X Torsion	Y Moment	Z Moment
1	0.00000	19.92000	0.00000	0.00000	0.00000	0.00000	0.00000
1	0.82000	19.92000	0.00000	0.00000	0.00000	0.00000	0.00000
1	1.64000	19.92000	0.00000	0.00000	0.00000	0.00000	0.00000
1	2.46000	19.92000	0.00000	0.00000	0.00000	0.00000	0.00000
1	3.28000	19.92000	0.00000	0.00000	0.00000	0.00000	0.00000

With a combined stress of 0.078Mpa and a tensile strength of tempered glass the σ=80Mpa it is clear that the column can easily bear 2 tones of weight.

8.3 Data: Simulation of the whole structure



Length Units	m
Section Length Units	mm
Force Units	kN
Moment and Torsion Units	kN-m
Pressure Units	MPa
Material Strength Units	MPa
Material Density Units	kg/m³
Mass Units	null
Translation Units	mm
Stress Units	MPa
Nodes	147
Members	13
Plates	1
Meshed Plates	100
Supports	13
Sections	1
Point Loads	0
Distributed Loads	0
Moments	0
Pressures	0
Area Loads	1
Self Weight	ON

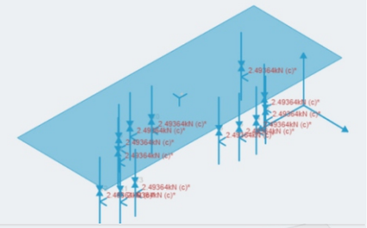
SECTIONS (mm, mm², mm⁴, deg)

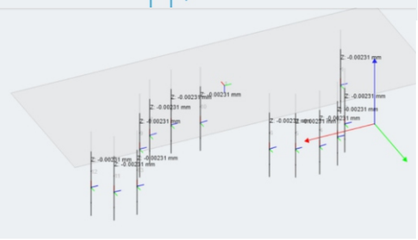
Section	Name	Shape	Depth	Width	Shear Area z (STRESS)	Shear Area y (STRESS)	Shear Area z (TIMO)	Shear Area y (TIMO)	Torsion Radius
1	equilateral	Hollow Triangular	762.100000	880.000000	11080.206229	11080.119805		-	292.832000

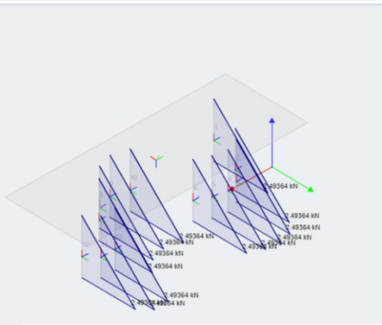
Section	Centroid y	Centroid z	Area	y-Axis MoI	z-Axis MoI	Torsion Constant	Principal Angle
1	254.033150	440.000000	28411.220680	1755797922.750000	1755287069.930000	1771456000.000000	0.000000

In this section, the load bearing capacity of the spine series of triangular columns while bearing a 280mm CLT plate will be tested.

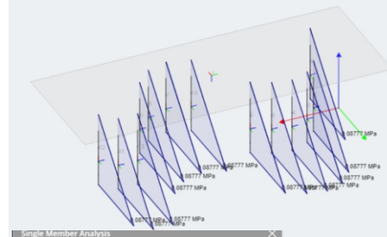
Diagrammatic Results

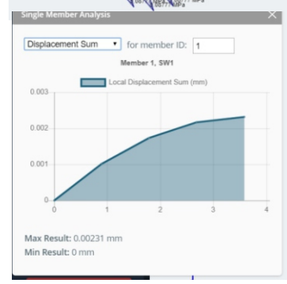


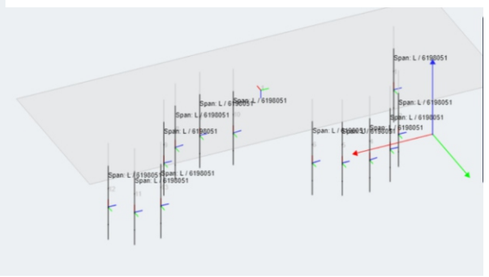




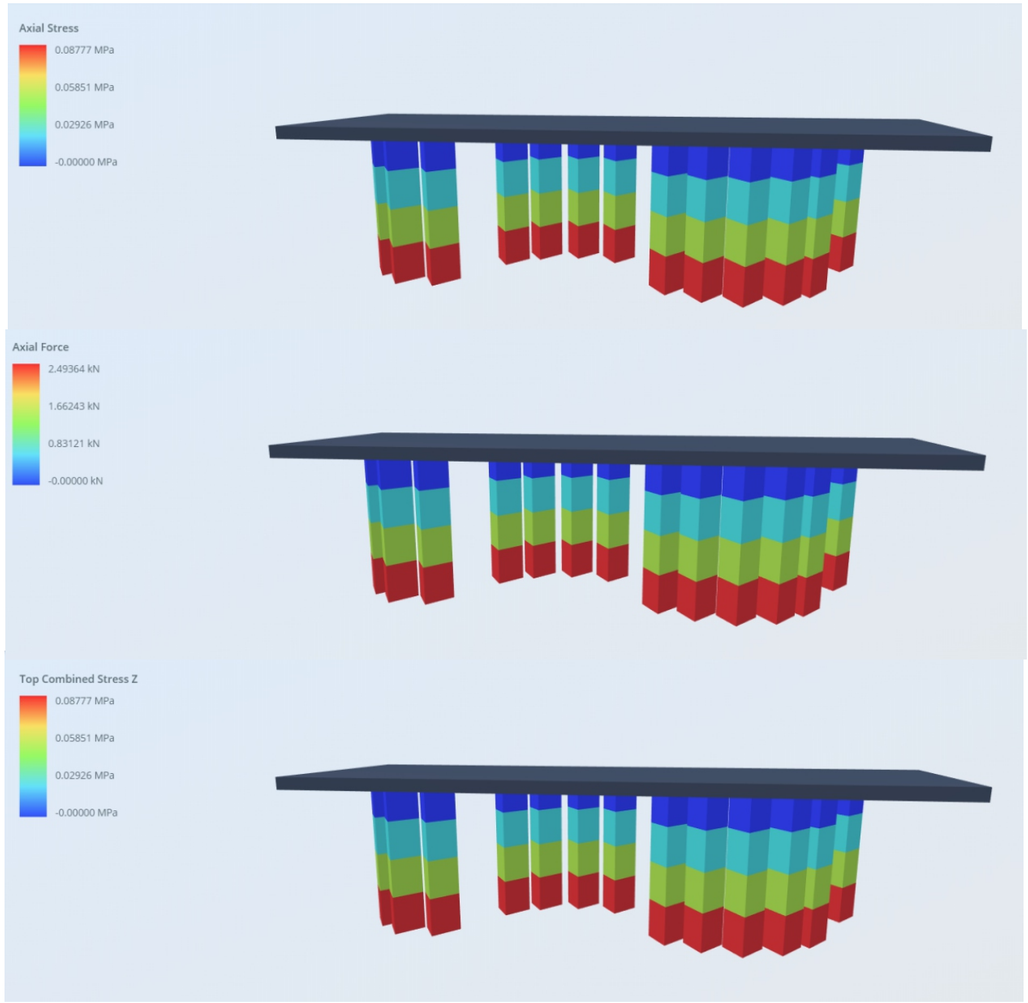
The maximum stress in the triangular columns is almost 0.9Mpa, which means that they can safely bare the weight of the CLT slab.







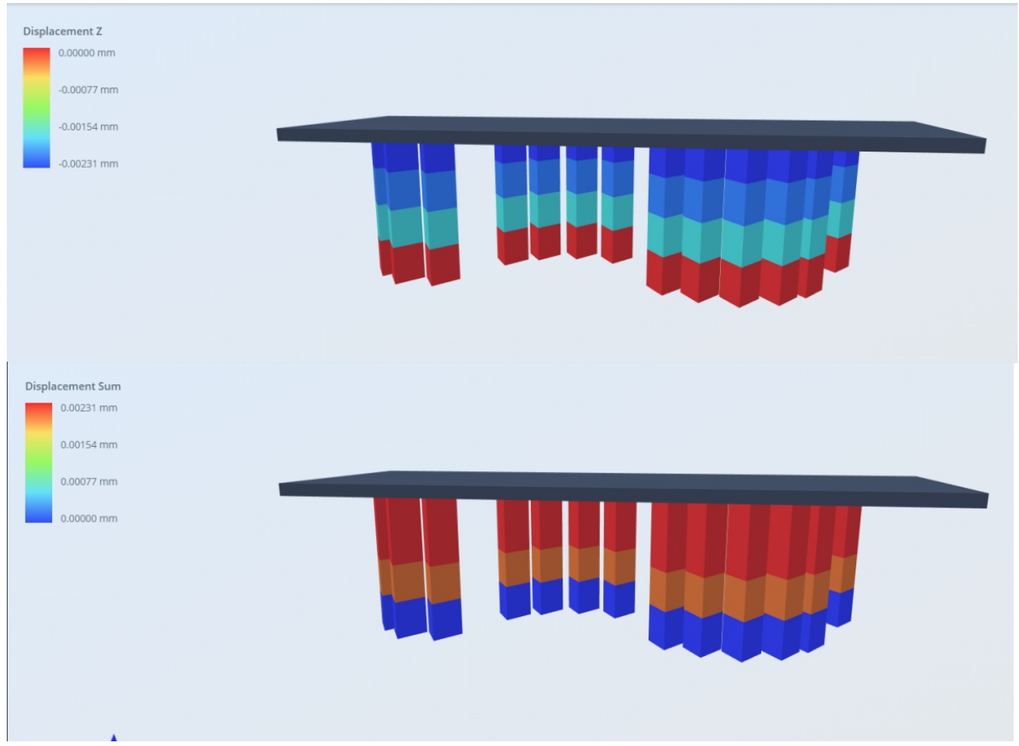
Simulation Results



Stress results of the columns under the weight of the CLT slab

Looking closely to the results for the whole design analysis, we assume that the columns again are staying intact with an axial stress ´σ=0,0887 Mpa and a close to zero displacement.

The simulation proves that the triangular columnns can bare the CLT slab succesfully.



9.Conclusions

This thesis showcases research on how the train windows from the old VIRM NS trains can be upcycled as a construction component. Having strictly in mind time and cost feasibility, circularity and the design of a continuous product loop, the main component designed. On the basis of the research and analysis presented the following research question was formulated:

“Which is the most cost and time effective approach on designing a construction component of reuse train windows, under circular terms for small scale, open constructions?”

From the start of the research circular economy principles and ways to be established in the design process discussed. This procedure demand the formation of a tool box that lead to a feasible circular design proposal. At the same time the possible module designs had to be categorized and filtered afact the lead to the plot of specific design criteria. Time, Cost , Structural Ability and mainly Simplicity formulated a net that lead to the propose design component. The balance between the criteria was the most difficult and complicated part. A qualitative comparisonn of the different categores took place giving an overview of its proposed design during the form finding process.This procedure was enough to estimate the benefits and the drawbacks pf each category and conclude to the proposed triangular column.

In the second design phase the detailing process tool place. The same criterial apllied and influence the detailing choices.It is obvious that the connections are gradually simplified. Step by step less and less materials are used to the proposed connection. Safety and structural stability on the one hand and simplicity on the other hand were tested under 5 detailing phases, to conclude in a balanced connection choice.

The assembly chapter is divided in two subchapters. The proposed one and the real one. This brought on the surface the reality of the construction. Although the proposed assembly manual explained detaily every possible step of the assembly in reality assembly barriers came up that lead to a second assembly manual to correct them.

The final research chapter concerns the stability of the proposed component and the stability of the proposed case study. Using the Finite element model the module and the whole structure had been tested. The supposed in the design chapter, sufficient structural ability of the module has been confirmed both as a unit but also in multiplication.

The main aim of the research was to design an architectural component of materials that weren’t supposed to be used in architecture. This fact causes incecurity and hesitation to architects and enginners.Proven that a construction component of this kind can be structurally safe, easily and simply constructed and with sufficient aesthetic results is convincing enough to draw the attention to the upcyle part of architectural design.

10.Discussion

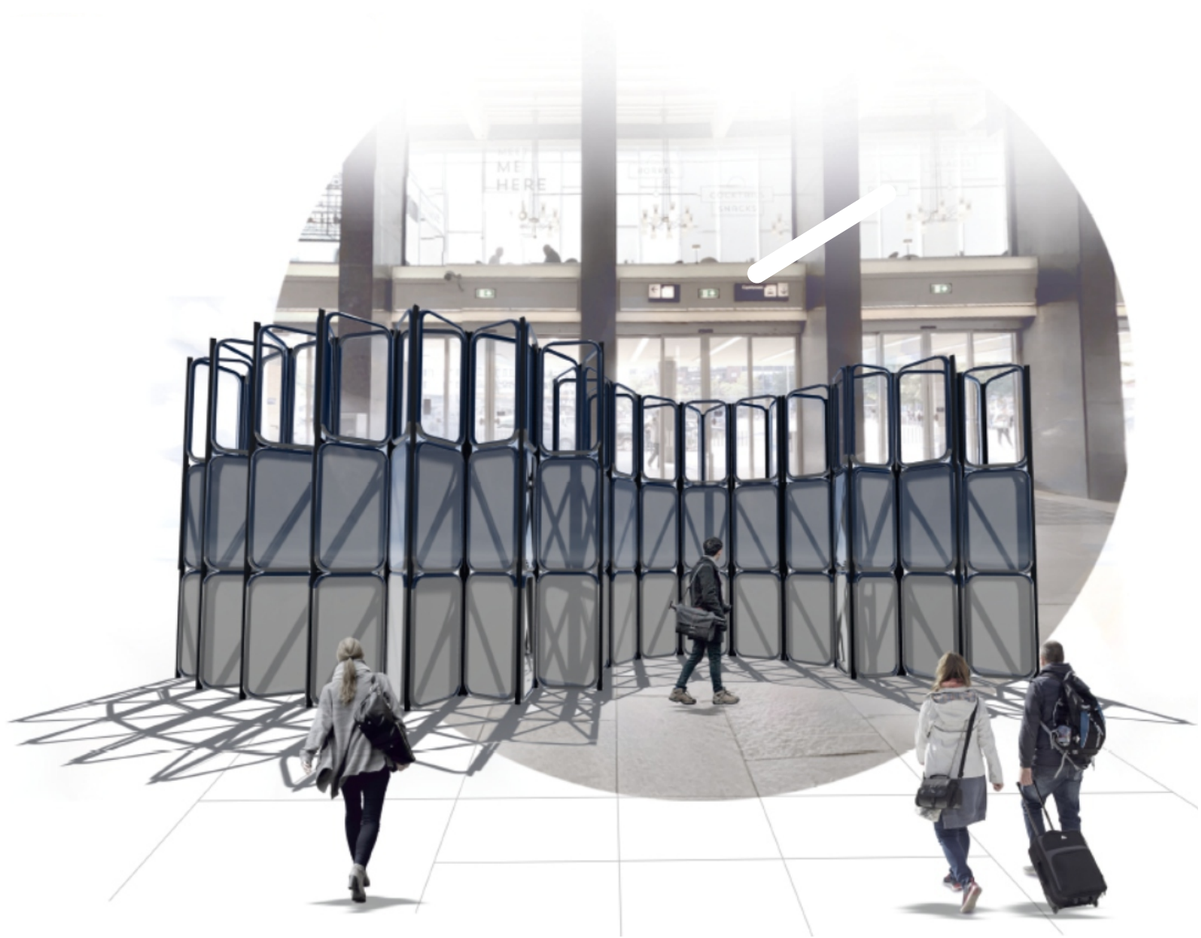
Adaptability of the module in permanent - sealed constructions

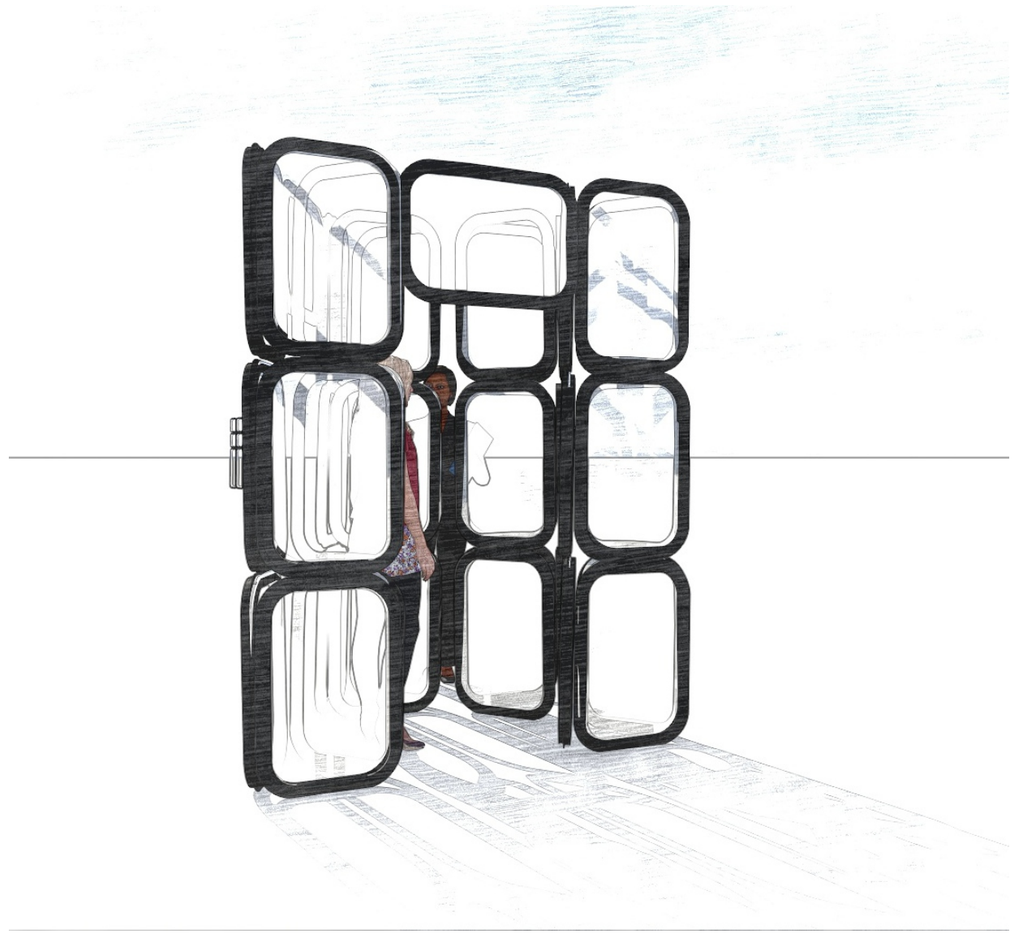
During the current research a modular component made from train windows has been developed. A structural column that can bare load and be easily assembled in short time frame, which make it a sufficient choice for modular temporary structure. Although ideas of using the component in permanent structures have to be discussed.

In case of a permanent-sealed construction the first issue tha could come up is the gaps inbetween the triangles. A component that could seal the gabs has to be deigned and tested. Furthermore the maintenance of the confections of the modules and the life expectancy of the windows have to further examined.

Last but no least, for taller and bigger constructions the safety and load capacity would differ significantly a fact that could create a whole different level of research on detailing and analysis.

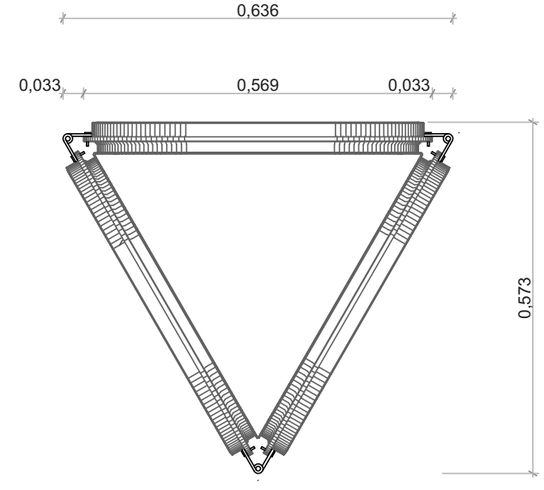
To conclude, this research proves the ability of a waste material to gain extra value , being Superused and upcycled under an efficient and simple design. The architectural proposal refers to temporary open structures , such as the proposed pavilion, bus stops, installations or landscape application of any kind in small scale.
However is a hint for a new research to start, on the further abilities of the component in larger scale structures.

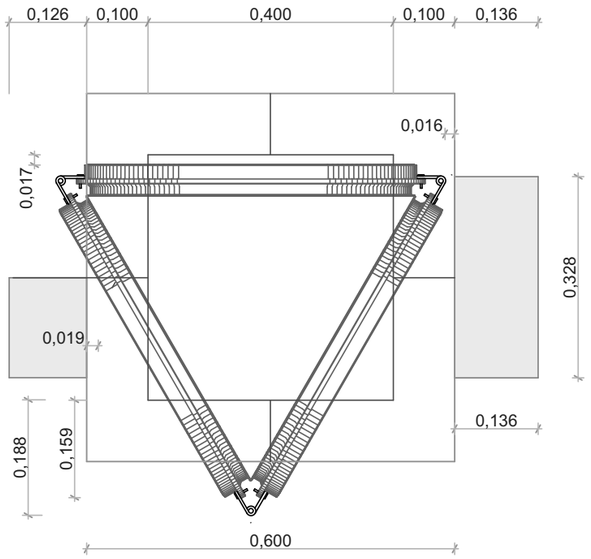




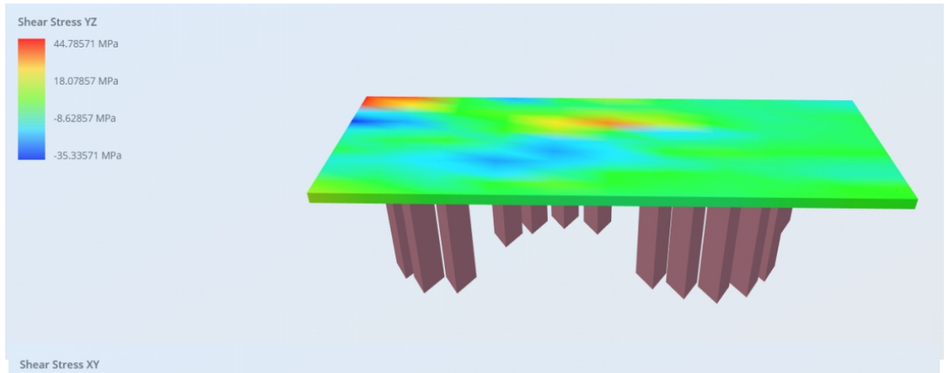
II.Appendix

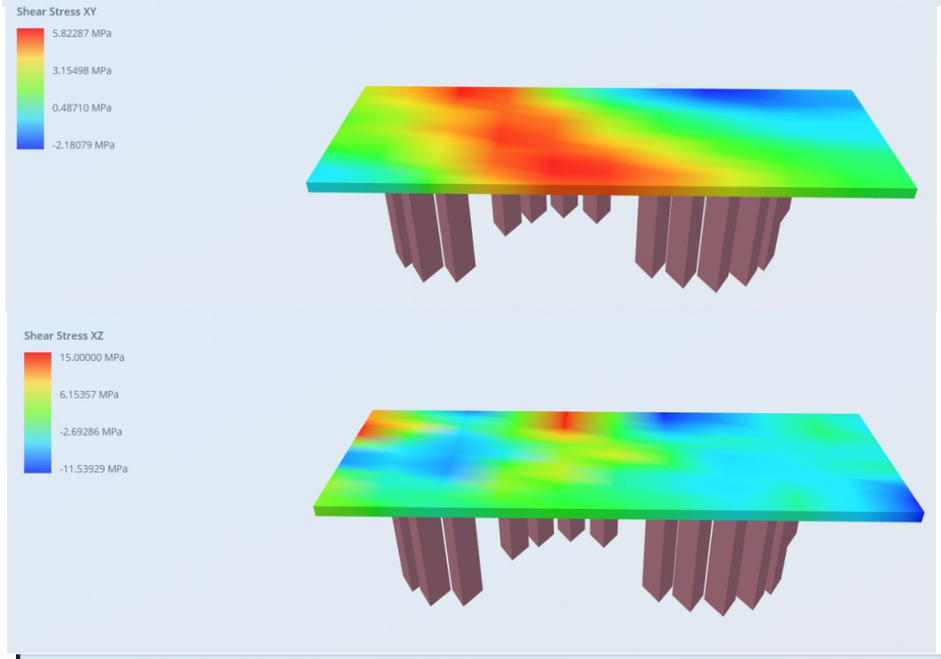
LAB TEST

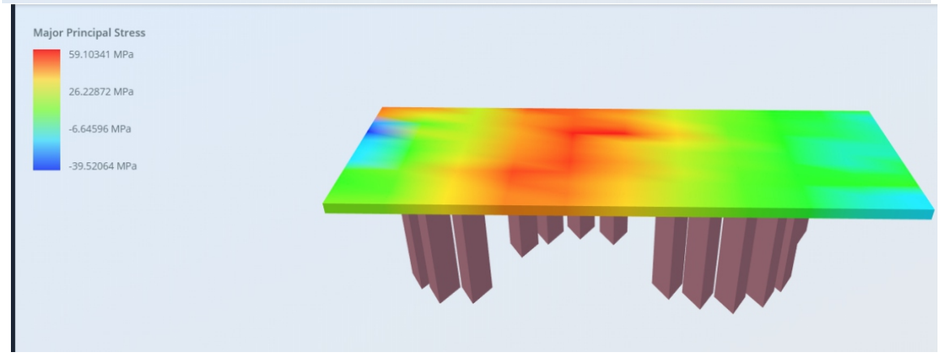


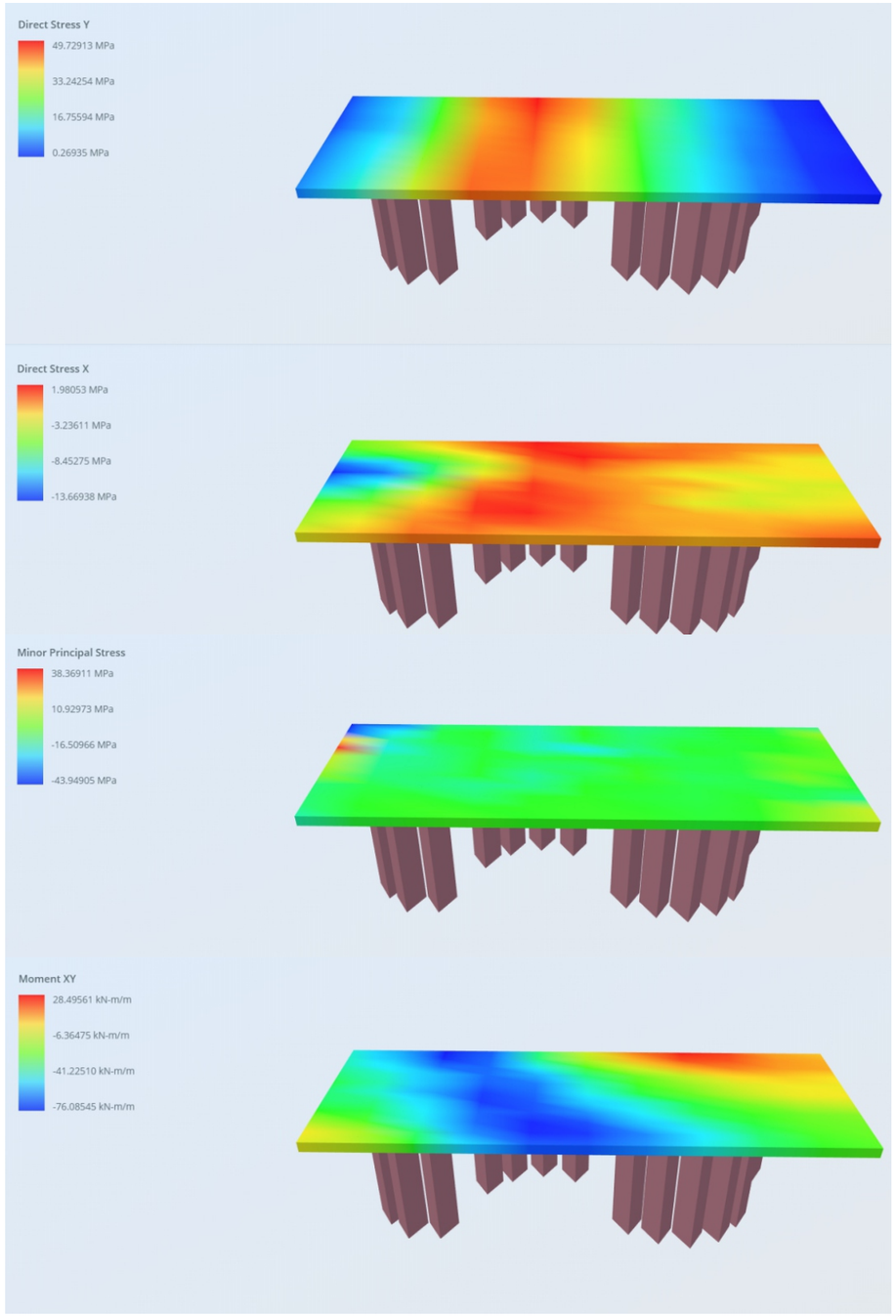


Slab simulation results








Direct Stress Y
49.72913 MPa
33.24254 MPa
16.75594 MPa
0.26935 MPa
Direct Stress X
1.98053 MPa
-3.23611 MPa
-8.45275 MPa
-13.66938 MPa
Minor Principal Stress
38.36911 MPa
10.92973 MPa
-16.50966 MPa
-43.94905 MPa
Moment XY
28.49561 kN-m/m
-6.36475 kN-m/m
-41.22510 kN-m/m
-76.08545 kN-m/m

References:

-Adriaanse, A., Brigenzu, S., Hammond, A., Moriguchi, Y., Rodenburg, E., Rogich, D. and Schutz, H. (1997). Resource Flows: The Material Basis of Industrial Economies. World Resources Institute, Washington DC.

-Matthews, E., Amann, C., Bringezu, S., Hüttler, W., Ottke, C., Rodenburg, E., ... & Weisz, H. (2000). The weight of nations-material outflows from industrial economies. In World Resources Institute.

-Boardman, B. (2004). Starting on the road to sustainability: Environmentally sustainable buildings: challenges and policies. Building Research & Information, 32(3), 264-268

-Graedel, T., & Howard-Grenville, J. (2005). Greening the industrial facility: perspectives, approaches, and tools. Springer, New York

-Ortiz, O., Castells, F., & Sonnemann, G. (2009). Sustainability in the construction industry: A review of recent developments based on LCA. Construction and Building Materials, 23(1), 28-39.

-Wiedmann, T. O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., & Kanemoto, K. (2015). The material footprint of nations. Proceedings of the National Academy of Sciences, 112(20), 6271-6276.

-ABN. (2014). Circulair Bouwen, Het fundament onder een vernieuwde sector.

-Allwood, J. M. (2014). Squaring the Circular Economy. In Handbook of Recycling (pp. 445–477). Elsevier. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/B9780123964595000301

Alonso, E., Gregory, J., Field, F., & Kirchain, R. (2007). Material Availability and the Supply Manufacturers' Usage of End of Life and End of Use Products. In R. Setchi, R. J. Howlett, Y. Liu, & P. Theobald (Eds.),Sustainable Design and Manufacturing 2016 (Vol. 52, pp. 179–187).Cham: Springer International Publishing. Retrieved from http://link.springer.com/10.1007/978-3-3 19-32098-4_16

"Annual report 2010". Nederlandse Spoorwegen. 1 January 2011. Archived from the original on 30 June 2011. Retrieved 18 July 2011

-Cossu, R., & Williams, I. D. (2015). Urban mining: Concepts, terminology, challenges. Waste Management, 45, 1–3. http://doi.org/10.1016/j.wasman.2015.09.040

-Economidou, M., Atanasiu, B., Despret, C., Maio, J., Nolte, I., & Rapf, O. (2011). Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings. Buildings Performance Institute Europe (BPIE).

-Ellen MacArthur Foundation. (2012). Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition. Ellen MacArthur Foundation Cowes, UK.

-European Commission, EU Transport in figures, Statistical pocketbook, Luxembourg 2013.

From the statistic of Environmental Protection Department (2005), Environmental protection, http://www.info.gov.hk/epd, Environmental Protection Department,

-Gremmen,L.(2018) Component Reuse in Construction The current building stock as a source of components for new buildings, TUDelft

-Guy, B., Shell, S., & Esherick, H. (2006). Design for deconstruction and materials reuse. Proceedings of the CIB Task Group, 39(4), 189-209.

International Union of Railways Annual Report, 2015.

Informational materials of Rail Vehicles Institute TABOR. Retrieved December 2013.

-Institution of structural engineers (IstructE). (2007).Temporary demountable structures Guidance on procurement, design and use. Third edition. Retrieved from

http://www.juicesound.co.uk/tempstructu resguidance1.pdf on 5 June 2017

International EPD Consortium, “Product category rules (PCR) for preparing an environmental product declaration (EPD) for rail vehicles”, UNCPC Code: 495, 2009.

International Standard, ISO 22628 – Road vehicles – Recyclability and recoverability – Calculation method, 2002.

-Jacobs, J. (1970). The economy of cities. New York: Vintage Books.

Merkisz-Guranowska,A. Merkisz, J. Jacyna,M. Pyza D.& Stawecka H. (2014) Rail vehicles recycling Hong Kong Special Administrative Region, China

-Ravetz, J. (2008). State of the stock—What do we know about existing buildings and their future prospects? Energy Policy, 36(12), 4462–4470. http://doi.org/10.1016/j.enpol.2008.09.02 6

-Swilling, M. (2011). Decoupling natural resource use and environmental impacts from economic growth. United Nations Environment Program (UNEP) http://www.
unep.
org/resourcepanel/decoupling/files/pdf/D ecoupling_Report_English.Pdf.

-SuperUseStudios| http://superuse-studios.com/?lang=nl

-Sustainability at NS | About NS | NS.”
Dutch Railways, www.ns.nl/en/about-ns/sustainability/sus tainability-at-ns.html.

The Ministry of Infrastructure’s Regulation of 12 October 2005 on the general technical conditions for railway vehicles’ exploitation, Dziennik
Ustaw no. 212, document 1771, Warsaw 2005.

-Uihlein, A., & Eder, P. (2009). Towards additional policies to improve the environmental performance of buildings. European Commission, JRC-IPTS, EUR, 23775. WBCSD. (2008). Sustainable consumption facts & trends: From a business perspective.