The material potential for Design for Disassembly

The Hessenbergweg 8 and the Circle house principle as case studies for the Design for Disassembly.

Abstract.
The European Union and the Dutch government have set goals for a sustainable future. They aim to do this through adapting a circular economy. This influences the way we have to deal with materials and one of the themes around a circular economy is the 'Design for Disassembly.' This paper compares three versions of construction of the same building, the Hessenbergweg 8, in Amstel III. The three versions are the original façade from 1986, a version built according to the Dutch 2018 building regulations and a version that is designed for disassembly. In these versions the re-use and re-cycle potential of the skin, the loadbearing construction and interior walls are compared. First the material re-use and re-cycle potential of the materials and components were compared. Subsequently an LCA analysis was conducted. This showed a huge potential for Design for Disassembly as most of the environmental impact is coming from the non-recyclable concrete, screed and gypsum boards. This means that the Design for Disassembly has a re-use and recycle potential in volume of 88%. This is significantly more than the 8% of traditional methods. In mass this is 90% in the Design for Disassembly construction opposed to the 2% of the traditional building. In terms of embodied energy coming from the LCA analysis the energy use for the design of the building is equal to roughly 7 years of operational energy, this might question the need for a Design for Disassembly, a method that is often more expensive. However at this point 87% of the total volume and 98% of the mass of a building ends up in landfill. A mass that will never be able to be recycled.

Keywords: circular design, Amsterdam, Design for Disassembly, circle house, re-use, re-cycle, LCA, embodied energy

Introduction.
In 2016 The Dutch government brought out a report with the sustainable goals for 2050 (Dijksma & Kamp). This report is the Dutch adaptation of the European goals (European Union, 2014). Both reports focus on the transition to a circular economy as a platform to make sustainable behaviour economically viable. The circular economy focusses on closing the material loop by forcing producers of products to take care of the recycling after use. This makes products cheaper if they are flexible, last longer and are easier to re-cycle and re-use. Because of the trade and knowledge-based economy of The Netherlands they have ambitious plans to become world leader in circular economy knowledge and share this knowledge with other countries. In collaboration with the Delft University of Technology, the Municipality of Amsterdam and Kasper Jensen of 3XN/GXN a book was made to display the upcycling opportunities of Amstel III (Dekker, Gao, Lukkes, Markus, & Bohle, 2018). This area requires major redevelopments to turn the current office-district into a flexible mixed-use neighbourhood. This means the existing stock of buildings (materials) has to be repurposed to allow for high-rise and apartments. The book concluded with five drivers to enable a circular economy. This report focusses on the third driver: the Design for Disassembly.

Method.
This paper will analyze the potential of Design for Disassembly in Amstel III by answering the following question: "What is the material and energy potential for a circular building in Amstel III." To give answer to this question one building will be analyzed: The Hessenbergweg 8. This is an office building in the middle of the Amstel III area and is expected to be either removed or renovated in the next 4 years to comply to the minimum energy label in 2023. This building is also representative for the rest of the area as it is built in 1986, a period in which most of these buildings were designed and it's relatively simple in its design and materialization. This

building will then be analyzed in three different versions of construction. The first version is the original building. The second version is the original building but adapted to the current Dutch (2016) energy requirements. The third version is designed around the same building layout and dimensions but Designed for Disassembly. This third version is a derivative of the Circle House by GXN (2018). This is a circular design principle for a housing project. As the Hessenbergweg 8 has an open plan with columns it was required to change the design of the Circular House to adapt columns. The research on this case will include a LCA-analysis on embodied energy, CO_2-eq impact and water usage. Next to the LCA the potential of the three versions to be re-used or re-cycled will be discussed. This paper will start off with the definition of terminology within the circular economy as often terms are misused. In the building sector 95% of waste is being recycled (Dijksma & Kamp, 2016, p. 59). This suggests that no real action is needed as it is already close to a theoretical maximum. However, out of the recycled products 85% finds its new purpose as a ground filler for new roads and only 3% will be re-used into building projects again.

The circular economy.

The circular economy is based on two principles. The first is to design out waste. Materials must be recycled and re-used at their highest value and for as long as possible. To achieve this recycling, it is important that raw materials can always be recycled and do not get contaminated in chemical processes. If there is no contamination, the by-products creating in the process and the final product after its use can be used again as raw materials. The second principle is to keep products and materials in use for as long as possible. Our current capitalistic economy is built around a disposable lifestyle. Often, we buy single-use and single-purpose products as they are cheaper and easier to deal with for the user, although they are far worse for the environment because they are usually not recyclable. But if we do buy long lasting products we tend to throw they away before they reach the end of their technical lifespan. To extend the lifespan of products they must become more robust and flexible in the sense that they become multi-purposed or that they can be easily adjusted to fulfil a purpose in a new or different product. The circular economy aims to make this possible by stimulating re-use and re-cycling. This will be done by mapping the complete impact of materials and processes onto the environment and stimulating cleaner processes. One example is the soon to be introduced CO2-tax on concrete to stimulate cleaner building techniques or reinvent the way concrete is made or used.

Re-use, re-cycle, down-cycle and waste.

To get an understanding of the circular economy on material level four terms are needed: re-use, re-cycle, down-cycle and waste. In image 01 this usual process is described. From the raw material, a yarn, a t-shirt is produced. This t-shirt can be re-used among multiple people. At the end of its lifecycle it can either be recycled into a yarn or the material of the t-shirt can be compressed with the addition of an adhesive to turn it into a new chair. This is called downcycling from a material perspective. From this product you will never be able to create a yarn again. This material might however again be re-used to create another shape until it reaches the end of this lifetime. After its lifetime the material downcycling can happen again until it reaches a point that the material has lost all functional properties and it can only be wasted. Here it will be either incinerated to turn it into CO2 and energy or it will be landfilled if the

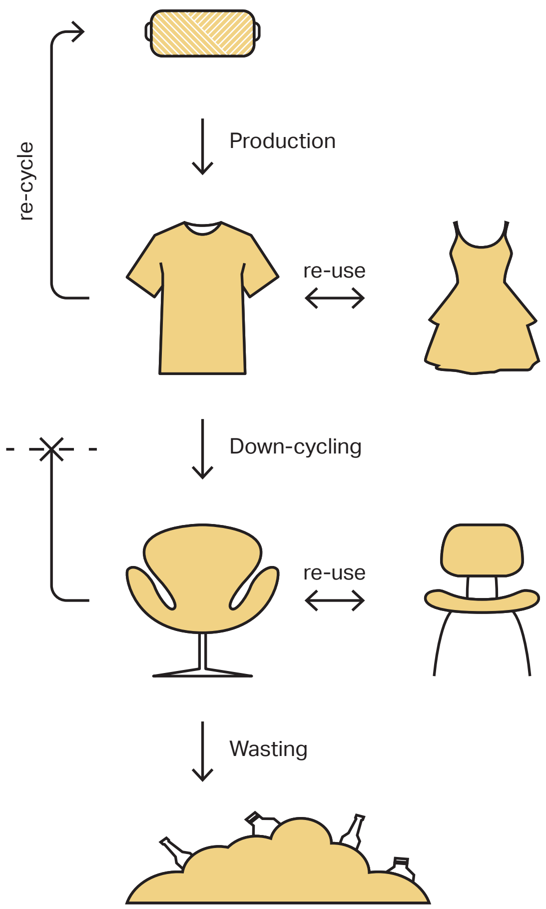


Image 01. The material life. (own ill.)

material is too contaminated to be incinerated.

Together re-use, re-cycle, down-cycle and waste often a fifth term is used: "up-cycle." Although this term assumes an increase in material value it is merely a synonym for downcycling as it fits the same description as given above: mixing it with a different material into an inseparable new material that after the mix will never be able to be recycled into the original raw material. This however is an interesting topic as the value of the new material can be discussed. You could argue that turning five 10-euro wasted t-shirts into a 100-euro chair is upcycling as the value of the material has increased significantly. However, it can also be argued that turning those 5 t-shirts into new t-shirts for a few more times has a lot more value is maintained as it will always be possible to return to the original raw material.

The building sector has to address similar issues. For example, when steel and chromium are mixed a new alloy is created: stainless steel, a material with great corrosion-resistant properties. This process can either be seen as downcycling as it is chemically inseparable, or it can be seen as the creation of a new raw material that, if documented well, can be re-cycled for an infinite amount of times. A more problematic issue is the creation of concrete, a material created by gluing sand and gravel together with water and cement. A building material we have grown very used to as it has excellent building properties. It has mass to accumulate heat and cold, great compressive strength and when we add steel to the mixture, it also has great tensile strength. The same issue arises for re-using on component level. If a product is produced, that no longer is revertible into its original raw materials, but technically has an infinite lifespan. Then is this still considered downcycling, but does the new value exceed the need for returning it into raw materials? This happens for example in the circle house (GXN, 2018). This project is built up from many flexible (concrete) components (illustration 02) that can be interchanged between different buildings and leave no waste when moved from one site to another site.

In the next chapters this issue will elaborate this in the form of a case study by extracting the components and materials from the Hessenbergweg 8 in the three different versions. Here the quality and potential of re-use and re-cycling will be discussed. In image 04 the three

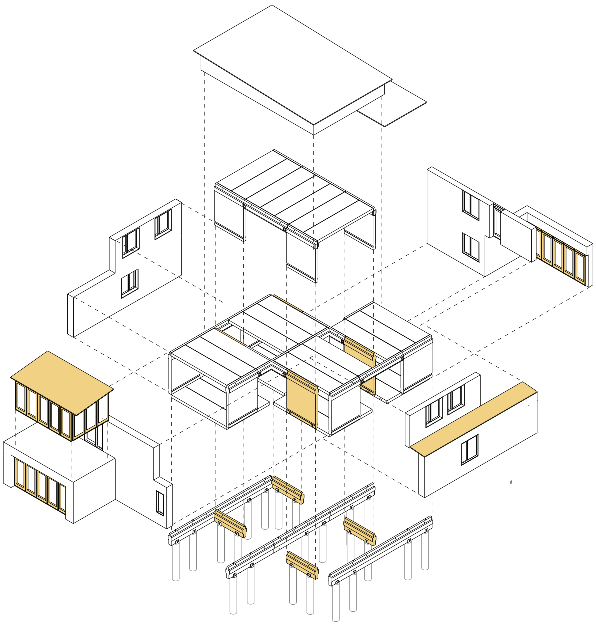
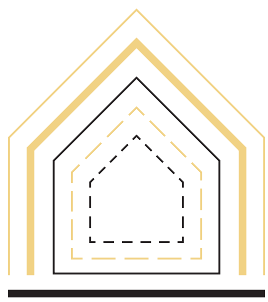


Image 02. The Circle House. (GXN, 2018, p. 110)

different facades of the Hessenbergweg are displayed. The first section is the building as it is built at this moment. The second image shows the same building but adopted to the current (2018) building regulations in terms of heat resistance. This gives the building an energy label A. The third section is an adoption of the Circle house by GXN. In this third section al building components are mechanically connected as opposed to the chemical connections in the traditional facades. The elements that will be taken into consideration are chosen according to the building layers (image 03) originally introduced by Duffy and Brand. In this case the Skin, Structure and space plan will be analysed. The stuff and services are too subject to change and do not add significant changes to the amount building materials. These layers can be broken down into 9 groups of building materials with their specific embodied energy, emissions and water consumption. These materials are found in table 01.



Layer	Lifetime (yr)
Stuff	0 - 5
Space plan	5 - 15
Installations	15 - 25
Structure	50 - 100
Skin	25 - 50

Image 03. The building layers. (own ill.)

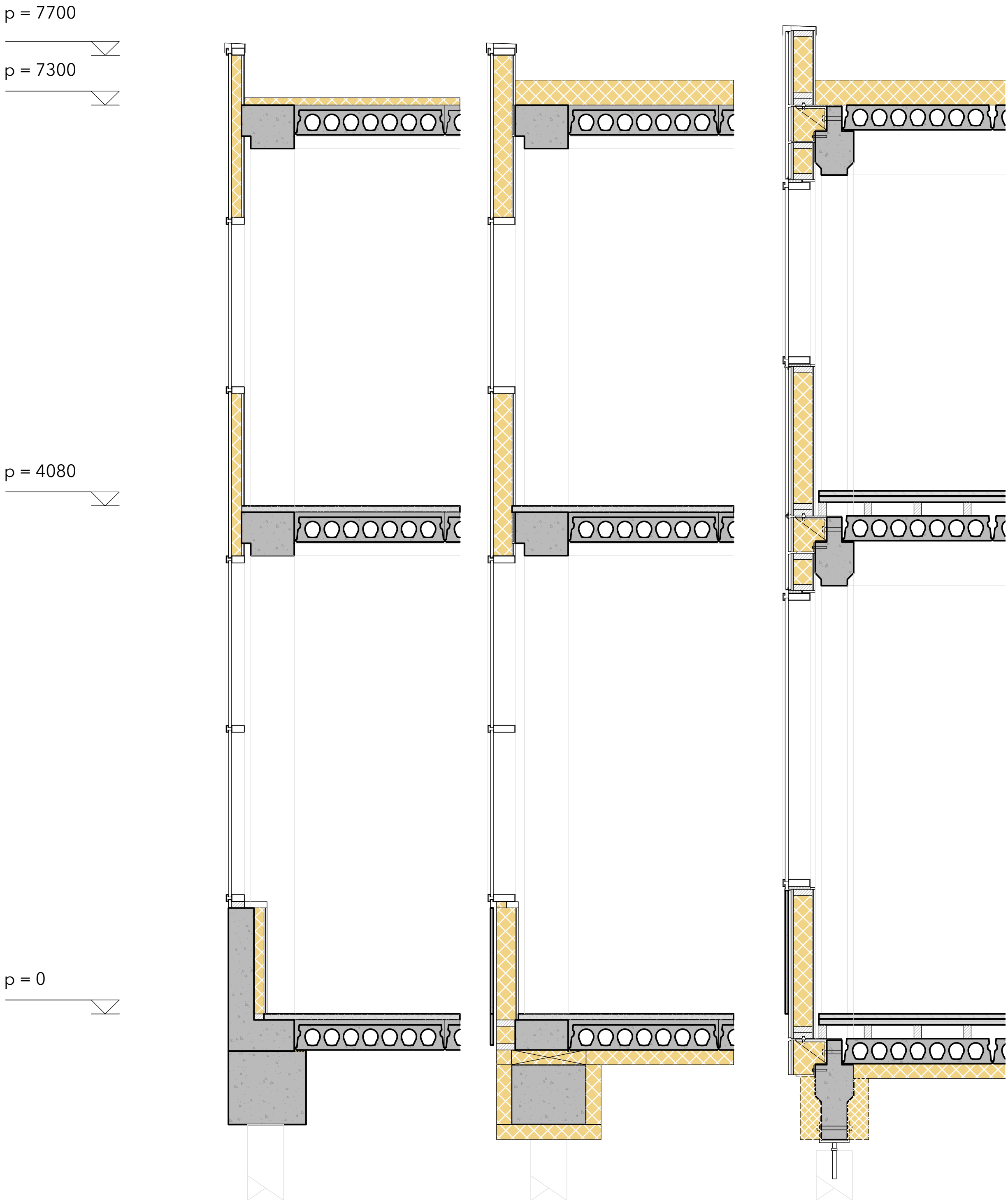


Image 04. The sections of the three different versions. From left to right the building from 1986, the same building according to current regulations and the building built for disassembly. (own illustration)

THE RE-USE AND RE-CYCLING POTENTIAL.

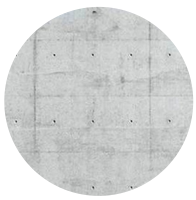
For the re-use and re-cycling potential of the Hessenbergweg 8, the building has to be analysed. With the original building drawings, a complex 3D model was built to generate the total volume of materials in the building. This also gave insight in the 9 main materials that are used in the building:

- Concrete
- Screed
- Polystyrene
- Rockwool
- Plasterboard
- Dry wood
- Plywood
- Aluminium
- Float glass

The material re-use and recycling potential of these materials is researched with the data from the NIBE database (NIBE, 2018). Most materials proved to be hard to re-use on their own, but as a modular building element they appeared to be more flexible and re-useable. The materials have been given a score on their re-usability, whether they can be modular on its own and its re-cycling potential has been given a score from 0-100% relative to their building mass.

Concrete

Reuse	low
Modular	high
Recycle	0.2%
Landfill	99.8%
Incineration	0%



Concrete has a low potential for re-using as the structure is not modular as it is all cast together into one solid mass. Cutting it into pieces is too time consuming and its structural qualities cannot be guaranteed after cutting it. However, if the elements are modular is has a great re-using potential as it is not fragile and has long durability. After use the concrete is downcycled into landfill or granulates. Only 0.2% is being recycled into new concrete.

Screed

Re-use	none
Modular	-
Re-cycle	0%
Landfill	90%
Incineration	10%

Screed has no potential of re-using as it has no structural value and it has already chemically settled. It has also no re-cycling potential. All of the material either gets landfilled or incinerated.

Polystyrene

Re-use	medium
Modular	-
Re-cycle	5%
Landfill	90%
Incineration	5%

Polystyrene has medium re-use potential as it is delivered in standard sizes and thus can be re-used in a new construction after disassembly. It can be recut on site with no special machinery although it needs careful handling as it the burning of the material can cause a carcinogenic hazard. Only 5% of the material is recycled due to the volume and the price of the material. This makes it too difficult and hard to separate and recycle. The second 90% ends up in incineration. The product is made from oil or nowadays from organic materials. When incinerated the only byproducts are CO2 and water. The last 5% brings a huge environmental risk as it breaks down to tiny particles easily in water. This makes it the most harmful marine polluter (Eartheasy, 2018).

Rockwool

Re-use	high
Modular	-
Re-cycle	95%
Landfill	5%
Incineration	0%

Rockwool gas a great potential for re-use as it is delivered in standard sizes and It can be easily recut into different sizes. It also has a high recycling potential as it can be used to produce new rockwool. Rockwool has started its own recollection points (Rockwool, 2018).

Dry wood

Re-use	low
Modular	high
Re-cycle	5%
Landfill	85%
Incineration	10%

The material itself has low potential to be reused as it is hard to detach, sizes are often irregular. As part of a modular product it has great re-use potential as it is relatively light and it can be easily mounted on another façade if the sizes match. It can either be recycled into laminated products or incinerated as a source of energy. As it is an organic renewable source it can be incinerated to generate energy after use.

Plywood

Re-use	low
Modular	high
Re-cycle	10%
Landfill	85%
Incineration	5%

If plywood is not finished with a paint it can be dismounted and re-used again. As part of a modular product it has the same re-use potential as dry wood. As it is an organic renewable source it can be incinerated to generate energy after use.

Plasterboard

Re-use	none
Modular	-
Re-cycle	5%
Landfill	95%
Incineration	0%

Plasterboard is impossible to re-use as it is too fragile and usually to firmly screwed and glued together. It has no potential to be recycled and can only be landfilled.

Aluminium

Re-use	medium
Modular	medium
Re-cycle	80%
Landfill	15%
Incineration	5%

Depending on the mounting method aluminum panels can have a great re-use potential. It can also be cut into smaller pieces and the waste material can be recycled as Aluminum has a great recycling potential. The second part of the aluminum coming from the Hessenbergweg are window frames. These also have the potential to be re-used if the frame allows for the thickness of the new glass that is needed according to building regulations.

Float glass

Re-use	none
Modular	-
Re-cycle	70%
Landfill	30%
Incineration	0%

Float glass has no re-use potential as it is too fragile to handle. It can however be easily recycled. However, this is not guaranteed of the same level as contamination in the glass production has to be avoided in high grade float glass.

Conclusion

Most of the material used in the building have a low recycling and re-using potential. Only 2% of the building mass has potential to be recycled in the traditional building.

LCA ANALYSIS

Based on the total volume of materials coming from the three facades and the LCA data from the ICE database (Hammond & Jones, 2011) and the information from Bribián, Capilla and Usón (2010) an analysis of the materials and their ecological impact could be made. The data for the nine materials are found in table 01

Material	*Energy MJ/kg*	*Emissions CO2-eq /kg*	*Water l/kg*
Concrete	*1.802*	*0.179*	*2.768*
Screed	*4.235*	*0.819*	*3.937*
Polystyrene	*105.4*	*7.336*	*192.7*
Rockwool	*26.39*	*1.511*	*32.38*
Plasterboard	*3.590*	*0.210*	*1.170*
Dry wood	*20.99*	*0.300*	*5.119*
Plywood	*27.30*	*0.541*	*8.366*
Aluminium	*136.8*	*8.571*	*214.3*
Glass	*15.51*	*1.136*	*16.53*

Table 01. The building materials

Table 02 displays the total amount of environmental impact, but also the total volume and mass of all the materials coming from the building. The volume is also displayed in image 05.

	Original	*Renovated*	*Circle*
Volume (m^3)	*986*	*1307*	*1297*
Mass (10^3 kg)	*1915*	*1871*	*1561*
Energy (GJ)	*6673*	*8090*	*7990*
Emissions (10^3 $CO_{2\text{-}eq}$)	*707*	*797*	*509*
Water use (l)	*8930*	*11449*	*10943*

Table 02. The environmental impact per type.

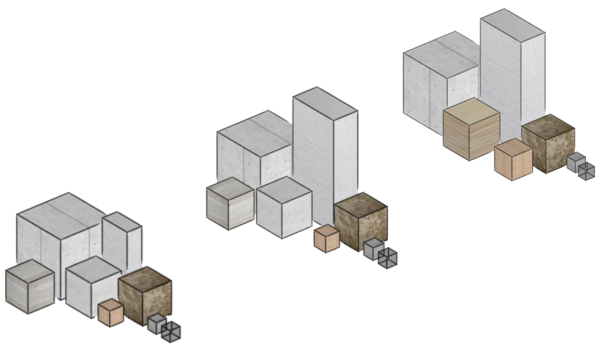


Image 05. The material volumes from left to right the original, renovated and circle structure. (own ill.)

Interesting to see is that the buildings don't differ too much from each other. The main difference from the original façade as opposed to the renovated and circle façade is the addition of insulation. This has a noticeable impact. The differences between the renovated façade and the circle façade are seen in Mass and CO_2 emissions. This can be explained by the floor type that has been used. The circle building uses a wooden floor and mechanically connected prefab hollow-core concrete slabs. The Original and renovated buildings have their hollow-core slabs chemically connected with a layer of concrete and are finished with a 50mm screed finish.

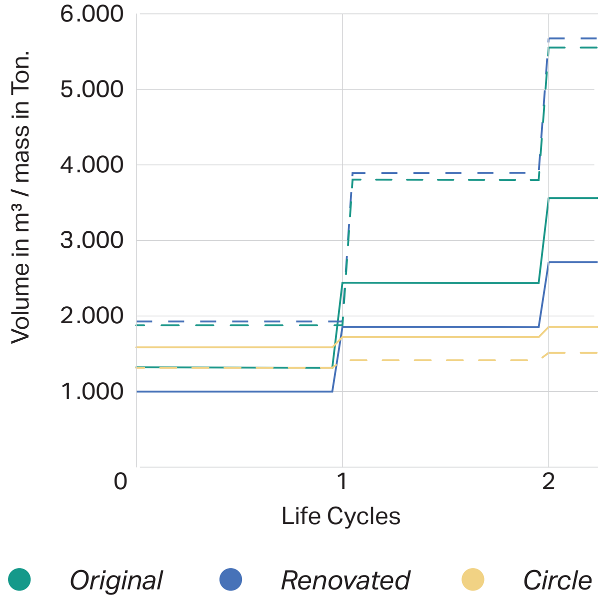
Re-use and recycle

When the materials from the building are connected to the re-use and re-cycling potential from the previous chapter the potential gains of Design for Disassembly can be calculated. This is done in Table 03. Although smaller items in the renovated building might be suitable for re-use the main impact is coming from the concrete structure and the screed. This makes up 95% of the total mass.

Building	*Volume m³*	*Mass 10³ kg*	*CO2 eq 10³ kg*
Re-use			
Original	*51*	*3*	*6*
Renovated	*85*	*4*	*14*
Circle	*1136*	*1405*	*458*
Re-cycle			
Original	*71*	*26*	*95*
Renovated	*89*	*29*	*121*
Circle	*29*	*2*	*6*
Waste			
Original	*865*	*1886*	*606*
Renovated	*1133*	*1837*	*662*
Circle	*101*	*154*	*44*

Table 03. The re-use, re-cycle and waste potential of the three phases.

When the re-use and re-cycling values are laid out against the lifespan of the building itself we can see the potential of buildings that are built for disassembly. In graph 01 after each cycle the materials that have no re-use or re-cycling potential have been replaced by new materials. The circle structure has a potential of using 90% re-used and recycled materials. This is significantly more than the 10% that can be re-used and re-cycled in the renovated building.



Graph 01. The re-use and re-cycle potential of the three phases in relation to lifecycles of the building.

Energy performance.

In this graph the embodied energy is purposely left out. The average energy consumption of an office building of 3.100 m² is around 1.1 TJ per year (Sipma, Kremer, & Vroom, 2017). This means that the embodied energy of the building elements, 8.0 TJ, is roughly the same as 7 years of operation. However, most of the materials, 87% of the total volume and 98% of the total mass, ends up in landfill as they will never be able to be recycled. This is a problem that must be tackled with new design methods.

Conclusions

This means that the material potential for a structure designed for disassembly is significantly higher than a traditional construction. The re-use potential in mass is 90% compared to the 2% of a traditional construction method. In terms of energy the difference is less significant as they require the same amount of energy to produce and this is only a small amount compared to the operational energy of the whole building during 25 or 50 years. Huge potential is to be gained in the re-use of concrete elements and other stone elements as they are not recyclable and take up the majority of the ecological footprint. Materials coming from the current construction are the softer and smaller object as they are usually still recyclable and offer a higher potential to be re-used. When the materials savings are set out against the lifecycles of the building, the potential of Design for Disassembly becomes really clear. This is important as in the end both the European and Dutch goal was to solve the long-term problem.

Towards the P2

This paper will be used as a map for the material stock and the identification of the possibilities of the different materials coming out of the current building stock. In the design of the p2 it is important accommodate space for the otherwise wasted materials or to enhance the re-use potential of materials. This report also shows that there are certain materials that should be avoided to keep a small and non-permanent footprint. Next to that I think there is a huge demand for a flexible system that knows to adapt to public space and housing. The circle structure used in this design was derived from the circle house and still a very rigid 90-degree structure. I see a great potential in a new frame that can adopt used materials and is flexible enough to accommodate change in function.

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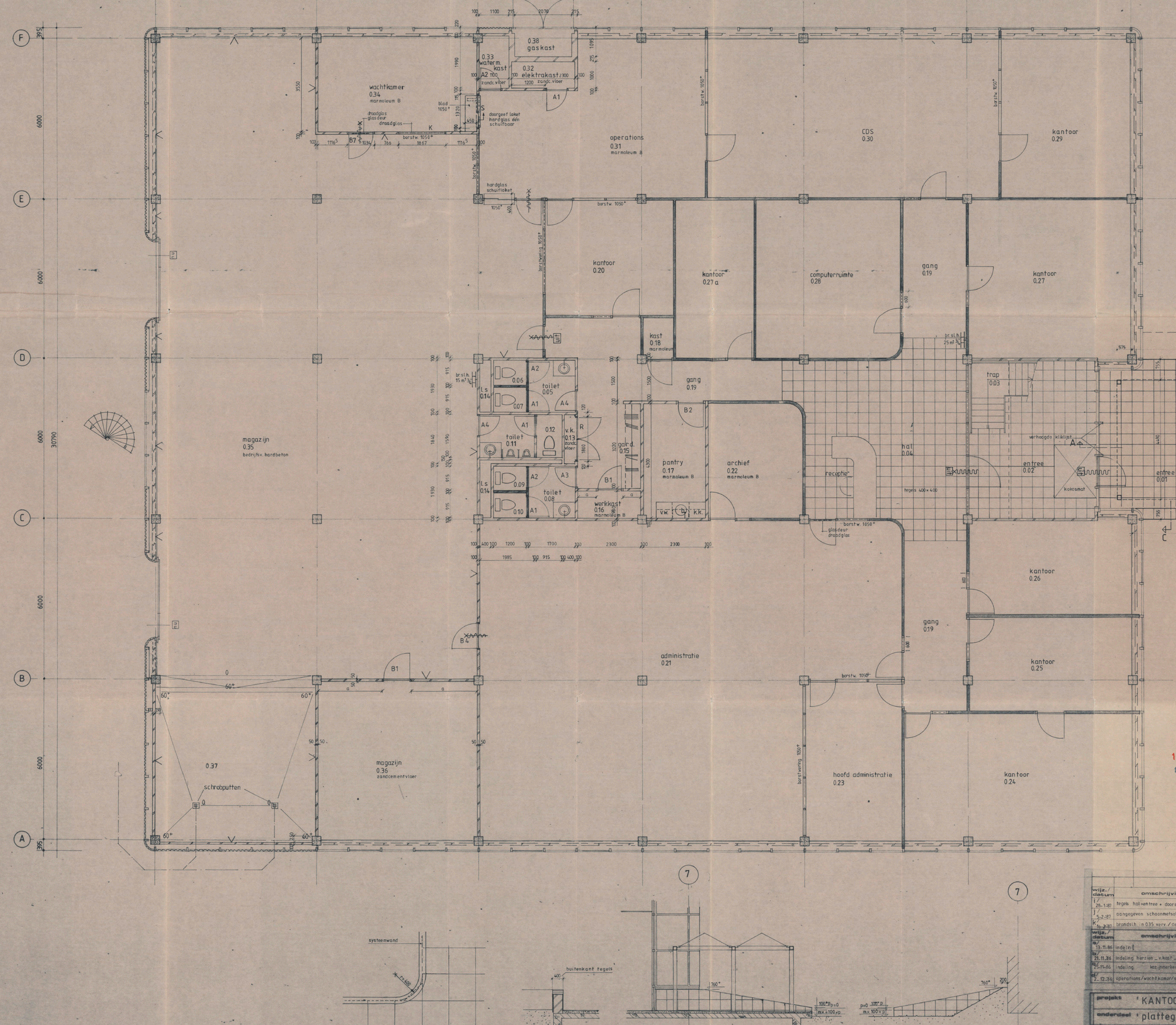
Appendix



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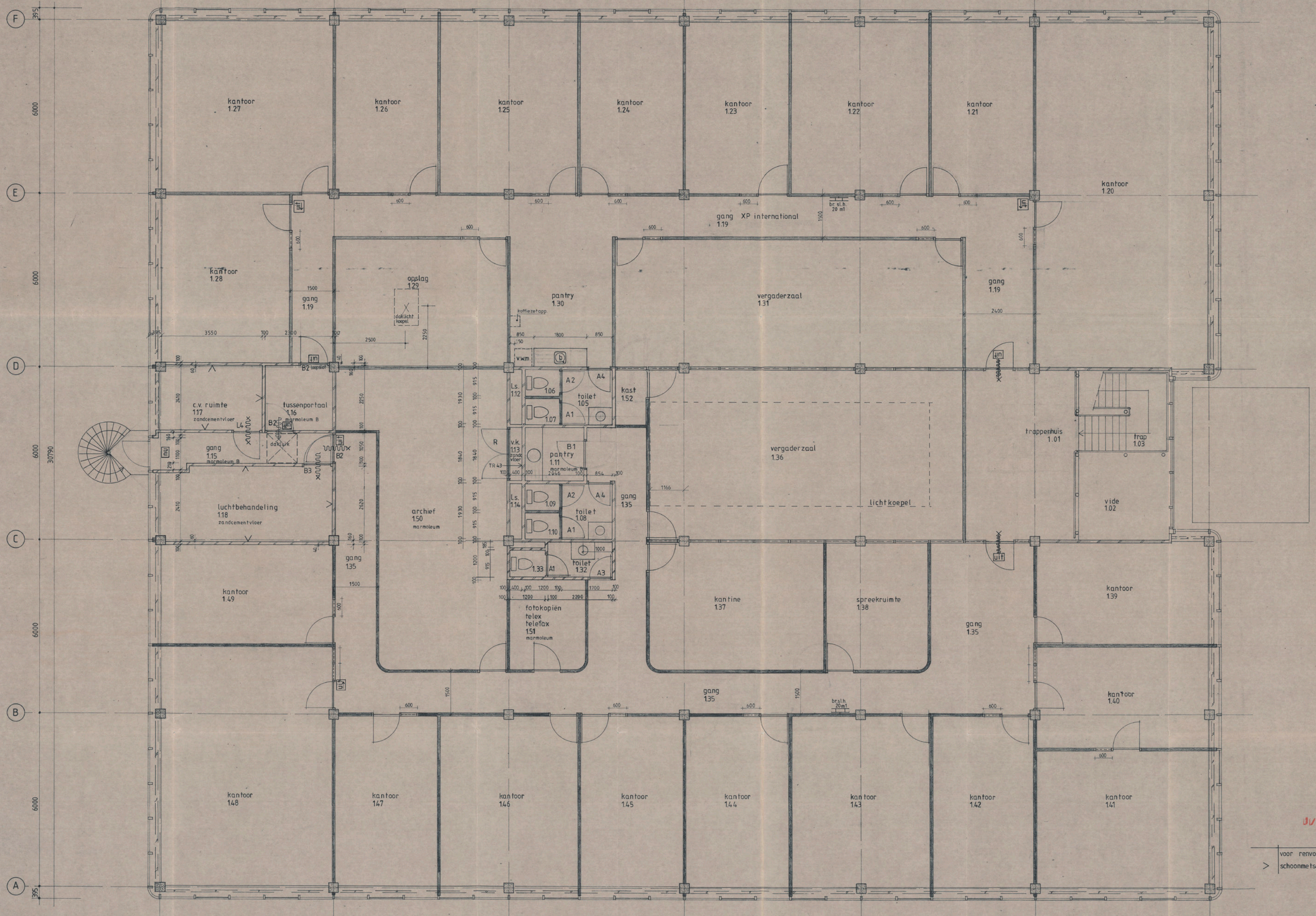

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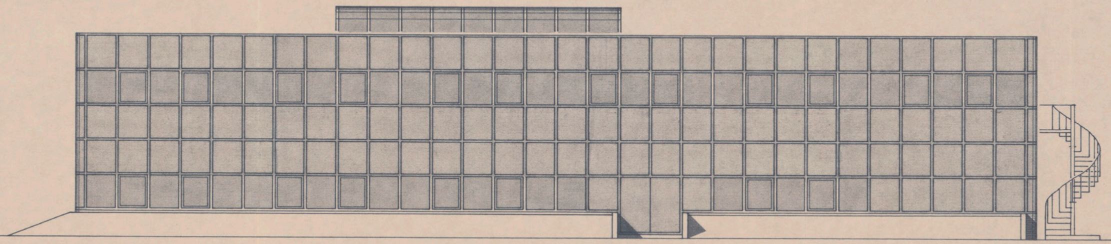
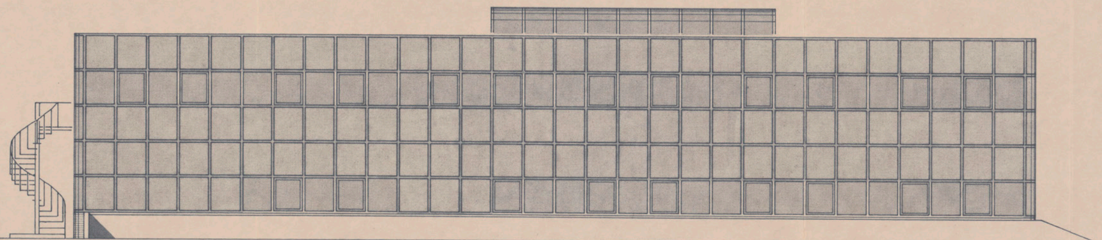


noordwestgevel

7 6 5 4 3 2 1



zuidoostgevel

1 2 3 4 5 6 7

1/7276 BWT 1986 DOSSIER 278871

13 JUN 1986

TOESTEMMING WORDT VERLEEND OM TEKENINGEN EN BEREKENINGEN VAN CONSTRUCTIES UITERLIJK EEN MAAND VOOR DE AANVANG VAN HET DESBETREFFENDE ONDERDEEL VAN HET WERK OVER TE LEGGEN.

Accord met de door de Commissie voor de Oude Stad ondertekende geveltekening

Met het bouwen mag niet worden begonnen, alvorens vanwege Burgemeester en Wethouders de hoogte van de weg ter plaatse van het bouwwerk is aangegeven. Belanghebbende dient zich hiervoor te wenden tot de afdeling Wegen van de Dienst Openbare Werken.

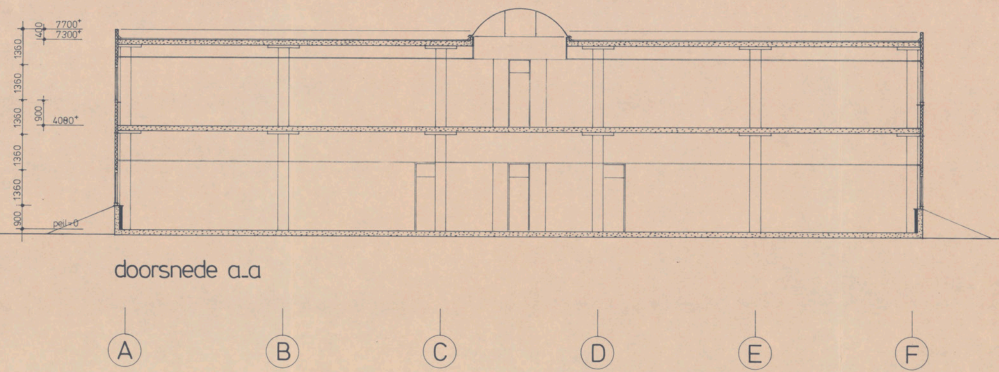
G&S Projekten b.v. PROJEKTNR.: P-147

WIJZ. DAT.	OMSCHRIJVING	WIJZ. DAT.	OMSCHRIJVING
A/		E/	
B/		F/	
C/		G/	
D/		H/	

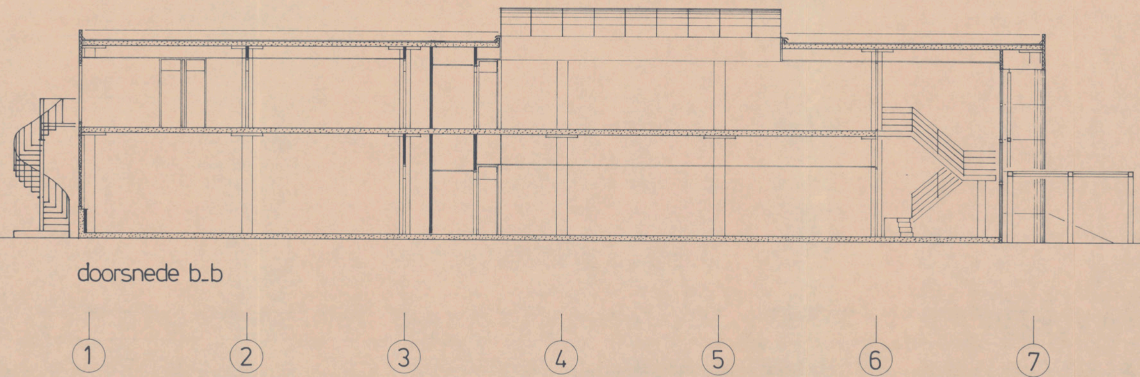
• AMSTELVEEN: LAAN NIEUWER-AMSTEL 3
TEL. 020-47 18 81 / TELEX 18608
POSTBUS 700 1180 AS AMSTELVEEN
• ALMERE: GROTE MARKT 19
TEL. 03240-2 01 84
POSTBUS 10041 1301 AA ALMERE-STAD

ZZOP ARCHITEKTEN MAATSCHAP

	MEDEW. ARCH.	GET. K
	GROEPSLEIDER/PROJEKTLEIDER	BUREAU amstelveen
ONDERDEEL: noordwest- en zuidoostgevel	SCHAAL: 1:100	FORMAAT: A1
	FASE: b.t.	DATUM: 02.06.1986
PROJEKT: bedrijfs- en kantoorgebouw XP amsterdam zuid-oost	PROJEKTNR.: 922	BLADNR.: 4



doorsnede a_a



doorsnede b_b

DAKAFWERKING
- eenlaagse dakbedekking 40 mm
- p.s. isolatie 60 mm

RAAMSTROOK
- isolerende beglazing kleur groen
- alu. stijlen gemoffeld kleur lichtgroen

BORSTWERING DICHTE STROKEN
- ondoorzichtig enkel glas kleur lichtgroen
- 80 steenwol
- 12,5 brandw. beplating in zicht
- alu. regels / stijlen gemoffeld kleur lichtgroen

BORSTWERING BEG.GR.
- 150 gew. beton
- 60 steenwol
- 105 kalkzandsteen
- 3 zijden taluds
- achterzijde tegels kleur lichtgeel

VLOER BEG.GR.
- 30 z.c. afwerkvloer
- 180 gew. beton
- 80 isolerende werkvloer

INGANGSLUIFEL
- staalprofielen kleur wit

EXPEDITIE- EN METERKASTDEUREN
- metaal kleur lichtgeel

NOODTRAP
- staal kleur wit

LICHTSTRAAT
- kunststof vlamdovend
  kleur helder

SYSTEEMPLAFONDS
- minerale wolfegels

TOESTEMMING WORDT VERLEEND OM TEKENINGEN EN BEREKENINGEN VAN CONSTRUCTIES UITERLIJK EEN MAAND VOOR DE AANVANG VAN HET DESBETREFFENDE ONDERDEEL VAN HET WERK OVER TE LEGGEN.

Met het bouwen mag niet worden begonnen, alvorens vanwege Burgemeester en Wethouders de hoogte van de weg ter plaatse van het bouwwerk is aangegeven. Belanghebbende dient zich hiervoor te wenden tot de afdeling Wegen van de Dienst Openbare Werken.

1/7276 B.W.T. 1986 : 27887

G&S Projekten b.v. PROJEKTNR.: P-147

WIJZ. DAT.	OMSCHRIJVING	WIJZ. DAT.	OMSCHRIJVING
A/		E/	
B/		F/	
C/		G/	
D/		H/	

ZZOP ARCHITEKTEN MAATSCHAP

- AMSTELVEEN: LAAN NIEUWER-AMSTEL 3 TEL. 020-47 18 81 / TELEX 18608 POSTBUS 700 1180 AS AMSTELVEEN
- ALMERE: GROTE MARKT 19 TEL. 03240-2 01 84 POSTBUS 10041 1301 AA ALMERE-STAD

MEDEW. ARCH.

GROEPSLEIDER/PROJEKTLEIDER

ONDERDEEL: doorsneden

SCHAAL: 1:100

FASE: b.t.

PROJEKT: bedrijfs- en kantoorgebouw XP amsterdam zuid-oost

PROJEKTNR.: 922

BLADNR.: 5

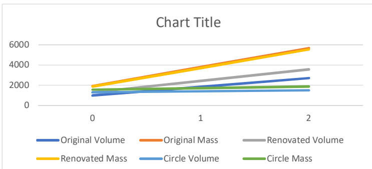
The calculation sheet

		Structure	Material	Dimensions d (m)	l (m)	b (m)	o (m²)	Amount pc.	Volume m³	Vol. mass kg/m³	Weight ton	Embodied E MJ / kg eq.	Embodied C CO² / kg eq.	Water Dema l / kg	EE GJ	CO² ton	Water Dema l
OLD	Columns	Structural column 0F	IN - Concrete, reinforced	3.83	0.40	0.40	0.16	24	14.7								
		Structural column 0F	IN - Concrete, reinforced	3.83	0.35	0.35	0.12	18	8.4								
		Structural column 1F	IN - Concrete, reinforced	3.02	0.40	0.40	0.16	24	11.6								
		Structural column 0F	IN - Concrete, reinforced	3.02	0.35	0.35	0.12	18	6.7								
		Joint	IN - Concrete, reinforced	0.10	0.60	0.60	0.36	84	3.0								
	Floor	Floor, main slab, afgiet	IN - Concrete, reinforced	0.24	6.00	6.00	36.00	90	77.8								
		Floor, main slab, kanaalpt	IN - Concrete, reinforced	0.20	6.00	6.00	36.00	90	388.8								
		Floor, edges, kanaalpt	IN - Concrete, reinforced	0.24	1.20	0.28	0.33	330	18.3								
	Foundation	Foundation	IN - Concrete, reinforced	0.60	1.50	0.60	0.90	42	22.7								
	Façade	Parapet	IN - Concrete, reinforced	0.20	1.20	0.90	1.08	110	23.8								
								Total	**575.7**	2546	1466	1.802	0.179	2.768	2641	262	4057
NEW	Columns	Structural column 0F	IN - Concrete, reinforced	3.83	0.40	0.40	0.16	24	14.7								
		Structural column 0F	IN - Concrete, reinforced	3.83	0.35	0.35	0.12	18	8.4								
		Structural column 1F	IN - Concrete, reinforced	3.02	0.40	0.40	0.16	24	11.6								
		Structural column 1F	IN - Concrete, reinforced	3.02	0.35	0.35	0.12	18	6.7								
		Joint	IN - Concrete, reinforced	0.10	0.60	0.60	0.36	84	3.0								
	Floor	Floor, main slab, afgiet	IN - Concrete, reinforced	0.24	6.00	6.00	36.00	90	77.8								
		Floor, main slab, kanaalpt	IN - Concrete, reinforced	0.20	6.00	6.00	36.00	90	388.8								
		Floor, edges, kanaalpt	IN - Concrete, reinforced	0.24	1.20	0.28	0.33	330	18.3								
	Foundation	Foundation	IN - Concrete, reinforced	0.60	1.50	0.60	0.90	42	22.7								
								Total	**552.0**	2546	1405	1.802	0.179	2.768	2532	252	3890
CIRCLE	xxx	xxx	xxx	0.00	0.00	0.00	0.00	0	0								
								Total	**0**	2546	0	1.802	0.179	2.768	0	0	0
OLD	xxx	xxx	xxx	0.00	0.00	0.00	0.00	0	0.0								
								Total	**0.0**	2546	0	1.802	0.179	2.768	0	0	0
NEW	Façade	Parapet	PR - Concrete	0.03	1.20	0.90	1.08	110	3.0								
								Total	**3.0**	2546	8	1.802	0.179	2.768	14	1	21
CIRCLE	Façade	Parapet	PR - Concrete	0.03	1.20	1.00	1.20	110	3.3								
	Columns	Structural column 0F	PR - Concrete, reinforced	4.20	0.31	0.31	0.10	42	17.0								
		Structural column 1F	PR - Concrete, reinforced	3.30	0.31	0.31	0.10	42	13.3								
		Beam dir. A	PR - Concrete, reinforced	6.89			0.13	105	90.4								
		Beam dir. B add.	PR - Concrete, reinforced	0.45			0.13	42	2.3								
		Beam dir. B	PR - Concrete, reinforced	4.49			0.13	108	60.6								
	Floor	Floor, main slab, kanaalpt	PR - Concrete Canal plt.	0.20	4.80	7.20	34.56	91	377.4								
								Total	**564.3**	2546	1437	1.802	0.179	2.768	2589	257	3977
OLD		Screed	Cement	0.05	6.00	6.00	36.00	60	108.0								
		Screed edges	Cement	0.05	1.20	0.25	0.30	330	5.0								
								Total	**113.0**	3150	356	4.235	0.819	3.937	1507	291	1401
NEW		Screed	Cement	0.05	6.00	6.00	36.00	60	108.0								
		Screed, edges	Cement	0.05	1.20	0.25	0.30	220	3.3								
								Total	**111.3**	3150	351	4.235	0.819	3.937	1485	287	1380
CIRCLE		xxx	xxx	0.00	0.00	0.00	0.00	0	0.0								
								Total	**0.0**	3150	0	4.235	0.819	3.937	0	0	0
OLD	Roof	Roof	Polystyrene	0.06	6.00	6.00	36.00	30	64.8								
		Roof, edges	Polystyrene	0.06	1.20	0.25	0.30	110	2.0								
	Façade	Element 1200 x 1360	Polystyrene	0.08	1.30	1.14	1.48	264	31.3								
		Parapet	Polystyrene	0.08	1.20	0.85	1.02	110	9.0								
								Total	**107.1**	30	3	105.486	7.336	192.729	339	24	619
NEW	Roof	Roof	Polystyrene	0.20	6.00	6.00	36.00	30	216.0								
		Roof, edges	Polystyrene	0.20	1.20	0.25	0.30	110	6.6								
	Floor	Floor	Polystyrene	0.12	6.00	6.00	36.00	30	129.6								
		Floor edges	Polystyrene	0.12	1.20	0.42	0.50	110	6.7								
	Foundation	Foundation	Polystyrene	0.12				42	14.2								
	Façade	Element 1200 x 1360	Polystyrene	0.15	1.14	1.30	1.48	264	58.7								
		Parapet	Polystyrene	0.15	1.20	0.85	1.02	110	16.8								
								Total	**448.5**	30	13	105.486	7.336	192.729	1419	99	2593
CIRCLE	Roof	Roof	Polystyrene	0.20	4.49	6.89	30.94	30	185.6								
		Roof, edges	Polystyrene	0.20	1.20	0.25	0.30	110	6.6								
	Floor	Floor	Polystyrene	0.12	4.80	7.20	34.56	30	124.4								
		Floor edges	Polystyrene	0.30	1.20	0.30	0.36	330	35.6								
	Foundation	Beam dir. A	Polystyrene	6.89			0.15	35	36.2								
		Beam dir. B add.	Polystyrene	0.45			0.15	14	0.9								
		Beam dir. B	Polystyrene	4.49			0.15	36	24.2								
	Façade	Element A, open	Polystyrene	0.15	1.00	2.95	2.95	88	38.9								
		Element B, dicht	Polystyrene	0.15	1.00	2.95	5.45	22	18.0								
								Total	**470.6**	30	14	105.486	7.336	192.729	1489	104	2721
		System wall 0f	Rockwool	0.08	6.00	3.80	22.80	**27**	49.2								
		System wall 1f	Rockwool	0.08	6.00	3.00	18.00	**36**	51.8								
								Total	**101.1**	60	6	26	2	32	160	9	196
		System wall 0f	Rockwool	0.08	6.00	3.80	22.80	**27**	49.2								
		System wall 1f	Rockwool	0.08	6.00	3.00	18.00	**36**	51.8								
								Total	**101.1**	60	6	26	2	32	160	9	196
		System wall 0f	Rockwool	0.08	6.00	3.80	22.80	**27**	49.2								
		System wall 1f	Rockwool	0.08	6.00	2.90	17.40	**36**	50.1								
								Total	**99.4**	60	6	26	2	32	157	9	193
		System wall 0f	Plasterboard	0.05	6.00	3.80	22.80	30	34.2								
		System wall 1f	Plasterboard	0.05	6.00	3.00	18.00	40	36.0								
		Finishing Façade	Plasterboard	0.03			3.48	88	7.7								
		Finishing Façade	Plasterboard	0.03			6.00	22	3.3								
								Total	**70.2**	800	56	4	0	1	202	12	66
		System wall 0f	Plasterboard	0.05	6.00	3.80	22.80	30	34.2								
		System wall 1f	Plasterboard	0.05	6.00	3.00	18.00	40	36.0								
		Finishing Façade	Plasterboard	0.03			3.48	88	7.7								
		Finishing Façade	Plasterboard	0.03			6.00	22	3.3								
								Total	**70.2**	800	56	4	0	1	202	12	66
		xxx	xxx	0.00	0.00	0.00	0.00	0	0.0								
								Total	**0.0**	800	0	4	0	1	0	0	0
OLD	xxx	System wall 0f	Dry Wood	0.08	6.00	3.80	22.80	3	5.5								
		System wall 1f	Dry Wood	0.08	6.00	3.00	18.00	4	5.8								
								Total	**11.2**	600	7	20.996	0.300	5.119	141	2	34
		System wall 0f	Dry Wood	0.08	6.00	3.80	22.80	3	5.5								
		System wall 1f	Dry Wood	0.08	6.00	3.00	18.00	4	5.8								
								Total	**11.2**	600	7	20.996	0.300	5.119	141	2	34
	Circle	System wall 0f	Dry Wood	0.08	6.00	3.80	22.80	3	5.5								
		System wall 1f	Dry Wood	0.08	6.00	3.00	18.00	4	5.8								
CIRCLE		Floor raisers	Dry Wood	1.32	0.06	0.06	0.00	1116	5.3								
		Floor underlayment	Dry Wood	4.58	0.04	0.04	0.00	1116	8.2								
		Element A, open	Dry Wood	27.40	0.15	0.05	0.01	88	18.1								
		Element B, dicht	Dry Wood	35.00	0.15	0.05	0.01	22	5.8								
								Total	**37.3**	600	22	20.996	0.300	5.119	470	7	115
OLD																	
	xxx	xxx	xxx	0.00	0.00	0.00	0.00	0	0.0								
								Total	**0.0**	540	0	27	1	8	0	0	0
	xxx	xxx	xxx	0.00	0.00	0.00	0.00	0	0.0								
								Total	**0.0**	540.000	0	27.309	0.541	8.366	0	0	0
		Floor	Plywood	0.05	4.80	7.20	34.56	60	103.7								
		Floor edges	Plywood	0.05	1.20	0.13	0.15	220	1.7								
		Finishing façade	Plywood	0.03			4.32	88	9.5								
		Finishing façade	Plywood	0.03			6.12	22	3.4								
								Total	**118.2**	540.000	64	27.309	0.541	24.761	1743	35	1580
OLD		Kozijn	Aluminum	6.96	0.06	0.15	0.00	208	2.0								
		Kozijn Inzet	Aluminum	6.48	0.06	0.06	0.00	78	1.0								
	façade	Element	Aluminum	0.00	1.16	1.32	1.53	264	1.2								
								Total	**4.1**	2700	11	136.803	8.571	214.341	1523	95	2386
NEW		Kozijn	Aluminum	6.96	0.06	0.22	0.00	208	2.9								
		Kozijn Inzet	Aluminum	6.48	0.06	0.06	0.00	78	1.3								
	façade	Element	Aluminum	0.00	1.16	1.32	1.53	264	1.2								
								Total	**5.4**	2700	14	136.803	8.571	214.341	1977	124	3098
CIRCLE		Kozijn 0F	Aluminum	6.96	0.06	0.22	0.00	66	0.9								
		Kozijn 0F Inzet	Aluminum	6.48	0.06	0.06	0.00	44	0.7								
		Kozijn 1F	Aluminum	5.16	0.06	0.22	0.00	54	0.6								
		Kozijn 1F Inzet	Aluminum	4.68	0.06	0.06	0.00	34	0.4								
		Element A, open	Aluminum	0.00			3.60	88	1.0								
		Element B, dicht	Aluminum	0.00			5.05	22	0.3								
								Total	**3.9**	2700	10	136.803	8.571	214.341	1427	89	2236
OLD		Window	Double Glazing	0.01	1.18	1.28	1.51	208	3.1								
		Window openable	Double Glazing	0.01	1.08	1.16	1.25	78	1.0								
								Total	**4.1**	2500	10	15.511	1.136	16.537	160	12	170
NEW		Window	Double Glazing	0.01	1.18	1.28	1.51	208	3.1								
		Window openable	Double Glazing	0.01	1.08	1.16	1.25	78	1.0								
								Total	**4.1**	2500	10	15.511	1.136	16.537	160	12	170
CIRCLE		Window 0F	Double Glazing	0.01	1.12	1.42	1.59	66	1.0								
		Window openable 0F	Double Glazing	0.01	1.00	1.30	1.30	44	0.6								
		Window 1F	Double Glazing	0.01	1.12	1.42	1.59	54	0.9								
		Window openable 1F	Double Glazing	0.01	1.00	1.30	1.30	34	0.4								
								Total	**2.9**	2500	7	15.511	1.136	16.537	113	8	121

Material percentages for re-use and re-cycling

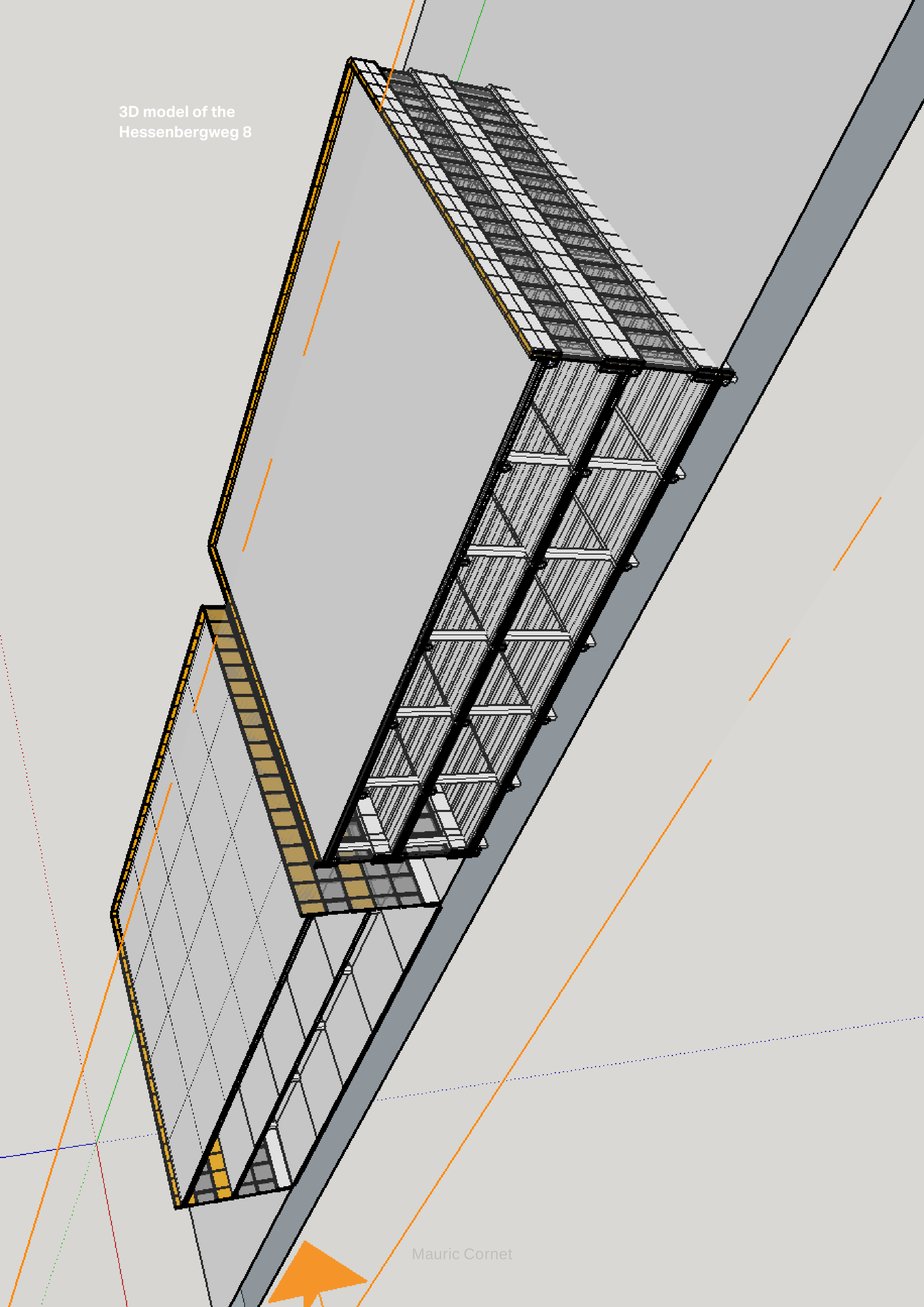
		Volume	m³		Mass	1000 kg		Energy Consumption	GJ		Greenhouse effect		Ton CO² eq	Water use		L
		Original	Renovated	Circle	Original	Renovated	Circle	Original	Renovated	Circle	Original	Renovated	Circle	Original	Renovated	Circle
Concrete		575.7	554.9	564.3	1466	1413	1437	2641	2546	2589	262	253	257	4057	3911	3977
Screed		113.0	111.3	0.0	356	351	0	1507	1485	0	291	287	0	1401	1380	0
Polystyrene		107.1	448.5	470.6	3	13	14	339	1419	1489	24	99	104	619	2593	2721
Rockwool		101	101	99	6.1	6.1	6.0	160	160	157	9	9	9	196	196	193
Plasterboard		70	70	0	56.2	56.2	0.0	202	202	0	12	12	0	66	66	0
Dry Wood		11.2	11.2	37.3	7	7	22	141	141	470	2	2	7	34	34	115
Plywood		0.0	0.0	118.2	0	0	64	0	0	1743	0	0	35	0	0	1580
Aluminum		4.1	5.4	3.9	11	14	10	1523	1977	1427	95	124	89	2386	3098	2236
Glass		4.1	4.1	2.9	10	10	7	160	160	113	12	12	8	170	170	121
Total		986	1307	1297	1915	1871	1561	6673	8090	7990	707	797	509	8930	11449	10943
Concrete		58%	42%	44%	76.5%	76%	92%	40%	31%	32%	37%	32%	51%	45%	34%	36%
Screed		11%	9%	0%	18.6%	19%	0%	23%	18%	0%	41%	36%	0%	16%	12%	0%
Polystyrene		11%	34%	36%	0.2%	1%	1%	5%	18%	19%	3%	12%	20%	7%	23%	25%
Rockwool		10%	8%	8%	0.3%	0%	0%	2%	2%	2%	1%	1%	2%	2%	2%	2%
Plasteboard		7%	5%	0%	2.9%	3%	0%	3%	2%	0%	2%	1%	0%	1%	1%	0%
Dry Wood		1%	1%	3%	0.4%	0%	1%	2%	2%	6%	0%	0%	1%	0%	0%	1%
Plywood		0%	0%	9%	0.0%	0%	4%	0%	0%	22%	0%	0%	7%	0%	0%	14%
Aluminum		0%	0%	0%	0.6%	1%	1%	23%	24%	18%	13%	16%	18%	27%	27%	20%
Glass		0%	0%	0%	0.5%	1%	0%	2%	2%	1%	2%	1%	2%	2%	1%	1%
Total		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Concrete	re-use	0	0	508	0	0	1293	0	0	2330	0	0	231	0	0	3579
Screed	re-use	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polystyrene	re-use	11	45	423	0	1	13	34	142	1340	2	10	93	62	259	2449
Rockwool	re-use	40	40	89	2	2	5	64	64	142	4	4	8	79	79	174
Plasterboard	re-use	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dry Wood	re-use	0	0	34	0	0	20	0	0	423	0	0	6	0	0	103
Plywood	re-use	0	0	106	0	0	57	0	0	1569	0	0	31	0	0	1422
Aluminum	re-use	0	0	3	0	0	9	0	0	1285	0	0	80	0	0	2013
Glass	re-use	0	0	3	0	0	7	0	0	102	0	0	7	0	0	109
Total	re-use	51	85	1167	3	4	1405	98	206	7191	6	14	458	140	338	9849
	re-use %	**5.2%**	**6.5%**	**90.0%**												
Concrete	re-cycle	1	1	0	3	3	0	5	5	0	1	1	0	8	8	0
Screed	re-cycle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polystyrene	re-cycle	5	22	24	0	1	1	17	71	74	1	5	5	31	130	136
Rockwool	re-cycle	56	56	5	3	3	0	88	88	8	5	5	0	108	108	10
Plasterboard	re-cycle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dry Wood	re-cycle	1	1	0	1	1	0	14	14	0	0	0	0	3	3	0
Plywood	re-cycle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aluminum	re-cycle	3	4	0	9	12	0	1218	1582	0	76	99	0	1909	2478	0
Glass	re-cycle	4	4	0	10	10	1	160	160	11	12	12	1	170	170	12
Total	re-cycle	71	89	29	26	29	2	1502	1920	94	95	121	6	2229	2897	158
		7.2%	**6.8%**	**2.2%**												
Concrete	waste	575	554	56	1463	1410	144	2636	2541	259	262	252	26	4049	3903	398
Screed	waste	113	111	0	356	351	0	1507	1485	0	291	287	0	1401	1380	0
Polystyrene	waste	91	381	24	3	11	1	288	1206	74	20	84	5	526	2204	136
Rockwool	waste	5	5	5	0	0	0	8	8	8	0	0	0	10	10	10
Plasterboard	waste	70	70	0	56	56	0	202	202	0	12	12	0	66	66	0
Dry Wood	waste	10	10	4	6	6	2	127	127	47	2	2	1	31	31	11
Plywood	waste	0	0	12	0	0	6	0	0	174	0	0	3	0	0	158
Aluminum	waste	1	1	0	2	3	1	305	395	143	19	25	9	477	620	224
Glass	waste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	waste	865	1133	101	1886	1837	154	5072	5965	705	606	662	44	6560	8214	937
		87.7%	**86.7%**	**7.8%**	**98.5%**	**98.2%**	**9.9%**									

	0	1	2	3	4
Original Volume	986	1851	2716	3581	4445
Original Mass	1915	3801	5687	7574	9460
Renovated Volume	1307	2440	3572	4705	5838
Renovated Mass	1871	3708	5546	7383	9221
Circle Volume	1297	1397	1498	1599	1700
Circle Mass	1561	1715	1870	2024	2178



Material properties for LCA

Material	Density kg/m³	Thermal Cond W/mK	Embodied Energy MJ / kg eq.	Embodied Carbon CO² / kg eq.	Water Demand l / kg
Lorry, road (m)	-	-	3.266	0.193	1.466
Fright rail (m²)	-	-	0.751	0.039	1.115
Freight ship (m³)	-	-	0.170	0.011	0.097
Ordinary brick	1800	0.950	3.562	0.271	1.890
Light clay brick	1020	0.290	6.265	-0.004	1.415
Sand-lime brick	1530	0.700	2.182	0.120	3.009
Ceramic tile	2000	1.000	15.649	0.857	14.452
Quarry tile	2100	1.500	2.200	0.290	3.009
Ceramic roof tile	2000	1.000	4.590	0.406	2.456
Concrete roof tile	2380	1.650	2.659	0.270	4.104
Fibre cement roof slate	1800	0.500	11.543	1.392	20.368
Plasterbaord	**800**	**0.160**	**3.590**	**0.210**	**1.170**
EPS Foam Slab	**30**	**0.038**	**105.486**	**7.336**	**192.729**
Rock wool	**60**	**0.040**	**26.393**	**1.511**	**32.384**
PU-rigid foam	30	0.032	103.782	6.788	350.982
Cork slab	150	0.049	51.517	0.807	30.337
Cellulose fibre	50	0.040	10.487	1.831	20.789
Wood Wool	180	0.070	20.267	0.124	2.763
Screed	**3150**	**1.400**	**4.235**	**0.819**	**3.937**
Cement Mortar	1525	0.700	2.171	0.241	3.329
Concrete reinf	**2546**	**2.300**	**1.802**	**0.179**	**2.768**
Concrete	2380	1.650	1.105	0.137	2.045
Sawn timber, softwood, planed, kiln dried	**600**	**0.130**	**20.996**	**0.300**	**5.119**
Sawn timber, softwood, planed, air dried	600	0.130	18.395	0.267	4.192
Glued laminated timber, indoor use	540	0.130	27.309	0.541	8.366
Particle board, indoor use	800	0.130	34.646	0.035	8.788
Plywood	**540**	**0.130**	**27.309**	**0.541**	**8.366**
Oriented strand board	430	0.130	36.333	0.620	24.761
Reinforcing steel	7900	50.000	24.336	1.526	26.149
Aluminium	**2700**	**239.000**	**136.803**	**8.571**	**214.341**
Polyvinylchloride	1400	0.170	73.207	4.267	511.999
Flat glass	**2500**	**0.950**	**15.511**	**1.136**	**16.537**
Copper	8920	380.000	35.586	1.999	77.794


3D model of the
Hessenbergweg 8
Mauric Cornet